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AGN Zoo and Classifications of Active Galaxies

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Abstract. We review the variety of Active Galactic Nuclei (AGN) classes (so-called "AGN zoo") and classification schemes of galaxies by activity types based on their optical emission-line spectrum, as well as other parameters and other than optical wavelength ranges. A historical overview of discoveries of various types of active galaxies is given, including Seyfert galaxies, radio galaxies, QSOs, BL Lacertae objects, Starbursts, LINERs, etc. Various kinds of AGN diagnostics are discussed. All known AGN types and subtypes are presented and described to have a homogeneous classification scheme based on the optical emission-line spectra and in many cases, also other parameters. Problems connected with accurate classifications and open questions related to AGN and their classes are discussed and summarized.

Keywords: AGN, quasars, Seyfert galaxies, LINERs, Starburst galaxies, radio galaxies, jets

1 Introduction

Active Galactic Nuclei (AGN) are the most interesting and crucial topic in extragalactic astronomy. Their studies are connected to galaxy evolution, understanding of energy sources, galaxy morphology, interactions and merging, binary and multiple structure and clustering. AGN are the most luminous persistent sources of the Universe, and as such can be used as means for discovery of distant objects. On the other hand, their evolution as a function of cosmic time also puts constraints on cosmological models of the Universe. According to modern views, AGN is a compact region at the centre of a galaxy having much higher than normal luminosity over the whole or at least some part of the electromagnetic spectrum. Such excess emission has been observed in radio, microwave, IR, optical, UV, X-ray and gamma-ray wavelengths. That is why it is so important to have an overall picture of radiation, multi-wavelength (MW) Spectral Energy Distribution (SED). AGN hosting galaxies are called active galaxies, however galaxies show **Starburst (SB)** activity as well (having high star-formation rate, SFR). So active galaxies may have either nuclear or starburst activity or both. The radiation from AGN is believed to be the result of accretion of mass by a **Super-Massive Black Hole (SMBH)** at the centre of its host galaxy having 10^6-10^{10} M$\odot$. Accretion can potentially give very efficient conversion of potential and kinetic energy to radiation, and SMBH has a high Eddington luminosity (the maximum luminosity of a body when there is balance between radiation and gravitation), and as a result, it can provide the observed high persistent luminosity. SMBHs are now believed to exist in the centres of the most if not all massive galaxies since the mass of the black hole correlates well with the velocity dispersion of the galactic bulge or with bulge luminosity. Thus AGN-like spectrum is expected whenever a supply of material for accretion comes within the sphere of influence of the central BH.

There is a number of **observational signatures to distinguish an AGN**. Here we list some important features that allow to identify an AGN:

- **Optical emission lines.** Depending on the physical conditions of the regions of their origin, they can be broad or narrow corresponding to Broad Line Regions (BLR, closer to the nucleus) or Narrow Line Region (NLR, relatively farther from the nucleus), respectively.
- **Optical continuum emission** comes from the nucleus and is visible whenever there is a direct view of the accretion disc. Jets can also contribute to this component. The optical emission has a roughly power-law dependence on wavelengths.
- **Radio continuum emission** always comes from a jet. It shows a spectrum characteristic of synchrotron radiation. However, radio structures show a big variety; from central ones to large radio lobes.
- **Nuclear IR emission** is detectable if the accretion disc and its environment are obscured by gas and dust close to the nucleus. They re-emit UV and optical radiation into IR. As it is thermal emission, it can be distinguished from any jet or disc emission by its distribution.
- **X-ray continuum emission** comes both from the jet and from the hot corona of the accretion disc through the scattering process and show power-law spectrum. In some radio-quiet AGN there is an excess of soft X-ray in addition to the power-law component.
- **X-ray line emission.** The illumination of cold heavy elements by X-ray continuum causes fluorescence of X-ray emission lines. Such well-known feature is Fe-K line centered at 6.4 keV. It may be narrow or broad. Using relativistically broadened Fe lines, one can study the dynamics of the accretion disc very close to the nucleus, hence the nature of the central SMBH.
- **Other manifestations of activity.** These may be jets, compact components, interactions, merging, etc., including those not directly related to the nucleus, but somehow resulting from its activity, so-called AGN feedback.

The variety of observational manifestations has led to the **variety of AGN types**, especially taking into account historical classifications, when any classification was made based on the not complete knowledge of the given epoch. And even though **unified models** (or unified schemes; Antonucci & Miller 1985; Antonucci 1993; Urry & Padovani 1995) propose that different observational classes of AGN are a single type of physical object observed under different conditions (in fact, their different orientations in the space and hence, angles of view to the observer), anyway one should carefully study and understand all observable features, and most importantly the optical emission-line spectrum of AGN. We focus on the observable characteristics of AGN, including optical spectrum and other wavelengths features that help classifying and understanding these objects among the zoo of various types.

Classification is especially important for further studies of any object, both to confirm or reject any observable (astronomical) or physical relation based on definite types of objects. In case of AGN, we study and set up their characteristics for different types based on accurate classifications, otherwise any study will involve errors and uncertainties. Hundreds of thousands of AGN have been discovered and catalogued; here we list some of the biggest and/or most important ones that serve as bases for homogeneous classifications:

- **Catalogue of Quasars and Active Nuclei**, 13th version, hereafter VCV-13, 168,940 objects (Véron-Cetty & Véron 2010).
- **SDSS-DR7 5th Quasar Catalog**, 105,783 quasars (Schneider et al. 2010).
- **SDSS-DR9 Quasar Catalog**, 87,822 quasars, mostly new ones (Pâris et al. 2012).
- **Large Quasar Astrometric Catalogue (LQAC-2)**, 187,504 quasars (Souchay et al. 2012).
- **Roma Multi-frequency Catalogue of Blazars (BZCAT)** 5th version, 3,561 blazars (Massaro et al. 2015; http://www.asdc.asi.it/bzcat/).
- **Low-frequency radio catalog of flat-spectrum sources (FSS)**, 28,358 sources (Massaro et al. 2014).
- **Catalogue of X-ray selected AGN (HRC/BHRC)**, 4,253 ROSAT objects identified as AGN (Paronyan & Mickaelian 2015).
- Some other AGN lists from SDSS and elsewhere: **Type II QSOs** (Zakamska et al. 2003), **Seyferts and LINERs** (Hao et al. 2005), **BL Lacs** (Collinge et al. 2005), etc.

However, none of these samples give accurate and detailed classifications. This is because VCV-13 uses classifications from source papers independent of their accuracy. Quasars in fact do not have any regular classification, and on the other hand, SDSS automatic procedures lead to a lot of erroneous classifications, as well as to misidentification of spectral lines and hence, redshift measurements. Moreover, there is no unique classification scheme that could be used in all these and other catalogues.

There are a number of issues related to AGN and other active galaxies classifications. Here we give some of them:

- **Physics.** Of course the main task is to understand what physics is underlying the observed spectrum and other observable features. What physical phenomena cause the given emission and absorption lines, and the continuum? How it works to produce the summarizing spectrum? Both observational (empirical) and theoretical approaches are useful that may solve direct or inverse problems.
- **Technical issues.** There are many technical problems to be solved for accurate reduction, measurements and classifications. Many parameters may play role: the slit/fiber size, distance of the observed objects and hence angular size, wavelength range, signal-to-noise (S/N) ratio, spectral resolution, variability, reduction/measurements effects, etc.
- **Methodology.** Reduction, measurement and classification methodology is also rather important; what we are distinguishing. Do we give importance only to optical spectra and hence lose hidden AGN (IR, X-ray)? Do we combine optical spectral data with those of other wavelength ranges?
- **Philosophy.** The philosophy of classifications is that one needs to have definite types of the studied samples and/or objects for making any conclusion. During the whole history of science, classifications have played important role in different science disciplines (astronomy, particle physics, chemistry, biology, etc.). Only after the classification one can study definite objects. However, they also introduce discontinuity, as intermediate

objects are artificially lost or neglected. Scientists try to find regular relations for all objects and properties, though this might not always be the case in the nature. This is the reason why most of the astronomers call most of the classifications as historical ones and different types of objects as historical types. One solution is to turn qualitative nomenclature to quantitative data and study everything quantitatively, which is much harder but much safer. An example could be the stellar classification into O-B-A-F-G-K-M-L-T. When studying properties of these definite types, one can for example compare those for A and F types. However we know that there are also subtypes (A0, A1, A2, ..., A8, A9, F0, F1, etc.) and e. g. A9 is much closer to F0 than to A1. However we combine all A subtypes together and may lose some fine characteristics. Therefore, quantitative relations (e. g. using the temperature or colour index rather than spectral type or even subtype) are much better. The same was with Seyfert galaxies. Until now we try to compare Sy1 and Sy2 types and find differences, because they have been classified differently, though intermediate subtypes were introduced later. Similarly, radio galaxies have a wide range of radio luminosities and one should not study all galaxies as of two types (radio loud and radio quiet) not to lose numerous characteristics of intermediate objects. The same is with FR I and FR II types sources.

Anyway, we give high importance to **accurate spectral reduction, line measurements and classifications**, as many parameters that we define and use for calculation and derivation of the physical properties and hence understanding the nature of objects depend on this; distribution of physical parameters, dependencies, flux ratios, etc.

2 Historical Classifications and AGN Zoo

Since the end of the XIX century, astronomers have noticed that many nebulae had emission lines; these were planetary nebulae, a number of diffuse ones, as well as since the beginning of the XX century some spiral nebulae also showed emission lines. The previous experience of the study of emission nebulae would play an important role for further investigations of galaxies.

In 1908, E. A. Fath observed first emission lines in spectrum of NGC 1068 (at that time known as nebula; Fath 1908). Later on, in 1917-1934, Slipher, Cambell, Moore, Hubble, Humason and Mayall confirmed the emission lines for NGC 1068 and observed such in NGC 5236, NGC 4151, NGC 4051 and NGC 1275 (Slipher 1917; Cambell & Moore 1918; Hubble 1926; Humason 1932; Mayall 1934). However, these papers were left without enough importance.

On the other hand, historically the first discovery of any kind of activity (from modern point of view) in galaxies was reported by Grote Reber in 1939 (Reber 1940), when he discovered Cygnus A as a radio source. Anyway, it was also not known as an extragalactic object.

Later on, Carl Seyfert (Seyfert 1943) observed emission-lines in the spectra of some spiral galaxies ("extragalactic nebulae"), including presently well-known AGN NGC 4151, 4051, 1068, 1275, 3516, 5548, 7469. Especially surprising were broad emission lines (or broad wings of lines) that were not observed in the spectra of the galactic nebulae. Out of Seyfert's 12 emission-line galaxies (NGC 1068, 1275, 2782, 3077, 3227, 3516, 4051, 4151, 4258, 5548, 6814, 7469), now only 8 are considered as genuine Seyferts.

In 1940s, after observations of discrete radio sources, some of them were for the first time identified with extragalactic objects (galaxies) and these galaxies were named **radio**

galaxies. Hey, Parsons and Phillips (Hey et al. 1946) discovered variations in the intensity of galactic noise from the direction of the constellation of Cygnus, with a period of about one minute-suggesting that this particular radiation has its origin in a discrete source, Cygnus A (later named as 3C 405). Several other radio galaxies (Per A = NGC 1275, etc.) were detected that seemed to have double structure (Bolton et al. 1949). These objects emitted huge amounts of energy attributed to the collisions of two galaxies (Baade & Minkowski 1954).

In the optical wavelengths, using three-color filter technique, 44 blue galaxies were found by Haro (1956), some of them showing emission lines in their spectra ([OII] 3727 doublet, etc.). However, very few observational facts were known in the middle of 1950s related to peculiar radiation from galaxies.

Since the beginning of 1950s, Ambartsumian carefully analyzed all accumulated data on emission-line galaxies (Seyfert 1943 and other papers), radio galaxies, blue components around giant galaxies, some other multiple galaxies (Zwicky 1956), Haro's blue galaxies (Haro 1956), etc. and came to a conclusion that all these various manifestations of activity related to the same physical phenomenon, namely activity of the galactic nuclei (Ambartsumian 1955; 1956). It was not straightforward and obvious, as the data were very few and each seemed to have independent explanation. Moreover, blue-UV emission of some nearby galaxies obviously came from their spiral arms and was explained by a large number of hot stars. Ambartsumian rejected the collisional model by Baade & Minkowski (1954) based on calculations of probabilities of collisions, which appeared to be almost impossible. According to Ambartsumian, manifestations or forms of activity could be rather different:

- emission or outflow of ordinary gas matter from the central part of the galaxy having velocities up to several hundreds of km/sec,
- continuous emission of fluxes of relativistic particles originating high-energy particles (forming radio halos around the nuclei),
- eruptive ejections/outbursts of gas matter (M82),
- eruptive ejections/outbursts of relativistic plasma (NGC 4486, NGC 5128),
- ejections/outbursts of blue condensations having absolute luminosities typical of dwarf galaxies, etc.

