Fine classification of the emission-line spectra of active galaxies

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Abstract

We refine the classification of galaxies by activity types based on a number of samples of objects having homogeneous optical medium resolution spectra from SDSS. SDSS spectra provide many spectral features and details that were not available before. Three diagnostic diagrams and eye examination have been used and the combined activity types have been derived. A fine classification scheme was developed, where QSOs have subtypes like Seyferts, Narrow Line QSOs are introduced, subclasses for Narrow Line Seyfert 1s are used and Composite spectrum objects have their subtypes. This classification scheme much better describes all fine details in the optical spectra and allows further study of active galaxies by the subtypes for better understanding the Unified model and the physical properties of AGN and Starbursts.

Keywords: *galaxies – galaxies: active – galaxies: starburst – AGN – techniques: spectroscopic – classification*

1. Introduction

Many active galaxies, especially active galactic nuclei (AGN), are strong emitters not only in optical, but also in Gamma- X-ray, UV, IR, submm/mm and radio wavelengths. That is why multiwavelength (MW) approach in classifications is the most acceptable. However, most of the classifications have been build up on the optical emission-line spectra. Even these classifications have a lot of disadvantages due to rough approach and not considering fine details. Based on homogeneous SDSS medium resolution classification of many samples we have worked out a general fine classification scheme for active galaxies, mainly for Active Galactic Nuclei (AGN), as well as Starbursts (SB). In this paper we give this classification scheme and describe all possible classes and subclasses based on their emission-line features, both main emission lines (H, NII, OIII, OI, SII) and other minor details. Our scheme is based on our research carried out during the last 10-15 years (HyperLEDA (2007), Mickaelian (2015), Mickaelian et al. (2007, 2011, 2018, 2021), Gavrilović et al. (2007), Abrahamyan (2020), Abrahamyan et al. (2018a,b, 2019a,b, 2020), Paronyan et al. (2019, 2020), Mikayelyan et al. (2019), and many others.) and has a strong observational basis. We give the details of the classification of all types and subtypes and give typical examples for most of the objects. We recommend to use this scheme for further homogeneous and detailed classification of most of the active galaxies that appear in SDSS spectroscopic database, as SDSS gives 90% of all available medium resolution spectra.

2. Fine classification of galaxies for activity types and subtypes

In a number of our papers, we have used unified approach to classify thousands of spectra for active galaxies from various samples (Abrahamyan, 2020, Abrahamyan et al., 2018b, 2019a, 2020, Mickaelian et al., 2018, Mikayelyan et al., 2019, Paronyan et al., 2019, 2020). Our approach is based on BPT diagrams (Baldwin et al., 1981, Veilleux & Osterbrock, 1987), however we use most recent options of such diagrams (Kewley et al., 2006, Reines et al., 2013). To guarantee the best accuracy and consider all possible details, we classify the objects in several ways and then consider all obtained types and subtypes:

- By the 1^{st} **diagnostic diagram** (DD1) using line intensity ratios $[OIII]/H_\beta$ vs. $[OI]/H_\alpha$

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- By the 2^{nd} **diagnostic diagram** (DD2) using line intensity ratios $[OIII]/H_\beta$ vs. $[NII]/H_\alpha$
- By the 3^{rd} **diagnostic diagram** (DD3) using line intensity ratios $[OIII]/H_\beta$ vs. $[SII]/H_\alpha$
- By comparison and using the **1st, 2nd and 3rd diagnostic diagrams** simultaneously
- **By eye** (considering all features and effects). Very often, the diagnostic diagrams do not give full understanding for all objects and only eye can reveal some details.

As it is known, the diagnostic diagrams are for classification of narrow line ratios, i. e. objects having Sy1 features (broad lines), QSOs, etc. cannot be classified by them. In addition, the classification by eye has been done in comparison with the classification by diagnostic diagrams because not all objects appear on them due to lack of line measurements data. The eye examination of spectra allows revealing broad lines (for Seyfert subtypes Sy1.0-Sy1.9), estimate (and later measure) the width of broad lines and reveal FeII lines on both sides of H_β to identify Narrow Line Seyfert 1s, etc., as well as classifying absorption line objects. On diagnostic diagrams, for Sy/LINER separation, we have used the criteria: $[OIII]/H_\beta > 4$, and to distinguish AGN from HII, we have used the criteria: $[SII]/H_\alpha > 2/3$ and $[OI]/H_\alpha > 0.1$ (Mickaelian et al., 2018, Reines et al., 2013). For all classifications, we have used the following lines:

- **Absorption lines**: NaI 5890/5896 doublet, MgI 5175, Hydrogen Balmer lines (mostly H_α and H_β), etc.
- **Emission lines**: most prominent are Hydrogen Balmer series lines (H_α 6363, H_β 4861, H_γ 4340, etc.), Oxygen lines ([OIII] 4959 and 5007, [OII] 3727 and [OI] 6300), Nitrogen lines ([NII] 6548 and 6484), Sulfur doublet ([SII] 6716/6731), Helium lines HeI 5876 and HeII 4686, etc.

3. The Classification Scheme

Our classification scheme is mainly based on types given by Osterbrock (1980, 1981), Véron-Cetty & Véron (2000, 2010), Winkler (1992), and HyperLEDA database at `http://leda.univ-lyon1.fr/leda/rawcat/a109.html` (Gavrilović et al., 2007, HyperLEDA, 2007). Here we give in Table 1 the detailed description of all types and subtypes we have used in our classification. In addition in Table 2, we also describe the types and subtypes used in many known catalogs, such as VCV-13. Some of the spectra are taken from our similar SDSS based classification papers, as here our goal is to explain the most typical features for each type and subtype (Mickaelian et al. (2021) and references therein).

Table 1: Detailed description of all types and subtypes of active galaxies based on the SDSS spectroscopy partially used in our classification from other available sources and those introduced by the authors for the first time.

QSO (Quasar, Quasi-Stellar Object, Quasi-Stellar Radio-source) – objects having very broad emission lines (FWHM = 5,000-30,000 km/s) with large redshifts, first discovered by Schmidt (1963). The optical spectra are similar to those of Sy1 nuclei, but the narrow lines are generally weaker. The direct images do not differ from those of the stars on DSS1 and even DSS2 or SDSS, however, objects typically brighter than 17^m and/or with redshifts smaller than 0.3 show weak "fuzz", indicating the host galaxy. They have very high luminosities (M_{abs} >-23). Quasar luminosities are often defined as M_B < -21.5 + 5 logh_0 (Schmidt & Green, 1983). QSO/S1 separation have been conditionally defined by the luminosity limits (M_B = -21.5. . . -24.0), extension (QSOs as star-like and Seyferts as extended objects), and redshift limit (z=0.1; Hewitt & Burbidge, 1993), however at present the first criterion is accepted, though also conditional. There are radio-loud QSOs (quasars or **RL QSOs**) and radio-quiet QSOs (or **RQ QSOs**) with a dividing power at $P_{5GHz} \approx 10^{24.7}$ W Hz^{-1}. RL QSOs are 5-10% of the total of QSOs. There is a big gap in radio power between RL and RQ varieties of QSOs. All radio quasars have FR II morphology.

