ZBL Lacertae concepts: Blazars (164); Jets (870); High energy astrophysics (739)
but none of them allows scientists to access the fully calibrated spectra of the sources with a homogeneous set of figures that permit to identify the spectral features detected in the spectra and then reuse the data for many different scientific aims. Motivated by these facts, we developed a new web-based database of BLL objects, namely Z BL Lacertae objects (ZBLLAC; https://web.oapd.inaf.it/zblac/), which is able to act as an online hub where optical spectra secured in the context of different publications with heterogeneous instrumentation are stored and made available to the community. We present in this paper the properties of the database and of the web application. ZBLLAC includes a smart representation of the data to provide a facilitated access to the basic information of each source and, specifically, to the machine readable 1D calibrated spectra along with a .pdf figure that shows the spectroscopic identification of firmly detected emission or absorption lines. The paper is organized as follows: in Section 2 we give an overview of our database and the website, while in Section 3 we detail on the format of our data. In Section 4 we discuss properties of the data set and we report our conclusions and future perspectives in Section 5.

2. The ZBLLAC Spectroscopic Database

At the time of writing of this work, the ZBLLAC database contains 337 objects considered as BLLs or BLL candidates in the literature. The sources were selected among heterogeneous criteria such as their detection in gamma-rays at GeV or TeV band (see, e.g., Atwood et al. 2009; Paiano et al. 2017c), Wide Field Infrared Survey Explorer (WISE) infrared color (Massaro et al. 2012a;
D’Abrusco et al. 2019; de Menezes et al. 2019, 2020, or the properties of their broadband SED (Padovani & Giommi 1995a, 1995b; Costamante & Ghisellini 2002; Costamante 2020). According to the properties of their optical spectra in ZBLLAC, we labeled 295 objects as BLLs by adopting spectral criteria based on the absence of emission features or, if detected, on the value of the equivalent width (EW), luminosities, and broadness of the lines. The remaining 42 targets exhibit spectra dominated by broad and intense emission lines, suggesting to us an alternative classification, and for this reason they have not been considered as BLLs.

For each object we give $\alpha$, $\delta$, the catalog name, the redshift, and the magnitude and provide a flux calibrated spectrum, dereddened for Galactic extinction. The spectra are available both in text format and with a .pdf figure that reports both the flux calibrated and normalized spectra. The main detected features, if present, are marked and identified (see examples of Figure 1). We also note that for 37 BLLs, more than one spectrum, secured in different epochs and with different instrumentation, is reported in the database.

The web interface of ZBLLAC is reported in Figure 2. The user can retrieve and interactively explore the data through the Spectroscopic Database page, which shows, by default, the full list of sources present in ZBLLAC. For each of them, the application displays basic information and a set of buttons to download the spectrum and the annotated .pdf figure. When more then one observation is associated to the same object, a further button is displayed allowing the user to select the spectrum, or figure, to download among all the available ones.

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Footnote:

7 Data were made available to us in electronic from directly from the authors. For further details see https://web.oapd.inaf.it/zbllac/refindex.html.
for the source. Finally, we implemented a Search Panel, shown on top of the page as reported in Figure 2, which permits us to actively filter the database according to various criteria such as being coordinated within a radius, target name, or redshift range.

3. Data Format and Technological Aspects

To store the data, we used the eXtensible Markup Language (XML\(^8\)) standard that allows us to define a proper data structure

\(^8\) \url{http://www.w3.org}

Figure 3. Schematic of the XML-based database adopted for the ZBLLAC database.

Figure 4. An example of the XML representation of the data for the object PKS 1553+113. For this source, three different spectra have been secured. The attributes pdf\_file and spc\_file contain the full link on our website to download the figure and the 1D calibrated spectra of the source. The lower blue panel shows how the row related to the source would be displayed on the ZBLLAC website.
and model by combining the possibility to easily query the database while being both machine and human readable. More specifically, the XML is a *markup language* that defines a set of rules for encoding plain-text documents in which the data are marked by tags or attributes (see Bosak & Bray 1999 for a full review). Data within XML documents are organized using a tree-like data structure, where each node may posses one or more leaves.

