AGN Physics with the Sloan Digital Sky Survey
*ASP Conference Series, Vol. **VOLUME***, 2004*
G.T. Richards and P.B. Hall, eds.

The Intimate Link Between Accretion and BELR

Fabrizio Nicastro
Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA

A. Martocchia
Observatoire Astronomique, 11 Rue de l'Université, F–67000 Strasbourg, France

G. Matt
Dipartimento di Fisica, Università Roma Tre, Via della Vasca Navale 84, I-00146 Roma, Italy

Abstract. In this paper I present evidence suggesting that the absence or presence of Hidden Broad Line Regions (HBLRs) in Seyfert 2 galaxies is regulated by the rate at which matter accretes onto a central supermassive black hole, in units of Eddington. I discuss the above findings in the context of a model proposed by Nicastro (2000), in which the existence of the BLRs is regulated by the disk accretion rate. For low enough accretion rates, the disk is stable, and the BLRs do not form.

1. Introduction

In the framework of orientation-based unificaton schemes (Antonucci, 1993), type-2 AGN are believed to be intrinsically the same as type-1 AGN, but seen at different angles (i.e. edge-on *versus* pole-on). This scenario was first proposed by Antonucci & Miller (1985) to explain the presence of polarized broad lines in the archetypical Seyfert 2 (Sy2), NGC 1068, and is now supported other than by spectropolarimetric observations of Hidden Broad Emission Line Regions (HBLRs) in several other sources, also by X–ray observations, which demonstrate that Sy2s have usually absorption columns largely exceeding the Galactic ones.

Despite observations do generally support orientation-based unification models for AGNs, important exceptions do exist. Purely orientation based unification schemes, for example, fail to account for all of the observed differences between two sub-classes of type 1 AGN: normal Seyfert 1s (Sy1s), and the so called Narrow Line Seyfert 1s (NLSy1s). NLSy1s have [OIII]/Hβ ratio typical of type-1 sources, but also BEL FWHM narrower than 2000 km s^{-1}. They also differ significantly from Sy1s in the X-rays, where they show much steeper soft (0.1-2 keV: Boller et al., 1996) and hard (2-10 keV: Brandt et al. 1997; Leighly, 1999a) continua, as well as faster variability (Leighly, 1999b). It has been suggested that the black hole mass, or the accretion rate, or both (e.g. Pounds et

al. 1995; Laor et al. 1997; Nicastro, 2000: hereinafter N00) are responsible for the observed differences between Sy1s and NLSy1s.
More importantly, orientation-based models fail in their fundamental prediction: only about 50 % of the brightest Seyfert 2s show the presence of HBLRs in their polarized optical spectra, while the remaining half do not (Tran, 2001; Gu & Huang, 2002).

Here I present evidence that suggests that the absence or presence of HBLRs is regulated by the ratio between the X-ray luminosity and the Eddington luminosity which, in the accretion–powered scenario, is a measure of the rate at which matter accretes onto the central supermassive black hole. This evidence is consistent with the model proposed by N00, in which the BLRs are formed due to accretion disk instabilities occurring in proximity of the critical radius at which the disk changes from gas pressure dominated to radiation pressure dominated. This radius diminishes with decreasing $\dot{m}$; for low enough accretion rates (and therefore luminosities), the critical radius becomes smaller than the innermost stable orbit, the disk is not longer unstable, and so BLRs do not form. Under the Keplerian assumption, this model is able to reproduce the whole range of observed BEL FWHM in AGN, as a function of the accretion rate in units of Eddington, and so also to explain the observed difference in BEL-FWHM between Sy1s and NLSy1s.

1.1. The Model

The model is based on two basic assumptions: (a) a vertical disk wind, originating at a critical distance in the accretion disk, is the origin of the BEL-Clouds (BELCs), and (b) the widths of the BELs are the Keplerian velocities of the accretion disk at the radius where the wind arises. The wind forms because of the existence of Lightman-Eardley (Lightman & Eardley, 1974) instabilities in the radiation pressure dominated region of a Shakura-Sunyaev (SS) disk (Shakura & Sunyaev, 1973), and so for external accretion rates higher than a minimum value below which a standard SS-disk is stable and extends down to the last stable orbit. The region of the disk where the wind forms is bound internally by the transition radius between the radiation pressure and gas pressure dominated parts of the disk,

$$r_{tran} f^{-16/21} \simeq 15.2(\alpha m)^{2/21} \left(\frac{1}{\eta}\dot{m}\right)^{16/21}, \tag{1}$$

and externally by the radius at which, in the context of the dynamical disk-corona model proposed by Witt, Czerny and Zycki in 1997 (WCZ97), the fraction of energy dissipated in the corona ($(1-\beta) \simeq 0.034(\alpha f \frac{1}{\eta}\dot{m})^{-1/4} r^{3/8}$) is maximum (see N00 for additional details) [1] :

$$r_{max} f^{-2/3} \simeq 8,000 \left(\alpha\frac{1}{\eta}\dot{m}\right)^{2/3}. \tag{2}$$

[1] In the WCZ97 model a transonic vertical outflow from the disk develops where the fraction of total energy dissipated in the corona is close to unity

In the above equations all quantities are dimensionless: $m = M/M_{\odot}$, $\dot{m} = \dot{M}/\dot{M}_{EDD}$, $r = R/R_0$, with $\dot{M}_{EDD} = 1.5 \times 10^{17}\eta^{-1}m$ g s^{-1}, and $R_0 = 6GM/c^2$, for a non-rotating black hole; here η is the maximum efficiency. Finally, f gives the boundary conditions at the marginally stable orbit: $f = f(r) = (1 - r^{-0.5})$.

