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UV Emission Line Studies of NGC-low Redshift Seyfert Galaxies, LINERS and HII Regions

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Abstract

Active galaxies as a special class of galaxies are characterized by very strong and broad emission lines. The strong emission lines such as Lyα, NV, Si IV, C IV, and Mg II observed in the UV spectra of Seyfert galaxies and quasars can be used to probe the physical conditions of the gas in the BLR regions surrounding the central accretion discs of these most luminous and exotic objects. In the standard model of broad line emission regions for active galaxies it is assumed that the broad permitted lines are emitted by the photo-ionization of a large number of spherically distributed optically thick clouds which are in Keplerian motion surrounding a central continuum source. However, issues related to variability time-scales, delays in the light curves and BLR sizes etc., remain unexplained consistent with observations. In this paper, a study of emission line properties 9 objects satisfying good SNR (> 5.0) out of 98 NGC (catalogued) IUE observed low redshift active galaxies (z ≤ 0.017) is presented. The International Ultraviolet Explorer (IUE) satellite launched in 1978 by NASA has made low redshift UV spectroscopic observations of many different kinds of UV sources including active galaxies till 1996 and the flux

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calibrated spectral data of almost all observations have been hosted in NED-IUE database. In the present studies, IUE spectral data of a complete sample of NGC-catalogued active galaxies has been undertaken to understand the emission line properties of low luminosity and low z active galaxies. We find that the emission lines such as Lyα, N V, Si IV, O III], C III], C IV, and Mg II are observed as strong and broad lines in the spectra of only 9 objects owing to the criterion of S/N ≥ 5.0 adopted for the spectral analysis. The Lyα has not been found to be a strong line unlike in high z Seyfert galaxies and quasars observed by IUE satellite. C IV and Mg II lines are observed to be stronger lines in all the nine objects consistent with their usual presence in the remaining (~ 400) active galaxies observed by the IUE satellite. These observations are indicative of different physical and geometrical conditions in the BLR regions surrounding the central accretion disk compared to the intermediate and high redshift Seyfert galaxies and quasars.

Keywords: Active galaxies, Emission lines, Low redshift and Seyfert galaxies

1. Introduction

Active galaxies are the most luminous objects in the universe. The nuclei of the active galaxies are very compact ($r < 10^{14}$ cm) [1] and generates copious amount of energy nearly constant over the entire electromagnetic spectrum from high energy γ-rays to the lowest energy radio waves. An important property of AGN spectra involves the observation of both high and low ionization lines (HILs and LILs). By low and high ionization lines we mean that these lines are emitted by ionic species with ionization potential ≤ 20 eV (hydrogen, singly ionized ionic species of magnesium, carbon, iron, calcium) and ≥ 40 eV (triply ionized carbon, helium, four times ionized nitrogen) respectively [2]. The spectra of these objects contain very broad and strong permitted and forbidden lines such as Lyα, N V, Si IV, C IV, O III], C III], Mg II and Balmer lines**.** Active galaxies have been broadly classified into different types based on their luminosity, emission line properties, appearance and variability characteristics into Seyfert1 and Seyfert2 galaxies, HII regions, LINERS, Quasars, Blazars and Optically Violent Variables, etc. In 1943, Carl Keenan Seyfert discovered that these galaxies have very bright star-like nuclei and produce strong and broad emission lines unlike the normal galaxies. Important characteristics of Seyfert galaxies were discovered, including the fact that their nuclei are extremely compact and have high nuclear mass ($\approx 10^8$ M_{sun}). The central ionizing source, a hot accretion disk heats and ionizes the circum-nuclear gas in the Broad Line Region (BLR) and Narrow line region (NLR) [3]. Most of the strong emission lines are emitted in the UV spectral range. The gas in the BLR region is considered to be photoionised by both thermal and non-thermal radiations and a study of these lines enables us to understand the physics at extreme physical conditions. The UV spectroscopic data of Seyfert galaxies can also be compared with those of high redshift quasars measured in a consistent manner by Baldwin [4] and Smith [5] as their work appears to be fundamental in unravelling the nature of active galaxies. With the availability of huge amount of non-simultaneous spectral data in the IR, optical, UV, X-rays and gamma rays for individual objects, realistic models can be computed for *individual objects* instead of computations based on the "representative spectrum" of quasars and Seyferts as different Seyferts and quasars show diverse spectral properties [6].