We decided to adopt a representation of the data by using the XML scheme reported in Figure 3. The root node of the structure is zbllac, which contains the set of all object of the ZBLLAC database as leafs. Each object (see Figure 3) contains as attributes all the relevant information to identify the source (name, coordinates, etc.) and two more nodes: the first one, named nedlink, contains the link to the object’s NED page while the second (spectra) harbors a set of spectrum nodes where the information about each observation and the relative HTTP links to download the data are saved. To further illustrate the organization of the data, we show in Figure 4 a sample node of our .xml file for the object PKS 1553+113 for which three different spectra have been secured.

Regarding, the website back-end, we made use of standard PHP pages coupled with XQuery and XPath protocols to retrieve the data throughout the .xml file.

4. Spectral Properties of BLLs

4.1. General Properties

The data set of BLLs, which currently encompass 295 targets, can be retrieved using the Spectroscopic database page (see Figure 2) by selecting the flag BLL.

For 103 (≈35%) objects, intrinsic spectral features are revealed, allowing us to firmly measure the redshift. In detail, for 31 objects, only emission lines are detected in their spectra, while in 55 BLLs, only features from the host galaxy (mainly ascribed to the Ca II and G bands) are present. In 17 cases, both emission and absorption features are revealed on the same spectrum. The median value of $z$ is 0.40, ranging between 0.071 and 1.636. The distribution of the redshifts is given in Figure 5 where we also report an histogram of $z$ for objects in which the host galaxy has been detected. As shown in Figure 5, the determination of the redshift for object at $z \gtrsim 0.80$ is assessed only through emission lines since the features from the host galaxy (e.g., [Ca II] $\lambda\lambda$ 3934-3968) start to move outside the covered spectral range (which is, on average, between 4000 Å and 8000 Å for objects in ZBLLAC).

Finally, for 35 BLLs that do not show intrinsic features, we detected intervening absorption systems along the line of sight, allowing us to establish a firm lower limit to their redshifts (see Section 4.3).

4.2. Emission Lines Properties

We detected emission features in 48 BLLs. The line identification and luminosities are given in Table 1.

In 28 cases, the only observed lines are narrow forbidden transition ascribed to [O II] ($\lambda$ 3934 Å) and [O III] ($\lambda$ 5007 Å) while broad spectral features, mainly associated to Mg II ($\lambda$ 2800) and C III ($\lambda$ 1908), are revealed in just eight targets. We also note that, for only four cases, broad and narrow emission lines are present on the very same spectrum. These facts may suggest that, in the majority of the cases, there is no trace of the broad line region, possibly meaning that either the physical conditions for its appearance are absent or that the lines are so broad and swamped by the continuum that they are not detected. We report in Figure 6 the distribution of the luminosity of emission lines ascribed to [O II] ($\lambda$ 3934 Å) and [O III] ($\lambda$ 5007 Å). The median luminosity for [O II] is $1.7 \times 10^{41}$ erg s$^{-1}$, while in the case of [O III], we found $1.3 \times 10^{41}$ erg s$^{-1}$.

Following the same approach described in Paiano et al. (2020), we compared our luminosities of [O II] and [O III] with those measured on spectra of low-redshift quasi-stellar objects (Shen et al. 2011, with similar luminosity on the continuum, assuming a beaming factor $\delta \sim 10$) and find that their mean values are roughly similar. This result is in agreement with Paiano et al. (2020), but in this case, our conclusions are based on a data set that is significantly larger.

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9 The up-to-date version of the database can be download at: https://web.oapd.inaf.it/zblac/zblac.xml.

10 http://ibm.com/developerworks/library/x-xpathphp/index.html
### Table 1

Properties of the Emission Lines Detected in the Spectra of BLLs that Belong to the ZBLLAC Database

