Cume #332 16 February 2008

The questions below were motivated by a reading of the paper entitled "Are the black hole masses in Narrow Line Seyfert 1 galaxies actually small?" by Roberto Derail, *et. al.*., a copy of which is attached.

There are nine (9) questions and all count equally. Number your answers (so I can tell which question you are answering) and staple your answer sheets together, preferably in question-order, so nothing gets lost. Your name on the pages helps. Sketches are good. Turn in your papers by 12:00 noon.

(The "added notes" were added after viewing the results of this cume.)

1. What are Seyfert galaxies? What are the observational distinctions between Seyfert 1 and Seyfert 2 galaxies?

Seyfert galaxies are defined (Seyfert 1943) as galaxies which show a bright unresolved ("stellar") nucleus which displays a spectrum of strong and broad emission lines. Seyfert's galaxies were all spirals. Emission lines are broad, with velocity widths ~500 km/s for the forbidden lines, and a wide range of ionization is represented. In about a quarter of these objects the permitted emission lines are much broader than the forbidden lines, with wings of width ~5,000 km/s or more; these are now designated as Seyfert 1 galaxies. Those in which the forbidden and permitted lines are of similar width are Seyfert 2 systems. (Note that there are sub classifications such as Seyfert 1.5 or Seyfert 1.8 *etc.*, based upon the relative strengths of the broad and narrower components of the permitted lines , and other spectroscopic criteria.) Seyfert galaxies are a subset of galaxies with active nuclei (AGN); this broader group includes the quasistellar objects, broad-line radio galaxies, N-galaxies, *etc.* The spectroscopic distinctions between Type 1 and Type 2 AGN are the same as for the Seyferts - the presence or absence of a much broader permitted line component.

Added Note: Again, Seyfert galaxies are defined by their optical morphology and nuclear line spectra. The type distinction is based upon the presence or absence of a broader permitted line component. X-ray emission, radio characteristics, variability, etc., are not defining criteria. The Seyfert galaxies are the prototypes of the AGN class.

2. What is the broad line region (BLR) and how is it physically and kinematically different from the narrow line region (NLR)?

It is generally accepted that the broadening of the lines in AGN is Doppler broadening and reflects the dispersion in the line-of-sight velocities of the emitting gas clouds. In that case, the broad line region (BLR) responsible for the broader components seen in permitted lines must be kinematically and spatially distinct from the regions (NLR) giving rise to the forbidden lines and the narrower components of the permitted lines. The NLR occupies a considerably larger spatial volume that the BLR; it is spatially resolved in some objects where the BLR is not. Moreover, the broad emission line components sometimes show temporal variations indicating physically small dimensions (*e.g.*, light-days) whereas the narrow line components do not. The absence of forbidden line emission from the smaller higher-velocity BLR is generally attributed to higher densities in the BLR; the forbidden line emission being suppressed by collisional processes at these higher densities.

Added Note: Collisional deexcitation of a forbidden line component in the BLR is really the only plausible mechanism to explain the absence of a broader forbidden line component in Type 1 AGN. Note that a narrower permitted line component (at least for the hydrogen lines) generally does arise from the NLR.

3. Nomenclature: What is meant by an "Fe II emission line" ? In what respects is it different from an " [O III] emission line" ? Finally, what is meant by an Hβ line with FWHM ≥ 2000 km/s?

An Fe II emission line results from permitted downward transitions in singly-ionized iron atoms. The [O III] emission arises from forbidden transitions in doubly-ionized oxygen. "Forbidden" simply means that the spontaneous transition probability is very small; such lines are generally excited by collisions, the permitted lines usually by the recombination cascade following ionization. The Hβ line ($4 \rightarrow 2$) is a permitted Balmer ($n \rightarrow 2$) transition in neutral hydrogen. FWHM stands for "full width at half maximum" and refers to the width of the line profile at half its peak intensity. In the present instance this is expressed as a velocity width, $\Delta v = c\,\Delta\lambda/\lambda$ or $c\,\Delta\nu/\nu$. FWHM = 2000 km/s corresponds to an Hβ line (λ = 4861Å) with a width about FWHM = 32Å in wavelength units.

Added Note: The forbidden lines are so designated because the transitions violate one or more of the selection rules for transitions between pure states (*e.g.*, that $\Delta l = \pm 1$). Their transition probabilities (or A-values) are not zero, just many orders of magnitude smaller than those for permitted transitions. Forbidden lines are generally excited by collisions; the permitted lines generally arise during radiative recombination cascades.

4. Why might someone think that the "customarily used [OIII] line is not a reliable surrogate for the stellar velocity dispersion"? (Subject is the width of the [OIII] line.)

The [OIII] line arises in a tenuous gaseous component which is subject to many forces (*e.g.*, forces due to radiation, fields, other gas components, ...) which generally have negligible effects on stellar motions. These forces can be particularly important in an AGN. Stellar kinematics are generally associated only with gravitational interactions. It is not at all obvious that the large-scale kinematics of the gas clouds, especially the global velocity dispersions, should be the same as for the stellar population, even if they share a common spatial volume - which they probably do not. (That the present work uses the [OIII] line width in this way greatly weakens their arguments and renders their conclusions suspect - in my opinion]

Added Note: Note also that the stellar velocity dispersion that is of interest in the M_{BH} - σ^*relation is that characterizing the whole bulge and its stellar mass. The [OIII] widths characterize the motion of the gas - and probably not the stars - in a very small and probably unrepresentative part of the bulge.