The study of UV continuum and emission lines can be used as diagnostic of inner regions of the hot accretion ($T_{BB} \sim 10^4$ K) [7, 8] disk surrounding the super-massive black hole. The redshifts of these emission lines would further allow us to observe the universe at earlier epochs. Thus active galaxies serve as distance candles in the vast expanse of the deep but otherwise un-observable universe. The observationally established luminosity function of active galaxies would provide a method of estimation of cosmological distances of active galaxies independent of luminosity distances. The active galaxies have been studied extensively both at optical and radio windows from ground based telescopes ever since their discovery in 1970s. On the contrary they have been less observed at EUV and UV regions. The launch of IUE in 1978 [9] has provided a big opportunity to study active galaxies spectroscopically in the 1100 – 3200 Å region. The UV observation of active galaxies has become very much essential to complement the observations at other wave bands of the electromagnetic spectrum and also to constrain/complete the unification models of AGN phenomenon [10]. The availability of huge UV spectral data active galaxies has motivated us to undertake the present studies as it enables us to study the active galaxies and the AGN phenomenology complementary to the present understanding of these very exotic objects at other wavelength regions. The optical images of the host galaxies of NGC7213, NGC3690 and NGC4593 objects for which we could measure emission line parameters taken by Hubble Space Telescope are presented in Figs. 1, 2 and 3 to illustrate the compactness of the central nuclear active region. The NGC 7213 and NGC 4593 are spiral galaxies and NGC 3690 is an interacting type as evident from their optical images. The brightness of the central region outshines the thermal emissions from the host galaxy as evident from the optical images. As a result, the morphological features of the AGN-host galaxies are difficult to be observed due to the extremely high amount of radiation emitted from the unresolved compact nuclear region outshining the host galaxy radiation. The optical images of three bright Seyfert galaxies observed by IUE and with good SNR spectra included in the emission line studies.

Prior to the launch of IUE satellite in 1978, it was strongly believed that the study of extragalactic objects in the UV region, especially the low luminosity Seyfert galaxies would be difficult. IUE has made low resolution (~ 5 Å to 8 Å) spectroscopic study of nearly 500 active galaxies in the redshift range of $z = 0.001$ to 3.5 comprising Seyfert galaxies, quasars, radio galaxies, BL Lac objects and LINERS. The precious archival data hosted in NED is more suitable for the study of relationship between emission line ratios, equivalent widths with the underlying thermal/non-thermal UV continuum. The simultaneous observations of a few Seyfert 1 type active galaxies namely Fairall 9, MRK 590, NGC 4051, 3C 273, NGC 5548, MRK 841, QSO 1821+643 and 3C 390.3) by IUE with EINSTEIN, EXOSAT, ROSAT and GINGA satellites have significantly contributed towards our understanding of the spectral energy distributions in active galaxies. These studies have established that the UV bump in the SEDs is variable in its nature [11]. In this paper emission line studies of a complete sample of NGC objects with good S/N spectra (> S/N = 5.0) and redshift $z \leq 0.017$ is presented. The IUE observations have also allowed us understand the physical conditions of BLR and NLR regions in active galaxies.

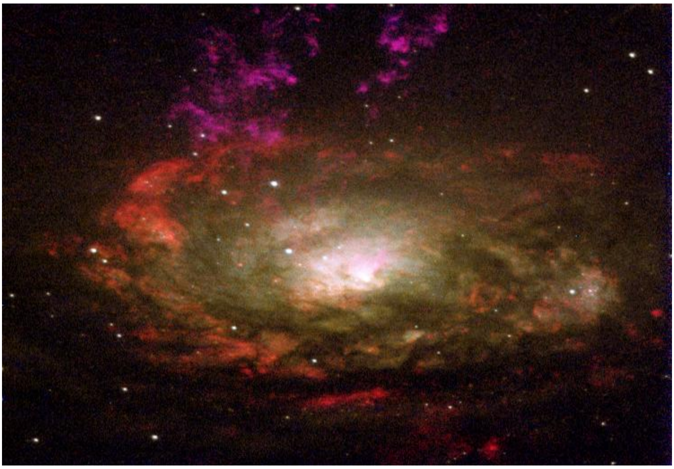

Figure. 1: Optical image of NGC 7213 (Courtesy: Hubble Space Telescope). NGC 7213 is a spiral galaxy

