ACCRETION DISK STRUCTURE AND ORIENTATION IN THE LENSED
AND MICROLENSED Q0957+561 QUasar

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ABSTRACT

Because quasars are unresolved in optical imaging, their structures must currently be inferred. Gravitational microlensing offers the possibility of producing information about the luminous structure provided that the Einstein ring diameter of the microlensing particle is comparable to or smaller than the radiating quasar components. Particularly interesting is the case of multiple-image gravitational lenses, where differences in the brightness histories of the multiple images can reveal the presence of the microlensing particles and allow inferences about the quasar’s structure. The long brightness history measured for the Q0957 quasar has been analyzed previously for information about the microlensing particles, and evidence for the existence of a cosmologically significant population of planetary-mass particles has been reported. The microlensing results have also directly determined the sizes of the ultraviolet light emitting surfaces in the quasar. Autocorrelation analysis of the same brightness record has produced evidence for complex structure in the quasar; if the quasar suddenly brightens today, it is probable that it will brighten again after 129, 190, 540, and 620 days. We interpret these lags as the result of luminous structure around the quasar, and in particular we interpret them in the context of the Elvis model of the quasar’s structure. We find that the autocorrelation peaks imply that beyond the luminous inner edge of the accretion disk, the biconic structures of the Elvis model must lie at a radial distance of $2 \times 10^{17}$ cm from the black hole, and $2 \times 10^{16}$ cm above and below the plane of the accretion disk. The quasar is apparently inclined $55^\circ$ to the line of sight. A second possible solution with lower inclination and larger structure is also indicated but statistically less probable.

Key words: dark matter — galaxies: halos — gravitational lensing — methods: data analysis — quasars: general — quasars: individual (0957+561)

1. INTRODUCTION

Structure in quasar accretion disks should be resolvable from gravitational microlensing if the structure size is comparable to the resolution scale of the microlensing object. We envision the typical gravitational lensing situation such as was first seen in the Q0957+561 AB quasar, in which the mass of a lens galaxy along the line of sight to a distant quasar creates multiple light paths to the quasar. In the Q0957 case, two images are seen (Walsh et al. 1979). Thus, measurement of brightness fluctuations in the two images allowed the lag between the arrival times of the images to be measured (Schild & Cholfin 1986), and it was immediately recognized that the brightness fluctuations seen in the two images are not identical (Grieger et al. 1988; Vanderriest et al. 1989). This causes complications in the determination of the time delay but has the potential to reveal something about the nature of the quasar’s brightness distribution and the nature of the missing mass objects in the halo of the lens galaxy.

Before their discovery, such microlensing brightness fluctuations were predicted by Chang & Refsdal (1979), Young (1981), and Gott (1981). Most of these calculations assumed that the luminous quasar source consisted of a simple accretion disk with an outer diameter $D$ and perhaps with an unimportant central hole of unknown diameter. The most recent calculations, by Schmidt & Wambsganss (1998), are still made with this assumption. This is perhaps justifiable because no standard physical model for a quasar accretion disk that explains all the complex observed phenomena exists yet.

While studies of quasar brightness have focused on the continuum emission, typically peaking in the ultraviolet at the quasar’s rest frame, it has long been known that the broad emission lines probably originate in a more extended region, and in order to explain the many spectroscopic phenomena observed, various unification models have been developed. However, there has been virtually no discussion of the possibility that continuum emission also originates in these larger regions. A further complication is that rapid quasar brightness fluctuations are frequently seen, albeit at low amplitude (Colley & Schild 2003), which has tended to be interpreted as evidence that the accretion disk is small.