5. What's the "reverberation mapping technique"?

The broad components of the permitted emission lines in some AGN exhibit temporal variations, apparently in response to (observed) variations in a (central?) continuum source. The associated delay suggests a configuration in which a central variable source undergoes a change in brightness which propagates outward to alter the physical state (ionization) and emissivity of the surrounding line-emitting gas. An overall time delay between continuum and line variations $\Delta\tau$ implies a dimension for the line emitting region of $R \sim c\Delta\tau$. Similarly the "rise times" of the continuum and line variations provide upper limits to the dimensions of the continuum source and the line emitting regions, respectively. For a compact continuum source embedded in a gas which responds promptly to changes in the local radiation field, the surfaces of constant time delay are paraboloids of revolution about the line of sight opening toward the observer. In principle, one should be able to extract information about the the spatial geometry and velocity fields of the BLR from observations of temporal variations in line profiles. In practice, estimates of BLR dimensions have been the best that can be achieved. It remains unclear whether the basic kinematics of the BLR in AGN are best described as inflows, outflows, rotation, turbulence, or something else. Even the symmetry (or lack thereof) is a matter of some ignorance.

Added Note: The fundamental idea here is that an extended object can't vary significantly in brightness over times shorter than R/c. I was hoping someone would make reference to "superluminal" motions or nova light echoes....

6. In section 2 reference is made to the AGN "unification model" (of Antonucci & Miller,1985). What is this unification model? What is its geometrical basis? (Draw a picture. Also, see question 9 below.)

The "unification model" envisions the structure of AGN as consisting of a central black hole and continuum source, presumably fed by an accretion disk, centered in a much larger "torus" of obscuring matter (dust). The BLR lies close to the central region and is of limited spatial extent so that this region (as well as the continuum source) is obscured by the torus when the system is viewed far from the symmetry axis of the torus. Objects so viewed would be classified as Type 2 (Seyfert 2) systems since only the NLR, which has extent considerably greater than the torus thickness, remains largely unobscured. Viewed from more modest angles one sees the emission form the continuum source, the BLR, and the NLR and the system would be classified as Type 1.

Added Note: The aim of the unification model was to interpret the differences between Sy1 and Sy2 systems in terms of just an inclination effect. This was accomplished by positing the existence of a dusty "torus" centered on the main activity region which would obscure the continuum source and the BLR when the system was viewed at large inclination angels. The presence of this torus, and a small BLR region within its "hole" is critical to the modes. X-rays, jets, radio properties, etc., played little rôle inn this model. We see nearly face-on galaxies with Seyfert 1 nuclei so the plane of any accretion disk need not coincide with the galactic plane - and the dust in the (distant) galaxy disc cannot be blamed for the Sy1-Sy2 distinction.

7. What is the Eddington Luminosity L_{Edd} and what is the significance of the Eddington ratio L/L_{Edd}? Derive an expression for L_{Edd}, defining your terms and their associated units.

The Eddington luminosity is the luminosity at which the outward mechanical force of radiation just equals the inward force of gravity. If the actual luminosity exceeds the Eddington luminosity the inflow of material necessary to fuel an accretion process should cease, so the Eddington luminosity should be a upper limit to the luminosity of an accretion-driven source. So what is the outward force of radiation? If κ (cm^2/gm) is the opacity of the gas (the cross section per unit mass of the material) then the rate of energy intercepted per unit mass is $L\kappa/4\pi r^2$ (erg/sec gm) and the momentum interception rate is $L\kappa/4\pi cr^2$ (cm/s^2). Setting this equal to the gravitational acceleration GM/r^2 gives the Eddington luminosity $L_{Edd} = 4\pi GMc/\kappa$. The opacity depends upon the composition and state of the absorbing or scattering gas; it is usually taken to be the electron scattering opacity which is $\sim 0.4 cm^2/gm$.

Added Note: "Radiation pressure" and "the mechanical force of radiation" are two very different things. An isotropic radiation field, or radiation in a medium which interacts not with the radiation, can have an immense radiation pressure but exert zero force on the matter. It is the mechanical force of radiation which is important in the present context. Note that assuming $L/L_{Edd} < 1$ the observed luminosity L provides an lower limit to the interior mass.

8. Derive, or at least justify, the form used to calculate (estimate) the black hole mass in equation (1).

Application of the virial theorem (2T+V =0) gives the result from: $m_{gas}<v_{gas}^2> - GM_{BH}m_{gas}/R_{gas}$
The purist will note that this presumes an equilibrium configuration with $M_{BH} >> m_{gas}$ and with the gas at some "characteristic radius" R_{gas}. But at least it isn't too restrictive as to velocity distribution. Consider matter in a circular Keplerian orbit at radius r and with velocity v about a (dominant) central mass M. Equating the centrifugal acceleration to the gravitational acceleration gives $v^2/r = GM/r^2$. Rearrangement gives $M = v^2R/G$ which is (1). This is less general than invoking the virial theorem, presuming rotational motions at a single v and R. Finally, the escape velocity (or free infall velocity) at R, which gives $M = 2v^2R/G$. This is neither a steady state nor equilibrium situation. The point, really, is that while equation (1) provides a useful estimator for the black hole mass, it depends upon some assumptions regarding the dynamic state of the system (Is it dynamically relaxed or not? Can non-gravitational forces be ignored?) and makes use of observationally-based estimators for "typical" speeds and dimensions. One can hope that the BLR of AGN are similar enough to one another in basic structure and scaling that something like (1) can, at least, provide consistently biased estimators for their masses.

Added Note: Again, this mass estimate is just that, an estimate, since it relies on untested assumptions about the state of equilibrium and the spatial and kinematic geometry of the BLR. One might worry about the extent to which M_{BH} might be underestimated, given that $L/L_{edd} \sim 0.1$ or so.

9. Derive the expression for R_{NLS1} given in section 2. What is the critical angle θ_{cr} for NLS1 if they constitute 15% of all Sy1 systems - and 40° is the critical angle for Sy1 systems? What fraction of all Seyferts (Sy1+Sy2) are Seyfert 1 (NLS1 +BLS1) systems in this scenario?

