Optical, UV, and X-ray Clues to the Nature of Narrow Line AGNs

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Abstract

AGNs with narrow Balmer lines show various extreme properties. In particular, rapid X-ray variability, steep X-ray spectra, peculiar optical and UV line ratios, and possibly peculiar line profiles. Since all these phenomena occur together they are likely to be related to one specific underlying physical parameter. I review recent evidence, based on HST imaging of low z quasars, which suggests that the H\(\beta\) line width and continuum luminosity of quasars provide a reasonably accurate estimate of the black hole mass. This implies that narrow-line AGN have relatively low black hole masses, and thus high \(L/L_{\text{Edd}}\), as independently suggested based on their steep X-ray spectra. I present additional evidence suggesting that the X-ray variability and the radio loudness are primarily driven by the black hole mass. The high mass inflow rate into the core of narrow-line AGNs may produce a denser and more enriched BLR, a high column radiation pressure driven outflow, and a smaller illumination angle for the NLR, as suggested by the observed emission line properties. Narrow-line AGNs may thus provide important clues for understanding the rich overall phenomenology of AGNs.

Key words: galaxies: active; quasars: general; quasars: emission lines

1 The Soft X-ray Clues

The term ‘Narrow-Line Seyfert 1 Galaxies’ (NLS1s) was coined by Osterbrock & Pogge (1985) who noted the overall peculiar optical emission-line spectra of Seyfert galaxies with narrow Balmer lines (see Pogge, these proceedings). Follow-up studies of their radio emission and optical polarization properties did not reveal anything outstanding. The first hint for their remarkable X-ray properties was found by Stephens (1989) who noted, based on Einstein data, that “X-ray selection may be an efficient way to find NLS1s.” This conclusion was much strengthened by Puchnarewicz et al. (1992) who found that...
$\sim 50\%$ of their *Einstein* ultrasoft survey AGNs were NLS1s, thus establishing that NLS1s have steeper than usual soft X-ray spectra. This result was further refined by Laor et al. (1994) who noted a remarkably strong correlation between the H$\beta$ FWHM and the *ROSAT* $\alpha_x$ in a sample of 10 PG quasars ($r_s = 0.842$, $Pr = 2 \times 10^{-3}$). This result was further strengthened when the complete sample of all 23 $M_B < -23$, $z < 0.4$, $N_{HI} < 1.9 \times 10^{20}$ cm$^{-2}$, PG quasars was analyzed (Laor et al. 1997a, hereafter L97; $r_s = 0.79$, $Pr = 7 \times 10^{-6}$). Boller, Brandt & Fink (1996) studied a large sample of NLS1s with *ROSAT* and noted the clear absence of broad line AGNs with a steep $\alpha_x$. However, they found a much larger scatter in the H$\beta$ FWHM vs. $\alpha_x$ relation. In particular, some of their NLS1s show normal $\alpha_x$ values, unlike the sample of L97 where all narrow-line quasars display steep $\alpha_x$ values. This difference most likely results from the large luminosity range of the AGNs in the Boller et al. sample. In particular, a plot of $\alpha_x$ vs. $L_X$ for the Boller et al. sample (using the data in their Table 1) reveals a clear trend of flattening of $\alpha_x$ with decreasing $L_X$. All the flat ($\alpha_x > -2$) NLS1s in the Boller et al. sample have low luminosity ($L_X < 1.3 \times 10^{44}$ erg s$^{-1}$), and all their luminous AGNs ($L_X > 1.3 \times 10^{44}$ erg s$^{-1}$) are steep ($\alpha_x < -2$). Thus, the Boller et al. sample indicates that a significant H$\beta$ FWHM vs. $\alpha_x$ correlation appears in bright AGNs, and not when lower luminosity Seyferts are included, consistent with the strong correlation in the Laor et al. sample which includes only $M_B < -23$ PG quasars. The H$\beta$ FWHM vs. $\alpha_x$ correlation thus involves luminosity as well. The luminosity dependence can be understood if the primary driver of this correlation is $L/L_{Edd}$, rather than just the H$\beta$ FWHM (see §2). It will be interesting to explore if lower luminosity AGNs do follow an H$\beta$ FWHM vs. $\alpha_x$ correlation, but offset towards flatter $\alpha_x$.