| Source         | z     | Line                  | EW Å  | FWHM (km s⁻¹) | L (erg s⁻¹) | Type |
|----------------|-------|-----------------------|-------|---------------|-------------|------|
| ZBLL J0035+5950 | 0.467 | [O II] (λ3727)        | 0.3   | 350           | 9.7 \cdot 10^{40} | N    |
| ZBLL J0050-0929 | 0.635 | [O II] (λ3727)        | 0.5   | 600           | 1.0 \cdot 10^{41} | N    |
|                 |       | [O III] (λ5007)       | 0.6   | 450           | 9.4 \cdot 10^{40} | N    |
|                 |       | H α(λ6563)            | 1.6   | 1300          | 1.6 \cdot 10^{41} | N    |
| ZBLL J0048+4223 | 0.302 | [O II] (λ3727)        | 1.4   | 920           | 4.6 \cdot 10^{40} | N    |
|                 |       | [O III] (λ5007)       | 1.2   | 350           | 4.2 \cdot 10^{40} | N    |
| ZBLL J0158+0101 | 0.4537| [O III] (λ5007)       | 5.0   | 350           | 7.0 \cdot 10^{40} | N    |
| ZBLL J0303-2407 | 0.2657| [O III] (λ5007)       | 0.2   | 300           | 8.5 \cdot 10^{40} | N    |
|                 |       | H α(λ6563)            | 0.2   | 300           | 7.7 \cdot 10^{40} | N    |
|                 |       | [N II] (λ6585)        | 0.2   | 500           | 1.0 \cdot 10^{41} | N    |
|                 |       | [O II] (λ3727)        | 0.1   | 450           | 1.2 \cdot 10^{41} | N    |
| ZBLL J0301-1652 | 0.278 | [O III] (λ5007)       | 1.5   | 400           | 3.4 \cdot 10^{40} | N    |
| ZBLL J0305-1608 | 0.312 | [O II] (λ3727)        | 2.0   | 800           | 1.7 \cdot 10^{41} | N    |
| ZBLL J0316-2607 | 0.443 | [O II] (λ3727)        | 0.52  | 1600          | 1.3 \cdot 10^{41} | N    |
| ZBLL J0340-2119 | 0.223 | [O II] (λ3727)        | 1.5   | 1500          | 2.9 \cdot 10^{40} | N    |
| ZBLL J0342-3756 | 1.105 | [N II] (λ6585)        | 0.6   | 1200          | 2.6 \cdot 10^{40} | N    |
| ZBLL J0509+0542 | 0.3365| [O II] (λ3737)        | 0.07  | 500           | 1.0 \cdot 10^{41} | N    |
|                 |       | [O III] (λ5007)       | 0.05  | 600           | 9.2 \cdot 10^{40} | N    |
| ZBLL J0550-3216 | 0.068 | [N II] (λ6585)        | 0.05  | 300           | 6.7 \cdot 10^{40} | N    |
| ZBLL J0757-0956 | 0.266 | [O II] (λ3727)        | 0.6   | 850           | 1.4 \cdot 10^{41} | N    |
|                 |       | [O III] (λ5007)       | 0.9   | 1100          | 1.9 \cdot 10^{41} | N    |
| ZBLL J0811+0146 | 1.148 | [O II] (λ3727)        | 1.0   | 3000          | 2.0 \cdot 10^{42} | B    |
|                 |       | [O III] (λ5007)       | 1.5   | 4000          | 3.0 \cdot 10^{42} | B    |
| ZBLL J0820-1259 | 0.539 | [O II] (λ3727)        | 1.2   | 1000          | 5.8 \cdot 10^{41} | N    |
|                 |       | H β(λ4862)            | 0.5   | 850           | 1.9 \cdot 10^{41} | N    |
|                 |       | [O III] (λ5007)       | 2.5   | 650           | 8.4 \cdot 10^{41} | N    |
| ZBLL J0930+5132 | 0.1893| [O III] (λ4960)       | 1.0   | 450           | 1.0 \cdot 10^{41} | N    |
| ZBLL J0942-0047 | 1.363 | [O II] (λ3727)        | 4.8   | 1200          | 4.5 \cdot 10^{41} | N    |
|                 |       | Mg II (λ2800)         | 5.0   | 1600          | 1.0 \cdot 10^{43} | N    |
| ZBLL J1008-3139 | 0.534 | [O II] (λ3727)        | 1.0   | 600           | 2.3 \cdot 10^{41} | N    |
| ZBLL J1012+0631 | 0.727 | Mg II (λ2800)         | 0.5   | 1200          | 4.0 \cdot 10^{41} | N    |
|                 |       | [O II] (λ3727)        | 0.3   | 900           | 5.0 \cdot 10^{41} | N    |
| ZBLL J1046+5449 | 0.252 | [O III] (λ5007)       | 4.0   | 700           | 1.2 \cdot 10^{41} | N    |
| ZBLL J1049-1548 | 0.326 | [O II] (λ3727)        | 0.3   | 1200          | 1.2 \cdot 10^{41} | N    |
| ZBLL J1058-8003 | 0.581 | Mg II (λ2800)         | 1.2   | 2500          | 4.6 \cdot 10^{42} | B    |
|                 |       | [O III] (λ4960)       | 0.5   | 600           | 8.3 \cdot 10^{41} | N    |
|                 |       | [O III] (λ5007)       | 1.4   | 600           | 2.5 \cdot 10^{42} | N    |
| ZBLL J1117+2014 | 0.140 | [O II] (λ3727)        | 0.8   | 1200          | 5.2 \cdot 10^{40} | N    |
| ZBLL J1203-3926 | 0.227 | [O II] (λ3727)        | 2.4   | 600           | 6.1 \cdot 10^{40} | N    |
|                 |       | [O III] (λ4960)       | 1.4   | 800           | 3.7 \cdot 10^{40} | N    |
|                 |       | [O III] (λ5007)       | 2.82  | 550           | 7.3 \cdot 10^{40} | N    |
| ZBLL J1215+0732 | 0.137 | H α(λ6563)            | 1.3   | 600           | 3.3 \cdot 10^{40} | N    |
| ZBLL J1217+3007 | 0.129 | [O II] (λ3727)        | 0.2   | 600           | 6.5 \cdot 10^{40} | N    |
|                 |       | [O III] (λ5007)       | 0.2   | 650           | 5.1 \cdot 10^{40} | N    |
4.3. Intervening Absorption Systems