Consider a set of randomly oriented objects which have well-defined symmetry axes. The *a priori* probability of observing an object at an angle between θ and $\theta + d\theta$ with respect to the symmetry axis is $dP(\theta) = \sin\theta \, d\theta$, where we take the range of θ-values to lie the interval $[0, \pi/2]$, with $\theta = 0$ corresponding to a "face-on" geometry. The probability of a viewing angle in the interval $[\theta_1, \theta_2]$ where $0 \le \theta_1 < \theta_2 \le \pi/2$ is obtained by integrating dP over this interval; this gives

$$P(\theta_1, \theta_2) = \cos\theta_1 - \cos\theta_2 \qquad 0 \le \theta_1 < \theta_2 \le \pi/2$$

For example, the fraction of all Seyfert systems which are Sy1 systems is, given a value of 40° for the maximum inclination beyond which the torus hides the BLR:

$$P(0°, 40°)/P(0°, 90°) = (1 - \cos 40°)/1 = 0.234$$

Actually one normally uses the observed incidence to infer the critical angle(s). ("About a quarter" gives about 41°). For example, about 15% of the Sy1 systems seem to fall in the NLS1 category. Given that these are taken to be the more nearly face-on Sy1 galaxies, we would have, for the "critical angle":

$$R_{NLS1} = P(0, \theta_{cr})/P(0°,40°) = (1 - \cos\theta_{cr})/(1 - \cos 40°) = 0.15, \text{ or } \theta_{cr} = 15.2°$$

Added Note: The inclination distribution $dP(\theta) = \sin\theta\, d\theta$ for randomly oriented objects comes up in the discussion of stellar rotation, binary star studies, and many other areas.

I didn't include the following uestion because I wanted to shorten the cume and wasn't sure if it was reasonable to expect that our first-year students would be familiar with the Tully-Fisher or Jackson-Faber relations

X. The paper states that σ^* is the "stellar velocity dispersion." What stars and what velocity is meant here? The M_{BH} - σ^* relation mentioned is essentially that the value of M_{BH}/σ^{*4} seems to be the same for all galaxies (excepting, perhaps the NLS1 systems discussed in this paper). What does this relation imply? (Hint: What are the Jackson-Faber and Tully-Fisher Relations?)

* The empirical M_{BH} - σ^*relation (check reference) is based upon measurements of the stellar velocity dispersion, not that of the [OIII] emitting gas. Using the latter as a "surrogate" for the former is probably unwise. Any correlation between BLR line widths and NRL line widths may provide some clues to the structures of active regions in AGN but probably provides no independent information about any black hole versus bulge mass relation. Indeed, has it been established that the [OIII] widths are correlated with BLR widths or with stellar velocity dispersions in other NLS1 and Sy1 systems? Answer: Yes. See references to Xu (Zhou *et al.*) and Botte*et al.* both of which indicate that widths of [OIII] significantly overestimate stellar dispersion line widths σ^* by factors ~2 and hence bulge masses by factors ~4. Botte *et al.* get a M_{BH} - σ^* relation that seems to fit the Tremaine, *et al.* relation reasonably well for their sample of 10 galaxies. However, Zhou, *et al.*, using a very much larger sample (~2000 galaxies) , find that most NLS1s fall systematically below this relation in terms of black hole mass at a given σ^*.

The empirical M_{BH} - σ^*relation (Tremaine, *et al.*, 2002) is essentially that $M_{BH} = K\sigma^{*4}$, where K is a constant. The Tully-Fisher relation for spiral galaxies gives $L \propto \sigma^{*4}$ whereas the Jackson-Faber relation gives $L \propto \sigma^{*4}/B$ for ellipticals, where B is the average surface brightness. In either case $M \propto \sigma^{*4}$ if one makes the assumption that the M/L ratio is the same for the members within either class. In the present context the implication is, then, that the M_{BH} - σ^* relation implies that $M_{BH} \propto M_{bulge}$for all galaxies - that all galaxies contain a black hole within their centers, whether active or quiescent.

Some Added Notes:

#1: Low excitation emission lines (HII, [OI], [NI], *etc.*) are observed in the disk and bulge regions of most spiral galaxies, but these are not usually confined to a "stellar" nuclear region nor are they very broad. The velocity width (FWHM) of spatially unresolved emission lines is typically ~100 km/s or less, characteristic of the disc rotational velocities in these galaxies. The "narrow" emission lines in Seyferts and other AGN are generally much wider with ~500 km/s being typical. The "broad" components observed in the permitted lines (principally HI, HeI, and HeII)of Type 1 Seyferts and AGN have widths in excess of ~1000 km/s with ~5000 km/s being fairly representative.

#2, 3: Again, the permitted lines are formed during recombination following (photo-) ionization. The forbidden lines, on the other hand are collisionally excited, mostly by electron collisions with ground-state ions. Generally emitting gas the gas in AGN (and in HII regions generally) is heated by photionization while the cooling is dominated by collisionally excited forbidden lines.

#4: In fact the [OIII] line widths roughly correlated with the line widths of the stellar component but the dispersion is large. That is, the first is a rather poor surrogate for the second in any given object.

#5: The idea is that, in principle, one should be able to take a time varying line intensity profile $F(\Delta v, t)$ arising from an observed continuum variation $F(t)$ and derive a density distribution $n(r)$ and a velocity distribution $v(r)$for the emitting species. In practice, it is also necessary to make additional assumptions about the geometry of the emitting regions to do this.

#6: In some Seyfert 2 galaxies on can actually see BLR line emission which has been scattered by electrons in the NLR well above the obscuring torus. That this is scattered BLR light is indicated by its polarization.

#7: The "traditional" Eddington Luminosity was invoked in the context of massive and hot stars where electron scattering could reasonably be assumed to dominate the opacity in the atmosphere as well as in the interior. Other opacity sources (even including absorption or scatering by grains) can be important in cooler situations. Generally one exptects the "true" limiting luminosity to be somewhat lower than that calculated assuming electron scattering alone.

#8: Remember that the virial theorem applies to equilibrium configurations and that not all steady-state configrations are equilibrium configurations. Infall (radial, disc-accretion) and outflow (stellar or nuclear winds, jets) are not equilibrium configutations.

