Homogeneous fine classification of Markarian galaxies based on SDSS medium-resolution spectroscopy

A. M. Mickaelian, H. V. Abrahamyayan, G. A. Mikayelyan, and G. M. Paronyan

NAS RA V. Ambartsumian Byurakan Astrophysical Observatory (BAO), Byurakan 0213, Aragatzotn Province, Armenia
E-mail: aregmick@yahoo.com

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ABSTRACT

Context. Markarian (Mrk) galaxies, revealed due to their ultraviolet excess are very famous; they play a significant role in many astrophysical problems and come in a variety of types: Seyferts (Sys), low-ionization narrow emission-line regions (LINERs), starbursts (SBs), blue compact dwarf galaxies (BCDGs), as well as some quasars (QSOs) and blazars. They also appear as sources of non-optical radiation, such as gamma-ray, X-ray, ultraviolet (UV), infrared (IR), and radio, including some extremely high-energy gamma-ray sources (Mrk 421, Mrk 501) and very high-luminosity IR galaxies (Mrk 231).

Aims. The classifications of Mrk galaxies for activity types have been carried out based on old mostly poor-quality and inhomogeneous spectra (relatively low-resolution photographic spectra and low S/N spectra). The Sloan Digital Sky Surveys (SDSS) provides ~90% of the existing medium-resolution spectra, and is a relevant homogeneous database for classification of galaxies. Our aim was to obtain homogeneous classifications of Mrk galaxies by means of the SDSS spectra.

Methods. Based on our work on the classification of newly revealed objects from various recent catalogs, we developed a fine classification scheme for activity types based on the homogeneous database of the SDSS spectroscopy. This scheme was applied to Mrk galaxies having spectra in the SDSS (779 out of 1544, 50.45%).

Results. As a result, 779 Mrk galaxies now have homogeneous optical spectral classification that can be used for further studies and statistics of their physical and spatial properties. We revealed 2 QSOs, 49 classical Seyferts (broad-line Seyferts 1, BLS1s), 17 narrow-line Seyferts 1 (NLS1s), 4 Sy2s, 12 LINERs, 11 active galactic nuclei (AGN) without a definite type, 31 Composite spectrum objects, and 533 HII/Starbursts. Due to low-quality spectra, some objects were left without definite activity types and were classified as emission or absorption galaxies.

Key words. techniques: spectroscopic – catalogs – surveys – galaxies: active – galaxies: Seyfert – galaxies: starburst

1. Introduction

The First Byurakan Survey (FBS, the Markarian Survey) was originally conducted to search for galaxies with ultraviolet (UV) excess. Markarian believed that this method might reveal many new AGN in order to have more statistics for their further studies. The discovery by Markarian and his colleagues of 1515 UV-excess (UVX) galaxies (later called Markarian galaxies) was the first and most important work based on the FBS plates (Markarian 1967; Markarian et al. 1989). Later on, a number of other surveys were accomplished based on the same observing material: FBS blue stellar objects (Mickaelian 2008), FBS late-type stars (Gigoyan et al. 2019), optical identification of IRAS point sources, and the lists of Byurakan-IRAS galaxies (BIGs; Mickaelian & Sargsyan 2004) and Byurakan-IRAS stars (BISs; Mickaelian & Gigoyan 2006). There are more than 200 Seyferts, dozens of QSOs, a few hundred starburst (SB) and/or HII galaxies, BL Lacs, objects, and radio, IR, and X-ray sources among them (Mazzarella & Balzano 1986; Markarian et al. 1997). The definition of SB galaxies was introduced based on Mrk galaxies (Weedman 1977). During the last 50–55 yr more than 5000 scientific papers have been published on the study of Mrk galaxies. There are many Markarian galaxies, which are the subject of study for understanding AGN phenomenon, SB activity and evolution of galaxies, high-luminosity IR radiation, AGN variability, double and multiple structure of the nucleus, composite spectrum AGN, galaxy interactions and merging, connections between different types of active galaxies, and other important topics of modern extragalactic astronomy. The study of Markarian galaxies led first to the spectral classification of Seyferts into Sy1 and Sy2 (Khachikian & Weedman 1971).

