Bull. Astr. Soc. India (2001) **29**, 463–466

Narrow-line Seyfert 1 galaxies

G.C. Dewangan

Dept. of Astronomy & Astrophysics, Tata Institute of Fundamental Research, Mumbai 400005, India

Abstract. Narrow-line Seyfert 1 (NLS1) galaxies form a distinct subclass of Seyfert 1 galaxies. Optical spectroscopic and X-ray spectral and timing results on NLS1 and the plausible underlying physical parameters thought to be responsible for the observed properties are discussed.

Key words : galaxies:active – galaxies:nuclei – X-rays:galaxies

1. Seyfert 1, Seyfert 2 and Narrow-line Seyfert 1 galaxies

Seyfert galaxies are low luminosity active galactic nuclei with $M_B > -21.5 + 5 log h_0$ (Peterson 1997; Schmidt and Green 1983), where h_0 is the Hubble constant in units of 100 km s^{-1} Mpc^{-1}, and showing strong, high ionization emission lines in their optical spectra. Historically, Seyfert galaxies are mainly classified into two types: Seyfert 1 and Seyfert 2 (Khachikian & Weedman 1974). Seyfert 1 galaxies show two sets of emission lines in their optical spectra. One set of emission lines is that of narrow emission lines (e.g., [O III]$\lambda\lambda$4959, 5007, [O I]λ6300, [N II]λ6548, 6583, [S II]λ6716, 6731 etc.) with full width at half maximum (FWHM) ~ 500 km s^{-1} characteristic of low density gas ($n_e \sim 10^3 - 10^6$ cm^{-3}). Another set of emission lines is that of broad permitted lines (FWHM ~ 5000 km s^{-1}), characteristic of high density gas ($n_e \sim 10^{10}$ cm^{-3}). Seyfert 2 galaxies show only one set of emission lines – "narrow" forbidden as well "narrow" as permitted lines. The discovery of broad permitted lines in the polarized light from Seyfert 2 galaxies like NGC 1068, led to the unification of the two type of Seyfert galaxies (e.g., Antonucci 1993). It is thought that the central engines of type 1 and type 2 Seyfert galaxies are physically the same but in Seyfert 2 galaxies, the broad-line region (BLR), responsible for the broad permitted lines, and the central engine are hidden from our view by a thick torus of dust and cold gas. In Seyfert 1 galaxies, our line of sight is such that we have a direct view of the BLR. On the basis of X-ray data, Lawrence & Elvis (1982) were first to suggest that Seyfert 2s are the Seyfert 1s with excess absorption in their lines of sight. Large absorbing column densities ($N_H \sim 10^{22}$ cm^{-2}) inferred in Seyfert 2s and small column densities ($N_H \lesssim 10^{20}$ cm^{-2}) inferred in Seyfert 1s from X-ray observations support the unification picture (e.g., Smith & Done 1996).

In 1985, Osterbrock & Pogge identified a special subclass of Seyfert 1 galaxies with the width of the Hβ line as implied by the full width at half maximum, $FWHM_{H\beta} \lesssim$ 2000 km s^{-1} and $\frac{[O\ III]\lambda5007}{H\beta} \leq 3$. These Seyfert galaxies are known as narrow-line Seyfert 1 galaxies because of the lower width of Hβ compared to that of normal or broad-line Seyfert 1s. Unlike Seyfert 2 galaxies, NLS1s show strong high ionization emission lines e.g., [Fe VII]λ6087, [Fe X]λ6375 and strong permitted Fe II lines as two broad humps around 4600 Å and 5300 Å (Rodriguez-Ardilla et al. 2000). These properties are also found among the broad-line Seyfert 1 (BLS1) galaxies, however, Fe II emission is stronger in NLS1 galaxies. Recently Rodriguez-Ardilla et al. 2000) have shown that the strength of the low ionization lines e.g., [S II]λλ6716, 6731, [N II]λλ6548, 6583, [O III]λ5007 etc. relative to the narrow component of Hβ line is weaker in NLS1s as compared to Seyfert 2 galaxies. For example, the flux ratio of [O III]λ5007 line and the narrow component of Hβ, $\frac{[O\ III]\lambda5007}{H\beta}$ ranges ~ 0.3 – 5 in NLS1s as compared to the value of ~ 10 found in Seyfert 2 galaxies (Rodriguez-Ardila et al. 2000; Dewangan et al. 2001a).