#9: There does not seem to be any indication that the symmetry axes of AGN, as defined by a disk axis or jet orientation, are terribly well correlated with the axes of the parent galaxies.

Summary

The authors' argument is that the anomalously low M_{BH} values derived for NLS1 systems are obtained using $f = 1$, whereas values $f \sim 3$ are more appropriate for NLS1 _if_ the BLR geometry of all Seyfert 1 systems is basically disk like. (The BLR gas flows, whether rotational or radial, would be largely confined to the disk plane in this picture.) This increases the corresponding MBH masses by factors $f^2 \sim 10$ and decreases the Eddington ratio by a similar factor. This is just what is needed to bring derived NLS1 masses into agreement with the M_{BH} - σ^* relation that seems to prevail among other AGN. But what are the _other_ properties distinguishing NLS1 systems form BLS1 systems which are consistent (or inconsistent) with a disc like geometry?

More Comments

* It is _not_ the case, as asserted in the paper, that $f = (3/4)^{1/2} = 0.866$ for an isotropic velocity distribution; its value depends upon the form of the distribution as well as its isotropy. For an isotropic Gaussian (*e.g.*, Maxwellian) distribution of velocities $f = (3/8\ln 2) = 0.736$, whereas for an isotropic expanding (or contracting) spherical shell, $f = 1/2 = 0.500$. It _is_ the case that for an isotropic velocity distribution with velocity variance σ^2 the variance characterizing the width of the line profile will be $\sigma^2/3$.

* Equation (3) asserts that an annular region of a disk rotating with Keplerian velocity will give a profile with FWHM = $2v_{kep}\sin\theta$ where θ is the inclination angle of the disc with respect to the observer. That is true, but it should be noted that the line profile emerging from such a disk will be a "horned" profile with a central minimum of the form $(1 - \xi^2)^{-1/2}$ where $\xi = v/v_{kep}\sin\theta$. For such a profile the peaks at the horns formally diverge at $v = \pm v_{kep}\sin\theta$ and FWHM is equal to the full width $2v_{kep}\sin\theta$. However, $v_{kep} = \sqrt{GM/r}$ so that different annuli will provide profiles of different widths. The FWHM will be defined by the innermost and fastest rotating annulus that contains emitting gas.

* It is hard to see how equation (4) was really motivated, much less derived. The emergent profile will depend not only upon the velocities at various locations in the disk (not just a single "typical" velocity) weighted by the gas densities and emissivities at these locations. Moreover, any characteristic turbulent velocity dispersion would be expected to vary with location.

Jackson-Faber and Tully-Fisher Relations

Consider a uniform spherically symmetric equilibrium configuration of total mass M and radius R which is in static equilibrium. From the virial theorem we would have

$$\langle v^2 \rangle = 3GM/5R \qquad (1)$$

where $\langle v^2 \rangle$ is the mean square velocity distribution of the component mass elements. Note that the mean square velocity dispersion in one direction σ^2 will be a third of this value for isotropic velocity distributions. For a more general class of mass distribution in equilibrium we expect

$$\sigma^2 = \alpha GM/R \qquad (2)$$

where $\alpha \sim 1$ is a dimensionless constant of order unity whose exact value depends upon the details of the configurations geometry. Note that we get similar forms for the escape velocity or free fall velocity or circular keplerian velocity in the vicinity of a point mass M

$$v_{esc}^2 = v_{ff}^2 = 2GM/R \quad \text{and} \quad v_{circ}^2 = GM/R \qquad (3)$$

Furthermore we expect that the velocity distribution of any one component, m, of the total mass M would also exhibit a velocity dispersion given by (2) above. We rewrite (2) as

$$M = \sigma^2 R/\alpha G \qquad (4)$$

Now σ^2 is, at least in principle, directly observable as a broadening of spectral lines, but R is not. What is directly observable is the average surface brightness within radius R as projected on the plane of the sky:

$$B = F/\Omega = L/4\pi R^2 = (4\pi d^2 F)/(4\pi d^2 \Omega) = F/\Omega \qquad (5)$$

Here F/Ω is the observed flux within the solid angle Ω on the sky subtended by a circle of radius R at distance d, and L is the luminosity produced by the mass M within R. From (5)

$$R = (L/4\pi B)^{1/2} \qquad (6)$$

We now <u>assume</u> that the matter within R is characterized by some mass-to-light ratio

$$M/L = \kappa. \qquad (7)$$

Then (6) can be written as $\quad R = (M/4\pi\kappa B)^{1/2} \qquad (8)$

Inserting this in (4) then gives

$$M = (4\pi\kappa\alpha^2 G^2)^{-1} (\sigma^4/B) \qquad (9)$$

or $\quad L = (4\pi\alpha^2 G^2)^{-1} (\sigma^4/B) \qquad (10)$

Note that σ^4 is the square of the mean-square one-dimensional velocity distribution. The latter is an observable - as is B. For a class of objects sharing geometrical similarities corresponding to a common value of we have $\quad L \propto (\sigma^4/B) \qquad (11)$

which provides the "theoretical" underpinning for the empirical <u>Jackson-Faber Relation</u> for elliptical galaxies. If members of a class also have similar surface brightness distributions and share a common value of B then $\quad L \propto \sigma^4 \qquad (12)$

This forms the basis for the empirical <u>Tully-Fisher Relation</u> for spiral galaxies*. The relation $L = K\sigma^4$, with K determined from nearby galaxies of known distances, can then be used to ascertain distances for galaxies from measurements of tie apparent brightnesses and velocity dispersions.

*Most spiral galaxies have exponential surface brightness distributions of the form

$$B(r) = B_o \exp(-r/r_o)$$

characterized by a range of scale lengths r_o but a common value of the central surface brightness B_o. If B is always defined as the average surface brightness within within the angular radius at which has fallen to exp(-x) of its observed central value B_o, where x is given *a priori* , then

$$B = (2B_o/x^2)[1 - (1 + x)e^{-x}]$$

which would be that same for all objects sharing a common central value. For x = 1, $B = 0.528 B_o$, for example.

