Infrared properties of blazars: putting the GASP-WEBT sources into context

C. M. Raiteri,1† M. Villata,1 M. I. Carnerero,1,2,3 J. A. Acosta-Pulido,2,3
V. M. Larionov,4,5,6 F. D’Ammando,7,8 M. J. Arévalo,2,3 A. A. Arkharov,5
A. Bueno Bueno,2,3 A. Di Paola,9 N. V. Efimova,5 P. A. González-Morales,2,3
D. L. Gorshanov,5 A. B. Grinon-Marin,2,3 C. Lázaro,2,3 A. Manilla-Robles,3
A. Pastor Yabar,2,3 I. Puerto Giménez2,3 and S. Velasco2

1 INAF, Osservatorio Astrofisico di Torino, via Osservatorio 20, I-10025 Pino Torinese, Italy
2 Instituto de Astrofisica de Canarias (IAC), E-38200 La Laguna, Tenerife, Canary Islands, Spain
3 Departamento de Astrofisica, Universidad de La Laguna, E-38205 La Laguna, Tenerife, Canary Islands, Spain
4 Astron. Inst., St Petersburg State Univ., Universitetsky pr., 28, 198504 Petrodvorets, St Petersburg, Russia
5 Pulkovo Observatory, Pulkovskoe sh., 65, 196140 St Petersburg, Russia
6 Isaac Newton Institute of Chile, St Petersburg Branch, St Petersburg, Russia
7 INAF, Istituto di Radioastronomia, I-40129 Bologna, Italy
8 DIFA, Università di Bologna, Viale B. Pichat 6/2, I-40127 Bologna, Italy
9 INAF, Osservatorio Astronomico di Roma, Via di Frascati, 33, I-00040 Monte Porzio Catone, Italy

Accepted 2014 May 1. Received 2014 April 29; in original form 2014 March 12

ABSTRACT
The infrared properties of blazars can be studied from the statistical point of view with the help of sky surveys, like that provided by the Wide-field Infrared Survey Explorer and the Two Micron All Sky Survey. However, these sources are known for their strong and unpredictable variability, which can be monitored for a handful of objects only. In this paper, we consider the 28 blazars (14 BL Lac objects and 14 flat-spectrum radio quasars, FSRQs) that are regularly monitored by the GLAST-AGILE Support Program (GASP) of the Whole Earth Blazar Telescope since 2007. They show a variety of infrared colours, redshifts, and infrared–optical spectral energy distributions (SEDs), and thus represent an interesting mini-sample of bright blazars that can be investigated in more detail. We present near-IR light curves and colours obtained by the GASP from 2007 to 2013, and discuss the infrared–optical SEDs. These are analysed with the aim of understanding the interplay among different emission components. BL Lac SEDs are accounted for by synchrotron emission plus an important contribution from the host galaxy in the closest objects, and dust signatures in 3C 66A and Mrk 421. FSRQ SEDs require synchrotron emission with the addition of a quasar-like contribution, which includes radiation from a generally bright accretion disc ($\nu L_\nu$ up to $\sim 4 \times 10^{46}$ erg s$^{-1}$), broad-line region, and a relatively weak dust torus.

Key words: galaxies: active – BL Lacertae objects: general – quasars: general.

1 INTRODUCTION
BL Lacertae objects (BL Lacs) and flat-spectrum radio quasars (FSRQs) make up the two classes in which the active galactic nuclei (AGNs) known as ‘blazars’ are divided. They share extreme properties, as noticeable flux variability at all wavelengths, from the radio to the $\gamma$-ray energies, and on a variety of time-scales, ranging from hours to years. Their radio-to-UV (in some cases also X-ray) emission is mainly non-thermal, polarized synchrotron radiation from a relativistic jet pointing at a small angle to the line of sight, which explains the superluminal motions inferred from the radio images and the extremely high brightness temperature implied by fast radio variability.