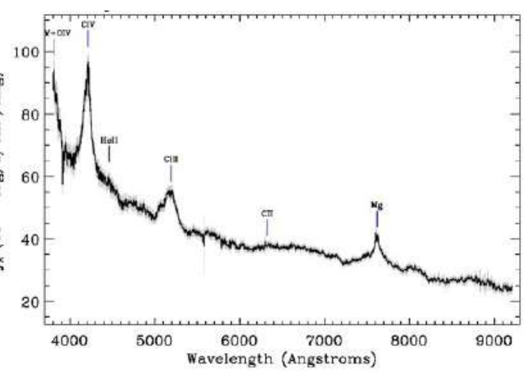

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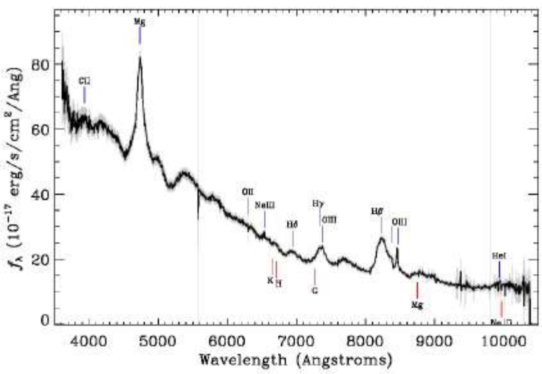
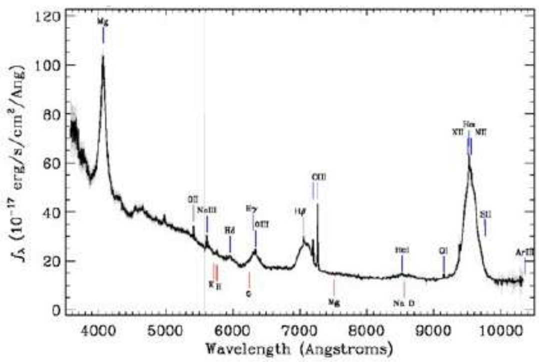
Table 1 Continued: Detailed description of all types and subtypes of active galaxies based on the SDSS spectroscopy partially used in our classification from other available sources and those introduced by the authors for the first time.

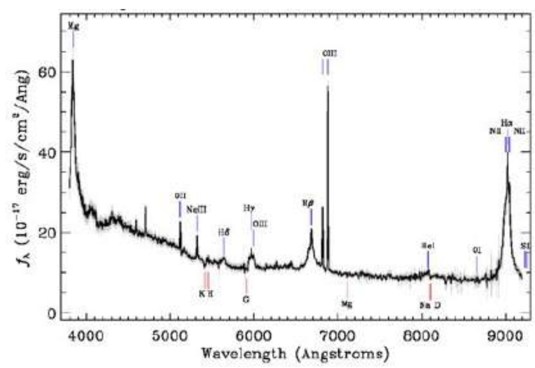
Q1.0 – objects that have quasar luminosities and similar to Seyfert 1.0s show only very strong broad permitted emission Balmer HI lines and narrow forbidden lines. Typically, the narrow lines are weak and due to large distances of many QSOs and lower S/N ratio, they are hardly observed over the noise. When the redshift is high and Balmer lines are not observed, we apply the same criteria for fine classification to MgII and other line profiles.



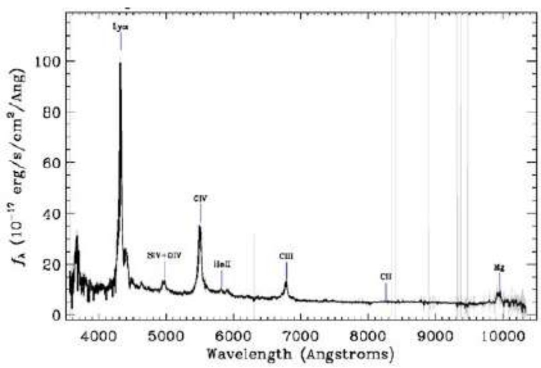
Q1.2 – objects that have quasar luminosities and similar to Seyfert 1.2s show very strong broad permitted emission Balmer HI lines and narrow forbidden lines, as well as weak narrow permitted Balmer lines. Typically, the narrow forbidden lines are also weak and due to large distances of many QSOs and lower S/N ratio, they are hardly observed over the noise. When the redshift is high and Balmer lines are not observed, we apply the same criteria for fine classification to MgII and other line profiles.



Q1.5 – objects that have quasar luminosities and similar to Seyfert 1.5s show strong broad permitted emission Balmer HI lines and narrow forbidden lines, as well as medium strength narrow permitted Balmer lines. The intensities of broad and narrow permitted Balmer lines is approximately equal. When the redshift is high and Balmer lines are not observed, we apply the same criteria for fine classification to MgII and other line profiles.



Q1.8 – objects that have quasar luminosities and similar to Seyfert 1.8s show broad permitted emission Balmer HI lines and narrow forbidden lines, as well as strong narrow permitted Balmer lines. The permitted lines show strong narrow components and weak broad components only for H_α and H_β. When the redshift is high and Balmer lines are not observed, we apply the same criteria for fine classification to MgII and other line profiles.



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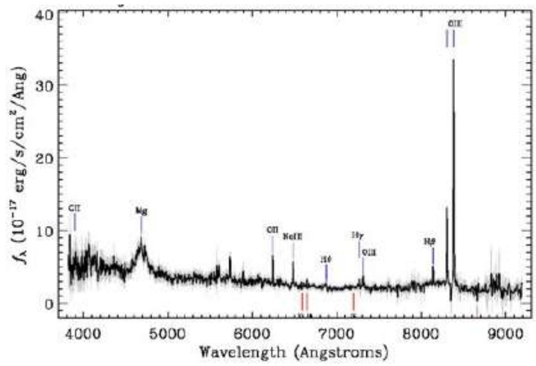
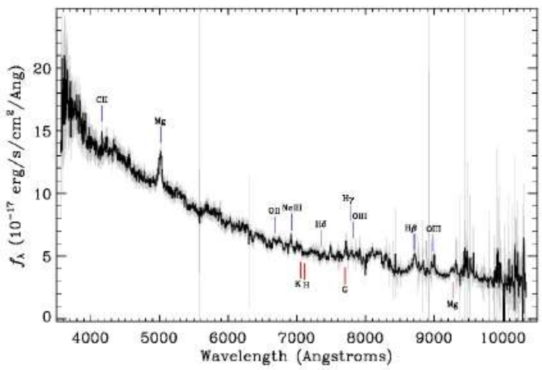
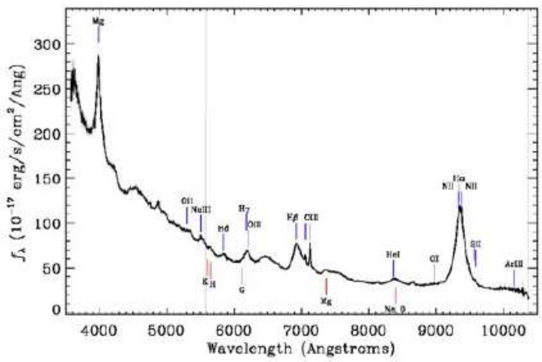
Q1.9 – objects that have quasar luminosity and similar to Seyfert 1.9s show broad permitted emission Balmer H_α line and narrow forbidden lines, as well as strong narrow permitted Balmer lines. The permitted lines show strong narrow components and weak broad components only for H_α. When the redshift is high and Balmer lines are not observed, we apply the same criteria for fine classification to MgII and other line profiles.