These various forms of activity were presented as different manifestations of the same phenomenon of the activity of galactic nuclei. The evolutionary significance of the activity in the galactic nuclei was emphasized and a further hypothesis was suggested on the ejection of new galaxies from AGN. Thus, a **hypothesis on the activity of galactic nuclei** was proclaimed by Ambartsumian (1955; 1956). Similar discussions and direct indication on massive nuclei were given by Woltjer (1959).

A comparative analysis of all these observational data shows that independent on their apparent differences, all these phenomena have a common physical nature. Ambartsumian came to such conclusion at the very beginning of investigations and reported this in important papers (Ambartsumian 1958; 1961). From the modern point of view, these ideas could be regarded as the same as a unified model for all types of AGN.

However, during many years in 1960s–1980s, all types of the revealed AGN were regarded as different kinds of objects, probably with different mechanisms of radiation. Moreover, all historical classifications (Seyfert 1 and 2, radio galaxy, QSO, LINER, BL Lac objects, etc.) supported an idea to explain them individually and then (if possible) try to find similarities or links between these classes.

The theoretical study of the numerous observational evidences of various sorts of physical instability in galaxies led Ambartsumian to a fundamental conclusion that in processes of origin and evolution of galaxies, the role of the central small in their sizes condensations, the nuclei of galaxies, is huge. He justified an essentially new understanding that all observational evidences of the instability of galaxies are a consequence of activity of the galactic nuclei. The hypothesis on the superdense protostellar matter was engaged to explain the observational data, though later on not accepted. Anyway, modern understanding on SMBH in the centre of AGN very much resembles Ambartsumian's ideas.

In 1959, after the completion of the 3rd Cambridge radio survey (3C Catalogue; Edge et al. 1959), many new radio sources were found and many of them were identified with extragalactic objects. Optical spectra of a number of the identified point-like objects showed peculiar emission lines that could not be identified. Using an optical spectrum obtained with the 200-inch Hale Telescope on Mt. Palomar, Maarten Schmidt was the first (Schmidt 1963) to interpret the spectrum of 3C 273 as having very largely redshifted (z=0.158) broad emission Balmer lines corresponding to recession velocity of 47,000 km/s. Immediately, Greenstein & Matthews (1963) identified spectral lines in the optical spectrum of the radio source 3C 48 (z=0.37). This discovery allowed other astronomers to find redshifts from the emission lines from 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)**.

In 1963, B. E. Markarian published a list of 73 galaxies having peculiar colours compared to their spectral types and showed that there should be some additional radiation (Markarian 1963). Based on this consideration and powered by Ambartsumian's ideas, in 1965 Markarian initiated a large objective prism survey for detection of galaxies with UV-excess (UVX) (Markarian 1967). 17,000 sq. degrees were covered in the Northern and some part of the Southern extragalactic skies and 2,000 plates were obtained. **Markarian Survey** (also known as the First Byurakan Survey, FBS) played an important role in the discovery of many new AGN and understanding their types and cosmic abundance. Weedman and Khachikian obtained many spectra for **Markarian galaxies** and due to more statistics classified Seyferts into Sy1 and Sy2 types (Weedman & Khachikian 1968; Khachikian & Weedman 1971; 1974); Sy1s having both broad and narrow emission lines and Sy2s having only narrow emission lines. Later on, Osterbrock introduced more subtypes: Sy1.0, Sy1.2, Sy1.5, Sy1.8, Sy1.9, and Sy2.0 (Osterbrock 1981). However, even Sy1 and Sy2 were regarded as different types of objects with different physical nature and radiation mechanisms. Based on Markarian galaxies, Weedman also introduced the class of the Starburst galaxy (Weedman 1977). Catalogues of Markarian galaxies were published by Mazzarella & Balzano (1986), Markarian et al. (1989; 1997) and Petrosian et al. (2007). Some important features of Markarian survey are:

- Markarian Survey was the first systematic objective-prism survey in the world
- Until now it is the largest objective-prism survey of the Northern sky (17,000 sq. deg)
- It was a new method of search for active galaxies
- 1515 UVX galaxies were discovered, including 181 Seyferts, 17 LINERs, 13 QSOs, 3 BLLs, 95 Starburst, 26 HII galaxies (Markarian et al. 1989)
- Classification of Seyferts was carried out into Sy1 and Sy2 (Khachikian & Weedman 1974)
- The definition of Starburst galaxies was introduced (Weedman 1977; Balzano 1983)

- Many new Blue Compact Dwarf Galaxies (BCDG) were discovered
- Similar surveys were conducted and many new AGN were discovered; Second Byurakan Survey (SBS, Markarian et al. 1983, Stepanian 2005) and others
- Other projects were carried out based on FBS plates: FBS Blue Stellar Objects (BSOs; Mickaelian 2008), FBS Late-Type Stars (Gigoyan & Mickaelian 2012), optical identifications of IRAS points sources; Byurakan-IRAS Stars (BIS; Mickaelian & Gigoyan 2006) and Byurakan-IRAS Galaxies (BIG; Mickaelian & Sargsyan 2004), including many new AGN and ULIRGs

More details on Markarian Survey are given by Mickaelian (2014).

In addition to Seyfert, Haro and radio galaxies known since 1940s-1950s, during 1960s-1980s, quasars (Schmidt 1963), peculiar galaxies (Apr 1966), Markarian galaxies (Markarian 1967), BL Lacertae objects (as extragalactic sources similar to quasars; Strittmatter et al. 1972), High surface brightness (Arakelian) galaxies (Arakelian 1975), Starburst galaxies (Weedman 1977), blazars (as a new class unifying BL Lacs and OVV/HPQ quasars; Spiegel 1978), LINERs (Heckman 1980), IR galaxies (after IRAS mission in 1983, the first big list was given by Soifer et al. (1989) and revised by Sanders et al. (2003)) were discovered either introduced. AGN zoo appeared with a big mixture of properties and confusion in definitions and classifications.

In 1985, Antonucci and Miller published a paper *"Spectropolarimetry and the nature of NGC 1068"* (a classical Seyfert 2 type showing only narrow emission lines) (Antonucci & Miller 1985). The polarized flux plot revealed the presence of very highly polarized, very broad symmetric Balmer lines and also permitted Fe II closely resembling the flux spectra of Seyfert type I nuclei. This line emission indicated that both polarizations were due to scattering, probably by free electrons which must be cooler than a million K. A model was suggested in which the continuum source and broad line clouds were located inside a thick disk, with electrons above and below the disk scattering continuum and broad-line photons into the line of sight. All of the narrow lines, including the narrow Balmer lines, had similar low polarizations, unrelated to that of the continuum. Further studies strengthened such a geometrical understanding of the difference between the AGN, so that each type (the classification) depended on the observed angle. So the major breakthrough in understanding the connection between Sy1s and Sy2s was the discovery of a "hidden" broad line region (BLR) in the Sy2 NGC 1068.

According to this understanding, Sy1s have nuclear emission line spectrum characterized by broad (a few thousands km s^{-1}) permitted lines and narrow (a few hundreds km s^{-1}) high excitation lines. Seyfert 2s have narrow emission line spectrum like the Seyfert 1s, but they are lacking both the compact nucleus and the broad emission lines. QSOs are high luminosity Sy1s. Seyferts and QSOs contain a compact nuclear continuum source ionizing a broad line region, surrounded by an optically thick torus of dust. Depending on the orientation of this torus with respect to the line of sight, the central object is seen or hidden; when it is hidden, we see only the narrow, extended emission line region; the galaxy is a Sy2. This is, very schematically, the generally accepted **Unified Scheme of AGN**. Thus, all kinds of AGN now are put in the same scheme and are regarded as a common phenomenon; an approach developed by Ambartsumian since the middle of 1950s.

Later on, new classes and subclasses of active galaxies were discovered and introduced, such as BCDGs (Thuan & Martin 1981), Narrow-Line Seyfert Galaxies (Osterbrock & Pogge 1985), composite spectrum objects (Véron et al. 1997), subtypes of Starbursts (Terlevich 1997; 2000), etc.

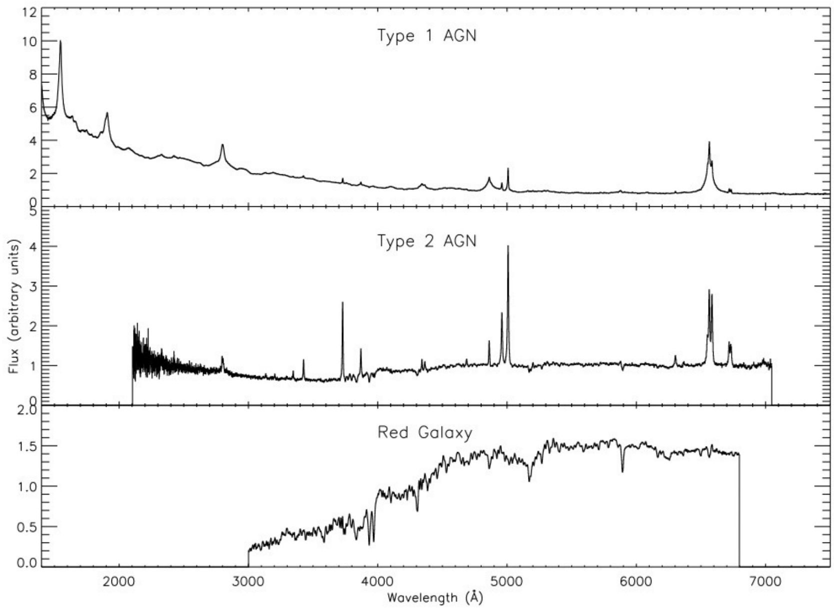

Figure 1: Three main types of optical spectra of galaxies: Type 1 AGN with both broad and narrow emission lines, Type 2 AGN with narrow emission lines, and normal galaxies with absorption lines.

3 Optical Emission Line Spectrum of Active Galaxies

The optical emission line spectrum of active galaxies contains narrow (line widths up to 300 km/s) and broad (line widths – several thousand km/s) lines. They have been crucial for understanding the physical processes in these galaxies and for classifications, as they are the most significant features and provide a big variety of information. First of all, one should distinguish normal (typically red) galaxies from active ones by their absorption spectrum. Active galaxies (both AGN and SB) show many emission lines, including H Balmer series, He, O at different ionization level, N, S, metallic lines, etc. Two big groups that should be distinguished immediately, are Type 1 and Type 2 AGN. Type 1 AGN have both broad and narrow emission lines, Type 2 AGN, as well as SB have only narrow emission lines, and normal galaxies have no emission lines (Fig. 1). Along with the spectral lines, an important role also plays the continuum; stronger the continuum, relatively weaker the lines and less accurate is the classification. Therefore, in many cases, templates for red elliptical galaxies are being built, fitted to the studied spectra and extracted to have pure emission line spectrum for accurate measurements and classifications. The presence of the underlying host galaxy is displayed by the level of the continuum with typical absorption galaxy shape and absorption lines (NaI 5890/5896 doublet, MgI, Hydrogen Balmer lines, etc.). Among the emission lines, in the optical range most prominent are Hydrogen Balmer series lines (Hα 6363, Hβ 4861, Hγ 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.

There are two kinds of emission lines: 1) Recombination lines (e.g. Balmer H lines) and 2) Collisionally excited lines. The first type lines are due to electric dipole transitions, so they occur easily, they have very short lifetimes, and are called “permitted” transitions and hence, **"permitted lines"**. Collisionally excited lines, ground state often split by small energies E $\sim$ kT thermal collisions can populate these low lying levels. De-excitation occurs either by collisions or radiatively; which dominates depends on which occurs fastest. Often, the radiative lifetimes are long, because the transitions are "forbidden" (they only occur via electric quadrupole or magnetic dipole transitions). The lines hence are called **"forbidden lines"** (usually taken in square brackets, e. g. [OIII]). They tend to be suppressed at high densities, when collision times are fast. At the critical density, the radiative and collisional rates are equal. In gas with density above the critical density, the line is not strongly produced (it is collisionally suppressed). For each forbidden line, there is its critical density. For some of the most important forbidden lines that appear in AGN and SB spectra, these critical densities in cm^{-3} (log) are: CIII] 1909 – 9.0, [OII] 3726.1 – 3.5 and [OII] 3728.8 – 2.8, [OIII] 5006.9 – 5.8, [OI] 6300.3 – 6.3, [NII] 6583.4 – 4.9, [SII] 6716.4 – 3.2, [SII] 6730.8 – 3.6. Permitted and semi-forbidden lines can be both broad and narrow, whereas forbidden lines never appear as broad ones.