What seems to be lacking in the discussion is the possibility that the quasar continuum emission comes from several regions, large and small, with smaller regions producing rapid brightness fluctuations as observed and larger regions producing the pattern of multiple peaks in the brightness curves observed. The multiple peaks are evidently produced when the central black hole’s variability produces brightness enhancements at the several continuum-emitting regions, which are seen at different times (lags) by the terrestrial observer. A double-ring quasar model by Schild & Vakulik (2003) has reproduced all the complex microlensing phenomena observed to date and will be the basis for the further developments in this report. Note the potential for confusion in referring to the “double-ring model.” The Elvis (2000) model has conic sections of revolution that produce a luminous ring above and below the accretion disk, whereas the Schild & Vakulik model has a small ring to represent the luminous inner edge of the accretion disk and an outer ring that is a simplification of the two rings in the Elvis model. Hereafter we refer to the Schild & Vakulik model as the double-ring model and the conic section model as the Elvis (2000) model.

Extensive brightness monitoring of the Q0957 quasar for time delay and microlensing studies has produced four relevant observations of quasar structure so far. First, the microlensing record that results from subtracting the time delay shifted brightness record of the first arriving A image from B produces a record of an event with an amplitude of 30% and lasting 10 yr,
followed by a 10 yr period with no secular increase on such timescales (Schild & Smith 1991; Pelt et al. 1998; Refsdal et al. 2000). Microlensing simulations (Young 1981; Kayser et al. 1986) have always suggested that the timescale for a solar-mass star crossing the luminous quasar structure should be approximately 30 yr, based on the expected diameter of the microlens’s Einstein ring. Of course, stars are presumed to exist in the outer portions of lens galaxy G1, since their light and spectra are observed, so the long secular microlensing drift is presumed to result from microlensing by stars.

A second and unexpected observational result is the more rapid microlensing reported in Schild (1996); cusp-shaped profiles having an amplitude of 5% and a timescale of 90 days were found and interpreted as indicative of a microlensing population of dark matter objects of planetary mass, $10^{-3} M_\odot$, and called “rogue planets, likely to be the missing mass.” The Schild & Vakulik model demonstrates how these profiles can originate in the strong shear of the solar mass microlenses provided that the quasar has sufficiently sharp structure. The even more rapid event, albeit at lower 1% amplitude, reported by Colley & Schild (2003) was of the type reported by Schild (1996) to be indicative of even lower mass microlenses, $10^{-6} M_\odot$, although very sharp quasar structure would then be implied.

A third important conclusion from the microlensing record is that no fluctuation of more than a factor of 2 has ever been recorded in Q0957 or in any other gravitationally lensed quasar, although microlensing of stars in the LMC and Galactic center have frequently produced such spectacular brightness increases (Alcock et al. 1995). An analysis by Schild (1996) of the Q0957 brightness record shows that the quasar images have only produced fluctuations of 0.45 mag in 100 yr of brightness monitoring. Analysis of the single event occurring on solar-mass microlensing timescales by Refsdal et al. (2000) shows that large quasar sizes are implied. A general theory of quasar brightness fluctuations has been published by Refsdal & Stabell (1991, 1993, 1997) and applied in Schild (1996) to the Q0957 system to show that the quasar luminous source must be at least as large as $10^{16}$ cm, and probably larger.

A fourth important inference, which is the starting point of this paper, comes from the quasar brightness curves directly, with microlensing playing only a minor role. Autocorrelation calculations of the brightness records show a network of peaks on time lags of order 200 proper days, suggesting that the quasar’s luminous structures are at size scales of 200 lt-days and that the source of this luminosity is probably scattered luminous regions on a time interval around 200 days and are selectively amplified, the two quasar images might differ in their brightness autocorrelation properties, as observed.

The purpose of this contribution is to consider what is known about possible structure in the autocorrelation properties of the brightness curves of the two quasar images, and to show how the structures indicated can be related to the predictions of the best available quasar model. The Elvis (2000) model finds that in addition to the accretion disk, a pair of conic section surfaces of revolution must be present to explain the observed emission and absorption line features long recognized in quasar spectra. These “biconic surfaces” are Compton-thick where illuminated by the black hole, and so they would be expected to scatter continuum radiation into our line of sight. We find that such structure predicts the pattern of ~200 day lags detected in the extensive Q0957 monitoring. Seen as a system of four equations and three variables, the problem is overconstrained and allows us to determine the inclination and dimensions of the quasar.