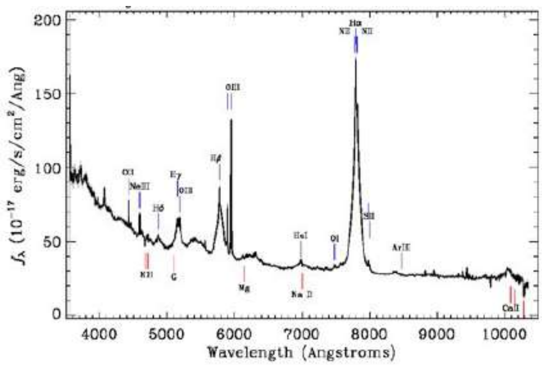
NLQ1 – (Narrow-Line Quasar 1) – QSO with relatively narrow broad lines. Analogous to NLS1 defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (∼2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization. The permitted lines may show or not show narrow component, depending on the subtypes. In case of low S/N and low quality, many objects are being classified as NLQ1 without a subclass.



NLQ1.0 – (Narrow-Line Quasar 1.0) – QSO with relatively narrow broad lines. Analogous to NLS1 defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (∼2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are abundantly present, as well as often strong [FeVII] and [FeX] lines with higher ionization. The permitted lines do not show narrow component.



NLQ1.2 – (Narrow-Line Quasar 1.2) – QSO with relatively narrow broad lines. Analogous to NLS1 defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (∼2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization. The permitted lines show weak narrow component.



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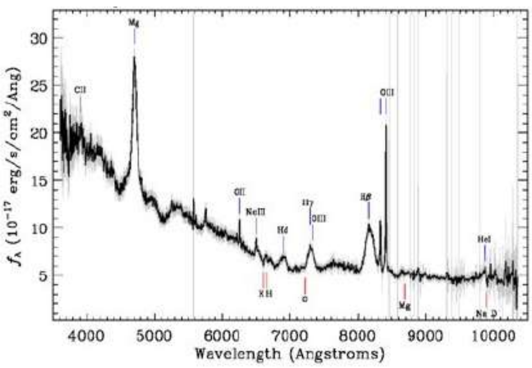
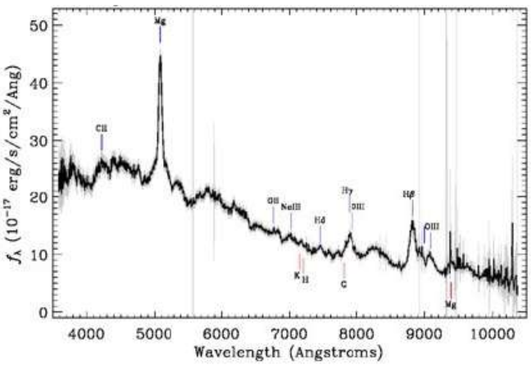
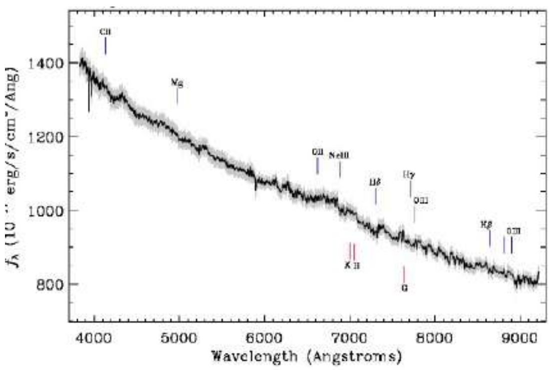
NLQ1.5 – (Narrow-Line Quasar 1.5) – QSO with relatively narrow broad lines. Analogous to NLS1 defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (∼2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization. The permitted lines show medium strength narrow component. The intensity ratio of broad and narrow components is approximately equal.



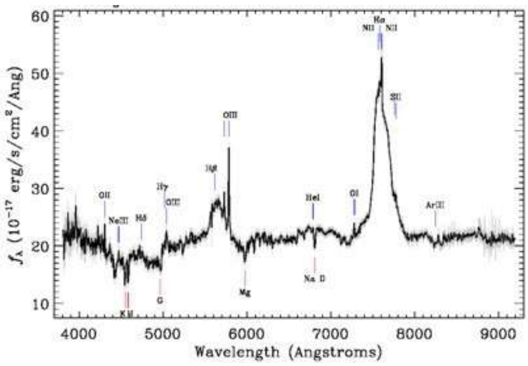
NLQ1.8 – (Narrow-Line Quasar 1.8) – QSO with relatively narrow broad lines. Analogous to NLS1 defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (∼2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization. The permitted lines show strong narrow components and weak broad components only for H_α and H_β.



BL Lac, BLL – BL Lacertae type object. BL Lac variable "star" is the prototype of this class (Hoffmeister, 1929), first such object to be identified as an extragalactic one (Schmitt, 1968). This class was proposed by Strittmatter et al. (1972) and BL Lac absorption lines were observed and redshift was measured by Oke & Gunn (1974). They are stellar in appearance with variable, intense and highly polarized continuum. Strong featureless continuum; no emission or absorption lines deeper than ∼2% are seen in any part of the optical spectrum, or only extremely week absorption and/or emission lines are observed, as a rule at minimum of their very highly variable phase. The weak lines often just appear in the most quiescent stages. So that their redshifts can only be determined from features in spectra of their host galaxies. Show polarization, and are strong radio sources with flat spectrum (Lawrence, 1987, Miller, 1978, Miller et al., 1978). The parent population of BLLs is made of FR I radio galaxies.



S1.0 (S1, Sy1.0, Seyfert 1.0 or BLS1, Broad-Line Seyfert 1) – Seyfert 1 with broad lines. Broad permitted Balmer HI, HeII and other lines (FWHM = 1,000–10,000 km/s; typical is 2,000–6,000 km/s) that originate in a high-density medium ($n_e \leq 10^9$ cm^{-3}) and narrow forbidden lines ([OIII], [NII], [SII], etc. with FWHM = 300–1,000 km/s) that originate in a low-density medium ($n_e \approx 10^3$-10^6 cm^{-3}). Narrow hydrogen lines are completely lost in strong broad components. Physically, these are the same objects as QSOs, but have lower luminosities (M_{abs} >-23). Typically, they are radio quiet. According to Winkler (1992), H_β/[OIII]5007 > 5.0. NGC 4151 is the prototype. The subtypes S1.0-S1.9 were introduced by Osterbrock (1981).