2 What Underlies the $\alpha_x$ vs. H$\beta$ FWHM Correlation?

The $\alpha_x$ vs. H$\beta$ FWHM correlation is remarkably strong. Excluding luminosity luminosity correlations, it is the strongest of the 294 different correlations measured by L97 (§3.1 there). Why should the 0.2–2 keV continuum slope, most likely generated by the inner accretion disk ($R \sim 2 - 10R_g$), have anything to do with the width of the Balmer lines produced in the Broad Line Region (BLR, $R \sim 10^4R_g$)? The strength of this correlation suggests that both parameters are controlled mostly by a single physical parameter. What is this parameter?

First, what is the width of the Balmer lines telling us? As discussed in various papers (e.g. Puchnarewicz et al. 1992; Laor et al. 1994; Boller et al. 1996), there are three plausible explanations: 1. The BLR velocity distribution is anisotropic, and in NLS1s we have a face-on view of a flattened BLR. 2. The distance of the BLR from the center is non-uniform, and in NLS1s it may be
larger than usual. 3. The black hole mass is non-uniform, and in NLS1s it may be lower than usual.

What is the steepness of $\alpha_x$ telling us? White, Fabian & Mushotzky (1984), and more recently Pounds, Done & Osborne (1995), noted a possible analogy of AGNs to Galactic Black Hole candidates, where $\alpha_x$ becomes steeper in their ‘high state.’ Pounds et al. therefore suggested that NLS1s, are ‘high state,’ or high $L/L_{\text{Edd}}$ AGNs. This suggestion basically overlaps explanation # 3 above for the narrow H$\beta$. A narrow H$\beta$ implies a low $M_{\text{BH}}$, therefore a high $L/L_{\text{Edd}}$, and therefore a steep $\alpha_x$.

Why should the H$\beta$ FWHM be so strongly tied to $M_{\text{BH}}$? This can be understood with the following two assumptions: 1. The BLR velocity field is dominated by gravity, i.e. $\Delta v^2 \simeq GM_{\text{BH}}/R_{\text{BLR}}$ (see recent evidence in Peterson & Wandel 1999). 2. The size of the BLR is set by the bolometric luminosity, specifically $R_{\text{BLR}} = 0.1L_{46}^{1/2}$ pc, where $L \equiv L_{\text{Bol}}$. The $L^{1/2}$ dependence is indirectly inferred by the weak, if any, dependence of the BLR clouds' density and ionization on luminosity, and it is expected theoretically if the gas in AGNs is dusty (Netzer & Laor 1993). It is experimentally verified in reverberation mappings of AGNs (Kaspi et al. 2000, though apparently with a somewhat steeper slope of $\sim 0.7$). Combining the two expressions for $M_{\text{BH}}$ and $R_{\text{BLR}}$ gives $m_9 = 0.18\Delta v_{3000}^2 L_{46}^{1/2}$, where $M_{\text{BH}} = 10^9 m_9 M_{\odot}$, and therefore $L/L_{\text{Edd}} = 0.44\Delta v_{3000}^{-2} L_{46}^{1/2}$ (Laor 1998). Luminous AGNs with narrow H$\beta$ thus have particularly high $L/L_{\text{Edd}}$, but low luminosity Seyferts with a similar H$\beta$ width, will have a lower $L/L_{\text{Edd}}$. This may explain why low luminosity NLS1s in the Boller et al. sample do not have a steep $\alpha_x$, they may simply not have a high $L/L_{\text{Edd}}$.