Because there are numerous lines in the optical part of the spectrum, their identification and classifications are not easy tasks. There also are a number of technical problems with emission lines that should be taken into account to consider further classifications. Here are some of them:

- **Reduction problems.** These cause different numbers in line measurements, slope of the continuum, etc. Even the SDSS spectra that are relatively good by their spectral resolution and signal-to-noise (S/N) ratio, very often are measured differently.
- **Host galaxies.** These produce significant continuum and absorption spectrum that strongly affect emission line measurements. Very often Balmer lines have both emission and absorption components superposed and it is not easy to define what the true values are for each. Better emission-line spectrum is obtained if only the central part of the galaxy is observed.
- **Fe lines.** AGN spectra contain numerous iron (FeI, FeII and FeIII) lines. They appear around Hβ (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. The best one is IZw1 FeII template obtained with MIDAS (Fig. 2).
- **Line identification.** Due to the presence of numerous lines, their identification becomes rather tricky. Most of the models use emission lines well defined from nebular spectra, as well as from emission-line stars. However, very often one needs to make own choice between many possibilities (Fig 3).
- **Multiple profiles.** Emission line systems are not unique. Depending on the physical properties of the regions producing these lines, several broad and narrow lines systems may appear. In this case the summarizing profiles have no physical sense and one should be careful when measuring any line parameter (Fig. 4).
- **Variability.** This causes change of both continuum and line parameters. AGN typically are optically variable (e. g. blazars, QSOs; Véron & Hawkins 1995). In this case typical (average) line parameters are given with possible limits of changes. However, one should carefully measure all parameters and in case of multiple observations, follow the changes in individual lines; both positions, intensities and widths (e. g. Goodrich 1995; Edelson et al. 2001, for NGC 4151). In Fig. 5 we give two examples of variable AGN spectra superposed on each other to show the changes in both continuum and emission lines.

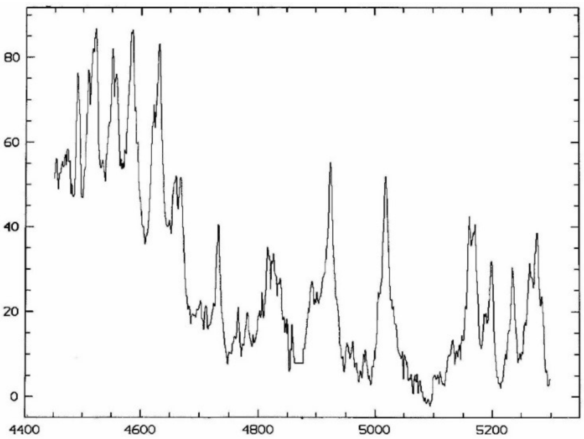

Figure 2: FeII template obtained from IZw1 spectrum and especially important around Hβ.

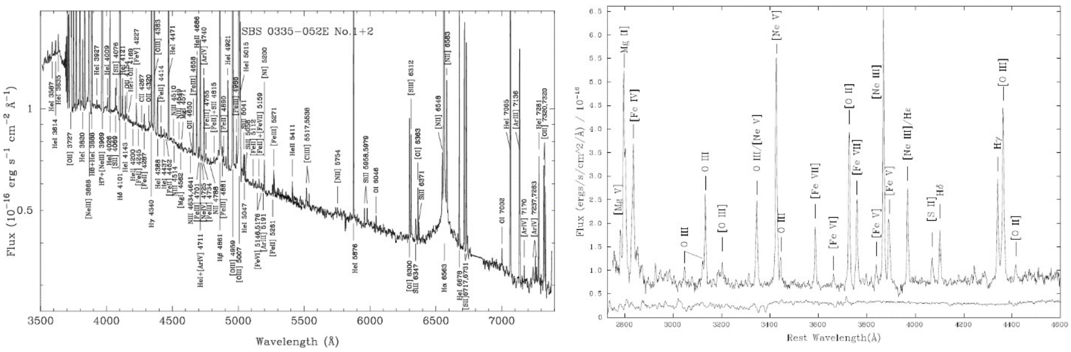

Figure 3: Numerous emission lines typical for optical spectra of active galaxies.

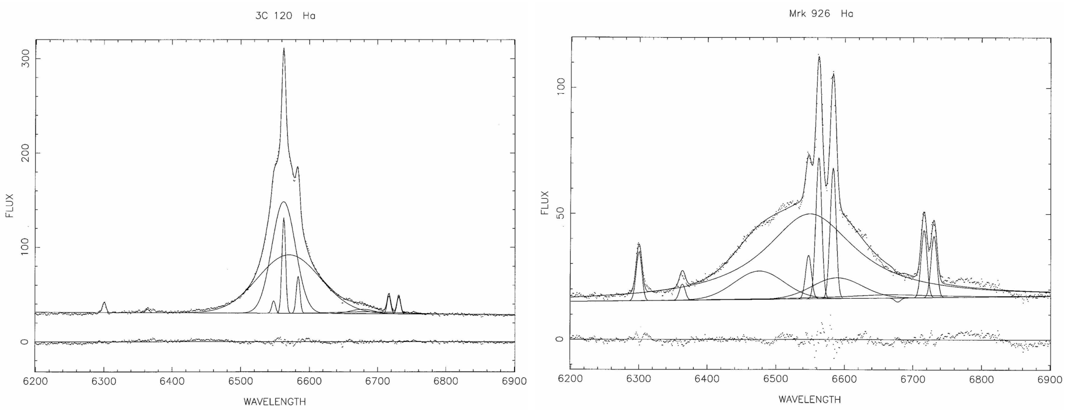

Figure 4: Individual line profiles and summarizing observed lines in spectra of 3C 120 and Mrk 926 (both in Hα region).

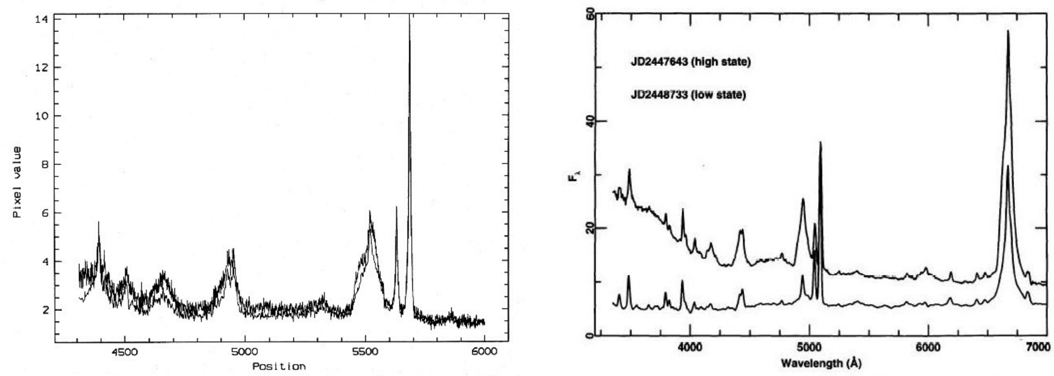

Figure 5: Examples of variable AGN spectra superposed on each other to show the changes in both continuum and emission lines. Left: Kaz 102 (Kazarian & Mickaelian 2007), right: J02447643.

Basic line parameters (of a given profile) are the **Position** of the maximum (to define redshifts), **Intensity** above the continuum level, **Full Width at 0 Intensity (FW0I)** and **Full Width at Half Maximum (FWHM)** and **Equivalent Width (EW)**. All spectral reduction software, including MIDAS, IRAF, etc. can easily measure these parameters. To describe the line width, FWHM is much more important rather than FW0I, as the latter is affected by the inaccurate measurements of the start and end wavelength due to uncertainties and noises in the continuum. FWHM is defined based on the Gaussian built on the observed profile and is measured with high accuracy.

Fine Analysis of Emission Line Spectra helps elimination of host galaxy continuum, accurate line identification, decomposition of composite line profiles and variability studies. We have carried out a number of studies to understand in detail the emission line spectra of active galaxies in collaboration with Véron and Véron-Cetty during 1997-2003. Of course, relatively high resolution spectroscopy is needed to have reasonable results (SDSS spectra can hardly satisfy these requirements; our OHP 1.93m telescope CARELEC 600 /mm grating spectra had 0.9 Å/pix dispersion and 3.2 Åspectral resolution and we obtained two spectra for each galaxy, one around Hβ and the other, around Hα). This study made use of the software SPECTRAI (Véron et al. 1980), in which the user gives start values for each profile: Amplitude, Line center (1+z) and Line width, as well as Continuum value and Slope. Up to 196 free parameters may be used, and we tested 166 spectral lines in the range 3700-7900Å(most important ones are given in Table 1 and may be used for investigation of any AGN spectrum). At the beginning, elliptic galaxy template (stellar continuum) and Fe II template from IZw1 galaxy are subtracted to exclude contamination and have better results. Fine analysis of emission line profiles for fitting of individual Gaussian (or Lorentzian) profiles to the observed summarizing ones was carried out. A comparison between the H and the H ranges observed in frame of the same project was done to accept the best solution. Detailed spectroscopic classification using the derived narrow-line intensities was carried out. Correlations between FWHM of Fe II and Balmer lines, Fe II and [O III] lines were investigated and fine details in spectra of AGN were found, including new lines, often observed very high ionization lines, etc.

Table 1: Most important emission lines in spectra of active galaxies used for fine classification. Spectral lines in the two left columns relate to Hβ range (4200-5300 Å) and those in two right columns relate to Hα range (5600-7300 Å).

Line	λ, Å	Line	λ, Å	Line	λ, Å	Line	λ, Å
Hγ	**4340.47**	[Fe VII]	4942.3	[Fe VII]	5631.1	[Fe X]	6374.51
[O III]	4363.21	**[O III]**	**4958.92**	[Fe VII]	5677.0	[A V]	6435.1
He I	4387.9	[Fe VI]	4967.1	[Fe VII]	5720.9	**[N II]**	**6548.03**
He I	4471.5	[Fe VI]	4972.5	[N II]	5754.8	**Hα**	**6562.79**
Mg I	4571.0	[Fe VII]	4988.9	**He I**	**5875.6**	**[N II]**	**6583.41**
C IV	4658.6	**[O III]**	**5006.84**	Na I	5889.9	[Fe VII]	6599.1
He II	**4685.7**	He I	5015.7	Na I	5895.9	He I	6678.1
[A IV]	4711.3	[Fe VI]	5145.8	He II	5977.0	Ni XV	6701.83
He I	4713.1	[Fe VII]	5158.9	[Ca V]	6086.4	**[S II]**	**6716.47**
[A IV]	4740.2	[Fe VI]	5176.4	**[Fe VII]**	**6086.9**	**[S II]**	**6730.85**
Hβ	**4861.33**	[N I]	5197.9	**[O I]**	**6300.30**	[A V]	7005.7
[Fe VII]	4893.9	[N I]	5200.3	Si II	6347.1	He I	7065.2
He I	4921.9	[Fe VII]	5276.4	**[O I]**	**6363.88**	[A III]	7135.8
[Ca VII]	4940.3			Si II	6371.4	[A IV]	7170.6
				[Fe X]	6372.9	[A IV]	7237.5

4 Diagnostic Diagrams for AGN Classifications

In this section we describe **AGN Optical Line Diagnostics** based on study of spectra in optical range, which allows to distinguish Seyfert galaxies, LINERs and Starburst (or HII regions). First diagrams were introduced by Baldwin, Phillips & Terlevich in 1981 (BPT diagrams; Baldwin et al. 1981). They used emission line intensities ratios ([OIII]5007/Hβ, [NII]6584/Hα, [OIII]5007/[OII]3727 and [OIII]5007/[OI]6300) to distinguish Seyferts against LINERs and Starbursts. Veilleux and Osterbrock improved this technique by modifying line rations to [OIII]5007/Hβ, [NII]6583/Hα, [OI]6300/Hα and [SII]6716+6731/Hα (Veilleux & Osterbrock 1987), as some BPT ratios need reddening correction while the Veilleux & Osterbrock ratios do not (being close in λ). In general Seyferts have strong [OIII]5007/Hβ, strong [NII]6583/Hα and strong [OI]6300/Hα ratios, i. e. a wide range of ionization degree. LINERs have lower ionization degree: weaker [OIII]5007/Hβ but strong [NII]6583/Hα and strong [OI]6300/Hα. HII regions have weaker [OIII]5007/Hβ, much weaker [OI]6300/Hα and somewhat weaker [NII]6583/Hα (Fig. 6).