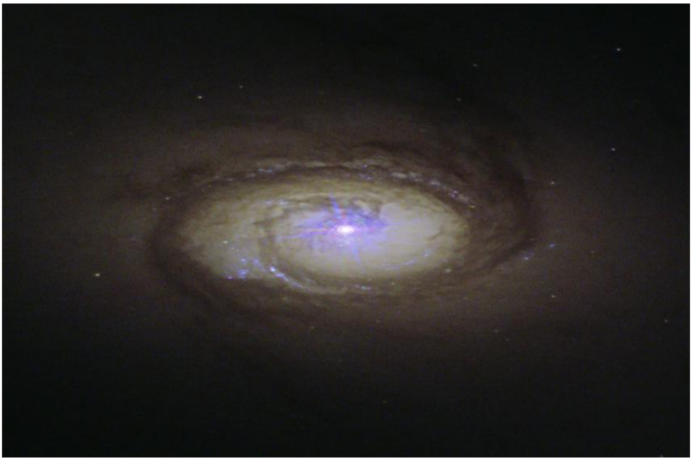

Figure. 2: Optical image of NGC4593 (Courtesy: Hubble Space Telescope)

Figure. 3: Optical image of NGC3690 (Courtesy: Hubble Space Telescope)

2. IUE Observations and Data Analysis

We have analysed the complete sample of NGC-objects observed by IUE satellite for the emission study of low redshift Seyfert galaxies, radio galaxies, HII regions and LINERS in the present study. The IUE launched in 1978 has made very successful measurements till 1996 and has provided valuable data in the UV (1100- 3200 Å) region. The more detailed information about IUE satellite, telescope design, construction details of EUV detectors etc are discussed by Boggess [9]. There are about 630 spectra available in the database from the complete sample of 107 NGC-objects observed by IUE satellite and have low redshifts ($z \leq 0.077$). Thus NGC-objects constitute a good and large sample of low redshift active galaxies observed by a single telescope consistently for the first time prior to the launch of HST and SDSS observations. IUE has observed quasars up to a redshift of $z \sim 3.5$. In this paper a study of emission line properties of complete NGC objects is presented excluding the long-term monitoring observations of NGC4151, NGC3516, NGC4593 and NGC7469. The analysis and results of these long term observations will be presented in future papers. Of 107 objects there are 7 HII galaxies, 35 LINERS, 41 Seyfert 1 galaxies, 17 Seyfert 2s, 4 Seyfert 3 types and 3 radio galaxies. There are no quasars and BL LAC objects included in the 107 NGC objects and thus qualify as homogeneous group of low luminosity active galaxies. As IUE has made low resolution spectral observations, the studies of only strong emission lines are reliable for their flux and equivalent width measurements. Owing to these limitations of the IUE spectra, we have chosen only good quality spectra with S/N ≥ 5.0. With this criterion adopted presently for the emission line studies, we finally obtained 9 nine objects with S/N ≥ 5.0 and their basic details are provided Table 1. Among these there are 4-Seyfert 1 galaxies, 3-Seyfert 2 galaxies, 1-Seyfert 3 and 1-HII region galaxies. Two of the Seyfert 2s have been dubiously classified as LINERS**.** The presence of OIII] and CIII] forbidden lines simultaneously with CIV line serve as an important diagnostic of probing the BLR and NLR regions in active galaxies. UV spectra of IUE become more important as the rest wavelengths of these lines happen to lie in the *Short Wavelength Prime* camera of IUE and thus eliminating the constrains of camera sensitivity variation, background noise and simultaneous observations.

The ionisation parameter U_1 defined in various forms is used in the theoretical computations of models for active galaxies as it can be used to estimate the ratio between the flux of ionising photons imping on broad line clouds and the electron density in the clouds. The C IV/ C III] ratio is a very good indicator of the ionisation parameter and also sensitive to reddening according to Davidson [12], Davidson and Netzer [13], Ferland and Mushotzky [14]. The high redshift quasars have a ratio of C IV/ C III] = 2, while it is ~ 5 for Seyfert galaxies. This difference is attributed to the difference in the optical depth of C IV line in quasars and Seyfert 1 galaxies. For example, if the clouds in the BLR regions in Seyfert 1 galaxies have smaller optical depths for CIV than in the quasars, then the Seyferts will have higher C IV/C III] ratios observationally [6]. The Kwan and Krolik model [15] calculations predict C IV/C III] = 3.5 - 6.5 for Seyferts corresponding to log U_1 = 8.4 – 8.7 and $n_e = 4\times10^9$ cm^{-3}.