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According to the classical definition by Stickel et al. (1991) and Stocke et al. (1991), the distinguishing feature of BL Lacs is that their spectra show optical emission lines with a rest-frame equivalent width smaller than 5 Å, if any. This classification is however unsatisfactory, as objects can change class depending on the level of non-thermal continuum from the jet. Even BL Lacertae itself was found not to behave as a BL Lac in faint states (Vermeulen et al. 1995; Corbett et al. 2000; Capetti, Raiteri & Buttiglione 2010). New criteria to separate BL Lacs from FSRQs have recently been proposed by Ghisellini et al. (2011) and Giommi et al. (2012), which are based on the luminosity of the broad-line region (BLR) in Eddington units and the ionization state, respectively.

Differences between the two blazar classes were observed in the wavelength-dependent behaviour of the optical polarization, when present (see e.g. Smith 1996). BL Lacs show increasing polarization towards the blue, likely due to causes intrinsic to the jet emitting region. An opposite behaviour characterizes FSRQs, because of the dilution effect towards the blue produced by the unpolarized thermal radiation from the accretion disc (Smith 1996; Raiteri et al. 2012). Moreover, very long baseline interferometry observations revealed different polarization structures, with BL Lacs exhibiting polarization position angles in the radio knots parallel, while FSRQs perpendicular, to the jet structural axis (e.g. Gabuzda et al. 1992).

From the point of view of parsec-scale jet morphology and kinematics, Karouzos et al. (2012) found that BL Lacs have in general wider and more bent jets than FSRQs, and that transverse motion of inner knots in BL Lacs is more pronounced than the radial one, which would suggest a helical jet structure. Variations of the innermost jet position angle in time are larger in FSRQs than in BL Lacs (Lister et al. 2013).

Besides the classification into FSRQs and BL Lacs, the latter sources are further divided into low-energy-peaked (LBL) and high-energy-peaked (HBL) BL Lacs, depending on the frequency at which the synchrotron emission component peaks in the spectral energy distribution (SED). The relation between LBLs and HBLs is still a matter of debate (e.g. Laurent-Muehleisen et al. 1999).

Observations by the Wide-field Infrared Survey Explorer (WISE) satellite (Wright et al. 2010) led to the development of a new diagnostic tool for AGN. In particular, it was noticed that blazars occupy a well-defined region of the W1 – W2 versus W2 – W3 plane: the so-called WISE blazar strip (Massaro et al. 2011), which includes a subregion delineating γ-ray emitting blazars (Massaro et al. 2012). This was used by D’Abrusco et al. (2013) and Massaro et al. (2013a) to recognize blazar candidates among the unidentified γ-ray sources detected by the Large Area Telescope (LAT) on board the Fermi satellite.

Using WISE data, Plotkin et al. (2012) concluded that there is no evidence of a dust torus in BL Lacs, which implies structural differences between the two types of blazars, possibly driven by different accretion rate regimes.

Statistical analysis of the blazar properties is facilitated by the presence of an online catalogue of blazars, the Roma-BZCAT2 (Massaro et al. 2009), as well as of many catalogues resulting from multifrequency surveys, from both ground and space, as the Sloan Digital Sky Survey1 (SDSS), the Two Micron All Sky Survey4 (2MASS), or the WISE All-Sky Database.5 However, generally surveys give information on a single state of each source, while blazars are rapidly and unpredictably variable objects at all frequencies.

On the other hand, the long-term multifrequency behaviour of blazars can be studied in detail only for a handful of sources, and this is usually achieved by large collaborations that share the observing effort. The Whole Earth Blazar Telescope6 (WEBT) was born in 1997 as an international collaboration of astronomers devoted to blazar studies. The advent of the new-generation satellites for γ-ray astronomy, Astro-rivelatore Gamma ad Immagini Leggero (AGILE) and Fermi (formerly GLAST), led the WEBT to organize a long-term monitoring of 28 blazars, 14 BL Lacs and 14 FSRQs, which were selected among the γ–loud, optically brightest and potentially most interesting sources for coordinated low-energy and γ-ray studies. This long-term monitoring project was called the GLAST-AGILE Support Program (GASP) and started its activity in 2007 (see e.g. Villata et al. 2008).