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Are the black hole masses in Narrow Line Seyfert 1 galaxies actually small?

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ABSTRACT

Narrow Line Seyfert 1 galaxies (NLS1s) are generally considered peculiar objects among the broad class of Type 1 active galactic nuclei, due to the relatively small width of the broad lines, strong X–ray variability, soft X–ray continua, weak [O III], and strong Fe II line intensities. The mass $M_{\rm BH}$ of the central massive black hole (MBH) is claimed to be lighter than expected from known MBH–host galaxy scaling relations, while the accretion rate onto the MBH larger than the average value appropriate to Seyfert 1 galaxies. In this *Letter*, we show that NLS1 peculiar $M_{\rm BH}$ and $L/L_{\rm Edd}$ turn out to be fairly standard, provided that the broad line region is allowed to have a disc–like, rather than isotropic, geometry. Assuming that NLS1s are rather "normal" Seyfert 1 objects seen along the disc axis, we could estimate the typical inclination angles from the fraction of Seyfert 1 classified as NLS1s, and compute the geometrical factor relating the observed FWHM of broad lines to the virial mass of the MBH. We show that the geometrical factor can fully account for the "black hole mass deficit" observed in NLS1s, and that $L/L_{\rm Edd}$ is (on average) comparable to the value of the more common broad line Seyfert 1 galaxies.

Key words: galaxies: active - galaxies: nuclei - galaxies: Seyfert

1 INTRODUCTION

Seyfert 1 galaxies (Sy1s) are often divided into two distinct classes, namely Broad Line Sy1s (BLS1s), whose Hβ line has FWHM $\gtrsim$ 2000 km/s (hence, as standard Type 1 AGN), and Narrow Line Sy1s (NLS1s), with lower velocities (e.g., Goodrich, 1989). NLS1s are a minority, $\simeq$ 15% of all the Sy1s, according to the optical spectroscopic classification of the SDSS general field (Williams Pogge & Mathur, 2002), the fraction depending on the AGN luminosity (with a peak at $M_{g'} \sim -22$), and on the radio loudness (radio loud NLS1s account only for $\sim$ 7% of the class, Komossa et al., 2006, but it is still debated if the NLS1s can be considered a peculiar radio-quiet sub-class among Sy1s, see e.g. Sulentic et al. 2007; Doi et al. 2007). NLS1s also show weak [O III] and strong Fe II emission line (Osterbrock & Pogge, 1985), strong variability, and a softer than usual X–ray continuum (Boller Brandt & Fink, 1996; Grupe et al., 1999).

Grupe & Mathur (2004) found that NLS1s have, on average, lower $M_{\rm BH}$ than expected from $M_{\rm BH}$–host galaxy relations such as $M_{\rm BH}$–σ_* (see Tremaine et al., 2002, and references therein), while BLS1 $M_{\rm BH}$ are in fairly good agreement to the same relation. The estimated low values of $M_{\rm BH}$ lead to an average Eddington ratio $L/L_{\rm Edd}$ for the NLS1 population which is almost an order of magnitude larger than the average value of BLS1s ($L/L_{\rm Edd} \simeq 1$ to be compared to $\simeq 0.1$, Grupe, 2004). Further evidence of low $M_{\rm BH}$ in NLS1s comes from the observed rapid X–ray variability (see., e.g., Green, McHardy & Lehto 1993, and Hayashida 2000).

Such results were interpreted as indications of a peculiar role of NLS1s within the framework of the cosmic evolution of MBHs and of their hosts. In a MBH-galaxy co-evolution scenario, NLS1s are thought to be still on their way to reach the $M_{\rm BH}$-σ_* relation, i.e., their (comparatively) small MBHs are highly accreting in already formed bulges. Recently Botte et al. (2005) and Komossa and Xu (2007) came to the conclusion that NLS1s have indeed smaller masses and higher $L/L_{\rm Edd}$ than BLS1, nevertheless they both do follow the $M - \sigma_*$ relation for quiescent galaxies. The authors argued that the customarily used [O III] line is not a reliable surrogate for the stellar velocity dispersion σ_*.

The Grupe and Mathur's results and interpretation have been recently confirmed and supported by several other groups, see, e.g., Zhou et al. (2006) and Ryan et al. (2007). Ryan et al. (2007) pointed out that IR-based mass measurements might be unreliable because of the extra IR contribute from the circum-nuclear star-forming regions in NLS1s. Notwithstanding, they suggested that this contamination can not significantly affect their data, and thus is insufficient to account for the MBH mass deficit. In the aforementioned papers, $M_{\rm BH}$ was computed as

$$M_{\rm BH} = \frac{R_{\rm BLR} v_{\rm BLR}^2}{G}, \quad (1)$$

where $R_{\rm BLR}$ is the broad line region (BLR) scale radius, and $v_{\rm BLR}$ the typical velocity of BLR clouds. $R_{\rm BLR}$ is found by means of the reverberation mapping technique (Blandford & McKee, 1982), or by exploiting statistical $R_{\rm BLR}$–luminosity relations (see Kaspi et al., 2000, 2005 and 2007); $v_{\rm BLR}$ can be inferred from the Hβ width as

$$v_{\rm BLR} = f \cdot {\rm FWHM}, \quad (2)$$

where the FWHM refers only to the broad component of the line, and f is a fudge factor which depends upon the assumed BLR model. For an isotropic velocity distribution, as generally assumed, $f = \sqrt{3}/2$.

Labita et al. (2006) and Decarli et al. (in preparation) found that in QSOs an isotropic BLR fails to reproduce the observed line widths and shapes, and a disc model should be preferred. A disc–like geometry for the BLR has been proposed by several authors in the past (e.g., Wills & Browne 1986; Vestergaard, Wilkes & Barthel 2000; Bian & Zhao, 2004). In this picture, the observed small FWHM of NLS1 broad lines are ascribed to a small viewing angle with respect to the disc axis, and no evolutionary difference is invoked whatsoever.