Markarian (Mrk) galaxies are among the most interesting extragalactic objects; they are very famous due to their importance in many astrophysical problems. They contain various types of objects, including many active galaxies, namely active galactic nuclei (AGN) (Mickaelian 2015). Mrk galaxies are very often strong emitters in gamma-ray, X-ray, UV, IR, and radio. Among the most famous Mrk galaxies are the following: Mrk 231 (the closest ultraluminous infrared galaxy (ULIRG), broad absorption line quasar (BAL QSO), and most luminous IR galaxy in the Local Universe; Morganti et al. 2016), Mrk 421 and Mrk 501 (objects among the highest known (TeV) energy sources; Aharonian 2012), Mrk 116 (=IZw18; one of the most metal-deficient blue compact dwarf galaxies, BCDGs; Musella et al. 2012), Mrk 938 (the first dynamic merger discovered observationally; Esquej et al. 2012), Mrk 110 (intermediate class between NLS1 and BLS1; FWHM = 4900 km s^{-1}; crucial for understanding the differences between BLS1s and NLS1s; Vincentelli et al. 2021), Mrk 6 (very high column density of...
2. Previous spectroscopic data on Markarian galaxies

The FBS–Markarian Survey was carried out in 1965–1980 and after the publication of the 15 Markarian lists, the active observations started by various astronomers. To date, most Mrk objects have been observed and classified. However, the techniques used from the 1960s to 1980s did not provide us with high-quality spectra, and very often different authors gave different classifications for the same Mrk object (as seen in Tables 1 and 2 in this paper). The most common disadvantage was the absence of weak lines and other fine features due to the low quality of the spectra.

Table 1. Optical classification of Markarian galaxies given by Petrosian et al. (2007).

<table>
<thead>
<tr>
<th>Optical spectral type according to Petrosian et al. (2007)</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>QSO</td>
<td>10</td>
<td>0.65</td>
</tr>
<tr>
<td>BL</td>
<td>4</td>
<td>0.26</td>
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<tr>
<td>Sy (all)</td>
<td>214</td>
<td>13.86</td>
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<tr>
<td>Sy3 (LINER)</td>
<td>22</td>
<td>1.42</td>
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<td>SB</td>
<td>161</td>
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<td>27</td>
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<tr>
<td>HI</td>
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<tr>
<td>Unknown</td>
<td>62</td>
<td>4.02</td>
</tr>
<tr>
<td>a (Mrk “Absorption” type)</td>
<td>178</td>
<td>11.53</td>
</tr>
<tr>
<td>a:e (Mrk “Absorption/Emission” type)</td>
<td>2</td>
<td>0.13</td>
</tr>
<tr>
<td>e:a (Mrk “Emission/Absorption” type)</td>
<td>72</td>
<td>4.66</td>
</tr>
<tr>
<td>e (Mrk “Emission” type)</td>
<td>728</td>
<td>47.15</td>
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<tr>
<td>Star</td>
<td>28</td>
<td>1.81</td>
</tr>
<tr>
<td>All</td>
<td>1544</td>
<td>100.00</td>
</tr>
</tbody>
</table>

H in X-rays; Mingo et al. (2011). Mrk 766 (one of the most important NLS1 galaxies; Mochizuki et al. 2023). Mrk 273 (a peculiar double-double nuclei galaxy; Liu et al. 2019). Mrk 266 (a multiple structure nuclear region; Beaulieu et al. 2023). Mrk 231 and Mrk 507 (two of five known super strong FeII emitters; FeII λ4570/Hβ > 2; Halpern & Oke 1987). However, Mrk galaxies do not represent a definite physical type of objects; the sample is based on the UVX observed via photographic plates, which appeared to be due to either the activity of the nucleus or starburst activity (Mickaelian et al. 2018b). It is extremely desirable to have a relevant and homogeneous classification of Mrk galaxies for further study, namely investigating the differences in physical properties between different types of objects. In 2007, Petrosian et al. (2007) published “The Optical Database and Atlas of Markarian galaxies”, which is mainly dedicated to morphological studies of these objects based on the thorough study of the Digitized Sky Survey (DSS) images; the authors give all the possible information, including the spectral classifications, available at that time. On the other hand, some other catalogs and the NASA/IPAC Extragalactic Database (NED) give the classification of Mrk galaxies available from various sources. We analyzed all these data and carried out our study based on them. This work utilizes the SDSS medium-resolution spectral classification of Mrk galaxies using our new classification scheme (Mickaelian et al. 2022) to obtain a distribution and statistics of homogeneous activity types with their all possible fine details.