In this paper, we first put into context the GASP sources by comparing their infrared properties with those of the other classified blazars. Then we present the results of the near-IR monitoring of the GASP sources performed at the Campo Imperatore (Italy) and Teide (Canary Islands, Spain) observatories in 2008–2013. We analyse their flux density variability, colours and SEDs with special attention to the differences between BL Lac objects and FSRQs.

### Table 1. The BL Lac objects in the GASP target list.

| IAU name | Other name | BZCAT name | $z$ | $E(B–V)$ |
|---------|------------|------------|-----|---------|
| 0219+428 | 3C 66A | BZBJ0222+4302 | 0.444 | 0.0847 |
| 0235+164 | AO 0235+16 | BZBJ0238+1636 | 0.940 | 0.0797 |
| 0716+714 | S5 0716+71 | BZBJ0721+7120 | 0.310 | 0.0312 |
| 0735+178 | PKS 0735+17 | BZBJ0738+1742 | 0.450 | 0.0359 |
| 0829+046 | OJ 49 | BZBJ0831+0429 | 0.174 | 0.0329 |
| 0851+202 | OJ 287 | BZBJ0854+2006 | 0.306 | 0.0283 |
| 0954+658 | S4 0954+65 | BZBJ0958+6533 | 0.367 | 0.1197 |
| 1101+384 | Mrk 421 | BZBJ1104+3812 | 0.030 | 0.0153 |
| 1219+285 | ON 231 | BZBJ1221+2813 | 0.102 | 0.0233 |
| 1652+398 | Mrk 501 | BZBJ1653+3945 | 0.035 | 0.0190 |
| 1807+698 | 3C 371 | BZBJ1806+6949 | 0.046 | 0.0340 |
| 2155−304 | PKS 2155−304 | BZBJ2158−3013 | 0.116 | 0.0219 |
| 2200+420 | BL Lacertae | BZBJ2202+4216 | 0.069 | 0.3280 |
| 2344+514 | 1ES 2344+514 | BZBJ2347+5142 | 0.044 | 0.2097 |

1 The WISE filters W1, W2, W3 and W4 have isophotal wavelengths of about 3.4, 4.6, 12 and 22 μm, respectively. These $A_{\text{iso}}$, together with the magnitude zero-points, are calibrated with respect to Vega (Wright et al. 2010).

2 BZCAT is available online at the ASDC website http://www.asdc.asi.it/bzcat.

3 http://www.sdss.org/

4 http://www.ipac.caltech.edu/2mass/

5 http://irsa.ipac.caltech.edu/

6 http://www.oato.inaf.it/blazars/webt/
Table 2. The FSRQs in the GASP target list.

| IAU name     | Other name | BZCAT name    | z    | E(B − V) |
|--------------|------------|---------------|------|----------|
| 0420−014     | PKS 0420−01| BZQ0423−0120  | 0.916| 0.1258   |
| 0528+134     | PKS 0528+134| BZQ0530+1331  | 2.070| 0.8450   |
| 0827+243     | QJ 248     | BZQ0830+2410  | 0.939| 0.0333   |
| 0836+710     | 4C 71.07   | BZQ0841+7053  | 2.218| 0.0301   |
| 1156+295     | 4C 29.45   | BZQ1159+2914  | 0.729| 0.0199   |
| 1226+023     | 3C 273     | BZQ1229+0203  | 0.158| 0.0206   |
| 1253−055     | 3C 279     | BZQ1256−0547  | 0.536| 0.0286   |
| 1510−089     | PKS 1510−08| BZQ1512−0905  | 0.360| 0.1010   |
| 1611+343     | DA 406     | BZQ1613+3412  | 1.397| 0.0178   |
| 1633+382     | 4C 38.41   | BZQ1635+3808  | 1.814| 0.0122   |
| 1641+399     | 3C 345     | BZQ1642+3948  | 0.593| 0.0131   |
| 1739+522     | 4C 51.37   | BZQ1740+5211  | 1.381| 0.0355   |
| 2230+114     | CTA 102    | BZQ2232+1143  | 1.037| 0.0718   |
| 2251+158     | 3C 454.3   | BZQ2253+1608  | 0.859| 0.1078   |

Extinction Service at IRS. Reddening is particularly important (> 0.1) for the BL Lacs 0954+658, 2200+420 and 2344+514, and for the FSRQs 0420−014, 0528+134, 1510−089 and 2251+158.