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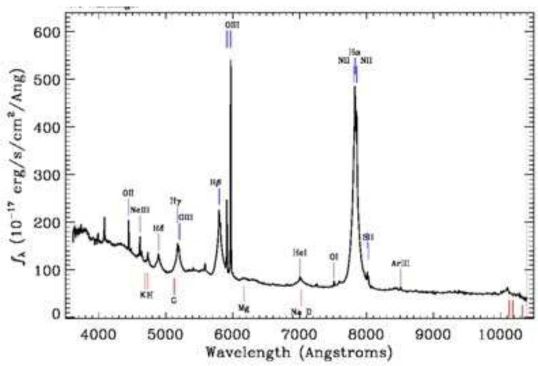
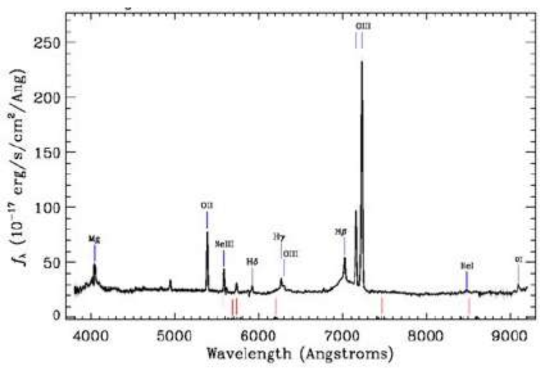
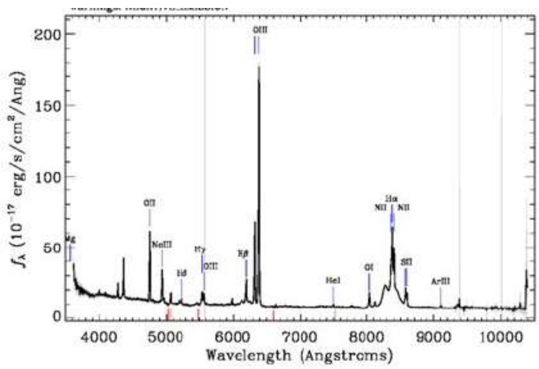
S1.2 (Sy1.2, Seyfert 1.2) – AGN with spectra that have parameters intermediate between classical Sy1 and Sy2 galaxies; i. e., both broad and narrow components of the resolved lines are present (in our case the H_α and H_β line profiles are of this kind) (Osterbrock, 1981), but the broad lines are stronger and the ratio of the narrow components 2.0<H_β/[OIII]5007<5.0 (according to Winkler, 1992). Often erroneously related to NLS1s or S1n.



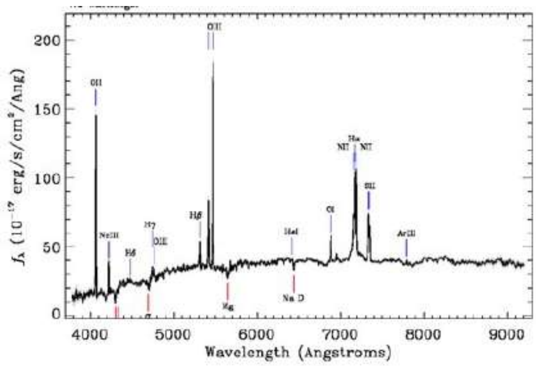
S1.5 (Sy1.5, Seyfert 1.5) – AGN with spectra that have parameters intermediate between classical Sy1 and Sy2 galaxies in which narrow and broad line components are observed. The Balmer series hydrogen lines have roughly equal intensities (narrow profile overlapped on broad wings) (Osterbrock, 1981), According to Winkler (1992), the ratio of the narrow component of H_β to [OIII]5007 is $0.333 <$ H_β/[OIII]5007 < 2.0. The intensities of the broad and narrow components are roughly equal.



S1.8 (Sy1.8, Seyfert 1.8) – AGN with spectra that have parameters intermediate between classical Sy1 and Sy2 galaxies. They have relatively weak broad H_α and H_β components superposed on stronger narrow lines (Osterbrock, 1981), and according to Winkler (1992), ratio of narrow components H_β/[OIII]5007<0.333.



S1.9 (Sy1.9, Seyfert 1.9) – AGN with spectra that have parameters intermediate between classical Sy1 and Sy2 galaxies and have a relatively fainter broad Ha component superposed on a stronger narrow line. Broad H_β component is not observed (Osterbrock, 1981), and according to Winkler (1992), narrow component of H_β/[OIII]5007 $<$ 0.333.



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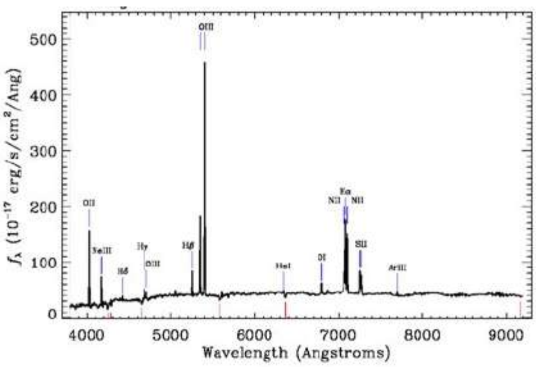
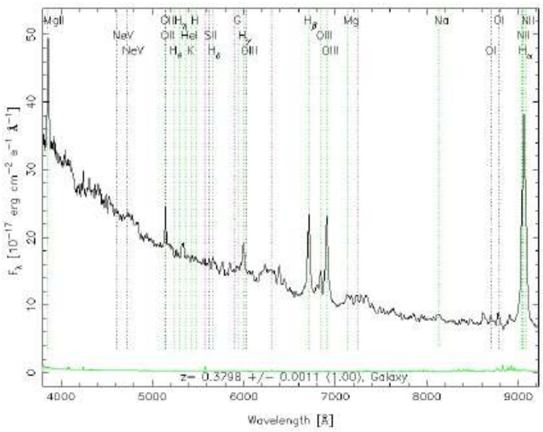
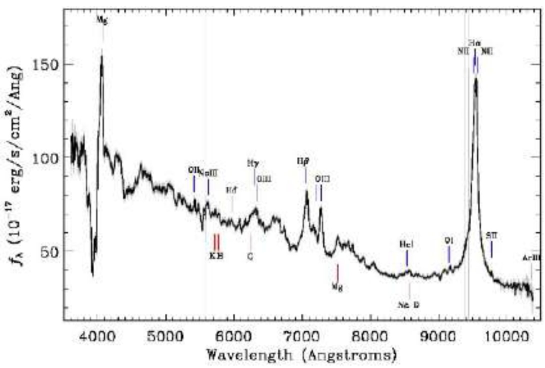
S2.0 (Sy2.0, Seyfert 2.0, also may be given as S2, as there are no other subtypes) – AGN with spectra displaying relatively narrow (compared to Sy1) resolved emission Balmer and forbidden lines with almost equal FWHM (≥300km/s), usually in the range of 300-1000 km/s (Khachikian & Weedman, 1974, Weedman & Khachikyan, 1968) that originate in a low-density medium ($n_e \approx 10^3$-10^6 cm^{-3}). The broad component is not visible. The condition [OIII]5007/H$_\beta$ ≥ 3, serves as a secondary classification criterion, so they can be distinguished against NLS1s (Lawrence, 1987, Veilleux & Osterbrock, 1987). NGC 1068 is the prototype.



NLS1 (Narrow-Line Seyfert 1, S1n) – Seyfert 1 with narrow lines. Defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (∼2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization, unlike what is seen in Seyfert 2s. The ratio [OIII]5007/H$_\beta$ < 3, but exceptions are allowed if there are also strong [FeVII] and [FeX] emission lines present. FWHM(H$_\beta$) < 2000km/s (Goodrich, 1989, 1995).