In §2 we show that the first arriving optical signal probably arrives from the inner edge of the accretion disk, which evidently has a proper size scale of approximately 3 lt-days, as estimated from the autocorrelation data. In §3 we identify the autocorrelation peaks suggesting the existence of larger quasar structure. In §4 we show that the autocorrelation peaks can be interpreted as originating in the biconic luminous structures found in the Elvis (2000) quasar model, and we determine the sizes of these structures and their orientations. We summarize our conclusions in §5.

2. THE INNER EDGE OF THE ACCRETION DISK

Extensive records of the brightness of the two Q0957 images have been compiled by Schild and colleagues; see Schild & Thomson (1995) and earlier references contained therein. A master data set was analyzed by Thomson & Schild (1997) and Schild & Thomson (1997a, 1997b), with the striking discovery that significant power is seen at four lags that we identify as $T_1 - T_4$ in Figure 1. An additional unexpected behavior was also seen for very short lags, of order 10 days (observer’s clock), or 4 proper days for a quasar redshift of 1.41. Although not seen very well in Figure 1, the autocorrelation has a small secondary peak at 10 days in the A image and a different, more complicated structure in the B image. Note that the Schwarzschild radius for a $3 \times 10^9 M_\odot$ black hole would be $9 \times 10^{14}$ cm, so the diameter of the innermost stable orbit is $6 \times 10^{13}$ cm, or about 2 lt-days, which is the size of the smallest structure inferred from the autocorrelation. We suspect that the differences between the two images results from microlensing of the luminous inner accretion disk edge. Because the quasar’s brightness has been sampled nightly, and assuming a finite thickness to the emitting region at the inner edge of the accretion disk, it would not be surprising if the microlensed inner edge of the accretion disk contributed some signal to the autocorrelation estimates on timescales of a few days. Therefore, in future work we plan to investigate the behavior on short timescales more completely by subsampling the long Q0957 brightness record in 1 yr subsets. For the present report we take the size of the luminous accretion disk inner edge to be a few proper light days. Following Schild & Vakulik (2003) and Colley et al. (2003), we estimate that approximately 20% of the quasar’s continuum originates there.

3. THE MEASURED TIME LAGS

Our Figure 1 autocorrelation plot for the quasar brightness history was calculated by the multiple-window technique as

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1 Available at http://cfa-www.harvard.edu/~rschild/fulldata2.txt.
described in Thomson & Schild (1997). Further discussion of the statistical complexities of the Q0957 data are given in Schild & Thomson (1997a, 1997b), particularly with reference to non-Gaussianity in the basic statistical processes. An important shortcoming to Figure 1 is the absence of error bars or confidence limits on the plotted curves. To date this has been a result of a lack of understanding of the basic statistics of the quasar's brightness fluctuations. Although confidence limits can be estimated for Gaussian statistics, it is well known that the basic statistics are not Gaussian, as noted above (Thomson & Schild 1997; Press & Rybicki 1997). Although the latter sought the non-Gaussianity via asymmetry of the brightness peaks, Thomson & Schild have concluded that the non-Gaussianity lies in the cuspy profiles resulting from microlensing. Relative to a Gaussian distribution, the cuspy profiles produce too many 2–5 σ discrepant points, as can be seen from a plot of the higher statistical moments of the brightness record.

One might imagine determining limits to the errors in estimating the autocorrelation by comparing the autocorrelation function for the two quasar images; after all, they are images of the same quasar. However, this would fail, for the reason that the different quasar images are seen through different microlensing cusp patterns originating in the lens galaxy, and the cusp patterns will magnify different parts of the quasar's brightness differently. Note that for lags greater than 600 days, the estimates for the two images differ by a factor of 2 over a wide range of lags, and such a result is unlikely to result from errors of estimation. As expected, it is the B image with the greater optical depth to microlensing that shows the stronger autocorrelation estimates for longer lags.