For example, when the noise is high, FeII lines are not observed on both sides of Hβ and it is not possible to classify the given object as narrow-line Seyfert 1 (NLS1) galaxy. Another example is when the Hα and Hβ profiles are not very clear, it is not possible to see the weak broad component at the bottom of the spectral lines (a necessary condition to be classified as Sy1.8/Sy1.9).

For optical investigation of Markarian galaxies, we have first used the list given by Petrosian et al. (2007), which includes 1544 Mrk objects with UV-excess radiation. In Table 1 we give the distribution of the number of Markarian galaxies by their spectral types, taken from Petrosian et al. (2007). Here the number of objects having a definite spectral type is larger than in all other catalogs and databases containing Mrk galaxies (Mazzarella & Balzano 1986; Markarian et al. 1989, 1997; Véron-Cetty & Véron 2010; Winkler 1992 Mickaelian Fine Classification of Active Galaxies 2022).

In their morphological catalog of Mrk galaxies, Petrosian et al. (2007) give the optical classifications of objects that were available at that time. We give this classification, where most of the Markarian galaxies have no relevant optical classification (see Table 1). Thus, only 502 (32.51%) have a definite classification, 1042 being of either unknown type or left with Markarian spectral-morphological classification based on the FBS low-dispersion spectra.

For more complete information on optical classifications of Markarian galaxies, we also use the catalog of Blazars BZCAT v.5 (Massaro et al. 2015), the Catalog of Active Galaxies and QSOs (13th version, hereafter VCV-13; Véron-Cetty & Véron 2010), and the NED database. In this case we have the distribution given in Table 2. Here some types and subtypes are combined to have more comprehensive picture of distribution by object. For further research, we give priorities to these catalogs and databases in the following order: VCV-13, BZCAT v.5, Petrosian et al. (2007), and NED; however, there are not many discrepancies between these classifications.

To date, only 533 (34.52%) out of 1544 Mrk galaxies have an optical classification (Table 2).

The SDSS (Abdurro’uf et al. 2022) provides a huge number of homogenous medium-resolution spectra. The total number is 4,851,200, and most of the objects observed spectroscopically are galaxies (2,541,424) and quasars (680,843). This is a very

1 https://www.bao.am/activities/projects/21AG-1C053/mickaelian/
good opportunity to study the spectra of objects at least in this area (Dec > 0 and \( |b| > 30, 10,000 \) sq. deg).

Winkler (2014) carried out a spectral re-examination of the Markarian AGN. He used his ZORROASTER catalog with optical spectral images, detailed spectral descriptors, and waveband-specific flux ratios where available. Version 2 includes all \( z < 0.1 \) objects from the list of Markarian. The activity classes and the spectral descriptions of the Markarian objects were reviewed, and comparisons of the flux ratios derived from the 100 ZORROASTER wavelength-specific pass bands are presented for those Markarian AGN for which SDSS spectra exist. However, as this scheme is different from those discussed above we did not use it for our further classification.

We give in Fig. 1 the sky distribution of Markarian galaxies in equatorial coordinates. Though the main SDSS area with \( |b| > 30 \) covers more than half of the Markarian Survey area (17,056 sq. deg), many Mrk galaxies are left out of the SDSS coverage. Out of 1544 Mrk galaxies, 779 (50.45\%) are found to have SDSS spectra. This is a great advantage to have the possibility of a homogeneous classification. Based on all previous existing data and using our fine classification scheme, we carried out fine optical classification of the Markarian galaxies into activity types using the SDSS spectra (Ahumada et al. 2020; Abdurro’uf et al. 2022).