NLS1.0 (Narrow-Line Seyfert 1.0) – Seyfert 1.0 with narrow lines. Defined by Osterbrock & Pogge (1985) as soft X-ray sources, having relatively narrow (∼2000 km/s) permitted lines only slightly broader than the forbidden ones. Various FeI, FeII, and FeIII emission lines are present, as well as often strong [FeVII] and [FeX] lines with higher ionization, unlike what is seen in Seyfert 2s. The ratio [OIII]5007/H$_\beta$ < 3, but exceptions are allowed if there are also strong [FeVII] and [FeX] emission lines present. FWHM(H$_\beta$) < 2000km/s (Goodrich, 1989).



NLS1.2 (Narrow-Line Seyfert 1.2) – Seyfert 1.2 with narrow lines. They are defined as soft X-ray sources; the resolved lines are relatively narrow (∼2000 km/s) and they have widths that are only slightly broader than the forbidden lines. FeI, FeII, and FeIII appear and often strong lines with higher ionization [FeVII] and [FeX] often, along with various emission lines (Osterbrock & Pogge, 1985).

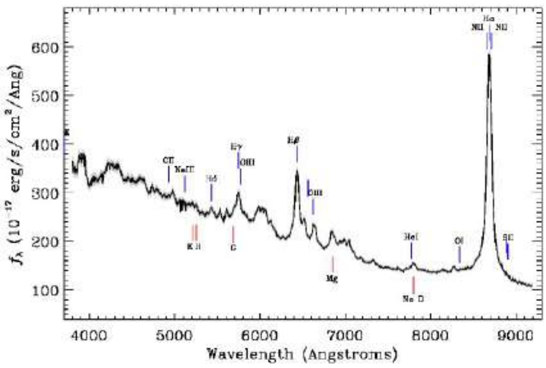


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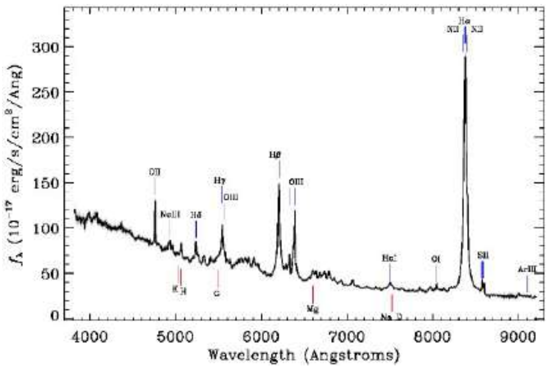
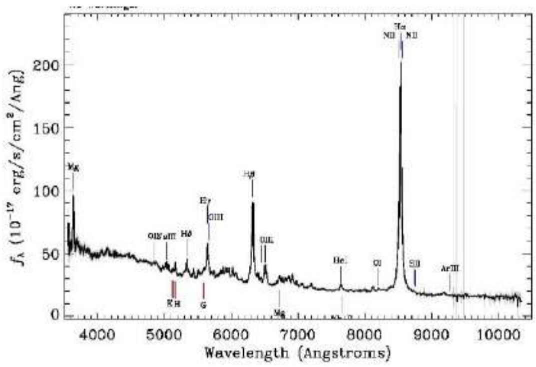
Table 1 Continued: Detailed description of all types and subtypes of active galaxies based on the SDSS spectroscopy partially used in our classification from other available sources and those introduced by the authors for the first time.

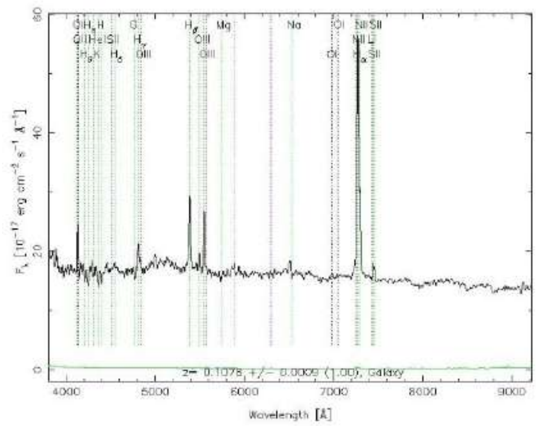
NLS1.5 (Narrow-Line Seyfert 1.5) – Seyfert 1.5 with narrow lines. They are defined as soft X-ray sources and the permitted broad lines are relatively narrow (∼2000 km/s) with widths only slightly exceeding those of the forbidden lines. FeI, FeII, FeIII appear and often strong lines with higher ionization [FeVII] and [FeX] often, along with various emission lines (Osterbrock & Pogge, 1985).



NLS1.8 (Narrow-line Seyfert 1.8) – these are soft X-ray sources having narrow permitted lines only slightly broader than the forbidden ones; many FeI, FeII, FeIII, and often strong [FeVII] and [FeX] emission lines present. Only H_α and H_β permitted broad components are observed, the same criterion as for S1.8 subtype (Osterbrock, 1981).



NLS1.9 (Narrow-line Seyfert 1.9) – these are soft X-ray sources having narrow permitted lines only slightly broader than the forbidden ones; many FeI, FeII, FeIII, and often strong [FeVII] and [FeX] emission lines present. Only H_α permitted broad components is observed, the same criterion as for S1.9 subtype (Osterbrock, 1981).



LINER (Low-Ionization Nuclear Emission-line Region, also given as S3, Seyfert 3). Galactic nuclei with emission lines formed in low ionization regions. Introduced by Heckman (1980), they are low activity AGN, the weakest form of AGN activity. They have S2-like spectra with relatively strong low-ionization lines ([OI], [OII]). The ratios [OII]3727/[OIII]5007 ≥ 1, [OI]6300/[OIII]5007 ≥ 1/3. [NII]6584/H_α > 0.6 according to Kauffmann et al. (2003). According to Ho et al. (1997), there are 2 classes of LINERs: type 1 shows broad Balmer emission analogous to S1s (weak broad H_α visible), and type 2, without broad H_α analogous to S2s. May be either radio quiet or radio loud. Most of the nuclei of nearby galaxies are LINERs. However, their emission line spectra are not necessarily caused by active nuclei.