Until the statistics of the basic brightness curves are better understood, we simply take the autocorrelation estimates at face value and attempt to interpret their peaks. We have identified the most prominent four peaks that are coincident in both the A and B image brightness records, and we attempt to interpret them in the context of the Elvis (2000) model of the luminous quasar structure. In this model, the quasar is expected to have an accretion disk, which does not need to be thick, and two biconic figures of revolution, one above and one below the accretion disk. The many optical, UV, and X-ray spectral lines seen in emission and absorption are understood to originate in these biconic structures. Quasars of different classes, such as the bright absorption line quasars and weak absorption line quasars, are understood to result from the different orientations in which the structures are viewed from Earth.

Of particular importance to us, since we are analyzing brightness records of the quasar's continuum emission, are the regions scattering the central continuum. According to the Elvis model, these will be two approximately circular rings at the $\tau \sim 1$ surface, one above and one below the accretion disk. The reader is referred to Figure 1 of Elvis (2000) for a cartoon illustrating these structures. Since in general the quasar axis will be inclined to our line of sight, light scattered from these surfaces will be received at Earth at different times. Thus different parts of the rings of Saturn would be seen at different times if one imagined a strobe light at the position of the center of the planet flashing very quickly. And as in the Saturn example, the light scattered from ring portions seen in projection nearest to the strobe light would have the shortest and longest lags. These topics have been covered extensively in Peterson (1997). The segments with the longest and shortest lags would be the brightest. In a similar way, we expect the surfaces of the Elvis model biconic structures to be most luminous in the segments having the longest and shortest lags.

![Fig. 1.—Estimated autocorrelation for the A (dotted curve) and B (solid curve) quasar images, from Thomson & Schild (1997). We have identified the four coincident autocorrelation peaks as $T_1-T_4$. Not well illustrated is the structure for lags of up to 10 civil days. Although autocorrelation estimates should be accurate for such lags because of the large amounts of data with appropriate time sampling, the autocorrelation estimates for the A and B images are in disagreement, apart from the four lags $T_1-T_4$.](image-url)
We have identified the four principal lags $T_1 - T_4$ in Figure 1 from simple visual inspection. We sought the four regions displaying the most prominent peaks in both the A and B image. We were biased away from the feature at 365 days, which could too easily be an artifact of sampling. We ignored the many prominent peaks seen in one image but not the other, such as the peaks at observed lags of 60 and 240 days in the A image. These could easily be the result of some locally strong microlensing of some portions of the emitting circular structures, where the lags are 60 and 240 days (25 and 100 proper days). The strongest lags in the autocorrelation plot are at 50, 75, 230, and 260 proper days (in the source-plane time frame). The 260 day peak is marginal. The peaks are resolved with widths of 15 proper days.

We thus seek to identify these four most prominent peaks, labeled $T_1 - T_4$ in Figure 1, with the near- and far-side emitting regions of the biconic sections (rings). Two simple configurations are possible for identifying the regions, which we call case 1 and case 2. Case 2 is the less probable, given that it requires that the pole of the rotating accretion disk be almost coincident with the line of sight to Earth. The pole of rotation is more inclined in case 1, and so case 1 is statistically more probably given that the line of sight to Earth and the pole of rotation are presumably random vectors.

Figure 2 is a cartoon showing the luminous quasar structures; we define the variables chosen to describe them for both case 1 and case 2. The biconic surfaces and the accretion disk are shown in their principal cross sections. In both cases we suppose that a disturbance near the black hole event horizon causes energetic emissions that are seen first as brightenings of the inner edge of the accretion disk, through some process of scattering or fluorescence. We then imagine that this starts our clock at $t = 0$, whence the radiation spreads to the biconic surfaces and causes them to brighten at appropriate lags; we also assume that the conversion to the radiation that we detect (electron scattering in the Elvis 2000 model) occurs on timescales short in comparison to the few days of the geometric lags. Then from the simple geometry shown in Figure 2, we easily write the equations for the predicted lags, as functions of the geometric variables $r$, the distance in units of proper light days from the central black hole to the luminous biconic structure, $\theta$, the angle between the line of sight  and the pole of the accretion disk, and $\epsilon$, the quasar structure variable describing the angular height of the luminous rings above the accretion disk as seen from the black hole:

$$T_1 = r[1 - \sin(\theta + \epsilon)] = 50,$$
$$T_2 = r[1 - \sin(\theta - \epsilon)] = 75,$$
$$T_3 = r[1 + \sin(\theta - \epsilon)] = 230,$$
$$T_4 = r[1 + \sin(\theta + \epsilon)] = 260.$$

Here we have four equations for three variables, so the system is overconstrained, and it is not assured that a solution can be found. On the other hand, we lack limits on the precision of the measured lags, so we do not concern ourselves about the existence of a solution. Particularly problematic is $T_4$, where the lag peak differs somewhat for images A (265 days) and B (257 days). In our calculation, we have used the average lag for $T_4$.

Our case 1 differs from case 2 in the order in which the lagged signals from the different emitting structures arrive at Earth. In both cases 1 and 2, the surface nearest the Earth is seen first. In case 1 the luminous surface behind the accretion disk from the first emitting surface is seen second; in case 2 it is seen third. Our solution for the statistically more probable case 1 is given by

$$(r, \theta, \epsilon) = (154 \text{ lt-days, } 54^\circ, \ 6^\circ).$$

For the less probable case 2 the equations are again easily written with the same variables:

$$T_1 = r[1 - \sin(\epsilon + \theta)] = 50,$$
$$T_2 = r[1 - \sin(\epsilon - \theta)] = 75,$$
$$T_3 = r[1 + \sin(\epsilon - \theta)] = 230,$$
$$T_4 = r[1 + \sin(\epsilon + \theta)] = 260.$$

Our case 2 solution is

$$(r, \theta, \epsilon) = (154 \text{ lt-days, } 7^\circ, \ 36^\circ).$$

Thus far our discussion has treated the autocorrelation peaks as delta functions and the circular scattering regions detected as very thin and well defined. In fact, the autocorrelation peaks have a mean FWHM of 15 proper lt-days. Thus we compute that the radial extent of the scattering rings is of order 15 lt-days, or $4 \times 10^{16} \text{ cm}$. Such estimates neglect inclination and other effects and are likely to be uncertain by a factor of 2.

The cartoon in Figure 2 has been drawn to approximate scale for the case 1 solution determined above.

4. COMPARISON WITH OTHER ESTIMATES OF QUASAR SIZE

Some inferences about size of the continuum emitting region in the Q0957 quasar have previously been advanced by Schild (1996). These estimates result from application of the Refsdal...
& Stabell (1991, 1993, 1997) theory of the amplitudes of the observed brightness fluctuations, applicable in the case of large quasar accretion disks. Schild showed that the Q0957 accretion disk is large enough for the Refsdal-Stabell theory to be applicable and gave an estimate of the size of the luminous region, expressed as the diameter of a luminous disk if it is assumed that the luminous source is such a structure. In fact, the theory applies to the present geometry just as well as for a solid disk of uniform luminosity as envisaged by Refsdal & Stabell, as long as the dimensions of the structures found are comparable to or larger than the Einstein ring of a microlensing particle. This condition is satisfied here; the radius and thickness of the luminous rings of the biconic structures in the Elvis model are $2 \times 10^{17}$ and $2 \times 10^{16}$ cm, whereas the Einstein ring radius for a half solar mass microlensing particle quoted in Schild (1996) is $2 \times 10^{16}$ cm. Thus it would be expected that the area of the emitting ring as estimated above from geometric factors inferred from metrical size scales should be in approximate agreement.