The $L/L_{\text{Edd}}$ interpretation thus seems to provide a very appealing explanation for the H$\beta$ FWHM vs. $\alpha_x$ correlation. But, how reliable is the $M_{\text{BH}}(\Delta v, L)$ determination? This mass estimate has been around for many years (e.g. Dibai 1981; Wandel & Yahil 1985; Padovani & Rafanelli 1988; Peterson et al. 1998), but it was generally viewed as highly uncertain. Possible problems include: 1. $R_{\text{BLR}}(L)$ is determined through reverberation mostly in AGNs with “normal” $\Delta v$. Do NLS1s simply have a larger $R_{\text{BLR}}(L)$? 2. $L$ may be anisotropic. Is $R_{\text{BLR}}$ in NLS1s larger because the BLR sees a brighter ionizing continuum than we do? 3. $v$ may be anisotropic. Is the BLR in NLS1s simply seen ‘face-on’? 4. $v$ may be dominated by radiation or magnetic pressure, and thus not related to $M_{\text{BH}}$.

Given this host of possible systematic effects, one cannot attach a reliable error bar to $M_{\text{BH}}(\Delta v, L)$ (though recent reverberation studies suggest that problems #1 and #4 may not be significant). Below, I describe recent new evidence that provides an indirect check on the $M_{\text{BH}}(\Delta v, L)$ estimate, and indicates it is most likely accurate to within a factor of 2–3.
3 An Independent Check of the $M_{\text{BH}}(\Delta v, L)$ Estimate.

Magorrian et al. (1998, and references therein) have recently obtained two outstanding results: 1. Most (possibly all) early type galaxies host a Massive Dark Object (MDO) at their center, most likely a massive black hole. 2. The MDO mass is correlated with the bulge mass. These results, if true, have a fundamental impact on our understanding of quasar and galaxy formation and evolution (e.g. Kauffmann & Haehnelt 2000).

The Magorrian et al. study is based on HST observations of an unbiased sample of 36 nearby early type galaxies (i.e. their selection was independent of a priori knowledge about core kinematics). They combined ground based spectroscopy with HST imaging and constructed simplified kinematic models with a constant $M/L$ plus a spatially unresolved MDO. Their simplified model allowed an acceptable fit in 32 galaxies. In 31 of these galaxies a MDO is allowed (best fit $M_{\text{MDO}} > 0$), and in 26 it is required (at $> 95\%$ significance level). The $M_{\text{MDO}}$ vs. $M_{\text{bulge}}$ correlation found in this study cannot be a selection effect since 31/32 MDOs were detected. A study which is based on a compilation of all published results would be strongly biased, as non detections are generally not published, and the minimum detectable $M_{\text{MDO}}$ is strongly correlated with $M_{\text{bulge}}$. This bias is not present in the Magorrian et al. study, and unless their $M_{\text{MDO}}$ values are wrong, the correlation they find is highly significant. Ongoing spectroscopy with HST should significantly improve the kinematic constraints on $M_{\text{MDO}}$.

How is all of the above related to quasars? The first hint came from the study of McLeod & Rieke (1995), who found that there is an upper limit for the quasar luminosity at a given host luminosity, a limit which grows roughly linearly with the host luminosity. McLeod (1997) speculated that this limit may be $L_{\text{Edd}}$, if $M_{\text{BH}}$ has an upper limit in a host of a given luminosity, and if this limit increases with the host luminosity.

Do quasar hosts follow the $M_{\text{BH}}$ vs. $M_{\text{bulge}}$ correlation suggested for normal galaxies? To explore this, one needs a high-quality sample of quasars (uniform, well defined, complete), with a high quality data set on their host luminosity. The closest we could get to this ideal is with the PG sample. Bahcall et al. (1997) and Kirhakos et al. (1999) provide careful and systematic measurements of the host luminosities of 23 quasars imaged with HST, of which 15 are PGs. Boroson & Green (1992, BG92) gives high quality spectroscopy, and Neugebauer et al. (1987) provide well calibrated spectrophotometry. Combining $L$ and $\Delta v$ provides $M_{\text{BH}}(\Delta v, L)$. Figure 1 presents the bulge luminosity vs. $M_{\text{BH}}$ relation for these 15 PG quasars, together with the distribution of the nearby galaxies from Magorrian et al. The quasar correlation is highly significant ($1.74 \times 10^{-3}$); it also overlaps the distribution of nearby galaxies,
and it indicates a non-linear $M_{BH}$ vs. $M_{bulge}$ relation. A least-squares fit to the quasars gives $M_v(bulge) = -21.76 - (1.50 \pm 0.38) \log m_9$, which implies $M_{BH} \propto M_{bulge}^{1.4}$, unlike the linear relation proposed by Magorrian et al. It is interesting to note that the three most accurate $M_{BH}$ determinations, M 87, NGC 4258, and the Galaxy, agree well with the non-linear quasar relation, as does the only NLS1 in the Bahcall et al. sample, NAB 0205+024.