At present very often these diagrams are called **BPT diagrams**, as later a number of new ones also appeared. However, there are some comments that should be taken into account when classifying galaxies with these diagrams:

- HII regions lie along a sequence in metallicity (Z): low Z have higher ionization. The sequence can reach [OIII]/H$\beta \sim 10$, so high [OIII]/Hβ is not unique for Seyferts.
- AGN are different because their ionizing spectra are broad, with a high energy component. Behind the fully ionized region lie large partially ionized regions kept hot by X-ray heating. It is in these regions that [OI], [NII] and [SII] lines are generated efficiently.
- Seyfert/LINER group may be considered as a single sequence in radiation parameter, U. Seyferts have intense hard radiation field and LINERs have weak hard radiation

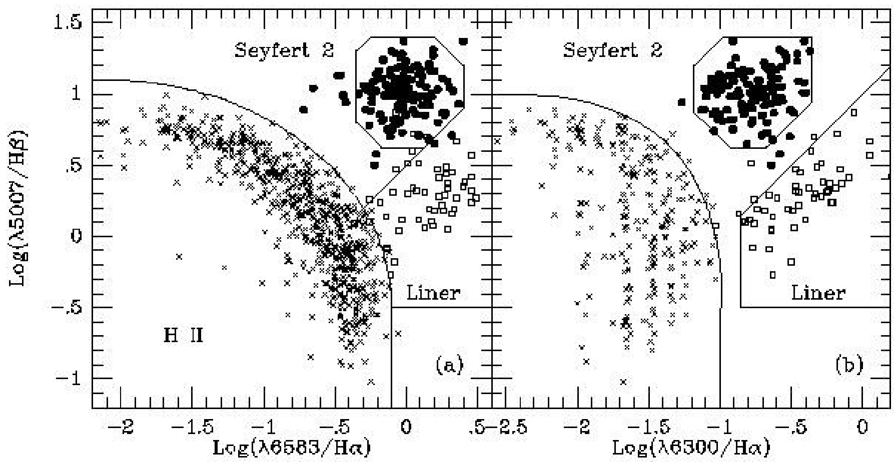

Figure 6: BPT diagnostic diagrams for classical Seyfert 2 galaxies (filled squares), LINERs (open squares) and HII galaxies (crosses). These diagrams allow to define exact regions for these three types in addition to the main lines separating them.

field.

- Very high ionization lines can be unambiguous indicators of AGN: e. g. [NeV]3426.
- Some non-AGN emission regions can show LINER spectra: e. g. cooling flows; shocks in starburst driven winds; bulge inter-stellar medium (ISM) ionized by post-AGB stars.
- Fast (500 km/s) shocks can also show Seyfert spectra, though no such clear cases are known.
- Before and in 1980s, [OIII] line width was used in defining AGN (when FWHM $>$ 300 km/s). However, now this is no more in use, as FWHM tracks bulge mass; many AGN now are known with FWHM $<$ 300 km/s.

Later on, a number of other diagnostic diagrams were suggested, both with the use of line ratios and other parameters, like colours and stellar masses, equivalent widths, etc. E. g. Lamareille and others (Lamareille et al. 2004; Lamareille 2010) have suggested similar diagram for [OIII]5007/Hβ vs. [OII]3727/Hβ ratios (so-called **Blue Diagram**).

In Fig 7 we give three diagnostic diagrams introduced by Veilleux & Osterbrock (1987) and used more frequently based on [NII]6583/Hα vs. [OIII]5007/Hβ (DD I), [SII]6716+6731/Hα vs. [OIII]5007/Hβ (DD II) and [OI]6300/Hα vs. [OIII]5007/Hβ (DD III) line ratios with distribution of Seyferts, LINERs, HII regions and so-called transition objects, which appear as intermediate objects between Seyferts and HIIs, LINERs and HIIs or Seyferts and LINERs. Such objects show features of two or three types and introduce confusion for the classifications. Later on, Véron et al. (1997) called them Composite spectrum objects and showed that these are the same spectra as Sy2, LINER and HII overlapped on each other. However, there have been a number of papers arguing the correctness of the **divisor lines between different types of AGN** (Kewley et al. 2001; 2006; Stasinska et al. 2006, etc.).

Some other diagnostic diagrams in addition to line intensity ratios (excitations) use colours, equivalent widths, stellar masses, etc. Stasinska et al. (2006) have used 4000-Åbreak index, $D_n(4000)$ vs. max (EW[OII]3727, EW[NeIII]3869) equivalent widths to distinguish

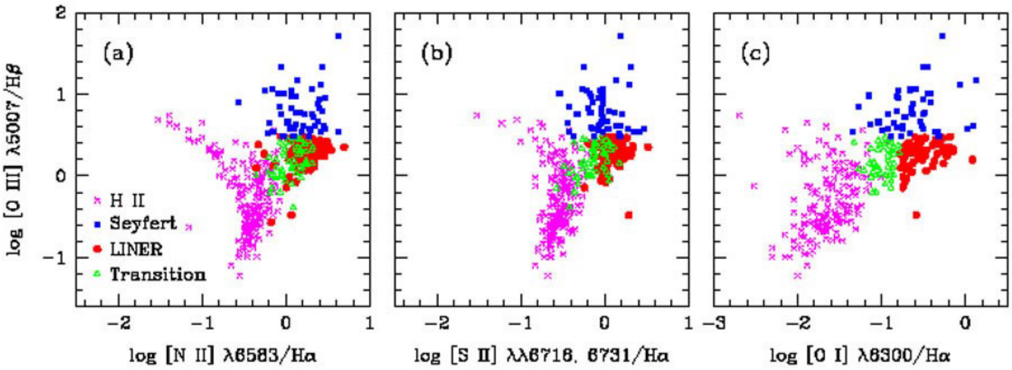

Figure 7: Three diagnostic diagrams (from left to right, DD I, DD II, DD III) with distribution of Seyferts, LINERs, HII regions and so-called transition objects.

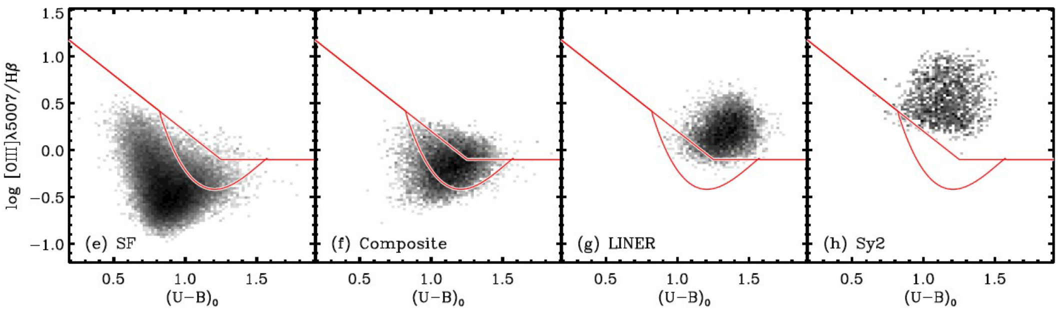

Figure 8: Diagnostic diagrams based on [OIII]5007/Hβ ratios and rest-frame U-B colour separately given for Star-Forming galaxies (SF), Composites, LINERs and Seyferts.

different type of objects (so-called **DEW Diagram**). They showed that none of BPT diagrams is efficient in detecting AGN in metal-poor galaxies, should such cases exist. Their diagram can be used with optical spectra for galaxies with redshifts up to z = 1.3, meaning an important progress over classifications proposed up to now. Since the DEW diagram requires only a small range in wavelength, it can also be used at even larger redshifts in suitable atmospheric windows. It also has the advantage of not requiring stellar synthesis analysis to subtract the stars and of allowing one to see all the galaxies in the same diagram, including passive galaxies.

Fig. 8 gives one of such alternative diagrams based on [OIII]5007/β ratio and rest-frame U-B colour (**Colour-Excitation or CEx Diagram**) separately for Star-Forming galaxies (SF), Composite objects, LINERs and Sy2s introduced by Yan et al. (2011). There is a strict separation for SF and AGN and the authors consider this diagram much more efficient for distinguishing different types.

Trouille et al. (2011) introduced a diagnostic diagram based on the rest-frame SDSS g-z colour vs. [NeIII]3869 / [OII]3726,3729 lines ratios, so-called **TBT Diagram** (after the authors names: Trouille, Barger, Tremonti). Cid Fernandes et al. (2011) introduced diagnostic diagrams based on EW of Hα (WHα) vs. [NII]/Hα (so-called **WHAN Diagram**).

Juneau et al. (2011; 2014) consider [OIII]5007/H line ratios against stellar masses to

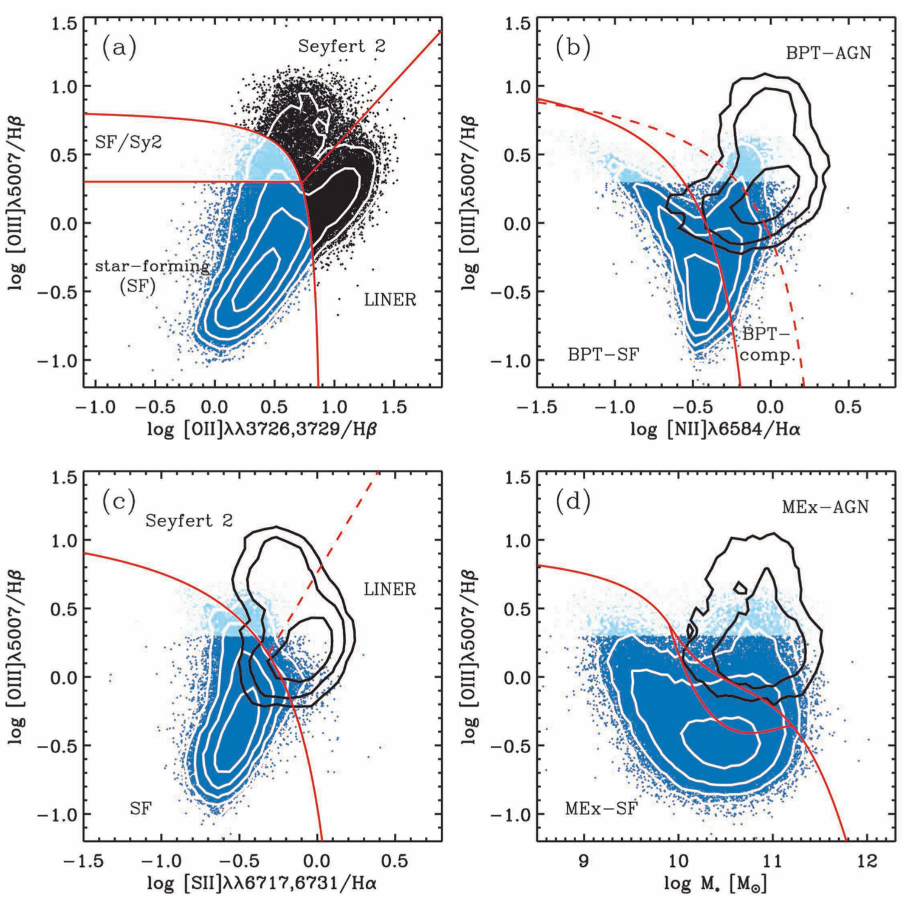

Figure 9: Mass-Excitation (MEx) diagrams by Juneau et al. (2011) demonstrating that combining [OIII]5007/Hβ and stellar mass successfully distinguishes between star formation and AGN.

distinguish Seyfert 2s, LINERs, and star-forming (SF) galaxies (Fig. 9). They are called **Mass-Excitation (MEx) Diagrams**. They are useful to identify AGN in galaxies at intermediate redshift. In the absence of near-infrared spectroscopy, necessary for using traditional nebular line diagrams at $z > 0.4$, they demonstrate that combining [OIII]5007/Hβ and stellar mass successfully distinguishes between star formation and AGN emission.

AGN Colour-Colour Diagnostics developed by Smolcic et al. (2006, 2008) is based on synthetic colours from a modified set of Stromgren uvby narrow (~200 Angstroms) bands. They adopt the filters: uz, vz, bz, yz, and show a sequence on the bz – yz vs. vz – yz colour-colour plane. P1 is defined as the location along the sequence, defined by their equations. The adopted dividing line is defined as P1 > 0.15.