3. Homogeneous SDSS fine classification of Mrk galaxies for activity types

The SDSS spectroscopic catalog is the major database for the redshifts of millions of galaxies and QSOs, as well as the classification of galaxies by activity types. For the majority of spectra, excluding the low S/N ones, the most important spectral lines are clearly seen and are measurable. In the case of active galaxies, most important are H\(_\beta\) with its neighboring [NII] lines and H\(_\alpha\) with its neighboring [OIII] lines. The [OII] 6300, [SII] doublet and sometimes [OIII] 3727 (when it is in the wavelength range) are perfect for the classification of LINERs. We mainly use the SDSS tabular data (line positions, line intensities, and line widths) as these are homogeneous measurements, so that all other authors can use the same data for their similar classifications.

In a number of our papers we used the same approach to classify by activity types thousands of objects from various samples using SDSS medium-resolution spectra (Gyulzadyan et al. 2017; Mickaelian et al. 2018a, 2022; Abrahanyan et al. 2018, 2019, 2020; Paronyan et al. 2019, 2020; MIkayelyan et al. 2019; Abrahamyan 2020; Mickaelian Fine Classification of Active Galaxies 2022\(^3\)). Our approach is based on BPT diagrams (Baldwin et al. 1981; Veilleux & Osterbrock 1987; Osterbrock 1980, 1981; Winkler 1992; Véron-Cetty & Véron 2000); however, we used the most recent options of these diagrams (Kewley et al. 2006; Reines et al. 2013). The diagnostic diagrams typically give narrow-line ratios of the selected emission lines that most often appear in the spectra of active galaxies. These are the ratios of [NII], [OII], and [SII] to H\(_\alpha\) (abscisses) and [OIII] to H\(_\beta\) (ordinates). Narrow-line active galaxies are separated in these diagrams by their locations: Seyferts, LINERs, and HII.

To guarantee the greatest accuracy and to consider all possible details, we classify the objects in several ways and then compare all the obtained activity types and subtypes. We make our decision based on the final classification:

- Classification based on the first diagnostic diagram (DD1) using line intensity ratios [OIII]/H\(_\beta\) vs. [OII]/H\(_\alpha\). This diagram is especially crucial for the spectral identification of LINERs and Composites containing a LINER, as the [OII] forbidden line \( \lambda 6300 \) is a signature of low-ionization regions.
- Classification based on the second diagnostic diagram (DD2) using line intensity ratios [OIII]/H\(_\beta\) vs. [NII]/H\(_\alpha\). This is the best diagram in the sense of line intensity measurements as these lines are among the strongest and appear in all spectra with reasonable S/N.
- Classification based on the third diagnostic diagram (DD3) using line intensity ratios [OIII]/H\(_\beta\) vs. [SII]/H\(_\alpha\). This diagram is also important for the spectral identification of LINERs and Composites containing a LINER. The [OII] line \( \lambda 3727 \) is very often outside of the SDSS spectral range when the redshift is smaller than 0.05 (Mrk galaxies).
- Comparison of the DD1, DD2, and DD3 simultaneously to derive the combined resulting type. Mostly the three diagrams give the same result, even if the simultaneous existence of two different components (Sy and LINER, Sy and HII, or LINER and HII) or all three possible components together can be controversial. Of course, the differences between the results from different diagnostic diagrams very often indicates some uncertain classifications, and in such cases we give preference to those based on stronger lines.
- By careful eye examination (considering all features and effects). Very often the diagnostic diagrams do not give full understanding for all objects (especially those cases when the object cannot be put into the diagram, due to insufficient tabular data, namely 23–29\% of objects for the three diagrams) and only eye examination can reveal some details. This is especially true for lower-quality spectra and for objects having broad emission lines (as the diagrams are for narrow-line objects). Hence, the first focus is made on the existence of broad lines and the ratio of the strengths of the broad to the narrow components, if observed simultaneously. This way we distinguish Sy subtypes between Sy1 and Sy2 (e.g., Sy1.2, Sy1.5). When no broad components are observed, the object is classified by the diagnostic diagrams.
Fig. 2. Diagnostic diagrams DD1, DD2 and DD3 for 779 Markarian galaxies. Some diagrams lack some objects with corresponding low-quality lines (especially OI 6300). The numbers of objects in these diagnostic diagrams are 595, 555, and 601, respectively.

Table 3. New optical types for 779 Markarian galaxies.