Fig. 1. The bulge luminosity vs. $M_{BH}$ relation for nearby normal galaxies (Magorrian et al.) and for PG quasars (Laor 1998). The positions of the three most accurate $M_{BH}$ determinations are indicated. NAB 0205+024 is a NLS1 from Bahcall et al.

The overlap of the PG quasar and the Magorrian et al. galaxy distributions in Fig.1 is remarkable given the fact that these are apparently unrelated types of objects, and that one is using completely different methods to measure $M_{BH}$. This overlap suggests that the $M_{BH}(\Delta v, L)$ estimate in quasars is probably accurate to a factor $\sim 2-3$, and provides the first indirect check for $M_{BH}(\Delta v, L)$. Is $M_{BH}$ directly related to some of the peculiar emission properties of NLS1s?

4 X-ray Variability and $M_{BH}$.

One of the outstanding properties of many NLS1s is their rapid and large amplitude soft X-ray variability (e.g. Boller et al. 1996 and references therein). More systematic results came from the pilot study of Fiore et al. (1998), who observed a complete and unbiased small sample of six PG quasars which included the three narrowest and three broadest H\textbeta quasars in the L97 sample. All the steep quasars varied significantly on a $10^5-10^6$ s timescale, while none of the flat $\alpha_x$ quasars did (both groups varied similarly on the $10^7$ s timescale), hinting at a strong correlation between X-ray variability and H\textbeta FWHM.

The variability of a much larger and heterogeneous sample of AGNs was explored by Turner et al. (1999) on a $10^4$ s timescale. They recovered the well
known variability vs. luminosity correlation, but discovered there is a much
tighter correlation of the variability amplitude with the H\(\beta\) FWHM. A quali-
tatively similar result was obtained by Leighly (1999), who found that NLS1s
obey the variability amplitude vs. \(L\) relation of broad-line AGNs, but were
displaced upwards towards larger variability amplitudes at a given \(L\). What
is the underlying physical parameter which controls these trends? Is it \(M_{\text{BH}}\),
or possibly \(L/L_{\text{Edd}}\)?

Comparison with GBHCs provides some clues. GBHCs can vary significantly
down to ms timescales, and most likely harbor a few \(M_\odot\) black holes. Seyfert
galaxies can vary significantly down to ks timescale, and most likely harbour
\(\sim 10^7 - 10^8 \ M_\odot\) black holes. Based on this simple empirical fact, it appears
plausible that the variability timescale (at a fixed variability amplitude) is
roughly proportional to \(M_{\text{BH}}\). This can occur if flux modifying disturbances
have some characteristic velocity in the X-ray emitting region (independent
of absolute luminosity), and if the size of this region scales with mass (i.e. it
is fixed in units of \(R_g = GM/c^2\)).