Other optical diagnostic diagrams have been developed by Kewley et al. (2001; 2006), Kauffmann et al. (2003), Stern et al. (2005), Hickox et al. (2009), Cid Fernandes et al. (2011), Del Moro et al. (2013), Teimoorinia & Ellison (2014), Vogt et al. (2014) and others. The latter used **ZQE diagrams**, which are a specific set of 3D diagrams that separate the oxygen abundance and the ionization parameter of HII region-like spectra and also enable observers to probe the excitation mechanism of the gas. Stephanie Juneau has developed a com-

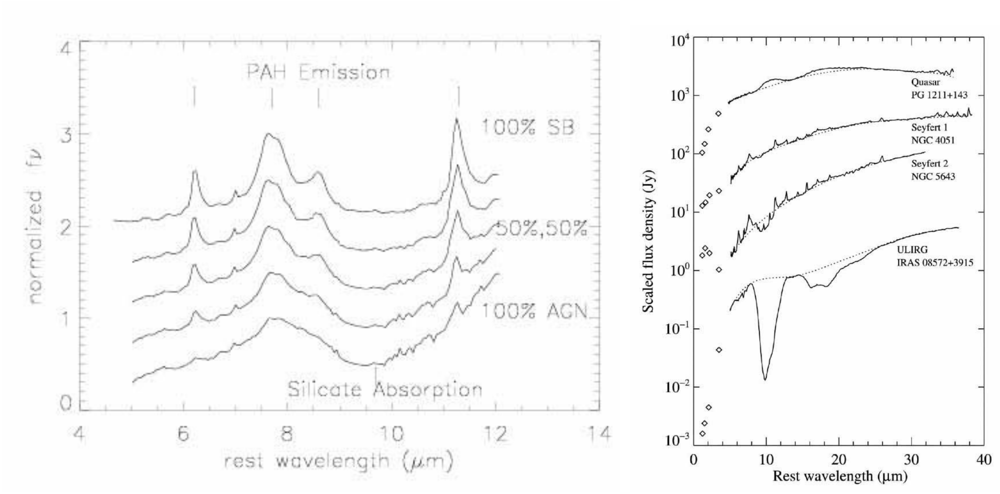

Figure 10: Mid-IR spectra of active galaxies and typical features to distinguish AGN against Starbursts: PAH emission and Silicate absorption (Houck & Weedman 2009; Levenson et al. 2014).

prehensive **AGN diagnostics website** at https://sites.google.com/site/agndiagnostics/, where both optical and other wavelengths are considered.

5 Classifications Based on other Wavelength Ranges

AGN Mid-IR Diagnostics. Mid-IR (MIR) Colour-Colour Diagrams and **MIR Emission Line Diagrams** have been used based on Spitzer Space Telescope IRAC/MIPS colours and IRS spectra (Donley et al. 2012; Weedman & Houck 2009). PAH emission is strong for Starbursts and is also present for objects with intermediate activity type given as 50% AGN and 50% SB. Silicate absorption is deeper for SB as well. These IR features give understanding on fractions of contribution of AGN and SB and may serve as even better classification than precise optical types, because very many nuclei show evidence of mixture of different types, classified as Composite (S2/HII, LINER/HII or other). Levenson et al. (2014) described larger range IR spectrum (5-35 μm) and compared AGN IR spectra to ULIRG one (Fig 10). AGN types are plotted separately as well (Quasar, S1 and S2) showing the change of the same features in the same direction, i. e. from stronger ones for SB to weaker ones for stronger AGN.

Other spectral ranges include **AGN Radio Diagnostics** based on FIR-Radio Correlation and **AGN X-ray Diagnostics**. Compared to optical diagnostic diagrams they are rather limited, however many AGN show no activity in optical wavelengths (obscured or hidden AGN) and one needs alternative means to identify them. Another limitation comes from smaller amount of observations (especially spectral ones) in these wavelengths, namely X-ray, UV, IR, sub-mm and radio. We will show in next section that only MW SEDs and much better, MW spectra can provide full understanding on the nature of the objects, including detection of differences between classes in various wavelength ranges and hence understanding of the processes putting constraints on AGN and/or Starburst emissions in optical range to be identified as classical AGN or SB.

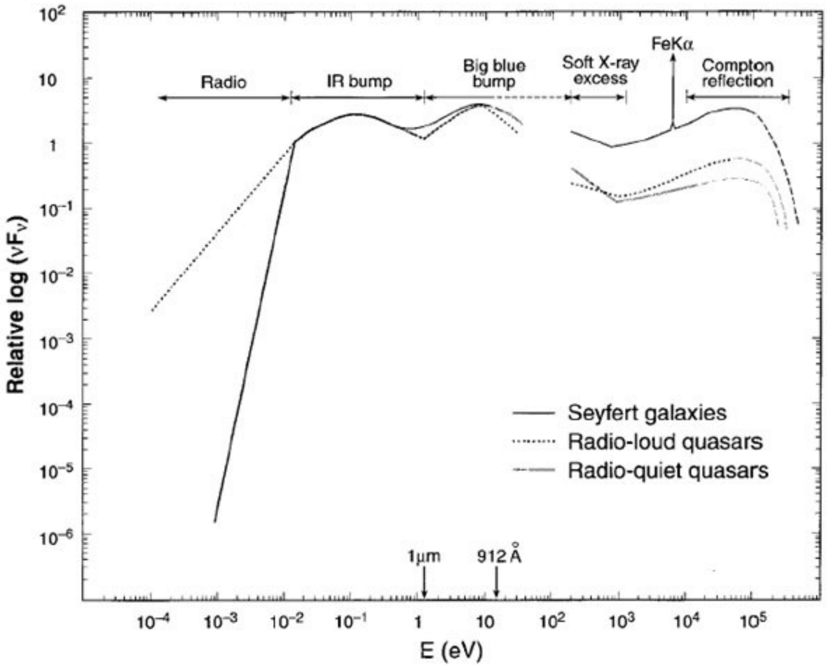

Figure 11: QSOs and Seyfert galaxies SEDs showing big difference between radio-loud and radio-quiet quasars and similarity for radio-quiet quasars and Seyferts.

6 Multiwavelength SEDs of active galaxies

Existence of active galaxies obscured in optical wavelengths and absence of radio and/or X-ray emission at most of the AGN means that multiwavelength spectrum may be the only clue to true classification. **Radio-loud and radio-quiet QSOs** have been discovered since 1960s (Sandage 1965), which already meant a significant difference in their SEDs. Sandage showed that radio-quiet QSOs were 10 times more than radio-loud ones. This meant that no prediction about radio emission could be made based on only optical spectrum. It is sometimes necessary to try to distinguish carefully between radio-loud and radio-quiet QSOs. A useful criterion (Kellermann et al. 1989) appears to be the radio-optical ratio of specific fluxes at 6 cm (5 GHz) and 4400 Å(680 THz); for radio-loud objects it is generally in the range 10-1000, and most radio-quiet objects fall in the range 0.1–1. **AGN MW SEDs** have been built since their first studies in other than optical wavelengths (Fig. 11; Elvis et al. 1994).

To understand the difference in radiation in various wavelength ranges, one should consider the **physical explanation of AGN spectral components**, i. e. mechanisms of radiation at different wavelengths (Fig. 12, Fig. 13). In near-UV (NUV) – optical range, the Big Blue Bump (0.1–1 μm) is emitted by the thermal Compton disc. Sometimes it appears as Small Blue Bump (Fig. 14) and there is also an IR bump coming from dust torus; 1 m inflection and mm break (~100μm); most of IR is being emitted by dust according to Lν = ν^{-3} at 0.1–3 mm wavelengths. Radio emission is conditioned by synchrotron jet. Soft X-ray excess (at ~0.1 keV), Fe Kα line and Compton reflection in γ rays are conditioned by thermal Compton hot corona (Compton Hump, ~10–30 keV) and inverse Compton jet. Fig. 12 shows differences in SEDs between various AGN types. Fig. 13 shows big differences in

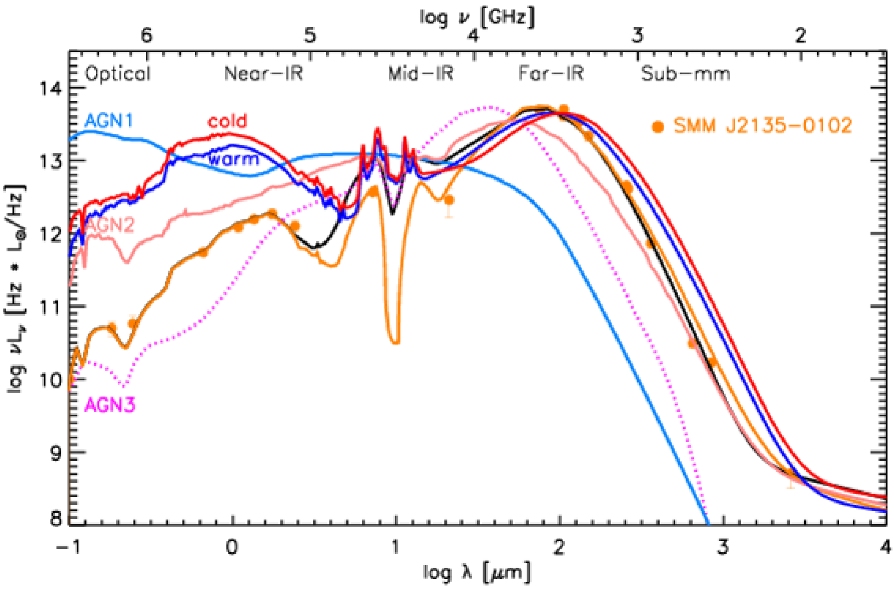

Figure 12: AGN multi-wavelength SEDs from optical to sub-mm wavelength ranges. Differences in SEDs between various AGN types are seen.

distributions for various radiation mechanisms present at different AGN types.

Science Data Center of the Italian Space Agency (ASDC, ASI Science Data Center) gives comprehensive SEDs for any object built by the selected catalogs from the list (www.asdc.asi.it/). Using this facility and other available data, we have carried out MW studies of Markarian galaxies (Mickaelian et al. 2013) and many other bright active galaxies, including IR ones (Sargsyan et al. 2001; Hovhannisyan et al. 2011; Mickaelian et al. 2012). Fig. 15 shows two remarkable Markarian galaxies, Mrk 231 (closest known ULIRG) and Mrk 421 (blazar, one of the rare TeV sources) broad-band spectra (MW SEDs) built by means of ASDC website. To have full understanding on AGN types and activity processes, one should compare all known optical (historical) classifications with MW SEDs and have enough statistics to obtain correspondence and derive relations between radiations in various wavelength ranges.

7 Classifications as a Multi-Parametric Problem

We described the AGN classification principles based on mostly optical, as well as other wavelength ranges. Most of optical diagnostic diagrams are based on emission line ratios. However, AGN classification is a multi-parametric problem. Emission lines (excitation mechanisms) cannot always explain all differences. Here we list those parameters that may somehow be related to AGN types and help the classification:

- Ratios of (narrow!) emission line intensities (diagnostic diagrams)
- Line widths: narrow lines, broad lines (BLS1/NLS1). Through the 1980s [OIII] linewidth was used in defining AGN (FWHM ¿ 300 km/s). At present it is no more used as FWHM tracks bulge mass; many AGN now known with FWHM ¡ 300 km/s. Anyway, linewidth can provide additional hint to classifications

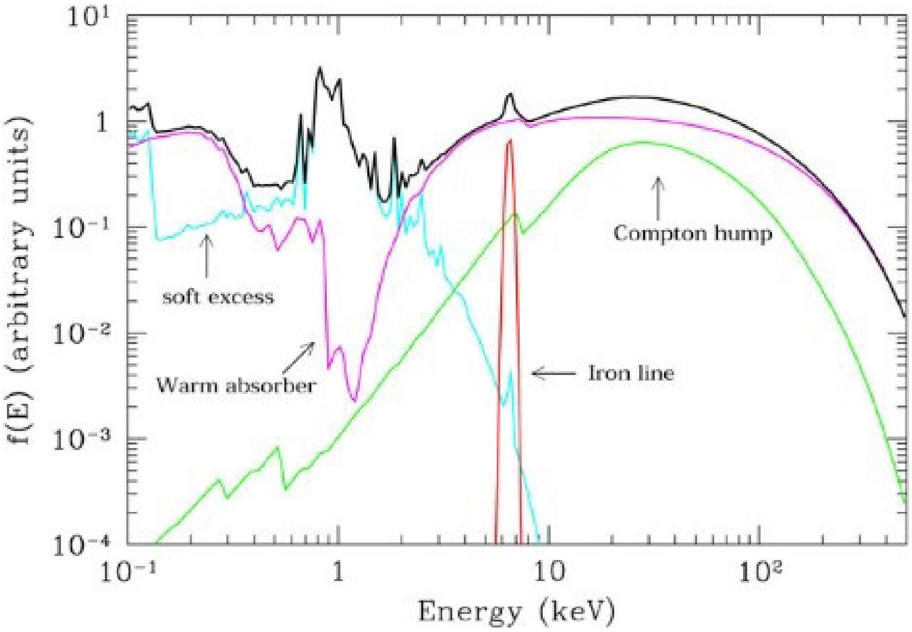

Figure 13: AGN SEDs for X-ray range. Big differences in distributions for various radiation mechanisms present at different AGN types are seen.