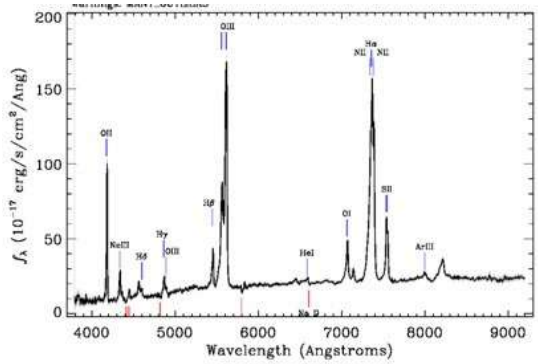


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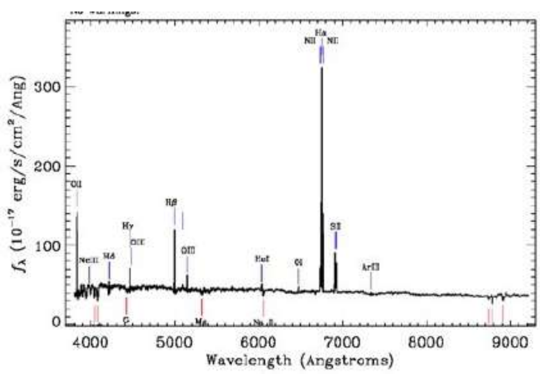
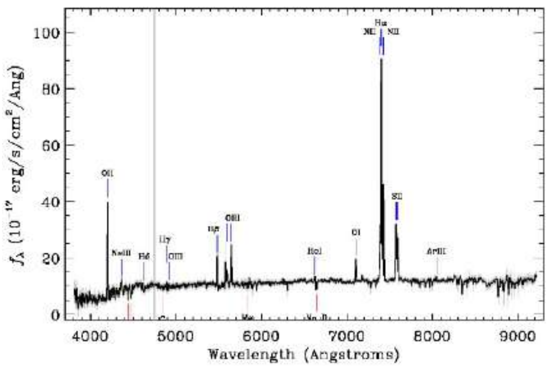
Table 1 Continued: Detailed description of all types and subtypes of active galaxies based on the SDSS spectroscopy partially used in our classification from other available sources and those introduced by the authors for the first time.

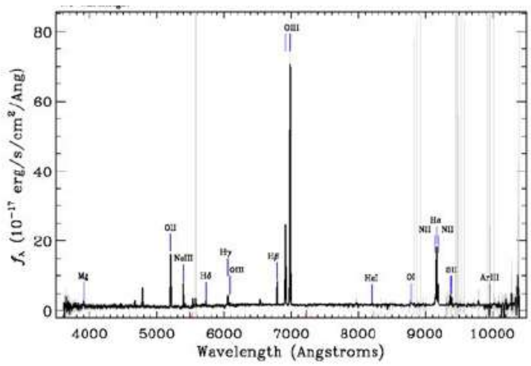
HII (HII regions, H2) – Isolated extragalactic HII regions as defined by Sargent & Searle (1970) or HII galaxies as defined by Terlevich et al. (1991). Have spectra similar to SB, i. e., spectra with strong narrow (FWHM $\leq$ 300 km/s) emission lines but with ratios [OIII]/H$_\beta \geq$ 3 and [NII]6583/H$_\alpha$ < 0.6, combined with a blue continuum (Veilleux & Osterbrock, 1987, Winkler, 1992). Essentially the same as SB, but for classification of SB the value of the star formation rate (SFR) is needed.



HII/LINER – Composite spectrum galaxy, having a mixture of HII and LINER features. Very often one of the emission line ratios may show on HII and the other ratio shows on LINER. Otherwise, a typical HII spectrum may show very strong [OII] 3727 and/or [SII] doublet.



HII/Sy – Composite spectrum galaxy, having a mixture of HII and Seyfert features. Very often one of the emission line ratios may show on HII and the other ratio shows on Seyfert.



LINER/Sy – Composite spectrum galaxy, having a mixture of LINER and Seyfert features. Very often one of the emission line ratios may show on LINER and the other ratio shows on Seyfert. Otherwise, a typical Sy spectrum may show very strong [OII] 3727 and/or [SII] doublet. We give an example of LINER/S2.0 composite.

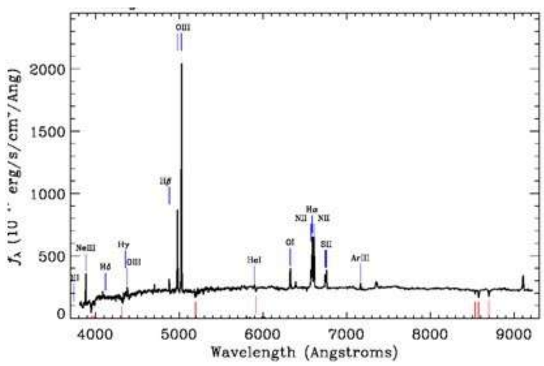


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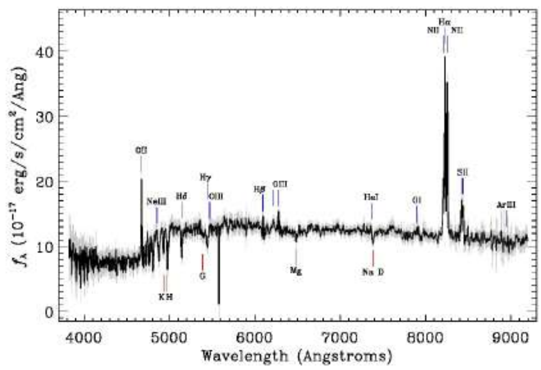
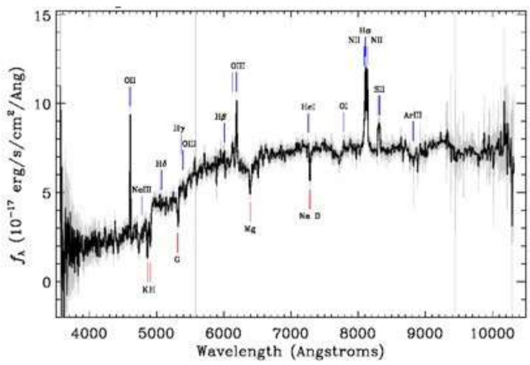
Table 1 Continued: Detailed description of all types and subtypes of active galaxies based on the SDSS spectroscopy partially used in our classification from other available sources and those introduced by the authors for the first time.

AGN (Active Galactic Nuclei) – AGN without a subclass due to relatively low-quality (both resolution and/or S/N) spectra in which only a few emission lines are observed, mainly H_α with NII lines and a $[NII]/H_\alpha$ ratio typical for AGN, i. e. Sy or LINER. Of course, the LINER spectra are not necessarily related to the activity of their nuclei, but this may aid in case of rough classification.



Em (Emission-line galaxy, ELG) – Relatively low-quality (both resolution and/or S/N) spectra in which only one or a few emission lines are observed (H_α, [NII]6584/6548, and [OII]3727) without the possibility of classifying them precisely. These spectra usually have a strong stellar component (continuum and absorption), and the emission lines are hard to see against continuum and absorption lines.



Abs (Absorption-line galaxy) – Spectra with only absorption lines superimposed on the continuum. Mainly the stronger stellar lines, MgII 5175 and NaI 5890-96 lines show up, along with the Balmer lines. No signs for any (nuclear or starburst) activity. Also called normal galaxies, though the latter ones may show some weak emission lines as well. IR, radio, or X-ray sources with spectra of this kind often may contain hidden AGN.

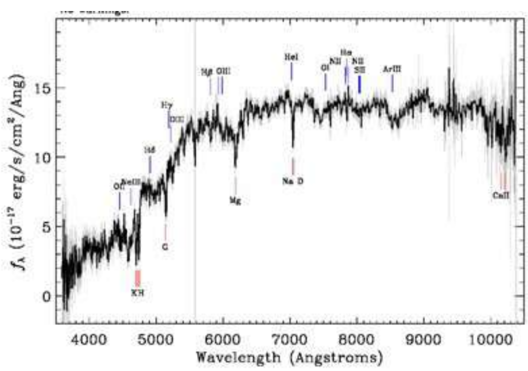


Table 2: Description of the types and subtypes of active galaxies used in other available sources, mainly VCV-13 and BZCAT.