Turner et al. provide \(L_x\) and H\(\beta\) FWHM for all their objects. I used these
parameters to obtain a rough estimate of \(M_{\text{BH}}\) and \(L/L_{\text{Edd}}\). For objects with
more than one value of \(\sigma_{\text{RMS}}^2\) in the Turner et al. paper, I used a mean value
(this reduces the scatter). Figure 2 presents plots of the correlations of \(\sigma_{\text{RMS}}^2\)
with \(L_x\), H\(\beta\) FWHM, and with the combinations roughly proportional to \(M_{\text{BH}}\)
and \(L/L_{\text{Edd}}\) (Spearman \(r\) and probabilities are indicated in each panel). The
correlation of \(\sigma_{\text{RMS}}^2\) with \(M_{\text{BH}}\) is the strongest (significance level \(5.5 \times 10^{-9}\)),
which suggests that \(M_{\text{BH}}\) is the underlying physical parameter which drives the
observed dependence of the X-ray variability on luminosity and on line width.
AGNs may have a universal power spectrum density (PSD) of X-ray fluctua-
tions, and \(M_{\text{BH}}\) may just set the timescale at a given amplitude (Hayashida,
these proceedings). Interestingly, there appears to be a certain \(L/L_{\text{Edd}}\) above
which the mean \(\sigma_{\text{RMS}}^2\) increases by a factor of \(\sim 10\). This may reflect a qual-
itative change in the nature of the X-ray variability. Does the inner, X-ray
emitting, accretion disk become strongly unstable above a certain fraction of
\(L_{\text{Edd}}\)?

Leighly (1999) provides similar data for a partly overlapping sample which
includes only NLS1s. This sample shows significantly weaker correlations, which
may be partly due to the smaller ranges in H\(\beta\) FWHM and \(L\) covered by
that sample. A proper study of the above correlations requires a much more
systematic study of a well defined sample, including accurate bolometric lumi-
nosities, and high-quality optical spectroscopy. Particularly careful analysis is
required for low luminosity AGNs where NLR and host galaxy contaminations
can be significant.
NLS1s are, with very few exceptions, radio quiet. The few radio-loud NLS1s are only marginally loud (Siebert et al. 1999), and may be intrinsically radio-quiet quasars where a weak jet is beamed at us. Why are there no radio-loud NLS1s? In fact, why are there no radio-loud Seyferts? Recent studies with HST have clearly demonstrated that all radio-loud quasars reside in elliptical (or interacting) galaxies, and that all quasars with spiral hosts are radio quiet. Being radio loud means having a powerful jet. The jet is formed within a mpc of the center, where the massive black hole resides. The fundamental puzzle is how does the inner mpc know about the host type? The answer may lie in the $M_{\text{BH}}$ vs. $M_{\text{bulge}}$ correlation. The jet formation is set by the black hole, and the black hole properties are related to the bulge properties. Spirals have small bulges, thus small black holes, and these do not produce powerful jets. On the other hand, bright ellipticals generally host very massive black holes, and these always channel much of the accreting gas into powerful relativistic outflows. Is the production of powerful jets directly related to the black hole mass?

This question can be explored directly, without using any information about the host properties. Figure 3 shows a plot of $R$ vs. $M_{\text{BH}}(L, \Delta v)$ for all 87 PG quasars from the BG sample, where $R \equiv f_{\delta \text{GHz}}/f_{\text{opt}}$ is taken from Kellerman et al. (1989). The answer appears to be positive. All quasars with $M_{\text{BH}} > 10^9 M_\odot$ are radio loud, and practically all quasars with $M_{\text{BH}} < 3 \times 10^8 M_\odot$ are radio quiet. This then provides a phenomenological understanding of why
Seyferts (inc. NLS1s), which do not have very massive bulges, are practically always radio quiet, and why radio-loud quasars require hosts with massive bulges. The remaining puzzle is why should the formation of a powerful jet be so critically dependent on $M_{\text{BH}}$?

6 Clues from the UV Emission Lines & Other Clues

Careful systematic studies of the UV emission line properties of complete samples of radio-quiet AGNs are beginning to emerge, and these clearly indicate that narrow-line AGNs have characteristic spectra, which are different from those of normal AGNs (e.g. Wills, these proceedings). The best studied NLS1 galaxy in the UV is the prototype, I Zw 1 (Laor et al. 1997b). Below I’ll briefly describe some of our results and what they may imply.

I Zw 1 shows unusual emission line properties. In particular, very weak C III], strong Al III, strong Fe III, and generally strong low ionization lines. Wills et al. (1999) explored a sample of 22 PG quasars, and found that the properties of I Zw 1 are common among NLS1s. In addition they found that many of the UV emission line properties show strong trends with the H\textbeta FWHM. The observed trends probably reflect an increase in the density and metallicity of the BLR as the H\textbeta FWHM decreases.