Further, the linear correlation observed between Lyα and C IV (1550 Å) line luminosity with the underlying continuum at 1450 Å and 2-10 keV in four quasars PKS 0405-123, PG 0953+415, MRK 205 and 3C 273 [6] and similar observation of linear correlation between Lyα and CIV line luminosity with UV continuum at 1125 Å and 1425 Å in IUE observations of 20 objects by Doddamani and Vedavathi [16] support the standard photoionization models of

Davidson and Netzer [13], Kwan and Krolik [15], Fillipenko [17], Collin-Souffrin et al. [18], and Krolik [19] with a few limitations such as observed low value of Lyα/Hβ ratios contrary to the higher ratio predictions. In the narrow line region, the gas density is expected to be ~ 10^3 - 10^6 cm^{-3} and hence the line transfer effects which are effective in lowering the Lyα/Hβ become less important. This range of density in NLR regions along with the ionisation parameter U_1 ~ 10^7 cm/s results into higher Lyα/Hβ ratios as expected from the case B approximation of standard photoionization models. The C IV/C III] ratio is a good indicator of U_1 [12] and it is insensitive to reddening. Davidson's ratio C IV/ C III] = 2.5 [12] based on power law continuum with α = 1 gives U_1 = 10^8 cm/s and agrees with Netzer's [20] value $U_1 = 2\times10^8$ cm/s for Seyfert 2 galaxy 3C 390.3.

The IUE spectra published in the NED-IUE database were only flux calibrated data and in the ***filename.mxlo*** format. These were not readily analysable under *specred* tasks of IRAF. We have converted ***filename.mxlo*** files into *filename.fits* files using IUETOOLS software programs. These spectra have been further reduced for "*galactic reddening*" using NHI values from NASA's HEASARC database available online [21]. For some objects, we have applied "galactic reddening" correction by using E(B-V) values published in the paper by Lockman [22]. The *dereddened* spectra have been further reduced for *doppler shifts* by using "*dopcor*" task of IRAF to bring the spectra into rest-frame wavelengths. We have made use of the redshift (z) values published in the IUE-ULDA access guide catalogue. We have undertaken the emission line studies using IRAF tasks such as "Gaussian single *deblend*" under "*specred*" tools. The Line profiles were fitted by deblending the lines and with "no" background subtraction. The continuum window (λ_1, λ_2) for emission line flux measurements have been chosen interactively by visual inspection. The line centre wavelength is also decided interactively fitting for the peak flux. The *deblend* task of IRAF returns the *line-center* wavelength, integrated *line-flux* along with 1 sigma rms deviations and equivalent width for deblended single Gaussian profile. The line flux and equivalent widths measured from good quality spectra are given in Tables 2 and 3. A representative sample of two *reddening* and *redshift* corrected spectra with high signal to noise ratio with same Julian Date are presented in Figs. 4 and 5. The date of observations are expressed in terms of *Modified J.D. = J.D. – 244,0000*. As our objects have low redshifts, the simple Hubble's law (non-relativistic case) D_{L1} = cz/H_0 has been used for the luminosity distance (D_L) estimations. We have adopted the currently used consensus value of Hubble's constant H_0 = 73 Km/sec/Mpc for the distance estimations owing to the tight limit set by WMAP observations on the Hubble's dimensionless parameter h = 0.712 [23]. We have also estimated the luminosity distances using Terrell [24] formula as the same involves the cosmological deceleration parameter q and important for the distance estimations of Seyferts and quasars. At present the deceleration parameter q = - 0.5 has been widely employed for the luminosity distance estimations of Type Ia Supernovae, Seyfert galaxies and quasars following significant discovery by Riess et al. [25]. For this significant work Adam G Riess, Brian Schmidt and Perl Mutter were awarded with Nobel Prize Physics in 2011. The luminosity distances of active galaxies are highly cosmological model dependent and diverge significantly with increasing redshifts beyond z ≥ 0.8 [26]. Hence, the luminosity-distances of active galaxies will have significant discrepancies for z ≥ 0.8 and remains as an important unsettled issue of active galaxies research in our opinion. We see from the distance estimations provided in table-1 that the two methods agree well within a discrepancy of 2 % and would not affect our conclusions. Finally, we have chosen the distances obtained by Terrell [24] formula for line luminosity calculations.