We start with an estimate of the area of the luminous outer ring as estimated above from geometric factors inferred from autocorrelation peaks and widths. Computing area $A = 2\pi r \Delta r$ with $r = 154$ lt-days or $2 \times 10^{17}$ cm and $\Delta r = 2 \times 10^{16}$ cm, then the total emitting area is $2.4 \times 10^{34}$ cm$^2$. Since two rings are present, the total luminous area estimated from geometric factors is $5 \times 10^{34}$ cm$^2$.

The above estimate can readily be compared with the microlensing based estimate that follows from application of the Refsdal-Stabell (1991, 1993, 1997) theory as previously discussed by Schild (1996); from Schild's diameter estimate we readily compute an estimate of the luminous area as $6 \times 10^{34}$ cm$^2$. We consider the two results to be in reasonable agreement, given that the emission from the luminous inner edge of the accretion disk contributes to brightness fluctuations but has been ignored, and we have assumed that the luminous rings in the Elvis model radiate isotropically. Thus we find two consistent area estimates of the quasar's luminous structure to be approximately $5 \times 10^{34}$ cm$^2$.

We conclude that the data from quasar brightness monitoring consistently indicate large sizes in the continuum emitting structures. This was already anticipated by Schild (1996) when he first computed the quasar size from the brightness fluctuations and noticed that the structure inferred from autocorrelation peaks was larger by a factor of 10; he concluded that “the quasar’s luminous source is structured, and consists of rings or clouds with a 10% filling factor.” The further development of this conclusion has produced the Schild & Vakulik (2003) model that can reproduce all the microlensing phenomena observed to date.

5. SUMMARY AND CONCLUSIONS

We have considered the implications of the autocorrelation analysis of continuum brightness fluctuations in the Q0957 quasar and found that structure on timescales of 200 lt-days is indicated. We have examined how peaks in the autocorrelation function for the two quasar images can be interpreted in the context of the Elvis (2000) model of quasar structure to determine the sizes and positions of the luminous structures, and perhaps the orientation of the quasar to our line of sight. Because the rotation axis is presumably aligned with the $31^\circ$ east of north radio jet (Roberts et al. 1985), we can fully specify the orientation of the quasar in three dimensions.

We do not consider that our analysis of the brightness record proves that the Elvis model is correct. On the one hand, the identification of four peaks produces an overconstrained problem which nevertheless produces a solution that agrees with other estimates of the quasar’s size and in particular the unique parameter $\epsilon$ that describes the height of the rings above the equatorial plane (accretion disk). On the other hand, one of the four autocorrelation peaks is weak (probably for a good reason), and it might be argued that the four correlation peaks have been rather arbitrarily identified with the quasar’s structure for a particular model. Nevertheless, we believe that there is compelling evidence for the existence of some kind of structure on proper time scales of 100 lt-days that affects a significant fraction of the quasar’s luminosity. Other structure on timescales of only several light days is probably also present, and we presume this to be the luminous inner edge of the accretion disk.

The existence of two distinct luminous regions in quasars has long been inferred from quasar spectral energy distributions (Elvis et al. 1994 and earlier references contained therein). Such energy distributions have long been characterized by a power law over a large spectral band extending from approximately the Lyman limit at 1216 Å to the near-infrared. The biconic surfaces are probably responsible for the power-law continuum and cover a radial distance range of approximately $2 \times 10^{16}$ cm. This is also probably the region where the emission lines are emitted, as inferred above. In addition, a “blue bump” has also been recognized as a feature in the ultraviolet, peaking at approximately 3000 Å. We attribute the blue bump to the approximately thermal radiation emitted by the luminous inner edge of the accretion disk, which is probably nearly homogeneous in temperature. The blue bump emitting region had previously been recognized as a spatially distinct region because its brightness has been found to fluctuate independently of the power-law continuum, and its probable partial origin in Fe ii emission lines has been noted (Wills et al. 1985).