2. X-ray properties of NLS1 galaxies

The excellent soft X-ray sensitivity of the Position Sensitive Proportional Counter (PSPC) detector on-board the *ROSAT* (Trümper 1983) satellite provided the first chance to study the spectral and variability properties of NLS1 galaxies in the X-ray regime. Like optical spectral properties, X-ray properties of NLS1s are also unusual. *ROSAT* observations of NLS1s have revealed the existence of giant soft excess X-ray emission (Boller 2000). Power-law model fits to the soft X-ray spectra of NLS1 results in an extremely steep photon indices (~ 2.5 – 4) with little or no absorption above the Galactic column (Grupe et al. 1998). For example, the narrow-line class objects RX J1334.2+3759 and RX J1236.9+2656 have photon indices of ~ 3.8, and 3.7, respectively (Dewangan et al. 2000, 2001a,b). On the other hand, BLS1s show flatter photon indices (~ 2) with little or no intrinsic absorption (Grupe et al. 1998). The steeper photon indices of NLS1s are thought to be due to giant soft X-ray excess emission. The soft X-ray power-law continua of NLS1s show a large diversity (Boller 2000 and references therein). *ASCA* observations of NLS1 galaxies have confirmed the soft X-ray excess emission below 1-2 keV and discovered that the hard X-ray (2 – 10 keV) power-law of NLS1s is also steeper than that for the normal Seyfert 1s (see Leighly 1999a). The mean photon index for a sample of NLS1s is 2.19 ± 0.10, while it is 1.78 ± 0.11 for normal Seyfert 1s (Leighly 1999a). The hard X-ray spectra of NLS1s are very different from that of BLS1s which show power-law with photon index of ~ 1.7 – 1.9 (Leighly 1999a). The *ASCA* spectrum of one of the well studied and typical NLS1 galaxy, RE 1034+39, is well described by a blackbody component with temperature, $kT_{BB} \sim 100$ eV accounting for the soft X-ray excess emission and a power-law of photon index ~ 2.6 (Pounds, Done, & Osborne 1995). The luminosity in the blackbody component is about 1.5 times the hard X-ray luminosity obtained by extrapolating the power-law upto 200 keV.

Another important *ROSAT* discovery on NLS1s is the remarkable soft X-ray variability (Boller 2000 and references therein). *ASCA* observations have also revealed that NLS1s are more variable than BLS1s in the hard X-rays as well (Leighly 1999b). Some of the NLS1s show extremely rapid variability with doubling time scales down to ~ *few* x 100 s (Dewangan et al.

2001a and references therein). The extreme variable events in NLS1s have extremely high value of the radiative efficiency $\eta > 0.3$, the largest value possible for an optimally accreting Kerr black hole. For example, extremely rapid X-ray variability has been observed in three NLS1-class objects: PKS 0558-504 ($\eta > 1.5$; Remillard et al. 1991). PHL 1092 ($\eta > 0.6$; Brandt et al. 1999), and RX J1334.2+3759 ($\eta > 0.6$; Dewangan et al., 2001a) and relativistic effects have been suggested to be responsible for the extremely rapid X-ray variability (Brandt et al. 1999).

3. Plausible underlying physical parameters

A significant correlation between the slope of the power-law continuum and the FWHM width of Hβ line has been found in NLS1 galaxies (Boller et al. 1996; Brandt et al. 1997). X-rays originate within ~ $3 - 50R_S$ ($R_S = 2GM/c^2$ is the Schwarzschild radius) from the central super-massive black hole (SMBH) while optical emission lines originate about 10^4 R_S away from the SMBH but the strength of the $\Gamma_X - FWHM_{H\beta}$ correlation suggests that both the parameters are controlled by the same physical parameter. In order to understand this parameter, we need to investigate the origins of the huge soft X-ray emission? Is it the result of re-processing of hard X-rays ? This is unlikely because the soft X-ray excess luminosity is higher than the hard X-ray luminosity (Pounds, Done, & Osborne 1995). If we make an analogy of AGNs to Galactic black-hole candidates (GBHCs) which show steeper continua in their high state, this suggests that NLS1s are AGNs in a high state or they are AGNs with high accretion rate relative to the Eddington accretion rate ($\frac{\dot{M}}{\dot{M}_{Edd}}$)(Pounds, Done, & Osborne 1995). A comparison of spectral energy distributions of NLS1s with that of other AGNs implies that the position of the big blue bump (BBB) is shifted towards higher energies and the excess soft X-ray emission could be the high energy tail of the BBB (Mathur 2000). This could result either from a lower mass of the SMBH or a higher $\frac{\dot{M}}{\dot{M}_{Edd}}$. The steeper hard X-ray power-law can be understood in terms of thermal Comptonization of softer photons in a cooler accretion disk-corona system because the huge soft X-ray emission would cool the disk rapidly resulting in a steeper spectrum (Pounds, Done, & Osborne 1995). Can the same physical parameter ($\frac{\dot{M}}{\dot{M}_{Edd}}$ or M) can explain the narrow width of the Hβ line ? If the BLR velocity field is dominated by gravity and the size of the BLR is determined by the bolometric luminosity, then smaller BH mass results in a narrower Hβ (Laor et al. 1997a). Wandel (1997) has argued that higher ionizing continua in NLS1s results in a larger size of the BLR and hence in a narrower Hβ. However, photoionization models with steeper ionizing continua overpredict the strength of low ionization emission lines and require some mechanisms for photon screening (Rodriguez-Ardilla 2000). There is yet another mechanism based on high $\frac{\dot{M}}{\dot{M}_{Edd}}$ which may produce narrow Hβ line. Higher $\frac{\dot{M}}{\dot{M}_{Edd}}$ has greater ability to drive substantial mass outflows because of the higher photon density per unit gravitational mass. The effect would be to increase the size and density of the BLR resulting in narrower Hβ and decrease the size of the NLR resulting in reduced strength of the low ionization emission lines originating in the NLR. A relatively high density ($\gtrsim 10^{11}$ cm^{-3}) BLR has been inferred from the UV spectrum of I Zw 1 – a prototype NLS1 object (Laor et al. 1997b). There is also observational evidence for outflows in the NLS1 galaxies e.g., a weak UV absorption system with a line of sight outflow velocity of ~ 1870 km s^{-1} has been detected from I Zw 1 (Laor et al. 1997b). In addition, Leighly et al. (1997) have found evidence for relativistic outflows from 3 NLS1 galaxies.