The critical radii r_{tran} and r_{max} (equations 1 and 2) depend both on the accretion rate and, interestingly, with similar powers. This results in a quasi-rigid radial shifting of the region delimited by these two distances as the accretion rate (in critical units) varies. Finally, for the transonic disk outflow (and so for the BELRs), the model adopts an intermediated radius r_{wind} computed weighting the radial distance between r_{tran} and r_{max} by $(1 - \beta)$.

Equation 1 allows us to define the minimum external accretion rate needed for a thermally unstable radiation pressure dominated region to exist. From the condition $r > 1.36$ (the limit of validity of the SS-disk solution) we have: $\dot{m} \gtrsim \dot{m}_{min}(m) \simeq 0.3\eta(\alpha m)^{-1/8}$. Throughout this paper I assume $\eta = 0.06$, and a viscosity coefficient of $\alpha = 0.1$, which give a minimum external accretion rate of $\dot{m}_{min} \sim (1-4) \times 10^{-3}$, for m in the range $10^6 - 10^9$ (see Fig. 1 of N00). At lower accretion rates a SS-disk (SS73) is stable down to the last stable orbit: we propose that all the available energy is dissipated in the disk and no radiation pressure supported and driven wind is generated. AGN accreting at these low external rates should show no BELs in their optical spectra.

2. Testing the Model at Low Accretion Rates

One of the consequences of the N00 model predictions is that a fraction of optically classified Sy2s should exist, which show no BELs in polarized light: all those source accreting at rates lower than the minimum allowed rate for the formation of BELRs. To test this prediction, we extracted a sub-sample of Sy2s from the Tran (2001; 'primary' sample) and Gu & Huang (2002; 'secondary' sample) spectropolarimetric samples, which were observed in the X-rays at least once with imaging X-ray satellites (Nicastro, Martocchia & Matt, 2003: NMM03). The goal was to derive reliable X-ray (i.e. 'nuclear') luminosities and central black hole masses for the sources of our sample, to get an estimate of the external accretion rate in units of Eddington. Details on the sample selection criteria and the techniques used to derive the black hole masses can be found in NMM03. Our final sample containes 15 Sy2s, 9 HBLRs and 6 non-HBLRs.

Results are summarized in Figure 1 that shows fractional luminosities in units of Eddington, versus black hole masses for all the 15 sources of our sample. We first note that a very broad range of accretion rates is spanned by the sources of our sample (more than three orders of magnitude), which are otherwise powered by central black holes with rather homogeneous masses (only a factor of about 15 across the entire sample). Most importantly, Figure 1 clearly shows that HBLR sources are accreting at much faster rates compared to non-HBLR sources.

The threshold value of $\dot{m}_{thres} \simeq 10^{-3}$ divides up HBLR from non-HBLR sources in the M_{BH} vs $\dot{m}$ plane (dashed vertical line in Fig. 1). The only exceptions are NGC 3081 and NGC 3281, both sources from our "secondary" sample (but see N00 for details and comments on the reliability of the X-ray and spectropolarimetric optical data of these two sources).

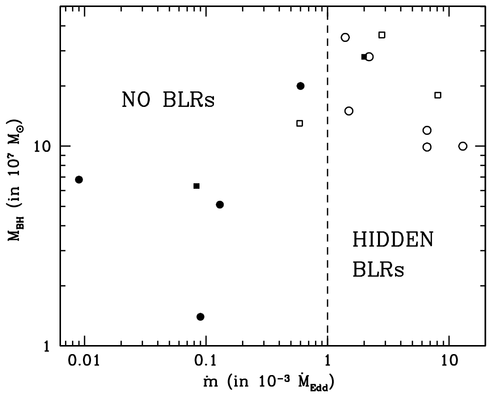

Figure 1. Black hole masses vs accretion rates (defined as $\dot{m} = \dot{M}/\dot{M}_{Edd} = L_{bol}/L_{Edd}$). Open and filled symbols refer to HBLRs and non-HBLRs. Circles and squares are sources from our primary and secondary samples, respectively (see N00 for details).

3. Conclusion

In this contribution I presented a model that links the physical mechanism responsible for the AGN activity (i.e. the accretion) with the existence and width of the BELs. This model seems to naturally (a) reproduce the Sy1-*versus*-NLSs1 observed differences, and (b) account for those 50 % of Sy2s for which no HBLRs has been observed. Additional testing of this model is needed, and requires larger samples both in the optical (e.g. SDSS photometry and spectra), and in the X-rays (e.g. *Chandra* and *Newton*-XMM spectra).

References

Antonucci, R. 1993, ARA&A, 31, 473

Antonucci, R. & Miller, J.S. 1985, ApJ, 297, 621

Boller, T., Brandt, W.N. & Fink, H., 1996, A&A, 305, 53

Brandt, W.N., Mathur, S. & Elvis, M., 1997, MNRAS, 285, L25

Gu, Q. & Huang, J. 2002, ApJ, 579, 205

Laor, A., et al. 1997, ApJ, 477, 93

Leighly, K.M., 1999a, ApJS, 125, 317

Leighly, K.M., 1999b, ApJS, 125, 297

Lightmnan A.P. & Eardley D.M., 1974, ApJ, 187, L1

Nicastro, F. 2000, ApJ, 530, L65: N00

Nicastro, F., Martocchia, A. & Matt, G., 2003, ApJ, 589, L13: NMM03

Pounds, K.A., Done, C. & Osborne, J.P., 1995, MNRAS, 277, L5

Shakura N.I. & Sunyaev R.A., 1973, A&A, 24, 337

Tran, H.D. 2001, ApJ, 554, L19

Witt H.J., Czerny B. and Zycki P.T., 1997, MNRAS, 286, 848: WCZ97