I Zw 1 also displays interesting trends among its UV emission line profiles. The line peaks get progressively more blueshifted as the ionization level increases, rising from zero shift for O I, Mg II, and Si II, to 250–500 km s$^{-1}$ for Ly$\alpha$, Si III], C III], and Al III, to $\sim$ 900 km s$^{-1}$ for C IV and N V, and finally to $\sim$ 2000 km s$^{-1}$ for He II. This trend is seen in other AGNs as well,
but the amplitude of the blueshifts in I Zw 1 is about 4 times larger than in typical AGNs. In addition, the UV lines develop increasing excess blue wing flux with increasing ionization. These trends may be interpreted as an outflowing component in the BLR, which is seen on the approaching side, but is obscured on the receding side (due to a disk?). The outflowing gas needs to get progressively more highly ionized as its velocity increases. We may actually be observing the edge of this outflow in I Zw 1, as it shows a weak absorption system in Lyα, N V, C IV, and Si IV with a blueshift of 1870 km s\(^{-1}\).

Is such an outflowing BLR component typical of NLS1s? We do not know yet, but one can speculate as to why it may be common. Bright NLS1s have a high \(L/L_{\text{Edd}}\). Radiation pressure which is incident on the BLR clouds must ablate a surface layer and drive an outflow. The radiation pressure can overcome gravity in a surface layer with a column density of \(N_H \leq 1.5 \times 10^{24} L/L_{\text{Edd}} \text{ cm}^{-2}\). Thus, the outflows in high \(L/L_{\text{Edd}}\) AGNs will be relatively thick, and may have enough emission measure to produce a noticeable contribution to the UV emission lines which comes from the denser cores of the BLR clouds. As the velocity of the outflow increases, its density drops (due to mass continuity), and its ionization state increases, thus explaining the observed profile trends with ionization level.

The UV and X-ray absorption properties of NLS1s may also be different from those of normal AGNs, as further discussed in Brandt et al. (2000), and Brandt (these proceedings). NLS1s also show peculiar optical emission line ratios, in particular strong Fe II, and weak [O III], as is clearly established in the seminal BG paper. These correlations were in fact already noted by Boroson & Oke (1984) and Boroson, Persson, & Oke (1985), who found that the above parameters also correlate with the host galaxy colors, the equivalent width of the extended [O III] emission, and the radio morphology. Amazingly enough, Boroson et al. suggested already back then that the underlying physical parameter was \(L/L_{\text{Edd}}\)\! This suggestion was based on the notion that the weakness of [O III] (extended and nuclear) is due to the thicker accretion disk which collimates the ionizing continuum over a smaller solid angle, and reduces the NLR illumination. It is remarkable that this suggestion was again reached based on each of the following unrelated properties; rapid X-ray variability, steep X-ray slope, and the narrow H\(\beta\).

7 Should the Definition of NLS1s be Revised?

Yes, in part. The current working definition for NLS1s is [O III]/H\(\beta\) < 3 and H\(\beta\) FWHM\(\leq\) 2000 km s\(^{-1}\). The first part is well justified. A given solid angle of the NLR typically produces equivalent widths [O III]:H\(\beta\) \(\simeq\) 10 : 1, while the same solid angle at the BLR produces about [O III]:H\(\beta\) \(\simeq\) 0 : 1. Thus,
\[ \text{[O III]} : \text{H} \beta \simeq \Omega_{\text{BLR}} \times 0 : 1 + \Omega_{\text{NLR}} \times 10 : 1 < 3 \rightarrow \Omega_{\text{BLR}}/\Omega_{\text{NLR}} > 2, \text{ i.e. it ensures that } > 2/3 \text{ of H} \beta \text{ is from the BLR. The narrowness of H} \beta \text{ is thus most likely not just an NLR contamination effect (though it’s always better to verify that by subtracting a properly scaled \[ \text{[O III]} \] profile from H} \beta \).}