4. Conclusions

Good progress has been made in defining the properties of NLS1 galaxies. These properties include strong soft X-ray excess, steeper power-law continua, extreme variability in X-rays and narrow permitted lines, weaker low ionization lines in the optical. The fundamental physical parameter responsible for the extreme properties of NLS1 is most likely either a lower BH mass or a higher $\frac{\dot{M}}{\dot{M}_{Edd}}$ or both.

5. Acknowledgements

I thank Prof. K.P. Singh for his guidance. I also thank Prof. A.R. Rao and Dr. B. Paul for the discussions on NLS1 and related objects. I thank the SOC of the XX^{th} ASI meeting for the invitation to give this talk at the DDV Gorakhpur University.

References

Antonucci R.R.J., 1993, ARAA, 31, 473
Boller Th., Brandt W.N., Fabian A.C., Fink H.H., 1997, MNRAS, 289, 393
Boller Th., 2000, New Astronomy Reviews, 44, 7
Brandt W.N., Mathur S., Elvis M., 1997, MNRAS, 285, L25
Brandt W.N., Boller T., Fabian A.C., Ruszkowski M., 1999, MNRAS, 303, L53
Dewangan G.C., Singh K.P., Szkody P., Hoard D.W., 2000, A&A, 360, 107
Dewangan G.C., Singh K.P., Jones L.R., McHardy M., Mason K.O., Newsam A.M., 2001a, 325, 1616
Dewangan G.C., Singh K.P., Jones L.R., McHardy M., Mason K.O., Newsam A.M., 2001b, BASI, this issue
Grupe D., Beuermann K., Thomas H.-C., Mannheim K., Fink H.H., 1998, A&A, 330, 25
Khachikian E.Ye., Weedman D.W., 1974, ApJ, 192, 581
Laor A., Fiore F., Elvis M., Wilkes B., McDowell J., 1997a, ApJ, 477, 93
Laor A., Jannuzi B.T., Green R.F., Boroson T., 1997b, ApJ, 489, L25
Lawrence A., Elvis M., ApJ, 256, 410
Leighly K.M., Mushotzky R.F., Nandra K., Forster K., 1997, ApJ, 489, L25
Leighly K.M., 1999a, ApJS, 125, 317
Leighly K.M., 1999b, ApJS, 125 297
Mathur S., 2000, MNRAS, 314, L17
Osterbrock D.E., Pogge R.W., 1985, ApJ, 297 166
Peterson B.M., 1997, "An Introduction to Active Galactic Nuclei", Cambridge University Press
Pounds K., Done C., & Osborne J., 1995, MNRAS, 277, L5
Remillard R.A., Grossan B., Bradt H.V., Ohashi T., Hayashida K., Makino F., Tanaka Y., 1991, Nature, 350, 589
Rodriguez-Ardila A., Binette L., Pastariza M.G., Donzelli C.J., 2000, ApJ, 538, 581
Schmidt M., Green R.F., 1983, ApJ, 269, 352
Smith D.A., Done C., 1996, MNRAS, 280, 355
Trümper J., 1983, Adv. Space Res., 2, 241
Wandel A., 1997, ApJ, 490, 131L