As mentioned in the Introduction, the IR survey undertaken by the WISE satellite provided a new tool to identify blazars. We searched the WISE All-Sky Source Catalog for the BZCAT sources. A cone search radius of 3 arcsec was found to be the best choice between having reliable identifications and completeness. Among the 1180 BL Lacs present in the BZCAT catalogue, we obtained 1122 WISE counterparts (95 percent), while we found 1608 identifications for the 1676 BZCAT FSRQs (96 percent). All of the GASP sources have a WISE counterpart.

Fig. 1 shows the colour–colour WISE diagram for the BZCAT blazars, separating FSRQs from BL Lacs. We assume that Galactic extinction is negligible at WISE wavelengths. The points referring to the GASP sources are overplotted in colour. The GASP FSRQs cover the region where most sources cluster and the GASP BL Lacs distribute along almost the whole BL Lac sequence extending towards the elliptical galaxies location. All the GASP sources were detected in γ-rays by Fermi-LAT (Nolan et al. 2012) and they all lie within the WISE Gamma-ray Strip (Massaro et al. 2012, see also D’Abrusco et al. 2012), when considering the refined analysis by D’Abrusco et al. (2013) and Massaro et al. (2013b). In the figure, the position of elliptical galaxies is indicated, using the SWIRE template (Polletta et al. 2007) of a 13 Gyr old elliptical galaxy for redshifts between 0 and 0.25, and that of a 5 Gyr galaxy for redshifts from 0.3 to 1. We notice that for a given galaxy age, i.e. a given stellar population, redshift variations result in a small scatter of the points, while changing the model produces a larger shift in the diagram. We also show the trace left by the SWIRE TQS01 template, i.e. a type 1 QSO with broad emission lines in the optical spectrum and prominent torus, for redshift values in the range z = 0−3. Finally, the straight line is obtained from a power-law spectrum \( F_\nu \propto \nu^{-\alpha} \) with spectral index \( \alpha = 0−1.5 \), and represents the typical non-thermal, synchrotron emission from blazar jets. The range of considered \( \alpha \) includes both flat (\( \alpha < 1 \)) spectra, as most BL Lacs show, and steep (\( \alpha > 1 \)) spectra, which characterize most FSRQs (see below). Deviation from the power-law line means that the source spectrum is not a pure synchrotron spectrum, but that either it is contaminated by other emission contributions (from host galaxy and QSO-like nucleus) or it presents a curvature in the WISE bands. This will be studied in depth in Section 5.

In Fig. 2, we plotted the redshift versus the WISE W1−W2 colour. We took into account new BL Lac redshift measurements by Landoni et al. (2012), Landoni et al. (2013), Sandrinelli et al. (2013) and Pita et al. (2014). The GASP FSRQs cover fairly well the strip formed by all the FSRQs, apart for the upper part, corresponding to the most distant objects. As for BL Lacs, the GASP source with higher redshift is 0235+164, but there are only few objects that are more distant, most of them with uncertain z. Here, again we plotted the position of elliptical galaxies and TQS01 spectra of different redshifts.

The same search radius of 3 arcsec was adopted to query the 2MASS catalogue for the BZCAT objects. This is the maximum radial offset between the WISE sources and associated 2MASS sources in the WISE catalogue. The 2MASS catalogue includes sources brighter than about 1 mJy in the J, H and K bands, with signal-to-noise ratio (S/N) greater than 10. We found 815 2MASS counterparts in the case of the BL Lacs (69 percent), and 686 for the FSRQs (41 percent). All the GASP sources have a 2MASS counterpart. We corrected for the Galactic extinction according to Schlegel et al. (1998), i.e. using the relative extinction values \( A(E(B − V)) = 0.902, 0.576 \) and 0.367 for the J, H and K bands, respectively, with \( E(B − V) \) downloaded from the Galactic Dust Extinction Service at IRSA mentioned above.