In the spectra of BLLs, absorption lines could arise intrinsically from the host galaxy, yielding directly to the determination of $z$, or from the intervening system if a cool gas cloud structure is intercepted along the line of sight. In this case, the detection of an intervening absorption gives a robust lower limit to the redshift of the source. We detected those systems in 35 objects and we report our measurements on Table 2. In the wavelength range covered by our collection of spectra, the main absorptions are those related to the Mg II doublet transition ($\lambda\lambda$ 2796–2803 Å), when the redshift of the absorber is between 0.40 $\lesssim z \lesssim$ 1.9. In fact, in 30 cases, we reveal spectral lines ascribed to Mg II ($\lambda$2800 Å) that allow us to set a lower limit to $z$. Furthermore, in three sources, both at redshift $z \gtrsim$ 2.00, we detected the onset of a Ly$\alpha$ forest (see Landoni et al. 2018; Paiano et al. 2017c for details) and a further intervening system, at a lower redshift, associated to Mg II, C IV, and Fe II (see Table 2). In a couple of targets,
The median value of our lower limits is $z \sim 0.64$ and we report their distribution in Figure 7. The peak around $z \sim 0.60$ is related to our spectral range, where the probability of the detection of Mg II is maximized. We note that lower limits for sources at $z \lesssim 0.40$ are in one case still ascribed to Mg II (ZBLL J0816–1311) because data has been obtained with the European Southern Observatory X-Shooter (Vernet et al. 2011) that provides increased spectral coverage in the UV (Pita et al. 2014), while the other two cases are associated with the intervention of Ca II ($\lambda 3934$ Å).

Finally, note that on the remaining 157 BLLs that still appear to be featureless. In our data, the total number of absorbers of Mg II, considering both multiple systems and those found in BLLs with $z$ is 46. However, according to Zhu & Ménard (2013) and Landoni et al. (2013), the expected number of detected Mg II systems in our data set in the redshift range $0.40 \leq z \leq 1.90$ (with EW $\gtrsim 1.00$ Å) should be of the order of $\sim 100$. This consideration suggests that, in order to cope with this statistic, the 157 featureless