BAL QSO – Broad absorption line QSO. Besides broad emission lines they show deep blue-shifted very broad (10,000-30,000 km/s) absorption lines with P Cyg type profiles corresponding to resonance lines of CIV, SiIV, NV. All of them are at $z \geq 1.5$ because the phenomenon is observed in the rest-frame UV. At these redshifts, they are about 10% of the observed population. BAL QSOs tend to be more polarized than non-BAL QSOs.	Peterson, B. (1997)
DLA QSO – Damped Ly-alpha QSO. Show unresolved absorption lines even on very high-resolution spectra (<1A), with typical widths of 10-12A, resulting in a column density of $>10^{23}$, indicating the presence of high-density galactic size masses along the line of sight.	Lanzetta, K. M. (2001)

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Table 2 Continued: Description of the types and subtypes of active galaxies used in other available sources, mainly VCV-13 and BZCAT.

Blazar – Combination of two most powerful AGN classes; BLL and OVV/HPQ (Optically Violent Variable quasar / High Polarization Quasar), introduced by E. Spiegel in 1978. These are believed to be objects with a strong relativistically beamed jet in the line of sight. When the angle between the relativistic jet axis and the line of sight is small, the jet is Doppler boosted by a large factor and the whole spectrum (from radio to γ-ray) is dominated by a compact, highly polarized, highly variable, superluminal, almost featureless continuum, called blazar. As these two types have many common and different physical properties, the question of definition of blazars is still open (Mickaelian, 2015). There are many parameters that may be regarded as criteria for definition of blazars, such as high luminosity, radio flat spectrum, presence of X-ray and γ-ray, optical and/or radio variability, polarizations, etc.	Kellermann, K. (1992)
S1i – S1 infrared. S1 with a broad Paschen Pa_β line, indicating the presence of a highly reddened BLR. Seyfert 1 with an absorbed BLR visible in NIR.	Goodrich et al. (1994), Véron-Cetty & Véron (2010)
S1h – S1 hidden. S2 showing S1 like spectra in polarized light (Antonucci, 1993, Antonucci & Miller, 1985, Barger et al., 2000, Miller & Goodrich, 1990, Tran et al., 1992, Urry & Padovani, 1995). Seyfert 1 with a hidden BLR.	Antonucci (1993), Antonucci & Miller (1985), Barger et al. (2000), Miller & Goodrich (1990), Tran et al. (1992), Urry & Padovani (1995), Véron-Cetty & Véron (2010)
SBN and **SBG** – Starburst nuclei or Starburst galaxy. M82 was the archetype SB galaxy. The major observable feature that distinguishes SB from Sy is their strong narrow emission lines FWHM $\leq$ 300km/s. According to Balzano (1983), SB is a spiral galaxy with a bright, blue nucleus that emits a strong narrow emission line spectrum similar to low-ionization HII region spectra. They have strong, narrow (FWHM $\leq$ 250km/s) low-ionization ([OIII]/H_β < 3) emission lines; absolute luminosities -17.5 > M > -22.5; characterized by having conspicuous stellar or semistellar nuclei. SB can occur in disk galaxies; however irregular galaxies often exhibit knots of SB spread throughout the galaxy. SFR is a few $M_\odot$ yr^{-1}, but may reach up to 10^3 $M_\odot$ yr^{-1} (the maximum is 2200-2300 $M_\odot$ yr^{-1}). Based on the relative energy output of the SB (L_{SB}) to that of the rest of the galaxy (L_G) and the SB age, R. Terlevich classified SB into 3 classes (subtypes): SB galaxies having $L_{SB} \gg L_G$, Galaxies with SB having $L_{SB} \sim L_G$, and Normal galaxies having $L_{SB} \ll L_G$ (Terlevich, 1997, 2001).	Balzano (1983), Weedman (1977)
BCDG – Blue Compact Dwarf Galaxy as introduced by Thuan & Martin (1981) and described by Gallego et al. (1996). Subtype of SB. Have HII spectra. Most of them have a high rate of star formation. Dwarf, low-mass, low-metallicity, dust-free objects. The BCDG classification involves spectral-morphological parameters; they are blue objects with M(B) > -17.5 and linear sizes of less than D $\leq$ 3-4kpc. IZw18 is the most well-known BCDG being the most metal poor one.	Gallego et al. (1996), Thuan & Martin (1981)
WR galaxy – Wolf-Rayet Galaxy. Subtype of SB having a large portion of bright stars as early-type Wolf-Rayet ones. Because these stars are both very luminous and have very distinctive spectral features, it is possible to identify them in the spectra of the entire galaxies. They show prominent broad emission lines of highly-ionized He and N or C. NGC 6764 and Mrk 309 are WRG prototypes.	Osterbrock & Cohen (1982)
S (Sy, Seyfert galaxy) – Seyfert galaxy (no accurate classification if given without a subclass). Emission-line galaxies observed by Seyfert (1943). Relatively low luminosity AGN with MB > -21.5 + logh_0. Their host galaxies are clearly detectable. Depending on the width of optical emission lines, Seyfert types 1 and 2 (Khachikian & Weedman, 1974, Weedman & Khachikyan, 1968) and subtypes (Osterbrock, 1981) were introduced.	Seyfert (1943)
S3b – LINERs (S3) with broad Balmer lines, the same as LINER type 1.	Ho et al. (1997), Véron-Cetty & Véron (2010)

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Table 2 Continued: Description of the types and subtypes of active galaxies used in other available sources, mainly VCV-13 and BZCAT.

S3h – LINERs (S3) with broad Balmer lines seen only in polarized light.	Véron-Cetty & Véron (2010)
Composite (Composite spectrum galaxy, HII/LINER, HII/Sy or LINER/Sy) – objects with composite spectra in which spectral features of two or more activity types (HII and LINERs, HII and Sy, or LINERs and Sy) are present, and in some cases, all three, as a rule, a combination of Seyfert, LINER and/or HII types. Before, they were regarded as transition objects due to their location in transition regions of diagnostic diagrams. Often, they are classified differently on different diagrams. They may be LINER/S2, HII/S2, HII/LINER or even a combination of S1 subtypes (S1.8, S1.9) and a LINER or HII. HII/S2 and HII/LINER are considered to be a superposition of S2 or LINER nucleus with circumnuclear HII regions.	Véron et al. (1997)

4. Summary and conclusions

Homogeneous classifications of active galaxies have always been a tricky task. Most of the classifications have appeared as historical ones based on some definite survey or spectroscopic material, and from the modern point of view, often having very low quality. Classifications based on optical emission-line spectra began as early as in 1943, when Carl Seyfert (Seyfert, 1943) observed emission-lines in the spectra of some spiral galaxies ("extragalactic nebulae"), including presently well-known AGN like: NGC 4151, NGC 4051, NGC 1068 (also known as M77), NGC 1275 (also known as Perseus A radio galaxy), NGC 3516, NGC 5548, and NGC 7469. Especially surprising was the presence of broad emission lines (or broad wings of lines) that were not observed in the spectra of the galactic nebulae. These objects were called Seyfert (Sy or S) galaxies. Using an optical spectrum obtained with the 200-inch Hale Telescope on Mt. Palomar, Maarten Schmidt was the first to interpret the spectrum of the radio source 3C 273 as having very largely redshifted (z=0.158) broad emission Balmer lines corresponding to recession velocity of 47,000 km/s (Schmidt, 1963). This discovery allowed other astronomers to measure redshifts from emission lines of other radio sources thus extending our knowledge to much farther extragalactic universe. These point-like extragalactic radio sources were called quasi-stellar radio sources (quasars) or quasi-stellar objects (QSOs). Later on, based on the presence or absence of broad emission lines, Seyferts were classified into S1 and S2, respectively (Khachikian & Weedman, 1974).