Fig. 3 shows the colour–colour diagram built with 2MASS data for both FSRQs and BL Lacs. Combining WISE and 2MASS information, we obtained the diagram of Fig. 4. In both plots, the GASP FSRQs are concentrated in the central region of the diagram, while BL Lacs are more distributed.

It is interesting to compare our results on the 2MASS BL Lac colours with those by Chen, Fu & Gao (2005). These authors started from the Véron-Cetty & Véron (2003) catalogue and found 511 BL Lacs with 2MASS counterparts, including uncertain sources. In the J−H versus H−K plot, the majority of both the Chen et al. (2005) and our sources lie in the region where both the colour indices values are in the range 0.2−1.2. However, Fig. 3 shows much more objects with \( J − H > 1.2 \), and a lack of sources in the region with \( H − K \) from −0.2 to 0.2 and \( J − H \) in the range 0−0.5, where instead there are several objects in the Chen et al. (2005) plot. The latter difference in the colour distribution likely reflects the presence of misclassified objects in the Véron-Cetty & Véron (2003) catalogue.

Finally, we searched the BZCAT FSRQs and BL Lacs in the SDSS. To be sure that our objects photometry passed all tests to be used for science, we set the CLEAN flag to one in the query form. We found 765 BL Lacs (65 percent of the sample) and 794 FSRQs (47 percent) for which clean photometric data in the u, g, r, i and z bands are available. Among them, only four BL Lacs and eight FSRQs belong to the GASP source list. In Fig. 5, we plot the SED of the BZCAT FSRQs and BL Lacs built with WISE, 2MASS and SDSS data. These latter have been corrected for the Galactic extinction in the same way as for the 2MASS data, i.e. adopting the \( A(E(B − V)) \) values given by Schlegel et al. (1998) (5.155, 3.793, 2.751, 2.086 and 1.479 from u to z), and \( E(B − V) \) as specified above. Transformation of de-reddened magnitudes into fluxes has been done by using the specific zero-mag flux densities. To avoid very uncertain data, we plotted only objects for which WISE data have \( S/N > 3 \) and SDSS magnitudes are less than the survey limits in all bands, which are 22.0, 22.2, 22.2, 21.3 and 20.5 mag in the u, g, r, i and z bands, respectively. The SEDs corresponding to the
Figure 1. Colour–colour diagrams built with WISE data for FSRQs (left) and BL Lacs (right). Only objects with S/N > 3 in all WISE bands were considered. The points corresponding to the 28 sources monitored by the GASP-WEBT are highlighted with coloured diamonds. The black squares in the bottom left represent the SWIRE templates of 5 and 13 Gyr old elliptical galaxies at different values of redshift. The locations of type 1 QSO spectra (TQSO1 SWIRE template) of various redshift, and power-law (PL) spectra with different spectral index are also plotted.

Figure 2. The redshift versus WISE W1 − W2 colour for FSRQs (left) and BL Lacs (right). Only objects with S/N > 3 in all WISE bands were considered. Black crosses indicate sources with uncertain redshift; black plus signs those with undetermined z. The points corresponding to the 28 sources monitored by the GASP-WEBT are highlighted with coloured diamonds. The black squares in the bottom left represent the SWIRE templates of 5 and 13 Gyr old elliptical galaxies at different values of redshift. The location of type 1 QSO spectra (TQSO1 SWIRE template) of various redshift is also plotted.

Figure 3. Colour–colour diagram built with 2MASS data for FSRQs (left) and BL Lacs (right). The 2MASS magnitudes have been corrected for Galactic reddening according to Schlegel, Finkbeiner & Davis (1998). GASP sources are overplotted with coloured diamonds.