In this *Letter*, we adopt the disc–like model for the BLR of Seyfert galaxies. We use the observed frequency of NLS1s to estimate their typical viewing angle, and then compute the appropriate geometrical factor f. Using eq. 1, we will show that the new estimates of $M_{\rm BH}$ for NLS1s nicely agree with the standard $M_{\rm BH}$–σ_* relation. In turn, the accretion rate of the class is found to be similar to that of BLS1s.

2 MODEL AND RESULTS

We model the BLR as a thin disc, and define ϑ as the angle between the line of sight and the normal to the disc plane. The FWHM is a measure of the velocity projected along the line of sight. In the assumption of a 2–D, keplerian BLR, the observed FWHM is correlated to the rotational velocity of the disc as following:

$$\text{FWHM} = 2\, v_{\rm kep} \sin\vartheta, \quad (3)$$

where $v_{\rm kep}$ is the keplerian velocity of the disc–like BLR. In this model the differences between the FWHM of NLS1s and BLS1s depend only on ϑ, so that the Sy1s observed nearly face–on are classified as NLS1s, while the ones observed at higher angles are considered BLS1s. As mentioned in the introduction, the fraction of NLS1s we consider is $\simeq 15\%$. In our unification scheme, the relative fraction $R_{\rm NLS1}$ is related to the maximum inclination angle of the subclass $\vartheta_{\rm cr}$ as $R_{\rm NLS1} = (1-\cos\vartheta_{\rm cr})/(1-\cos\vartheta_{\rm max})$, where $\vartheta_{\rm max} \sim 40^o$ is the maximum inclination angle for Type-I AGNs in the unification model (e.g., Antonucci & Miller, 1985; Antonucci, 1993; Storchi–Bergmann, Mulchaey & Wilson, 1993).

Some authors suggested that the BLR can not be completely flat (see, e.g., Collin et al., 2006). Alternatively, discs may have a finite half thickness (H), or a "flared" profile

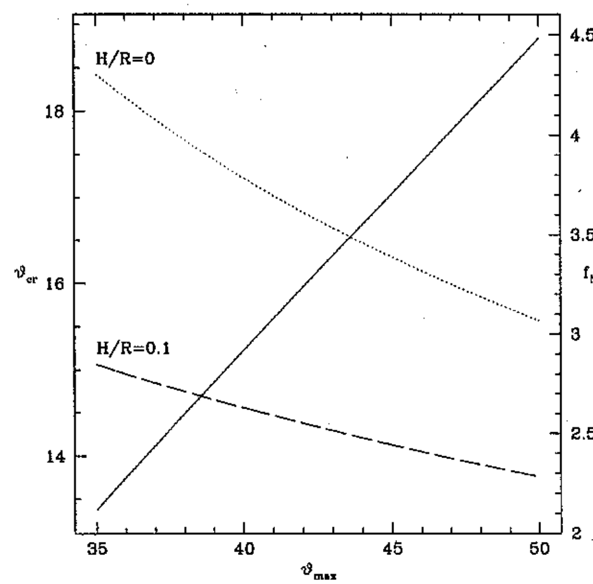

Figure 1. The dependence of $\vartheta_{\rm cr}$ (red, solid line) and $f_{\rm NLS1}$ on $\vartheta_{\rm max}$. The blue, dashed line and the magenta, dotted line refer to values $f_{\rm NLS1}$ calculated assuming $H/R = 0.1$ and 0 respectively.

(with H increasing more than linearly with the disc radius R, see, e.g., Dumont & Collin-Souffrin, 1990). Other models proposed include warped discs (Wijers & Pringle, 1999), and the superposition of discs and wind components (Murray & Chiang, 1995, 1998; Elvis, 2000; Proga & Kallman, 2004). In this *Letter* we employ the simplest model, i.e., a disc with finite thickness, a choice minimizing the number of required parameters. As it will be shown in the following, this minimal set–up can resolve the apparent dichotomy between NLS1s and BLS1s.

In a finite thickness disc model for the BLR, the geometrical factor f, as defined in equation 2, is related to the inclination angle ϑ of the disc as

$$f = \left[2\sqrt{\left(\frac{H}{R}\right)^2 + \sin^2\vartheta}\right]^{-1}. \quad (4)$$

The ratio H/R is related to the relative importance of isotropic (e.g. turbulent) vs rotational motions. The average geometrical factor for each class, $f_{\rm NLS1}$ and $f_{\rm BLS1}$, is computed by averaging equation 4 over the relevant solid angle ($0 < \vartheta < \vartheta_{\rm cr}$ for NLS1s, $\vartheta_{\rm cr} < \vartheta < \vartheta_{\rm max}$ for BLS1s).

Fig. 1 shows the dependence of $\vartheta_{\rm cr}$ and $f_{\rm NLS1}$ on $\vartheta_{\rm max}$, with $35^o \lesssim \vartheta_{\rm max} \lesssim 50^o$. The critical angle ranges between 13^o and 19^o, while $f_{\rm NLS1}$ is found between $\simeq 3$ and 4.5 in the limit $H/R = 0$, and between $\simeq 2.2$ and 2.9 for $H/R = 0.1$. We also find $0.9 \lesssim f_{\rm BLS1} \lesssim 1.2$ independently of $0 < (H/R) < 0.1$.

We adopt a fiducial value $\vartheta_{\rm max} = 40^o$, leading to $f_{\rm NLS1} \simeq 3.8$ and $\simeq 2.6$ for $H/R = 0$ and $H/R = 0.1$, respectively, and $f_{\rm BLS1} \simeq 1$.