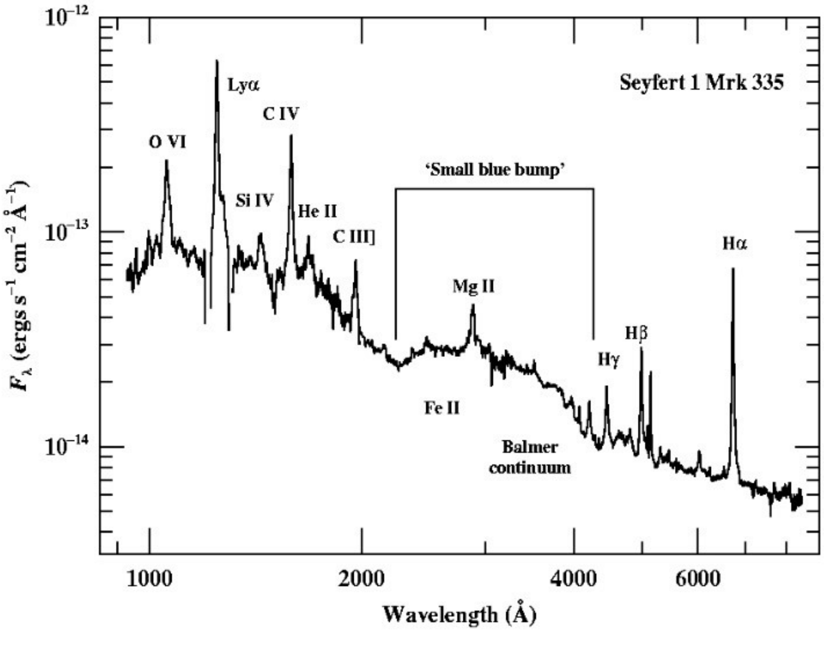

Figure 14: Small Blue Bump in the spectrum of Seyfert 1 galaxy Mrk 335.

Figure 15: Two remarkable Markarian galaxies, Mrk 231 (ULIRG) and Mrk 421 (Blazar) broad-band spectra (multiwavelength SEDs) from ASDC website.

- Ratio of narrow and broad lines (Osterbrock 1981 subtypes for Seyferts)
- IR diagnostics (estimation of fractions of presence of AGN and SB)
- Sub-mm diagnostics (based on molecular lines)
- Other wavelength ranges (X-ray and radio may serve as criteria for the activity)
- Variability (typically indicates on the activity)
- Polarization (many AGN show highly polarized radiation)
- Host galaxies structure? Jets, lobes, blue components, interactions, merging, etc. may serve as signs of activity
- X-ray / UV / opt / NIR / MIR / FIR / sub-mm / radio flux ratios (typically AGN have higher X-ray/opt and radio/opt flux ratios, subject to be studied statistically in more details)
- Luminosities? AGN are higher luminosity objects, however this may serve as only a statistical criterion
- Other parameters?

8 Types of Active Galaxies

Here we give description of optical emission-line spectrum for known activity types (mainly based on types given in Véron-Cetty & Véron 2010), as well as some other parameters and other than optical wavelengths characteristics. A similar (however less detailed) scheme for activity types was developed by us for HyperLEDA database available at http://leda.univ-lyon1.fr/leda/rawcat/a109.html (Gavrilović et al. 2007). We have developed this classification based on homogeneous SDSS spectra (Ahn et al. 2014). SDSS covers large region of the sky (14,555 deg^2), it has obtained spectra for >4 million objects over 11,600 deg^2, including 3 million galaxies; 200,000 (z<2.3) and 20,000 (z>2.3) QSOs; some 500,000 stars; and other objects.

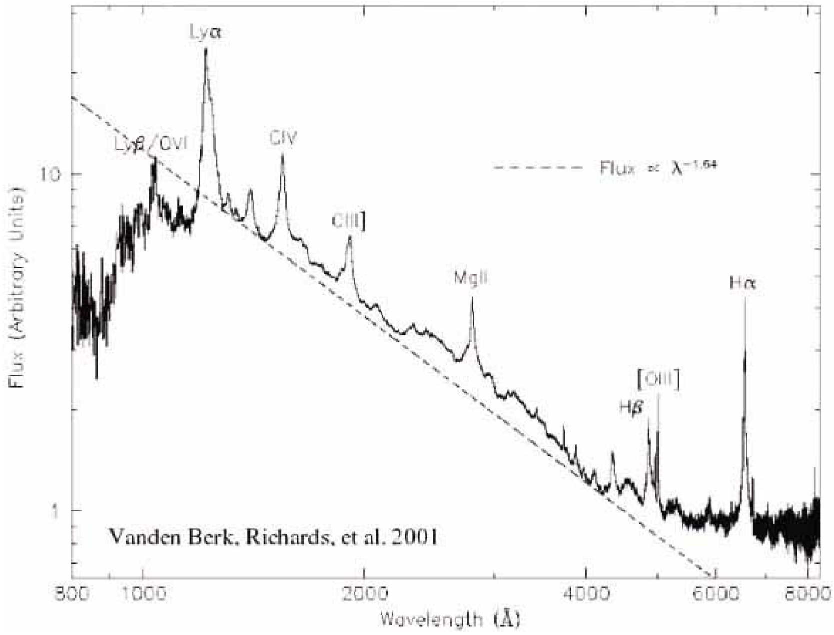

Figure 16: Broad-band synthetic spectrum for QSOs built on the basis of 2dF quasars (Croom et al. 2001; 2004).

Roughly, we distinguish different types of narrow-line active galaxies by following criteria; AGN from HII by [NII]/H$\alpha > 0.6$ and [OI]/H$\alpha > 0.1$, Seyferts from LINERs by [OIII]/H$\beta >$ 3. Diagnostic diagrams are being used with bordering curves between the 3 types of objects (Seyferts, LINERs and HII) (Kauffmann et al. 2003; Stasinska et al. 2006; Kewley et al. 2006; these recent papers are based on SDSS spectra).

QSO, Quasar – Quasi-Stellar Object, Quasi-Stellar Radio-source (Fig. 16). Have very broad emission lines (FWHM = 5,000–30,000 km/s) with large redshifts. 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, however, objects typically brighter than 17m and/or with redshifts smaller than 0.3 show weak "fuzz", indicating the host galaxy. Have very high luminosities (Mabs>-23). Quasar luminosities are MB < -21.5 + 5 $\log h_0$ (Schmidt & Green 1983). The optical spectra are similar to those of S1 nuclei, but the narrow lines are generally weaker. QSO/S1 separation have been conditionally defined by the luminosity limits (MB = -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 one is accepted, though also conditional. 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 $\cdot$ 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.

BAL QSO – Broad absorption line QSO (Fig. 17). 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 ≥ 1.5 because the phenomenon is observed in the rest-frame UV. At these redshifts, they are about 10

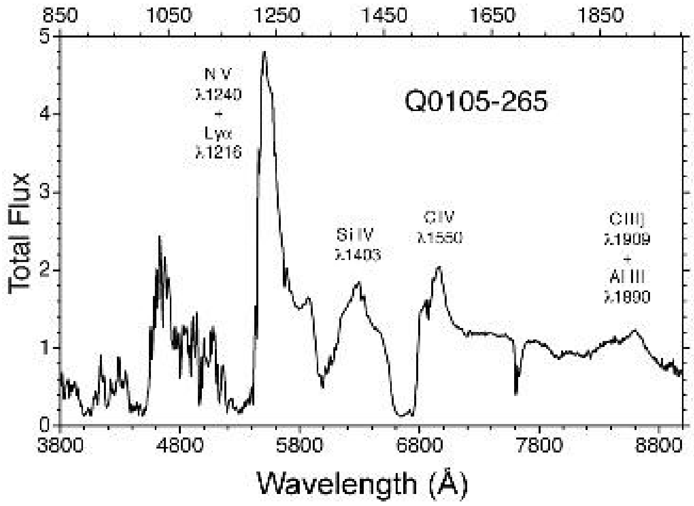

Figure 17: BAL QSO Q0105-265 showing deep blue-shifted very broad absorption lines with P Cyg profiles.

DLA QSO – Damped Ly-alpha QSO. Show unresolved absorption lines even on very high resolution spectra (<1Å), with typical widths of 10–12Å, resulting in a column density of $>10^{23}$, indicating the presence of high density galactic size masses along the line of sight.

OVV QSOs – Optically-Violently Variable QSOs. Similar to BLL but with normal QSO spectrum. They are radio loud.

HPQ, HP – Highly Polarized Quasars. Polarization is typically >3%. Typically are combined with OVV quasars as a single class. The parent population of HPQs is made of FR II radio galaxies.

BL Lac, BLL – BL Lacertae type object (Fig. 18). 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). 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.

Blazars – Combination of two most powerful AGN classes; BLL and OVV/HPQ, introduced by E. Spiegel in 1978. Blazars encompass BL Lacs and OVV/HPQ QSOs. 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

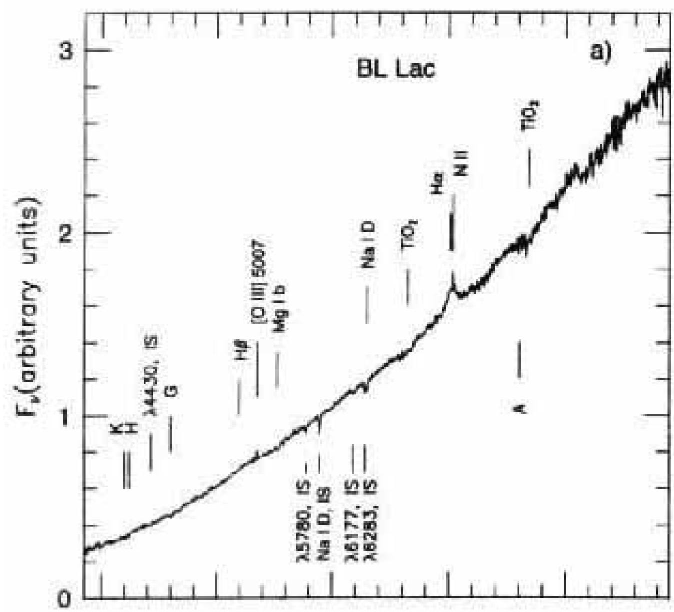

Figure 18: BL Lac optical spectrum showing very weak emission and absorption lines.

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 et al. 2015). There are many parameters that may be regarded as criteria for definition of blazars, such as high luminosity, radio flat spectrum, X-ray and γ-ray, optical and/or radio variability, polarizations, etc.

S – Seyfert galaxy (no accurate classification if given without a subclass). Relatively low luminosity AGN with MB > -21.5 + logh_o. Their host galaxies are clearly detectable. Depending on the width of optical emission lines, Seyfert types (Khachikian & Weedman 1974) and subtypes (Osterbrock 1981) were introduced.

S1, S1.0 or BLS1 – Broad-Line Seyfert 1. Have 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}). Physically are the same objects as QSOs, but having smaller luminosities (M_{abs}¿-23). They are radio quiet. According to Winkler (1992), Hβ/[OIII]5007 > 5.0. NGC 4151 is the prototype.

NLS1, S1n – Narrow-line Seyfert 1, S1 narrow. Defined by Osterbrock & Pogge (1985) as 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 are present, unlike what is seen in Seyfert 2s. The ratio [OIII]5007/Hβ < 3, but exceptions are allowed if there are also strong [FeVII] and [FeX] emission lines present. FWHM(Hβ) < 2000km/s (Goodrich 1989). A spectrum of NLS1 is given in Fig. 19 taken from SDSS (note the wrong

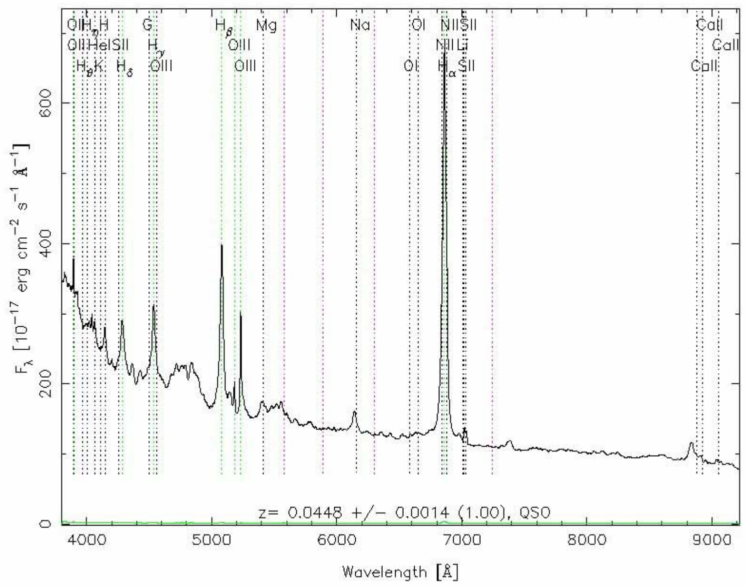

Figure 19: NLS1 galaxy spectrum taken from SDSS. Note relatively narrow broad line components and strong FeII lines on both sides from Hβ.

automatic classification by SDSS as QSO because of FeII features seen as broad emission lines).