GASP sources are highlighted in colour. They show discontinuities between different data sets as a consequence of variability, since the observations by WISE, 2MASS and SDSS were carried out at different epochs, when the sources were evidently in different brightness states. We also display average SEDs. These are within the GASP SEDs or just below them for FSRQs, while they are quite below the SEDs of the GASP BL Lacs, meaning that the GASP choice of BL Lacs is more biased towards the brightest objects than in the case of FSRQs. The average FSRQs SED shows a steep spectrum in the WISE bands, while it turns into a flat spectrum in the 2MASS and SDSS bands. The upturn signs the transition from a dominant synchrotron emission contribution to the ‘big blue bump’, which is ascribed to thermal emission from the accretion disc. In contrast, the average BL Lacs SED follows the synchrotron hump, with the peak between the 2MASS and SDSS bands.
In conclusion, the GASP sources show a variety of infrared colours, redshifts and infrared–optical SEDs, and thus form an interesting mini-sample of blazars that can be analysed in detail and that is likely representative of the bright objects.

3 NEAR-IR FLUX VARIABILITY

Regular monitoring of the GASP sources in the near-IR bands is carried out at the Campo Imperatore (Italy) and Teide (Canary Islands, Spain) observatories.

The observations at Campo Imperatore were obtained by using the 1.1 m AZT-24 telescope and the SWIRCAM camera (D’Alessio et al. 2000). SWIRCAM is based on a Rockwell PICNIC array having 256 × 256 pixels with a size of 40 μm, that corresponds to 1.04 arcsec on the sky. Every final image is composed from five dithered raw images after preliminary processing, that includes sky subtraction, flat-fielding and recentering.

The observations at Teide Observatory (Canary Islands) were obtained with the 1.52 m Carlos Sanchez Telescope (TCS), using the near-infrared camera CAIN. This camera is equipped with a 256 × 256 pixels NICMOS-3 detector and it provides a scale of 0.254 arcsec pixel−1 with the wide field optics (4.2 arcmin × 4.2 arcmin). Data were acquired in the three filters J, H and Ks. Observations were performed using a five-point dither pattern in order to facilitate a proper sky background subtraction. At each point, the exposure time was about 1 min, split in individual exposures of 10 s in the J filter and 6 s in the H and Ks filters to avoid saturation by sky brightness. The dither cycle was repeated twice, except for faint sources where the number of cycles was increased.

Image reduction was performed with the CAINDR package developed by Rafael Barrena-Delgado and Jose Acosta-Pulido under the IRAF environment.12 Data reduction includes flat-fielding, sky subtraction and the shift and combination of all frames taken in the same dither cycle. Photometric calibration was performed using an IDL routine kindly provided by P. Ábrahám (Obs. Konkoly, Hungary), which uses the 2MASS catalogue (Cutri et al. 2003). The photometric zero-point for each combined image was determined by averaging the offset between the instrumental and the 2MASS magnitudes of catalogue sources within the field of view. Whenever deviant targets appear they are excluded before computing the average.

In Figs 6 and 7, we show the near-IR light curves of the GASP BL Lac, while in Figs 8 and 9 those of the GASP FSRQs are displayed. In a few cases (0219+428, 0851+202, 1226+023 and 2344+514), we found offsets due to different source calibration between the Campo Imperatore and Teide data, and corrected for them.

To quantify variability, magnitudes are converted into flux densities as explained in Section 2 and then the mean fractional variation is calculated. This is defined as

\[
f = \frac{\sqrt{\sigma^2 - \delta^2}}{F},
\]