The new estimates of the geometrical factor allow us to reconsider the values of $M_{\rm BH}$ for the sample of Sy1s presented in Grupe & Mathur (2004), who instead employed

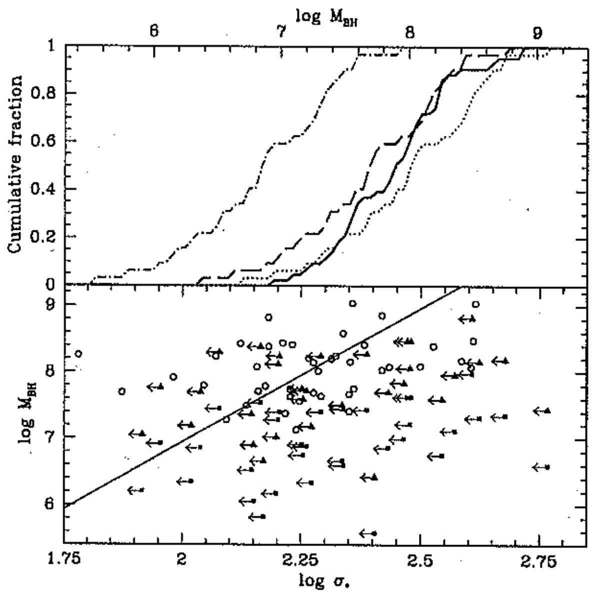

Figure 2. *Upper panel* – the cumulative fraction distribution of Grupe & Mathur (2004) sample as a function of $M_{\rm BH}$. The black, solid line refers to BLS1s, after applying our correction. The red, dot-dashed line refers to NLS1s with $f_{\rm NLS1} = \sqrt{3}/2$. The blue, dashed and the magenta, dotted lines refer to NLS1s assuming $H/R = 0.1$ and 0, respectively. *Lower panel* – the distribution of Grupe & Mathur (2004) sample on the $M_{\rm BH}$–σ_* plane. Black, empty circles refer to BLS1s, when $f_{\rm BLS1} \simeq 1$ is adopted. Red, filled squares are NLS1 values, using $f_{\rm NLS1} = \sqrt{3}/2$. Blue filled triangles refer to the NLS1s after the correction described in the text, assuming $H/R = 0.1$. The arrows highlight that the values of σ_* for NLS1s have to be considered upper limits, as discussed in the text. The Tremaine et al. (2002) relation is also plotted for comparison.

a fixed $f = \sqrt{3}/2$ for all objects. Our results are shown in Fig. 2. In the *upper panel* the blue long–dashed (magenta dotted) line refers to the corrected $M_{\rm BH}$ of NLS1s for $H/R = 0.1$ ($H/R = 0$). NLS1 black hole masses are increased by $\simeq 0.84$ ($\simeq 1.16$) dex, while BLS1 black hole masses by a mere $\simeq 0.05$ ($\simeq 0.07$) dex, with respect to the Grupe & Mathur values. The mass distributions for the two classes are now remarkably similar, without any significant difference between NLS1s and BLS1s.

The *lower panel* of Fig. 2 shows the BLS1 and NLS1 populations in the $M_{\rm BH}$–σ_* plane. The black, empty circles refer to BLS1s, assuming $f_{\rm BLS1} \simeq 1$. The red, solid squares are NLS1s for $f_{\rm NLS1} = \sqrt{3}/2$, while the blue solid triangles refer to the NLS1s after the correction described in the text is applied, assuming $H/R = 0.1$. The estimates of σ_* are from Grupe & Mathur (2004), and are derived from [O III] line width. It should be noted that, as Botte et al. (2005) and Komossa & Xu (2007) pointed out, the [O III] surrogate poorly correlates with σ_* measured from stellar absorption lines, so that the plotted σ_* values have to be considered upper limits, as indicated by the arrows. This caveat is particularly important for X–ray selected samples, as the one used here (Marziani et al., 2003), as wind components to [O III] lines may be significant.

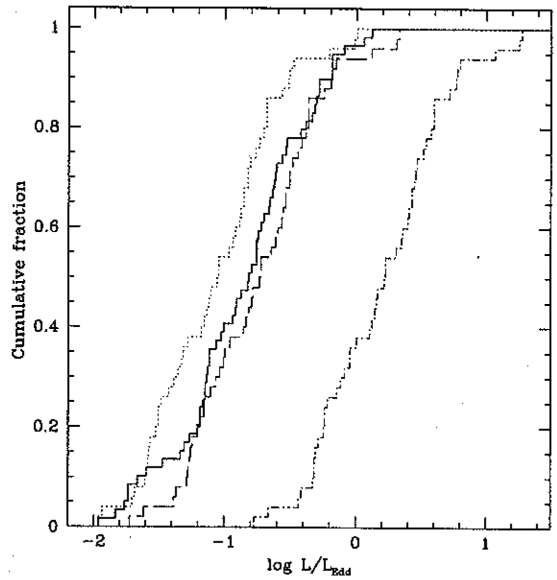

Figure 3. Cumulative fractions of NLS1s and BLS1s as a function of the Eddington ratio. The color/line–type code is the same as in Fig.2, *upper panel*.

We can now estimate the corrected Eddington ratio for the same sample (Grupe, 2004). The cumulative fractions of NLS1s and BLS1s vs $L/L_{\rm Edd}$ are shown in Fig. 3. Not surprisingly, having comparable luminosities, and now, comparable masses, NLS1s and BLS1s radiate at the same Eddington ratio. This result supports the pole-on orientation model for NLS1s.

3 DISCUSSION AND CONCLUSIONS

In this *Letter*, we have assessed the claimed peculiarity of Narrow Line Seyfert 1 galaxies within the framework of cosmic evolution of massive black holes, and their host bulges. Indeed, the optical properties of NLS1s, their X–ray fast variability and the faintness of their bulges can be accounted for if one admits lower black hole masses and higher accretion rates (in Eddington units) than standard Broad Line Seyfert 1 galaxies (BLS1s), placing NLS1s in an early evolutionary stage (Grupe & Mathur, 2004; Grupe, 2004; Botte et al., 2004; Zhou et al., 2006; Ryan et al., 2007). If this is true, by observing local NLS1s we can have hints of the infancy of the ubiquitous population of super–massive black holes.