<table>
<thead>
<tr>
<th>Activity type/subtype</th>
<th>Number</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>QSO</td>
<td>2</td>
<td>0.26</td>
</tr>
<tr>
<td>Sy1.0</td>
<td>4</td>
<td>0.51</td>
</tr>
<tr>
<td>Sy1.2</td>
<td>21</td>
<td>2.70</td>
</tr>
<tr>
<td>Sy1.5</td>
<td>11</td>
<td>1.41</td>
</tr>
<tr>
<td>Sy1.8</td>
<td>8</td>
<td>1.03</td>
</tr>
<tr>
<td>Sy1.9</td>
<td>5</td>
<td>0.64</td>
</tr>
<tr>
<td>NLS1</td>
<td>4</td>
<td>0.51</td>
</tr>
<tr>
<td>NLS1.2</td>
<td>8</td>
<td>1.03</td>
</tr>
<tr>
<td>NLS1.5</td>
<td>5</td>
<td>0.64</td>
</tr>
<tr>
<td>Sy2.0</td>
<td>4</td>
<td>0.51</td>
</tr>
<tr>
<td>LINER</td>
<td>12</td>
<td>1.54</td>
</tr>
<tr>
<td>AGN</td>
<td>11</td>
<td>1.41</td>
</tr>
<tr>
<td>Sy1.8/HII</td>
<td>1</td>
<td>0.13</td>
</tr>
<tr>
<td>Sy1.9/LINER</td>
<td>6</td>
<td>0.77</td>
</tr>
<tr>
<td>Sy1.9/HII/LINER</td>
<td>1</td>
<td>0.13</td>
</tr>
<tr>
<td>Sy1.9/HII</td>
<td>2</td>
<td>0.26</td>
</tr>
<tr>
<td>Sy2.0/LINER</td>
<td>2</td>
<td>0.26</td>
</tr>
<tr>
<td>Sy2.0/HII</td>
<td>1</td>
<td>0.13</td>
</tr>
<tr>
<td>LINER/HII</td>
<td>18</td>
<td>2.31</td>
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<tr>
<td>HII/Starburst</td>
<td>533</td>
<td>68.42</td>
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<tr>
<td>Em</td>
<td>52</td>
<td>6.68</td>
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<tr>
<td>Abs</td>
<td>65</td>
<td>8.34</td>
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<tr>
<td>Star</td>
<td>3</td>
<td>0.39</td>
</tr>
<tr>
<td>Total</td>
<td>779</td>
<td>100.00</td>
</tr>
</tbody>
</table>

A detailed description of our developed scheme is given in Mickaelian et al. (2022) and Mickaelian et al. (2021), and on the dedicated webpage of our classification (Mickaelian Fine Classification of Active Galaxies 2022). The novelty of this classification scheme is the introduction of subtypes of the NLS1 and Composite spectrum objects. The advantage is that the analog of older classifications can be used when the spectrum is not high enough in quality to define the subtype; for example, NLS1 means that we cannot define whether the object is NLS1.0 or NLS1.2 or any other.

To present the general classification scheme, here we give a short description of the types and subtypes that were applicable to Mrk galaxies (the classification scheme also introduces QSO types and subtypes). We use the following scheme:

– (Classical) Broad-line Seyfert 1 galaxies (BLS1): subtypes BLS1.0, BLS1.2, BLS1.5, BLS1.8, BLS1.9;

– Narrow-line Seyfert 1 galaxies (NLS1; objects having relatively narrow broad lines): subtypes NLS1.0, NLS1.2, NLS1.5, NLS1.8, NLS1.9;

– Narrow-line active galaxies: subtypes: S2.0, LINER (or S3.0), and HII (Starburst, SB), mostly classified by diagnostic diagrams line ratios;

– Composites (Composite spectrum object): objects showing properties of different types or subtypes. When a broad component is present and the object shows features of BLS1/NLS1, very often the narrow-line ratio does not show a Seyfert galaxy but a LINER (strong lines having low ionization; OI, OII, SII) or HII. In this case the object is clearly a Composite. In many objects that only have narrow lines, different line ratios show different classes, for example Sy2.0 and LINER, or LINER and HII. Hence, we use all possible combinations of Composites (e.g., BLS1.2/LINER, NLS1.5/HII, LINER/HII).