where \( F \) is the mean flux, \( \sigma^2 \) the variance of the flux, and \( \delta^2 \) the mean square uncertainty of the fluxes (e.g. Peterson 2001). The advantage of this quantity is that it takes into account the effect of errors, which produce apparent variability. Tables 3 and 4 report the mean fractional variation for the GASP BL Lacs and FSRQs, respectively. For a given object, this quantity obviously depends on the considered period and on the amount of data collected. Only one BL Lac (0235+164) and three FSRQs (0420−014, 2230+114 and 2251+158) have \( f \geq 1 \), and 0235+164 is the most variable source. Note that 0235+164 has sometimes been claimed to belong to the FSRQs (e.g. Raiteri et al. 2007; Ghisellini et al. 2011). The values of the mean fractional variation indicate that FSRQs are typically more variable than BL Lacs. Average \( f \) values for the whole BL Lac sample in each of the near-IR bands are around 0.35 per cent, while they are \( \sim 60 \) per cent in the case of FSRQs. Moreover, in general BL Lacs are slightly more variable in the J band and FSRQs in the K band. This recalls what happens in the optical domain, where BL Lacs are generally more variable in the blue than in the red, while for FSRQs the opposite is true. The smaller variability of FSRQs towards the blue is a clue in favour of an additional emission component, i.e. thermal emission from the disc (showing as a ‘big blue bump’ in theSED) and BLR (producing a ‘little blue bump’ in theSED). Indeed, the contribution from this ‘blue’ component is expected to extend into the near-IR band, behaving as a base-level under which the flux cannot fall, and affecting the J flux density more than the K one.

4 NEAR-IR COLOUR VARIABILITY

To analyse the near-infrared spectral variability, we first binned the J, H and K data of each observatory acquired within 30 min and then coupled the binned data with error less than 0.1 mag to build \( J − H \) and \( H − K \) colour indices. Figs 10 and 11 show the colour variability of the GASP sources in the \( J − H \) versus \( H − K \) plot, compared to the 2MASS value (see Fig. 3). Correction for Galactic extinction has been performed as explained in Section 2. In Tables 3 and 4, we report colour indices average values, their standard deviations and mean fractional variations (see equation 1). The latter are often imaginary numbers for BL Lacs, which means that the corresponding colour index variability is dominated by noise. When this is not the case, the value is however low, in the range 1–7 per cent. This is also true for 0235+164, the source with the largest flux variability, which nonetheless is the BL Lac showing the most noticeable spectral changes. In general, larger near-IR spectral variability characterizes FSRQs because of the interplay between synchrotron and quasar-like emission components, the latter including contributions

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10 http://www.oa-roma.inaf.it/preprocess/preprocess.html
11 http://www.astro.spbu.ru/staff/vlar/NIRlist.html
12 Image Reduction and Analysis Facility – http://iraf.noao.edu/
Figure 5. SEDs of the BZCAT FSRQs (left) and BL Lacs (right) built with infrared and optical data from WISE, 2MASS and SDSS. WISE and SDSS data are plotted only for objects with S/N > 3 and magnitudes brighter than the survey limits, respectively, in all bands. The 2MASS and SDSS data are corrected for the Galactic extinction according to Schlegel et al. (1998). Mean SEDs are highlighted with black plus signs; GASP sources are overplotted with coloured diamonds.

from the accretion disc, BLR, and torus (see Section 5). Exceptions are 3C 273, PKS 1510−089 and 3C 345. The sources exhibiting the largest colour indices changes are 3C 454.3 and CTA 102.

By looking at Figs 10 and 11, one can see that sometimes the 2MASS value is outside the region where most of our points collect. This may partly reflect cross-calibration problems, but may also indicate an even larger variability.

Two sources show clear trends in the colour–colour diagram. The anticorrelation between $J - H$ and $H - K$ in the 3C 273 plot suggests that there is a spectral break in the $H$ band. In contrast, a correlation is visible in the colour–colour plot of 3C 454.3, where the lower-left group of points refer to the source faint state from 2011 onwards, while the upper-right group of points come from the bright state before 2011. The colour–colour plot then tells us that the near-IR spectrum is bluer in faint states and redder in bright states. A redder-when-brighter trend has already been noticed when analysing the optical spectrum of this source (e.g. Villata et al. 2006; Raiteri et al. 2008). These spectral behaviours will become clearer in the next section, where SEDs are presented and interpreted in terms of different emission contributions.