S1i – S1 infrared. S1 with a broad Paschen Pa-β line, indicating the presence of a highly reddened BLR (Goodrich et al. 1994). Seyfert 1 with an absorbed BLR visible in NIR.

S1h – S1 hidden. S1 showing S1 like spectra in polarized light (Antonucci & Miller 1985; Miller & Goodrich 1990; Tran et al. 1992). Seyfert 1 with a hidden BLR.

S1.2 – AGN with spectra, which share parameters that are intermediate between those of classical Sy1 and Sy2 galaxies, i. e. both broad and narrow components are present for permitted lines (Osterbrock 1981). According to Winkler (1992), the ratio of the narrow component of Hβ to [OIII]5007 is $2.0 < H\beta/[OIII]5007 < 5.0$. Often erroneously related to NLS1s or S1n.

S1.5 – AGN which share parameters that are intermediate between those of classical Sy1 and Sy2 galaxies; have easily discernible narrow HI profile superposed on broad wings (Osterbrock 1981). According to Winkler (1992), the ratio of the narrow component of Hβ to [OIII]5007 is $0.333 < H\beta/[OIII]5007 < 2.0$. Fig. 20 shows a typical S1.5 spectrum taken from SDSS (again SDSS automatic classification was incorrect due to the broad line components).

S1.8 – AGN which share parameters that are intermediate between those of classical Sy1 and Sy2 galaxies; have relatively weak broad Hα and Hβ components superposed on strong narrow lines (Osterbrock 1981). According to Winkler (1992), narrow component of $H\beta/[OIII]5007 < 0.333$.

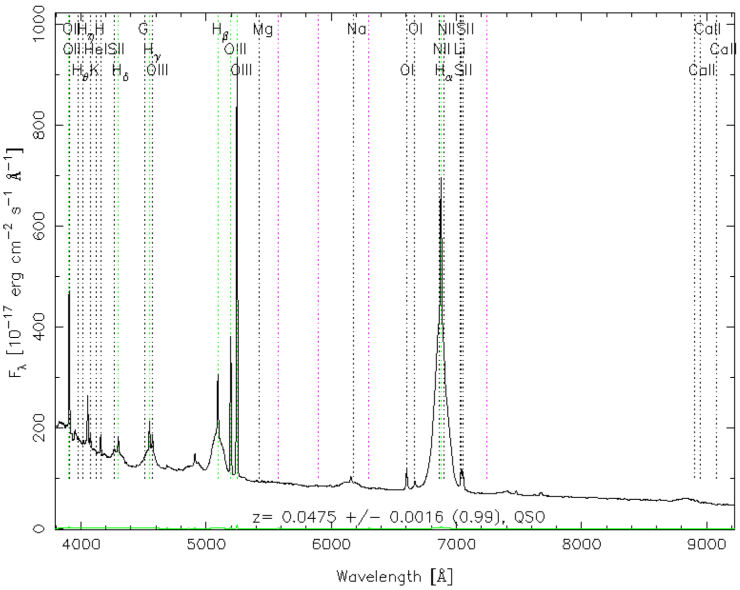

Figure 20: A typical S1.5 spectrum taken from SDSS. Broad line and narrow line components have similar intensities and due to their superposition narrow line peaks are seen higher.

S1.9 – AGN which share parameters that are intermediate between those of classical Sy1 and Sy2 galaxies; have relatively weak broad Hα component superposed on a strong narrow line. The broad component of Hβ is not seen (Osterbrock 1981). According to Winkler (1992), narrow component of Hβ/[OIII]5007 < 0.333.

S2, S2.0 – AGN showing relatively narrow (compared to S1s) emission in both permitted Balmer and forbidden lines (Khachikian & Weedman 1974), with approximately the same FWHM>=300km/s, typically in the range of 300-1000 km/s that originate in a low-density medium ($n_e \approx 10^3$–10^6 cm^{-3}). No broad component is visible. A secondary classification criterion is [OIII]5007/H$\beta \geq 3$, to distinguish against NLS1s (Veilleux & Osterbrock 1987; Lawrence 1987). NGC 1068 is the prototype.

S3, LINER – Low-Ionization Nuclear Emission-line Region. 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]). [OII]3727/[OIII]5007 ≥ 1, [OI]6300/[OIII]5007 $\geq 1/3$. [NII]6584/H$\alpha > 0.6$ according to Kauffman 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 Hα visible), and type 2, without broad Hα analogous to S2s. May be either radio quiet or loud. Most of the nuclei of nearby galaxies are LINERs. However, their emission line spectra are not necessarily caused by active nuclei.

S3b – LINERs with broad Balmer lines, the same as LINER type 1 (Ho, Filippenko & Sargent 1997).

S3h – LINERs with broad Balmer lines seen only in polarized light.

AGN – AGN without a subclass because of spectra with relatively low quality. Show emission line spectra with strong forbidden lines; a few emission lines are observed, mostly Hα with NII lines where NII/Hα ratio indicates an AGN, i.e. either Sy or LINER.

SBN and SBG – Starburst nuclei or Starburst galaxy (Weedman 1977). 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]/Hβ $<$ 3) emission lines; absolute luminosities -17.5 $>$ M $>$ -22.5; 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}. Based on the relative energy output of the SB (LSB) to that of the rest of the galaxy (LG) and the SB age, R. Terlevich classified SB into 3 classes: SB galaxies having LSB $\gg$ LG, Galaxies with SB having LSB $\sim$ LG, and Normal galaxies having LSB $\ll$ LG (Terlevich 1997).

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.

WR galaxy – Wolf-Rayet Galaxy (Osterbrock & Cohen 1982; Conti 1991). 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.

HII, 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 that is a strong narrow (FWHM $\leq$ 300 km/s) emission line spectrum but with a ratio [OIII]/Hb $\geq$ 3 and [NII]6584/Ha $<$ 0.6, coupled with a blue continuum (Veilleux & Osterbrock 1987).

NSF – normal star-forming galaxies. This classification is often used to distinguish against both AGN and SB.

Composite spectrum objects – galaxies with presence of features of two or more activity types, as a rule, a combination of Seyfert, LINER and/or HII types (Véron et al. 1997; Fig. 21). 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 S2/LINER, S2/HII, LINER/HII or even a combination of S1 subtypes (S1.8, S1.9) and a LINER or HII. S2/HII and LINER/HII are considered to be a superposition of S2 or LINER nucleus with circumnuclear HII regions.

ELG, Em – Emission Line Galaxy. Show one or several emission lines (Ha, [NII]6584/6548, and [OII]3727). Absorption lines are very weak or absent. No accurate classification because of relatively low quality of spectra.

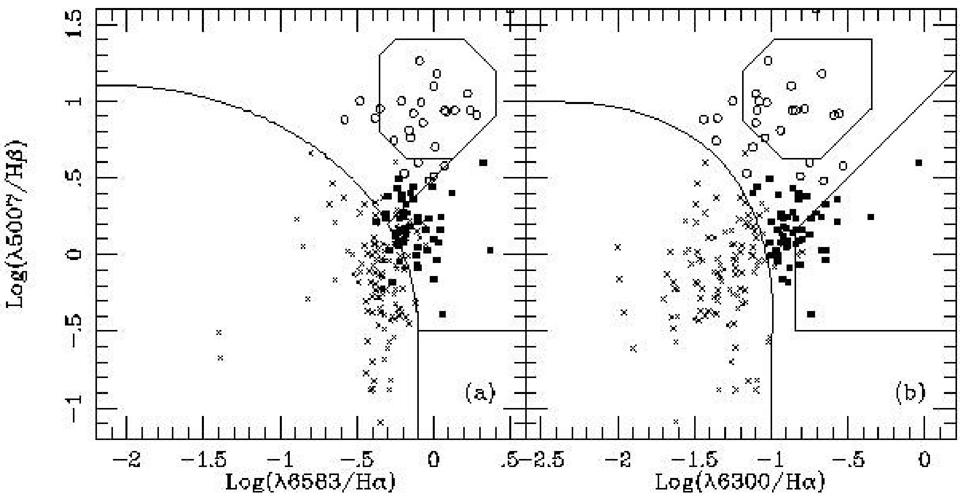

Figure 21: Diagnostic diagrams showing many Composite spectrum objects between the regions of Seyferts, LINERs and HIIs.

Abs – Absorption line galaxy. Only absorption lines are seen. No signs for any (nuclear or starburst) activity. Also called normal galaxies, though the latter ones show some weak emission lines as well.

UVX – Ultra-Violet Excess galaxies, those that are not classified as one of the known activity types or starbursts. Can have both emission and/or absorption lines. Mainly appeared from Markarian Survey (Markarian et al. 1989), Second Byurakan Survey (SBS; Stepanian et al. 2005), Kazarian galaxies (Kazarian et al. 2010) and some other low-dispersion or colorimetric surveys.
Other classifications use other than optical spectrum criteria, including radio, IR and X-ray wavelengths.

Radio wavelengths

RG – Radio Galaxy (Fig. 22). Related objects to radio-loud QSOs and Blazars, they are very luminous in radio wavelengths, with luminosities up to 1039 W between 10 MHz and 100 GHz. The host galaxies are almost exclusively large elliptical galaxies. Optical spectra are similar to Seyfert galaxies. The radio emission is due to the synchrotron processes and the observed radio structure is determined by the interaction between twin jets and the external medium, modified by the effects of relativistic beaming. The lobes of radio galaxies are powered by relativistic jets.

BLRG – Broad-Line Radio Galaxy. Their optical spectra are similar to S1 but they are radio loud.

NLRG – Narrow-Line Radio Galaxy. Their optical spectra are similar to S2 but they are radio loud.

N galaxies – Radio galaxies with compact nucleus.

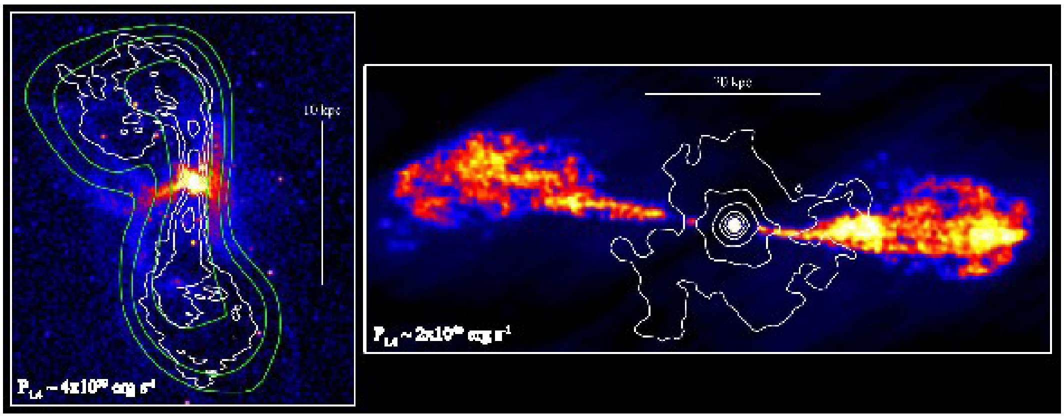

Figure 22: Radio structure of typical radio galaxies. They have central emission, as well as powerful radio lobes.

D galaxies – Giant radio galaxies.

cD galaxies – Giant radio galaxies dominant in their clusters.

FR I – Fanaroff-Riley class I radiogalaxy (Fanaroff & Riley 1974). Sources whose luminosity decreases as the distance from the central galaxy or quasar host increase. These sources are called also edge-darkened. Show radio luminosity in relation to the hosting environment and is measured by the ratio R of the distance between the two brightest spots and the overall size of the radio image; FR I have $R < 0.5$. These are lower luminosity sources. They make the parent population of BLLs. FR Is have a weak low excitation emission line spectrum, similar to LINERs or no detectable emission at all.

FR II – Fanaroff-Riley class II radiogalaxy (Fanaroff & Riley 1974). Sources exhibiting increasing luminosity in the lobes. Show the radio luminosity in relation to the hosting environment and is measured by the ratio R of the distance between the two brightest spots and the overall size of the radio image; FR II have $R > 0.5$. Most radio galaxies have double lobe structure; these high radio luminosity sources have edge-brightened lobes. They make the parent population of HPQs. FR II radio galaxies have the nuclear emission line spectrum of Seyferts and are divided into BLRGs and NLRGs based on the width of emission lines. All radio quasars have FR II morphology.