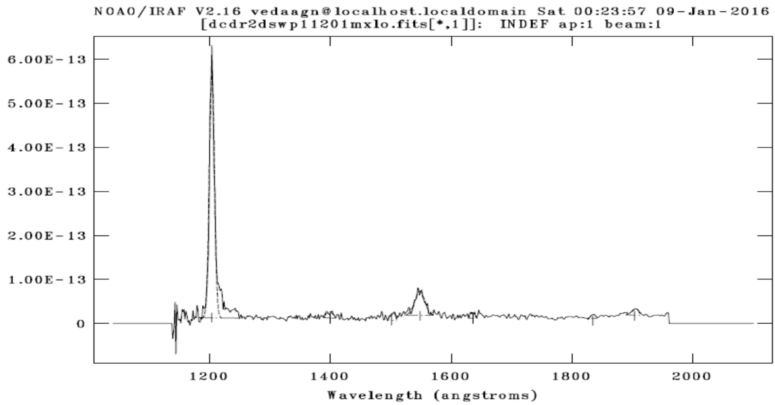

Figure. 1: Rest frame *Short Wavelength Prime* spectrum of NGC 7213. Deblended Gaussian Profile fitted to Lyα, C IV and C III] lines (swp11201mxlo.fits) using IRAF tasks

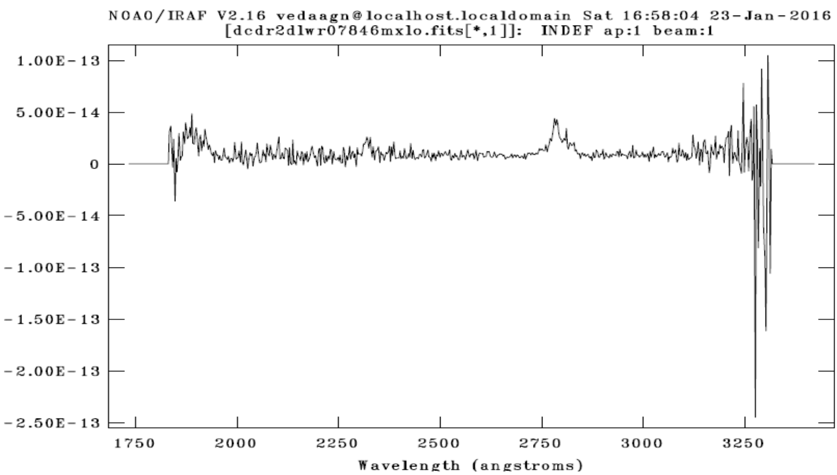

Figure. 4: Rest frame Long Wavelength Redundant camera spectrum of NGC 7213 (dcd2dlwr07846mxlo.fits-reddening and redshift corrected)

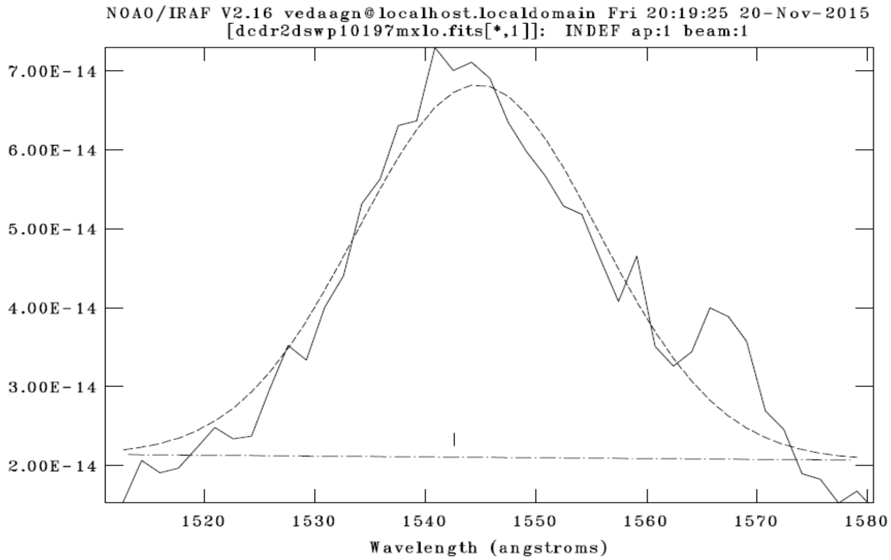

Figure. 5: The single deblended gaussian profile fit (dotted curve) to C IV 1549 Å emission line of NGC 4593