AGN zoo appeared with a big mixture of properties and confusion in definitions and classifications. Optical Emission Line Diagnostics of AGN is based on study of spectra in optical range, which allows to distinguish 11 Seyfert galaxies, LINERs and Starburst (or HII regions). First diagrams were introduced by Baldwin, Phillips and Terlevich in 1981 (BPT diagrams; Baldwin et al. 1981). They used emission line intensities ratios to distinguish Seyferts against LINERs and Starbursts. Veilleux & Osterbrock improved this technique by modifying line ratios to [OIII]5007/H_β, [NII]6583/H_α, [OI]6300/H_α and [SII]6716+6731/H_α (Veilleux & Osterbrock, 1987), as some BPT ratios need reddening correction while the Veilleux & Osterbrock ratios do not (being close in λ). There are a number of other diagnostic diagrams as well. Stephanie Juneau has developed a comprehensive AGN diagnostics (Juneau et al., 2014), where both optical and other wavelengths are considered. AGN spectra contain numerous iron (FeI, FeII and FeIII) lines. They appear around H_β (from both sides) and elsewhere and interfere accurate line identification and measurements. Fe templates have been built to be fitted and subtracted from a given spectrum. Especially numerous and intense are Fe lines in NarrowLine Seyfert 1 Galaxies (NLS1). On the other hand, Osterbrock (1981) introduced intermediate Seyfert subtypes based on the presence and significance of broad and narrow lines. Many other subtypes were introduced as well, and AGN zoo very often creates problems for overall understanding of these objects.

In this paper, we have developed a fine classification scheme for active galaxies and accordingly carried out classification of the SDSS spectra for active galaxies.

The most important result related to the classification of active galaxies and other results is introducing the fine classification scheme for active galaxies using SDSS spectroscopy. This became possible for the first time, as SDSS quality spectra were not available before. Detailed description of the types and subtypes of active galaxies is given, including many of them **introduced for the first time**.

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The most important novelties in our classification scheme are the following:

- **Introducing QSO subtypes** analogous to Seyferts (Osterbrock, 1981): Q1.0, Q1.2, Q1.5, Q1.8 and Q1.9;
- **Introducing Narrow Line Seyfert 1** (NLS1; Osterbrock & Pogge 1985) **subtypes** based on the same criteria used by Osterbrock (1981); NLS1.0, NLS1.2, NLS1.5, NLS1.8, NLS1.9;
- **Introducing Narrow Line QSOs and their subtypes analogous to NLS1s** (Osterbrock, 1981, Osterbrock & Pogge, 1985); NLQ1.0, NLQ1.2, NLQ1.5, NLQ1.8 and NLQ1.9;
- **Fine classification of Composite spectrum objects** (Véron et al., 1997); Sy/LINER, Sy/HII, LINER/HII, as well as Sy/LINER/HII (with all variety of subtypes of Seyferts participating in each subtype of Composites).

To summarize our types and subtypes, we give Table 3 for comparative analysis of all properties. Here we give only most important types and subtypes and those, which often appear in our classifications.

Table 3. A comparative analysis of all properties for different types and subtypes of AGN and Starbursts.

Types	**Broad lines**			**Narrow lines**					
	H_α	H_β	Other	HI	[OII]	[OIII]	[OI]	[NII]	[SII]
Q1.0	Strong	Strong	yes	No	Weak	Strong	Not obs	Strong	Not obs
Q1.2	Strong	Strong	yes	Weak	Weak	Strong	Not obs	Strong	Not obs
Q1.5	Strong	Strong	yes	Medium	Weak	Strong	Not obs	Strong	Not obs
NLQ1.0	Strong	Strong	yes	No	Weak	Strong	Not obs	Strong	Not obs
NLQ1.2	Strong	Strong	yes	Weak	Weak	Strong	Not obs	Strong	Not obs
NLQ1.5	Strong	Strong	yes	Medium	Weak	Strong	Not obs	Strong	Not obs
S1.0	Strong	Strong	yes	No	Weak	Strong	Weak	Strong	Weak
S1.2	Strong	Strong	yes	Weak	Weak	Strong	Weak	Strong	Weak
S1.5	Medium	Medium	yes	Medium	Weak	Strong	Weak	Strong	Weak
S1.8	Weak	Weak	No	Strong	Weak	Strong	Weak	Strong	Weak
S1.9	Weak	Not obs	No	Strong	Weak	Strong	Weak	Strong	Weak
NLS1.0	Strong	Strong	yes	No	Weak	Strong	Weak	Strong	Weak
NLS1.2	Strong	Strong	yes	Weak	Weak	Strong	Weak	Strong	Weak
NLS1.5	Medium	Medium	yes	Medium	Weak	Strong	Weak	Strong	Weak
NLS1.8	Weak	Weak	No	Strong	Weak	Strong	Weak	Strong	Weak
NLS1.9	Weak	Not obs	No	Strong	Weak	Strong	Weak	Strong	Weak
S2.0	No	No	No	Strong	Weak	Strong	Weak	Strong	Weak
LINER	No	No	No	Strong	Strong	Strong	Strong	Strong	Strong
HII	No	No	No	Strong	Weak	Weak	Weak	Weak	Weak
Comp	Any	Any	Any	Strong	Any	Any	Any	Any	Any

As seen from Table 3, almost all subtypes (beside S2.0, LINER and HII) have strong, medium or weak broad lines (at least H_α), which makes impossible their classifications by the diagnostic diagrams. Among the narrow forbidden lines, some ([OIII], [NII], etc.) are almost always observable, however when the broad lines are strong, better resolution spectra are needed to distinguish [NII] from broad H_α and narrow H_α and H_β from their broad components. In general, one has to accept that any classification works well for the given spectral range and quality (spectral resolution and S/N ratio). When classifying other than SDSS spectra, new features and details may appear. However, our classification scheme may be useful for many studies, as 4.3 million SDSS spectra at present comprise some 80% of all medium and high resolution spectra available in astronomy (dozens of millions of low-resolution spectra are provided by objective prism surveys, such as DFBS (Mickaelian et al., 2007), HQS (Hagen et al., 1995), HES (Wisotzki et al., 1996) and will be available from Gaia, however very poor and only preliminary classification will be possible based on them).

The fine classification of AGN may strongly support the understanding of the Unified Scheme and all details about the position (angle of observation) of different types and subtypes of AGN in this scheme.

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To summarize the results of this paper, one can emphasize the development of a detailed homogeneous fine classification scheme for active galaxies considering all available spectral features in SDSS spectroscopy. We have based on the available historical classifications and used the newest BPT-type diagnostic diagrams; however, many new subtypes have been introduced to fit the same approach for QSOs and Seyferts, broad (BLS1) and narrow (NLS1) line Seyfert 1s.

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