FSR – Flat Spectrum Radio source. Core Dominated Radio Loud Quasar (CD-QSR); optically similar to QSO. Spectral index (α in $F\nu$=$\nu\alpha$) at ν=1GHz is flat (with α=-0.4 limit).

SSR – Steep Spectrum Radio source. Lobe Dominated Radio Loud Quasar (LD-QSR); usually FR II radio morphology; optically similar to QSO. Spectral index (α in $F\nu$=$\nu\alpha$) at ν=1GHz is steep (α=-0.4 limit).

CSS – Compact Steep Spectrum radio sources. CSS sources are compact, powerful radio sources with well-defined peaks in their radio spectra (near 100 MHz). They are contained entirely within the host galaxy ($\leq$ 15 kpc). CSS sources at all redshifts exhibit high surface brightness optical light (most likely emission-line gas) that is aligned with the radio axis.

GPS – Gigahertz Peaked Spectrum radio sources. GPS sources are compact, powerful radio sources with well-defined peaks in their radio spectra (near 1 GHz). They are entirely contained within the extent of the NLR ($\leq$ 1 kpc). X-ray observations of high-redshift GPS quasars and a couple of GPS galaxies suggest the presence of significant columns of gas toward the nuclei.

PRG-II – Powerful Radio Galaxy of Fanaroff-Riley class II. Edge brightened, powerful jet; unspecified optical spectrum (could be BLRG/NLRG/LINER).

RG-I – Radio Galaxy of Fanaroff-Riley class I. Similar to PRG-II except lower radio luminosity and FR I class. Edge darkened, lower power jet.

Masers – Extragalactic molecular masers. Conditions for Masers are long low v path through dense gas exposed to strong pumping radiation. These conditions are met in many AGN nuclei; the most famous is NGC 4258. The path lengths will be at their largest for edge-on dense gas disks. Many Sy2s are H2O masers, consistent with expectations for obscuring tori.

IR wavelengths

QSO2, Q2 – Type-2 QSO. Same as QSO but missing broad lines; not many such objects are currently known (some are IRAS QSOs). They are radio quiet. Most of them appeared from NIR surveys (Cutri et al. 2003).

AGN2 – Type-2 AGN. Similar to QSO2 but with lower luminosity.

Obscured AGN – IR revealed AGN not having emissions lines in optical range. Mostly appeared after IRAS mission (e. g. Sargsyan et al. 2008).

LIRG, ULIRG, HLIRG – Luminous, Ultra-Luminous and Hyper-Luminous InfraRed Galaxy (Sanders & Mirabel 1996). They were introduced after IRAS mission and are based on IR (L_{ir}, luminosity in the range 8-1000 μm) and far-IR (L_{fir}, luminosity in the range 40-500 μm) luminosities calculated in $L_\odot$ according to Duc et al. (1997):

$$L_{ir} = 5.6\cdot10^5 R^2 (13.56 f_{12} + 5.26 f_{25} + 2.54 f_{60} + f_{100})$$

$$L_{fir} = 5.6\cdot10^5 R^2 (2.58 f_{60} + f_{100})$$

where R is the distance of objects in Mpc and f_{12}, f_{25}, f_{60} and f_{100} are IRAS fluxes in the bands at 12, 25, 60, and 100 μm, respectively. LIRGs are galaxies having $L_{ir} > 10^{11}$ $L_\odot$, ULIRGs have 10^{12} $L_\odot < L_{ir} < 10^{13}$ $L_\odot$ and HLIRGs have $L_{ir} > 10^{13}$ $L_\odot$. These are generally extremely dusty objects. The UV radiation produced by the obscured star-formation is absorbed by the dust and reradiated in the IR at around 100μm. It is not known for sure that the UV radiation is produced purely by star-formation, and some authors believe at least part of ULIRGs to be powered by AGN. Well-studied ULIRGs include Arp 220 and Mrk 231. Veilleux (2002) has shown that the fraction of AGN increases among the higher luminosity IR galaxies. Hou et al. (2009) have found 308 ULIRGs among SDSS galaxies. Lee et al. (2011) have classified 115 ULIRGs and showed that they may be either broad-line or narrow-line AGN or show no nuclear activity.

ELF – Extremely Luminous far-IR Galaxy.

X-ray range

Hidden AGN – X-ray revealed AGN not having emissions lines in optical range (Barger et al. 2000; Treister et al. 2005). May be classified as X-ray AGN (XAGN; Paronyan & Mickaelian 2015). Among other AGN detected in optical wavelengths, a small fraction displays X rays (Véron-Cetty et al. 2004).

NELG (NLXG) – Narrow Emission Line Galaxy (Narrow-Line X-ray Galaxy). Most likely obscured Seyfert galaxies.

A homogeneous classification by activity types was carried out for all Markarian galaxies spectroscopically observed in SDSS (Mickaelian et al. 2014; Winkler 2014). Out of 779 objects present in SDSS spectroscopic catalogue (DR7-DR9), we have found 126 AGN or Composites (16.2%). 533 objects are HII, 52 are Em, 65 are Abs, and 3 are stars. Among the Composites, we have LINER/HII, Sy/HII, Sy/LINER or Sy/HII/LINER subtypes. On the other hand, we have a number of NLS1 galaxies with different subtypes, as NLS1.0, so as NLS1.2 and NLS1.5, which we have introduced for more accuracy.

Summarizing, here we described more than 50 activity types (including 30 in optical range), which proves the variety of AGN and other active galaxies present in the Universe. Most probably, there may exist more classes to be discovered in future surveys or more subtypes may be introduced to describe the varieties more accurately, as we did in case of the classification of Markarian galaxies.

9 Summary

AGN may be defined as objects where the total luminosity is radiation not ultimately related to stellar atmospheres. Alternate energy sources should be involved. At present, the most popular explanation for the AGN powerhouse involves accretion of gas onto a most probably spinning SMBH. This is the **Unified Model** or **Unified Scheme**. Probably the first to mention this possibility was Rowan-Robinson (1977). Different regimes of accretion have been invoked to constitute the basis of a unified picture of AGNs. Observed AGN energies are explained through the release of gravitational energy. In fact, the concept of a SMBH surrounded by a viscous disk (of 10^{-3} pc) accreting matter gained popularity in 1960s (Zeldovich & Novikov 1964), and now became the standard model for AGN.

The formation of the torus is crucial to support the unified model of AGN. Further studies strengthened such an understanding of the AGN energy sources. However, there still are many difficulties and the discovery of new objects with new properties encounter challenges in their explanation in frame of the general scheme.

From the point of view of Unified Scheme, we give here the regions and mechanisms that build AGN spectra at different wavelengths. Relativistic Accretion Disk (AD) at 20 AU sizes and 10^{15} cm^{-3} densities and is responsible for Fe Kα line; it also gives variable X-ray emission (minutes-hours). UV accretion disk at 200 AU sizes gives UV radiation. Optical AD (the BLR) at 2000 AU has 10^{10} cm^{-3} densities and gives broad optical emission lines (few 1000 km s^{-1}). Compact, flat-spectrum radio core is the outer BLR at 0.1 pc scale and the jet is detectable with VLBI. Inner NLR (inner bulge) has 10 pc sizes. The main

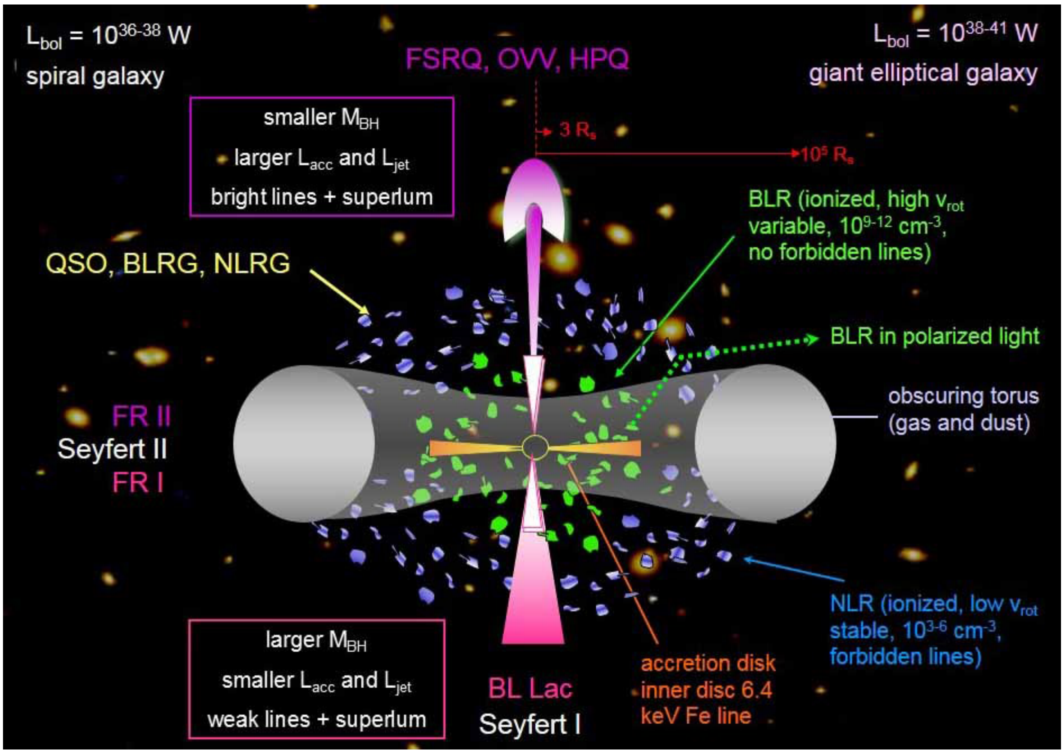

Figure 23: Schematic view of the Unified Model. Different regions emitting with different mechanisms and in different wavelength ranges are given.

bulge (also NLR) at 100 pc size with 10^3–10^6 cm^{-3} densities gives forbidden emission lines (few 100 km s^{-1}) and the radio jet is detectable with VLA. We give in Fig 23 a schematic view of the Unified Model, where different regions emitting with different mechanisms and in different wavelength ranges are given and explained.

However, observationally it is not easy to discover accretion disks or SMBHs. The diameter of an accretion disc around a 108 M BH is at Solar system scale seen at 100 Mpc has an angular resolution of $\sim$ 1 as, which is not yet detectable. The same seen at the distance of Andromeda galaxy (M31) is still 0.1 mas.

There still are a number of **open questions** related to AGN and their classifications. Here we list most important of them:

- Definition and taxonomy of AGN (the problem of historical types and their relevance to present understanding)
- Discontinuity of classes; classification as science trigger or break?
- Non-optical wavelength data; understanding the true fraction of heavily obscured AGN to determine the true luminosity function and its variation with z
- Have all AGN types been discovered?
- Blazars: their duality (BLL and HPQ), luminosities, etc.

- Understanding possible evolutionary and/or physical connection between different classes of AGN, i. e. their consistency with the unification model; AGN vs. ULIRGs and other high-L objects
- AGN growth, structure versus cosmic time
- AGN spectral energy distributions (SEDs) versus cosmic time
- The importance of AGN feedback, relation of AGN to host galaxies
- AGN seeds in the Early Universe
- Future AGN surveys, data mining and overall use of MW data for full understanding of AGN structure, physical processes behind the observed phenomena and energy sources

At the end, we recommend some review papers and books on active galaxies for further reading and study (full bibliography is given in the list of references):

Alloin, Johnson & Lira 2006, *Physics of Active Galactic Nuclei at all Scales*
Aretxaga, Mújica & Kunth (Eds.) 2000, *Advanced Lectures on the Starburst-AGN Connection*
Beckmann & Shrader 2012, *Active Galactic Nuclei*
Harutyunian & Mickaelian 2010, *V.A. Ambartsumian and the Activity of Galactic Nuclei*
Kembhavi & Narlikar 1999, *Quasars and Active Galactic Nuclei*
Krolik 1999, *Active Galactic Nuclei: From the Central Black Hole to the Galactic Environment*
McNamara & Nulsen 2007, *Heating Hot Atmospheres with Active Galactic Nuclei*
Mickaelian & Sanders (Eds.) 2014, *Multiwavelength AGN Surveys and Studies*
Osterbrock 1989, *Astrophysics of gaseous nebulae and active galactic nuclei*
Peterson 1997, *An Introduction to Active Galactic Nuclei*
Robson 1996, *Active Galactic Nuclei*
Sanders & Mirabel 1996, *Luminous Infrared Galaxies*
Véron-Cetty & Véron 2000, *The emission line spectrum of active galactic nuclei and the unifying scheme*

NASA/IPAC Extragalactic Database (NED) has Level 5 "A Knowledgebase for Extragalactic Astronomy and Cosmology" supported by B. F. Madore et al. (https://ned.ipac.caltech.edu/level5/), which we strongly recommend both for AGN and other studies related to galaxies and cosmology.

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