3. Results, Discussion and Conclusions

We have observed Lyα (1216Å), Si IV+O IV? (1396 Å), Si II (UV2) (1530 Å), C IV (1549 Å), O III] (1663 Å), Si III] (1892 Å), C III] (1909 Å), O III] + C II] (2321 Å, 2326 Å) and Mg II (2800 Å) lines as broad and strong emission line features in the spectra of 9 objects. The rest wavelengths some of the forbidden lines are adopted from Ulrich [26]. The numbers in the parenthesis represent the rest wavelengths of the strong lines. As IUE spectra are obtained with low spatial resolution (10′′ x 10′′ aperture) and have low SNR, we have not considered weak lines for the analysis. We observe Si II, Si III] and O III] + C II lines as additional line features characteristic of LINERS and not observed very much routinely in the spectra of Seyfert 1 galaxies. The Lyα has been found to be the strongest line in the spectra whenever present, but not as strongly observed routinely in high redshift Seyfert 1 galaxies, radio galaxies and quasars. This feature appears special and characteristic of low redshift active galaxies and needs further confirmation from observations in other wavelength windows of the electromagnetic spectrum for other lines too. All other emission lines are found to be relatively less-stronger when compared with Lyα by an order of magnitude in their fluxes. The emission line fluxes also have varied over repeated observations along with the associated line parameters in response to continuum changes. The measured line fluxes, equivalent widths and the luminosities calculated using Terrell [24] formula of all the strong lines are given in Table 2. These emission line parameters can be used as the diagnostics of physical conditions in the BLR region surrounding the accretion disk. From the similarity in the values of line widths and luminosities presented in table-2 for both permitted and forbidden lines, we conclude that all these lines are emitted from the same region of the BLR consistent with the conclusions of Robson [27].

It is found that the Lyα/C IV line-ratio in the range 4.66 - 71.19 for observations on the same day and is thus more reliable from the ratios of fluxes obtained for observations on different days as most active galaxies are found to be variables intrinsically. The Baldwin effect [4] of anti-correlation between line-flux and equivalent width observed in IUE observations could not studied due to the limited observational data involved in the present study (nine objects). The range of CIV/CIII] ratios obtained are consistent with the predictions of Kwan and Krolik [18] model for Seyfert galaxies. Similar values of C IV/C III] ratios have been reported by Chi-Cho Wu et al. [6]. It may be noted that C IV/CIII] ratio of 2.5 and 2.3 obtained for NGC 1068 and MRK 3 by Chi-Cho Wu et al. [6] are comparable to our values presented in table-3. These observations therefore, are in conformity with general photoionization models [20] and constrains the ionization parameter to lie in the range of log U_1 = 8.4 – 8.7 and $n_e \sim 4 \times 10^9$ cm^{-3} for Seyfert galaxies based upon the discussion in section 1.2. However, this conclusion needs more observations to improve it statistically and make the Kwan and Krolik [15] model generally acceptable. We conclude that emission line properties characteristic to Seyfert galaxies and Quasars have been observed for Lyα, N V, Si IV, C IV, C III] and Mg II lines for statistically in a small fraction of the NGC catalogued galaxies (nine objects out of 107 ~ 8.3 %) at the lower redshift range up to $z \leq 0.8$. The origin of the AGN activity observed in such a statistically smaller fraction of the normal galaxies needs further investigations encompassing studies across other wavelength regions expanding the redshift domain.

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References

[1] R. A. Edelson *et al.*, “Multiwavelength observations of short-timescale variability in NGC 4151. IV. Analysis of multiwavelength continuum variability,” *Astrophys. J.*, vol. 470, p. 364, 1996.

[2] P. Marziani *et al.*, “UV spectral diagnostics for low redshift quasars: estimating physical conditions and radius of the broad line region,” *Astro-phy. GA arXiv1410.3146*, 2014.

[3] M. J. Rees, "Black hole models for active galactic nuclei," *Annu. Rev. Astron. Astrophys.*, vol. 22, no. 1, pp. 471–506, 1984.

[4] J. A. Baldwin, "Luminosity indicators in the spectra of quasi-stellar objects," *Astrophys. J.*, vol. 214, pp. 679–684, 1977.

[5] P. S. Osmer and M. G. Smith, "Discovery and spectrophotometry of the quasars in the-40 deg zone of the CTIO Curtis Schmidt survey," *Astrophys. J. Suppl. Ser.*, vol. 42, pp. 333–349, 1980.