Table 2

| Source       | Line       | EW (Å) | $z_{\text{min}}$ |
|--------------|------------|--------|-----------------|
| ZBLL J0003+0841 | Mg II ($\lambda$ 2800) | 1.50  | 1.5035 |
| ZBLL J0008+4712 | Mg II ($\lambda$ 2800) | 2.00  | 1.659  |
| ZBLL J0033–1921 | Mg II ($\lambda$ 2800) | 0.20  | 0.505  |
| ZBLL J0038+0012 | Mg II ($\lambda$ 2800) | 0.70  | 0.80   |
| ZBLL J0234–0628 | Mg II ($\lambda$ 2800) | 7.00  | 0.63   |
| ZBLL J0251–1831 | Mg II ($\lambda$ 2800) | 3.50  | 0.615  |
| ZBLL J0338+1302 | Mg II ($\lambda$ 2800) | 3.00  | 0.382  |
| ZBLL J0441–2952 | Mg II ($\lambda$ 2800) | 2.15  | 0.68   |
| ZBLL J0644+6038 | Mg II ($\lambda$ 2800) | 5.00  | 0.581  |
| ZBLL J0649–3139 | Mg II ($\lambda$ 2800) | 3.00  | 0.563  |
| ZBLL J0816–1311 | Mg II ($\lambda$ 2800) | 0.15  | 0.2882 |
| ZBLL J0848+7017 | Mg II ($\lambda$ 2800) | 11.30 | 1.2435 |
| ZBLL J1107+0222 | Mg II ($\lambda$ 2800) | 2.00  | 1.0735 |
| ZBLL J1129+3756 | Mg II ($\lambda$ 2800) | 9.10  | 1.211  |
| ZBLL J1231+0138 | Ly α ($\lambda$ 1216) | 15.00 | 3.140  |
| ZBLL J1231+0138 | Mg II ($\lambda$ 2800) | 6.00  | 2.004  |
| ZBLL J1450+5201 | Mg II ($\lambda$ 2800) | 5.00  | 2.004  |
| ZBLL J1511–0513 | Mg II ($\lambda$ 2800) | 2.10  | 0.451  |
| ZBLL J1540+8155 | Mg II ($\lambda$ 2800) | 0.60  | 0.672  |
| ZBLL J1730–0352 | Mg II ($\lambda$ 2800) | 7.50  | 0.776  |
| ZBLL J1955–1603 | Mg II ($\lambda$ 2800) | 3.00  | 0.638  |
| ZBLL J1959–4725 | Mg II ($\lambda$ 2800) | 2.30  | 0.519  |
| ZBLL J2107–4828 | Mg II ($\lambda$ 2800) | 4.30  | 0.519  |
| ZBLL J2115+1218 | Mg II ($\lambda$ 2800) | 4.00  | 0.497  |
| ZBLL J2119–4235 | Ca II ($\lambda\lambda$ 3934–3968) | 0.25  | 0.0087 |
| ZBLL J2212+2759 | Mg II ($\lambda$ 2800) | 3.90  | 1.529  |
| ZBLL J2236–1433 | Mg II ($\lambda$ 2800) | 0.70  | 0.490  |
| ZBLL J2236–1433 | Mg II ($\lambda$ 2800) | 0.90  | 0.493  |
Table 2 (Continued)

| Source         | Line     | EW (Å) | $z_{abs}$ |
|----------------|----------|--------|-----------|
| ZBLL J2247-0000 | Mg II ($\lambda$ 2800) | 3.00   | 0.898     |
| ZBLL J2255+2410 | Mg II ($\lambda$ 2800) | 0.70   | 0.8633    |
| ZBLL J2319+1612 | Mg II ($\lambda$ 2800) | 1.50   | 0.970     |
| ZBLL J2323+4210 | Ca II ($\lambda$ 3934-3968) | 0.50   | 0.267     |
|                | Na I ($\lambda$ 5892)    | 0.35   | 0.267     |

Table 2 shows the detection of Mg II in 157 featureless objects, statistically suggesting the presence of Mg II in these objects.

5. Concluding Remarks

We described the ZBLLAC database that currently contains optical spectra for 295 BLLs. We discussed the spectroscopic properties of the objects in this data set, finding that, for 35% of them, intrinsic spectral features are revealed, allowing us to solidly measure the redshift. We reported on 35 targets in which, by detecting intervening absorption systems, we set tight lower limits on their $z$. Based on the absence of absorption lines ascribed to Mg II in 157 featureless objects, we statistically suggest that they should lie at low redshifts $z \lesssim 0.70$.

BLLs should lie statistically at redshifts $z \lesssim 0.70$ (see also Paiano et al. 2020 for similar conclusions).

References

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Figure 7. Distribution of the redshift lower limits of 35 BLLs. The two red vertical bars show the redshift range $0.35 \lesssim z \lesssim 1.90$ in which our spectral coverage allows us to detect intervening absorption lines from Mg II.
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