We have explored an alternative explanation to the narrowness of Hβ lines in NLS1s, namely, pole–on orientation of a disc–like broad line region. If BLS1s and NLS1s differ only by the observation angle of the BLR disc, the frequency of NLS1s among the Syl class gives the limiting viewing angle of NLS1s. Then, assuming $H/R \lesssim 0.1$ for the disc, we computed corrected geometrical factors linking the observed FWHM to $M_{\rm BH}$, and found $f_{\rm NLS1} \gtrsim 2$ and $f_{\rm BLS1} \simeq 1$, in agreement with recent estimates given by Labita et al. (2006). The idea of a disc–like BLR is not new (e.g., Wills

& Browne 1986; Vestergaard, Wilkes & Barthel 2000; Bian & Zhao, 2004), but for the first time, by re-calculating masses and Eddington ratios for a sample of Sy1s, we found that mass and luminosity functions are similar for NLS1s and BLS1s. In a sense, we can say that all Sy1s are normal, but some are more "normal" than others.

We note that, though NLS1s seem to lie in the same region of the $M_{\rm BH}$–σ_* plane, the adopted σ_* values can be largely over-estimated (Komossa & Xu, 2007; Mullaney & Ward, 2007), and then firm conclusions on the $M_{\rm BH}$–σ_* issue can not be drawn at this stage.

Can a simple orientation model, as the one we adopted here, explain the unique observed properties of NLS1s? NLS1s differ from standard Sy1s not just in the width of optical lines, but, more noticeably, in what are their X–ray properties, both spectral and temporal. The X–ray emission of NLS1s has been studied and discussed in great details by, among others, Boller et al. (1996), using *ROSAT* data, and by Brandt, Mathur & Elvis (1997) using *ASCA* data. NLS1s have generally both soft and hard X–ray spectra which are steeper than normal Sy1s, and show large amplitude, rapid variability. Boller et al. (1996) showed how different models, invoking extreme values of one or more of the followings: pole–on orientation, black hole mass, accretion rate, warm absorption, BLR thickness, all explain some aspects of the complex NLS1 soft X–ray phenomenology, but, still, all appear to have drawbacks.

If pole–on orientation has to be the main cause of the uniqueness of the X–ray features of NLS1s, then a necessary condition is that the hard power–law emission is not intrinsically isotropic, e.g., a thermal extended corona (as in Haardt & Maraschi, 1991; 1993) is not a viable option. Models in which the X–rays of type I radio quiet AGNs are funneled or beamed have been proposed by several authors (e.g., Madau, 1988; Henri & Petrucci, 1997; Malzac et al., 1998; Ghisellini, Haardt & Matt, 2004). For example, Ghisellini et al. (2004) showed that an aborted jet model, in which X–rays are produced by dissipation of kinetic energy of colliding blobs launched along the MBH rotation axis, can explain the steep and highly variable X–ray power law. The model, in its existing formulation, does not allow clear predictions of spectral and temporal features other than in the X-rays. To assess its relevance for NLS1s would require a much more detailed modeling. In particular, the peculiar Fe II and [O III] properties must be accounted for.

The statistics of radio-loud NLS1s is low. In several works the existence of differences in the radio properties between NLS1s and BLS1s has been discussed (see, e.g. Komossa et al. 2006; Zhou et al. 2006; Sulentic et al. 2007; Doi et al. 2007). Doi et al. (2007) suggested that ~ 50 % of radio-loud NLS1s are likely associated with jets with high brightness temperatures, requiring Doppler boosting. This interpretation supports the pole–on orientation model (for a different point of view see Komossa et al. 2006).

Our results, if confirmed, indicate that a population of accreting, undermassive MBHs (with respect to the $M_{\rm BH}$–σ_* relation) has to be found yet. This may suggest that the $M_{\rm BH}$–σ_* relation was established long ago, during the MBH accretion episodes following the first major mergers of the host galaxies. Moreover, Komossa & Xu (2007) found that NLS1s do follow the $M_{\rm BH}$–σ_* relation of non–active galaxies, but still they have smaller $M_{\rm BH}$ and larger $L/L_{\rm Edd}$ than BLS1s. If this is the case, then σ_* of the host bulges of NLS1 needs to evolve accordingly in order to preserve the $M_{\rm BH}$–σ_* relation, or, alternatively, NLS1s are the low mass extension of BLS1s, and the NLS1 high $L/L_{\rm Edd}$ is a short–lived phenomenon. We note here that the interpretation of Komossa & Xu (2007), as well as the one of Grupe & Mathur (2004), implies that $M_{\rm BH}$ and $L/L_{\rm Edd}$, in principle independent quantities, somehow conspire to produce comparable luminosities as observed in NLS1s and BLS1s. Applying our correction to the $M_{\rm BH}$ as well as the one to the σ_* proposed by Komossa & Xu (2007), the NLS1s would be even off–setted towards higher masses with respect to the $M_{\rm BH}$–σ_* relation.

There are however two possible problems with the pole–on orientation model. First, according to the orientation model, the polarization properties of broad emission lines should depend on the inclination angle, in the sense that nearly pole–on Sy1s should not be polarized. However, Smith et al. (2004) found polarized broad lines in few NLS1s, and traces of broad Hα polarization were also found by Goodrich (1989) in 6 out of 17 NLS1s. A second issue is discussed by Punsly (2007), who finds larger line broadening in face–on quasars, possibly due to large isotropic gas velocities or winds.

In conclusion, we found that orientation effects can account for the different optical properties of NLS1s compared to the more common BLS1s. The model is particularly appealing, as it naturally sets masses and accretion rates of NLS1 to fairly standard values. To validate this interpretation, orientation must be able to explain the extreme X–ray properties of NLS1. Jetted models for radio quiet AGNs may be promising in this, and we urge a detailed, critical comparison of such models with the bulk of NLS1 data.

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