We should note that our scheme works for all types, including the broad-line objects not available for the diagnostic diagrams. On the other hand, the fine analysis and decomposition technique allows narrow lines to be distinguished even for broad emission.
Table 4. SDSS Activity Types for 20 Markarian galaxies out of 779.

<table>
<thead>
<tr>
<th>Name</th>
<th>Mrk</th>
<th>SDSS ra</th>
<th>SDSS dec</th>
<th>SDSS u</th>
<th>SDSS g</th>
<th>SDSS r</th>
<th>SDSS i</th>
<th>SDSS z</th>
<th>BZCAT</th>
<th>Petrosian</th>
<th>NED</th>
<th>Veron</th>
<th>New activity type</th>
<th>Redshift</th>
<th>Abs. mag</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>132.91276208</td>
<td>57.10741431</td>
<td>17.052</td>
<td>15.964</td>
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<tr>
<td>3</td>
<td>139.18342467</td>
<td>59.77904574</td>
<td>16.095</td>
<td>15.523</td>
<td>15.295</td>
<td>15.326</td>
<td>15.216</td>
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<tr>
<td>4</td>
<td>147.12866350</td>
<td>57.97072521</td>
<td>15.952</td>
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<td>5</td>
<td>147.37629276</td>
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<td>54.51328335</td>
<td>17.355</td>
<td>16.437</td>
<td>16.213</td>
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<td>9</td>
<td>154.47406709</td>
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<td>154.90950035</td>
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</table>

4. Results: activity types of Markarian galaxies based on SDSS spectra

For optical classification, we used SDSS spectra (Abdurro’uf et al. 2022; Abumada et al. 2020) for Markarian galaxies. In total, 779 objects out of 1544 have spectra in SDSS. Based on the table data given in SDSS we built diagnostic diagrams for these 779 objects (Fig. 2). It is worth mentioning that the three diagnostic diagrams do not always give the same result. That is why we need to combine all three classifications; moreover, we carried out a thorough eye examination of objects to eliminate any artificial and doubtful features. Very often the differences between the three diagnostic diagrams, when appropriate, result in the classification into Composite types or subtypes. The resulting classification is a thorough analysis of all possible data for each object; when it is different for the three diagnostic diagrams, we need to decide which characteristics better fit it or if it is a mixture of different types. The numbers of objects in these diagnostic diagrams are 595, 555, and 601, respectively, for DD1, DD2, and DD3 (76%, 71%, and 77% of objects), thus giving a reasonable confidence for the classification of the vast majority of objects. In Table 3 we give the new SDSS optical spectral classification by activity types for 779 Markarian galaxies.

As seen in Table 3, most of the objects are HII/Starbursts (533, 68.42%). Here we do not go into detail to distinguish Starbursts among HII’s as the correct star-formation rate (SFR) is needed to identify the Starburst. BCDGs are also included in the HII/Starburst category as the abundance of He and/or metals is needed to identify a BCDG. Other types by decreasing numbers are: absorption spectrum objects (Abs, 65); emission line objects (Em, 52); Sy1.2 (21); Composites of subtype LINER/HII (18), LINERs (12), Sy1.5; and AGN without definite types (11 each). Combined, we have 2 QSOs, 49 BLS1s, 17 NLS1s, 4 Sy2s, 12 LINERs, 11 AGN without definite types (Sy or LINER), 31 Composites, 533 HII/Starbursts, 52 emission-line galaxies, 65 absorption-line galaxies, and 3 previously misidentified stars.

As a result of our new classification, most of the 779 objects have changed their optical spectral type or have been classified for activity types for the first time. Moreover, the number of objects with indefinite types (AGN, Em, and Abs) is only 128 out of 779 (16.4%). As mentioned, this is mostly due to low-quality spectra.

In Table 4, as an example, we present the list of 20 Markarian galaxies with new and old optical classifications. The full list of 779 objects is available only at the CDS. The columns present: 1) Mrk number, 2–3) SDSS coordinates (a big progress in Mrk galaxies positions), 4–8) SDSS ugriz photometry, 9–12) BZCAT, Petrosian et al. (2007), NED, and VCV-13 classification when available, 13) new activity type, 14) redshift, and 15) absolute magnitude.
31 Composite spectrum objects, and 533 HII/Starbursts. Some objects are still left without definite activity types (e.g., emission or absorption galaxies).