What about the H\beta FWHM criterion? The observed distribution of H\beta FWHM is not bimodal, and thus there is no natural H\beta FWHM cutoff for NLS1s (in contrast with, e.g., R of radio loudness). Furthermore, it is now clear that NLS1s lie at the extreme end of a continuous distribution of emission properties, and therefore the specific H\beta FWHM cutoff is obviously arbitrary. The crucial question is what underlying extreme physical parameter are we interested in? If we are looking for high \( L/L_{\text{Edd}} \) objects, say \( L/L_{\text{Edd}} > 1 \), that translates (see §2) to \( \Delta v < 2000L_{46}^{1/4} \text{ km s}^{-1} \). Thus, the H\beta FWHM cutoff needs to be luminosity dependent.\footnote{The BG database suggests that \( \Delta v_{\text{min}} \sim 2000L_{46}^{1/4} \text{ km s}^{-1} \), i.e. \( L/L_{\text{Edd}} \leq 1 \)} For example, an \( M_V = -27 \) quasar with H\beta FWHM\( \sim 2000 \text{ km s}^{-1} \) should have about the same \( L/L_{\text{Edd}} \) as an \( M_V = -22 \) Seyfert with H\beta FWHM\( \sim 600 \text{ km s}^{-1} \). If one is looking for low \( M_{\text{BH}} \) objects (e.g. for rapid X-ray variability), say \( M_{\text{BH}} < 10^7 M_\odot \), that translates to \( \Delta v < 700L_{46}^{-1/4} \text{ km s}^{-1} \), i.e. one can accommodate broader lines as one goes to lower \( L \).

8 Conclusions, Speculations and Open Questions

The highly simplified \( M_{\text{BH}}(\Delta v, L) \) estimate in quasars appears to be accurate to within a factor of about 2-3. NLS1s thus most likely have a relatively low \( M_{\text{BH}} \), and if they are not very faint, a relatively high \( L/L_{\text{Edd}} \). The rapid X-ray variability of NLS1s is mostly due to their low \( M_{\text{BH}} \), but there may also be some enhancement of variability for NLS1s with the highest \( L/L_{\text{Edd}} \). NLS1s, and Seyferts in general, are radio quiet most likely because of their relatively low \( M_{\text{BH}} \). The UV lines suggest the BLR is denser and possibly more enriched. A possible scenario is that the high \( L/L_{\text{Edd}} \) results from large amounts of gas being dumped into the center of the galaxy. This increased accretion rate brings in denser gas (implied by the UV line ratios), enhances star formation rate and therefore metalicity (implied by the strong N V), and possibly blocks most of the NLR illumination (implied by the weak narrow lines). The increased \( L/L_{\text{Edd}} \) may enhance the column of the radiation-pressure ablated surface layer in the BLR (implied by the UV line profiles).

Clearly, there are many open questions which need to be addressed to reliably establish or disprove the above scenario. Specifically: 1. Do NLS1s follow the \( M_{\text{BH}} \) vs. \( L_{\text{bulge}} \) relation? The best way to proceed here is to extend the analysis of Bahcall et al. and Kirhakos et al. to lower luminosity PG Quasars which
qualify as NLS1s. 2. How tight is the X-ray variability vs. $M_{\text{BH}}$ relation? One needs a well defined sample, high quality optical spectroscopy, and long X-ray integrations (if the PSD is non-stationary). 3. Do NLS1s generally show the UV emission-line profile trends seen in I Zw 1? One needs high-quality UV spectroscopy for a well defined sample of NLS1s, and the PG sample can again be a very useful parent sample. 4. Are AGN absorption outflows related to $L/L_{\text{Edd}}$? The ideal route here is to survey the UV absorption properties of AGNs spanning a large range in $L$ and in $L/L_{\text{Edd}}$ (the PG sample again!). 5. What controls the strength of [O III]? Is it the NLR gas covering factor? Ionization state? Density? A careful study of various line ratios in the NLR is required for a conclusive answer. 6. What controls the other intriguing correlations noted by Boroson et al (host colors, extended [O III], and radio morphology)? Follow-up studies of these correlations with higher quality data is the first step required here.

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