[6] C.-C. Wu, A. Boggess, and T. R. Gull, "Prominent ultraviolet emission lines from Type 1 Seyfert galaxies," *Astrophys. J.*, vol. 266, pp. 28–40, 1983.

[7] G. A. Shields, "Theory of active galactic nuclei," *Publ. Astron. Soc. Pacific*, vol. 98, no. 600, p. 130, 1986.

[8] M. A. Malkan and W. L. W. Sargent, "The ultraviolet excess of Seyfert 1 galaxies and quasars," *Astrophys. J.*, vol. 254, pp. 22–37, 1982.

[9] A. Boggess *et al.*, "The IUE spacecraft and instrumentation," *Nature*, vol. 275, pp. 372–377, 1978.

[10] R. Antonucci, "Unified models for active galactic nuclei and quasars," *Annu. Rev. Astron. Astrophys.*, vol. 31, pp. 473–521, 1993.

[11] R. Walter *et al.*, "Simultaneous observations of Seyfert 1 galaxies with IUE, ROSAT and GINGA," *Astron. Astrophys.*, vol. 285, pp. 119–131, 1994.

[12] K. Davidson, "On photoionization analyses of emission spectra of quasars," *Astrophys. J.*, vol. 218, pp. 20–32, 1977.

[13] K. Davidson and H. Netzer, "The emission lines of quasars and similar objects," *Rev. Mod. Phys.*, vol. 51, no. 4, p. 715, 1979.

[14] G. J. Ferland and R. F. Mushotzky, "Broad line region clouds and the absorbing material in NGC 4151," *Astrophys. J.*, vol. 262, pp. 564–577, 1982.

[15] J. Kwan and J. H. Krolik, "The formation of emission lines in quasars and Seyfert nuclei," *Astrophys. J.*, vol. 250, pp. 478–507, 1981.

[16] V. H. Doddamani and P. Vedavathi, "Ultraviolet Line-Continuum properties of Seyfert 1 galaxies and quasars," *Proc. Int. Astron. Union*, vol. 9, no. S304, pp. 233–235, 2013.

[17] A. V Filippenko, "New evidence for photoionization as the dominant excitation mechanism in Liners," *Astrophys. J.*, vol. 289, pp. 475–489, 1985.

[18] S. Collin-Souffrin, S. Dumont, and J. Tully, "Hydrogen line spectrum in quasars. II-A critical discussion of model calculations for the broad line region," *Astron. Astrophys.*, vol. 106, pp. 362–374, 1982.

[19] J. H. Krolik, "The origin of broad emission line clouds in active galactic nuclei," *Astrophys. J.*, vol. 325, pp. 148–152, 1988.

[20] H. Netzer, "The spectrum of 3C 390.3 and the hydrogen line problem," *Mon. Not. R. Astron. Soc.*, vol. 198, no. 2, pp. 589–603, 1982. Online Data for E(B-V) values: http://heasarc.gsfc.nasa.gov/ cgi-bin/tools/w3nh.pl

[21] F. J. Lockman and B. D. Savage, "The Hubble Space Telescope Quasar Absorption Line Key Project. 10: Galactic HI 21 centimeter emission toward 143 quasars and active Galactic nuclei," *Astrophys. J. Suppl. Ser.*, vol. 97, pp. 1–47, 1995.

[22] D. A. Ostlie and B. W. Carroll, *An introduction to modern astrophysics*. Addison-Wesley, ch. 27, p. 1057, 2007.

[23] J. Terrell, "The luminosity distance equation in Friedmann cosmology," *Am. J. Phys.*, vol. 45, no. 9, pp. 869–870, 1977.

[24] A. G. Riess *et al.*, "Observational evidence from supernovae for an accelerating universe and a cosmological constant," *Astron. J.*, vol. 116, no. 3, p. 1009, 1998.

[25] V. H. Doddamani and P. Vedavathi, "Luminosity-Distances of IUE observed Active Galaxies," *Proc. Int. Astron. Union*, vol. 9, no. S304, pp. 37–38, 2013.

[26] M. H. Ulrich *et al.*, "Detailed ultraviolet observations of the quasar 3C 273 with IUE," *Mon. Not. R. Astron. Soc.*, vol. 192, no. 4, pp. 561–580, 1980.

[27] I. Robson, "Active galactic nuclei", John Wiley and Sons, Chichester, ch. 3, p. 72, 1996.