It appears that we have introduced proper classification for 548 (779 minus 231) Mrk objects, which is 70.35% of the sample. These objects had very poor low-dispersion classifications or similar. Out of the 231 objects with an existing classification, due to higher-quality SDSS spectra, we improved the classifications for 62 more objects. Hence, only 169 out of 779 Mrk galaxies (21.69%) in the SDSS area were properly classified before our study and we give here 610 (78.31%) new classifications. Moreover, if also considering subtypes, then almost all objects have new classifications. For example, in case of Sy1s, many were re-classified into Seyfert 1.2 or another subtype of BLS1 or even to one of the NLS1 subtypes. Especially obvious are the new NLS1s and Composites, which were almost absent in previous classifications.

5. Discussion and summary

Given the importance of Markarian galaxies and their wide usage in various extragalactic studies, it was important to
have a homogeneous spectral classification for activity types, which became possible thanks to SDSS medium-resolution spectroscopy. Moreover, given our recently suggested fine classification (Mickaelian et al. 2022), subtypes are also available for most of the objects, when it is allowed by the quality of spectra.

We carried out a thorough analysis and classification considering both SDSS tabular data (three diagnostic diagrams, DD1, DD2, and DD3, using line intensity ratios [OIII]/Hβ vs. [OI]/Hα, [OIII]/Hβ vs. [NII]/Hα, and [OIII]/Hβ vs. [SII]/Hα, respectively, when available) and accurate examination of the spectra to reveal all possible features, for example, presence of...
weak broad-line components together with strong narrow lines of Hα and Hβ. The novelties of our study are as follows:
- Homogeneous spectral classification for 779 Mrk galaxies based on the SDSS medium-resolution spectroscopy (on average much higher quality than the previously used ones);
- Introduction of fine details (subtypes of objects) in the classification scheme based on the Mickaelian Fine Classification of Active Galaxies (Mickaelian et al. 2022);
- Correction of old incorrect or partly incorrect (misclassified) types and subtypes (mostly due to lower-quality spectra);
- Spectral identification of Mrk galaxies into 2 QSOs, 49 classical Seyferts (BLS1), 17 NLS1s, 4 Sy2s, 12 LINERs, 11 AGN without definite type, 31 Composite spectrum objects, and 533 HII/Starbursts.

Concerning the efficiency of our revised classification, we introduced proper classifications for 548 (out of 779) Mrk objects, which is 70.35% of the sample. Out of the remaining 231 objects with an existing classification, we improved the classifications for more 62 objects. Hence, we give here 610 (78.31%) new classifications. Moreover, if also considering subtypes, then almost all the objects have new classifications.

Further studies are planned to investigate Mrk galaxies for various physical and spatial properties using the new classification to reveal differences in the distribution of objects by the given property. We will in fact repeat many studies based on Mrk galaxies using the new types and subtypes compared to their old ones. Specifically, we will investigate the redshift and luminosity distributions, luminosity evolution, morphology, by activity types. These studies are useful to follow the luminosity evolution and evolution of some other properties for different physical types rather than considering all Mrk galaxies together.

On the other hand, the remaining 765 Mrk galaxies (that are outside of the SDSS area) also need proper classification. A possible observing campaign will be conducted to spectroscopically observe these objects with a spectral resolution and S/N, possibly similar to SDSS, to have a full homogeneous picture of activity types for all 1544 Mrk galaxies.

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Fig. 5. Examples of some typical SDSS spectra of Markarian galaxies of different activity types and subtypes (part 3).

<table>
<thead>
<tr>
<th>Table 5. Old and new optical spectral types for 779 Markarian galaxies.</th>
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<tbody>
<tr>
<td><strong>Old optical spectral types</strong></td>
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<tr>
<td><strong>Type</strong></td>
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<tr>
<td>QSO</td>
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<tr>
<td>Blazars</td>
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<tr>
<td>S1 (all types)</td>
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<tr>
<td>NLS1 (all types)</td>
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<td>S2</td>
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<td>LINER</td>
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<td>AGN</td>
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<td>Composite</td>
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<td>HII/Starburst</td>
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