Our determination of luminous quasar structure on size scales of 154 lt-days is probably consistent with the Peterson et al. (1991, 1992) determination of size in the emission line forming region of Seyfert galaxy NGC 5548. From their monitoring of brightness fluctuations in the continuum and in the emission lines, these authors concluded that emission lines originate in a region 15 proper lt-days from a luminous continuum source, presumably the luminous inner edge of the accretion disk. The smaller inferred sizes of structures in NGC 5548 are probably consistent with a lower mass central black hole. The Elvis model predicts that emission lines originate on the biconic surfaces of revolution above and below the accretion disk for NGC 5548 and for Q0957, and thus it is likely that the same volume of gas that is producing emission lines in the quasar is also producing the nonthermal continuum, and a characteristic size scale and distance from the center has apparently now been measured.

The existence of multiple emitting regions probably also explains how the quasar can exhibit ultraviolet brightness fluctuations on very short timescales of approximately a day. These rapid brightness fluctuations have long been recognized in quasar optical brightness records (Sandage 1964) and were first reported in Q0957 by Vanderriest et al. (1982), and were already evident in the contemporaneous data of Schild & Weekes (1984). They could most easily arise in the smallest quasar structure that we identify, the inner edge of the accretion disk. We have already shown that the innermost stable orbit in the accretion disk is only 2 lt-days from the center of the black hole for our estimated black hole mass, and our observations of the autocorrelation lags for the inner structure suggest a diameter of approximately $t/(1 + z) = 10/2.41$ lt-days, in agreement with expectations. As emphasized by Schild (1996, 1999), the
failure of time series analysis to easily find a cross-correlation peak with a timescale of 1 day, the normal sampling frequency, suggests that microlensing of these small inner structures must be important. For the normally estimated transverse velocity of the microlensing screen originating in the lens galaxy, 1000 km s$^{-1}$, microlensing particles of $10^{-6} M_\odot$ would cross the luminous structure in a day. Recall that the continuously observed microlensing is measured at an extremely low amplitude, only 0.01 mag, on daily timescales (Schild 1999; Colley & Schild 2003). Note that because the quasar structure might be resolved by the Einstein ring of such small microlenses, the brightness fluctuations might not have a strongly cusplike character. This is largely what is observed; Schild (1996, Figs. 2 and 5) has demonstrated a sharply cusplike microlensing pattern on 90 day timescales, but the more rapid fluctuations, with day timescales, seem less peaked (Colley & Schild 2003).

It is also useful to recall that the radio emission has a component originating in some region with dimensions comparable to those found here. Cross-correlation of the radio brightness records measured at 6 cm with the optical brightness records has shown a time lag of approximately 30 days measured, or 12 proper days (Thomson & Schild 1997; Schild & Thomson 1997a). The radio emission presumably originates in a region above (and below) the accretion disk and evidently is a response to the same disturbances responsible for the ultraviolet brightness fluctuations observed at 6500 Å. Because the radio emission presumably originates in ionized gas being accelerated away from the black hole, it is not surprising that the ultraviolet radiation from the inner edge of the accretion disk is seen first, and our autocorrelation lag of 12 proper days probably represents the difference between light travel time to the accretion disk and to the polar region of brightest radio emission. Thus the radio-bright region centers 16 proper lt-days above the black hole and accretion disk.

It does not escape our attention that the Elvis structures above and below the accretion-disk plane are not a common feature of standard quasar models. However, the mass scale–invariant rotating magnetic models of Romanova et al. (2002, Figs. 16 and 17; 2003, Figs. 2 and 3) feature such outflow structures. These Romanova et al. simulations also feature an inner ring-like structure similar to the inner ring of the Schild & Vakulik (2003) empirical model. The Romanova et al. models are non-relativistic and therefore relevant to the nonrelativistic region where the Elvis structures that they feature form; thus the models are presumably relevant in Galactic black hole candidate objects and in quasars. General relativistic effects will predominate in the region of the inner ring of the Schild & Vakulik (2003) model, and the fully relativistic “magnetic propeller” models of Robertson & Leiter (2002, 2003) feature such an inner ring structure. Such models, when scaled up from stellar to quasar masses, imply that the quasar MECO (magnetic eternally collapsing object) operates in a low-hard spectral state.

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