5 INFRARED-TO-OPTICAL SED

In this section, we present the infrared-to-optical SEDs of the GASP sources. They are built with the survey data already presented in Section 2 (WISE, 2MASS, SDSS), literature data and the results of our near-IR monitoring at Campo Imperatore and Teide. Note that a WISE single exposure source data base is available, containing multiple observations of the GASP sources. However, the use of this data base is discouraged because it includes all single exposure images regardless of their quality,\(^{13}\) so we did not consider it. From the literature, we extracted data from the Infrared Astronomical Satellite (IRAS; Impey & Neugebauer 1988), the Infrared Space Observatory (ISO; Haas et al. 2004) and the Spitzer satellite (Malmrose et al. 2011; Ogle et al. 2011). Herschel data for 3C 454.3 are from Wehrle et al. (2012). For 3C 273 and 3C 371, we used the optical spectra acquired at the Telescopio Nazionale Galileo by Buttiglione et al. (2009), which are available on the NASA/IPAC Extragalactic Database.\(^{14}\) In a few cases, we reported SEDs from papers involving data from the GASP-WEBT Collaboration for a more accurate modelling: D’Ammando et al. (2011) for PKS 1510−089; Raiteri et al. (2012) for 4C 38.41, Raiteri et al. (2011) for 3C 454.3. Although in general the SEDs do not contain simultaneous data, they can help us understand what are the photons sources intervening in this frequency range. In Figs 12 and 13, we show the SEDs together with model fits that take into account the possible emission contributions:

(i) synchrotron radiation from the jet, which is modelled as a log-parabola following Massaro et al. (2004),

$$\log[v F(v)] = \log[v_p F(v_p)] - b (\log v - \log v_p)^2,$$

where $v_p$ is the frequency of the synchrotron peak $v_p F(v_p)$;

(ii) host galaxy emission, for which we consider the SWIRE template of a 13 Gyr old elliptical galaxy;

\(^{13}\) http://wise2.ipac.caltech.edu/docs/release/allsky/expsup

\(^{14}\) http://ned.ipac.caltech.edu
(iii) QSO-like nuclear contribution from accretion disc, BLR, and dust torus, all included in the QSO1 SWIRE templates, i.e. templates of QSO with broad emission lines;

(iv) thermal radiation from a blackbody to simulate dust signatures in the infrared or to enhance the accretion disc flux in FSRQs.

In the plots presented for BL Lacs in Fig. 12, sometimes catalogue data are shifted in $\nu F_\nu$ (the shift is marked by arrows) in order to simulate simultaneous SEDs that can ease the modelling task. Although this is not strictly correct because the spectral shape may change with flux, it is justified by the small spectral variability that we noticed in Section 4 for BL Lacs.
Fits to the SEDs of BL Lacs require a synchrotron emission, plus the contribution of a host galaxy for the nearest objects. This is dominant in the near-IR in the cases of Mrk 501 and 1ES 2344+514, and it is very important for Mrk 421 and 3C 371. For only two BL Lacs (3C 66A and Mrk 421), the far-infrared data from IRAS suggest the presence of dust, as already noticed by Impey & Neugebauer (1988).

In general, the FSRQs SEDs need a synchrotron plus a QSO-like emission contribution due to accretion disc, BLR and torus. There are three QSO1 templates in the SWIRE data base. We first used TQSO1 because it shows a prominent Hα line, which is known to be present in the spectra of our objects. However, its high IR/optical flux ratio (rest frame) appears inadequate to model some FSRQs SEDs, so we built a composite QSO1 template, combining the higher frequency part of TQSO1, i.e. its disc plus BLR emission, with the lower frequency part of BQSO1, representing a fainter torus emission. Moreover, in some FSRQs a brighter disc is required, which we obtained by adding a blackbody component to the QSO1 template. In the following, we comment on single source features.

5.1 BL Lac objects

5.1.1 0219+428

The model fit indicates that the synchrotron peak falls at optical frequencies. As already noticed by Impey & Neugebauer (1988), there is good evidence for thermal dust emission, which we fitted with a blackbody spectrum with temperature of ~41 K.

5.1.2 0235+164

This is the farthest among the GASP-WEBT BL Lacs and has often revealed an FSRQ-like behaviour (e.g. Raiteri et al. 2007; Ghisellini et al. 2011). As discussed in Section 4, notwithstanding the strong variability in the near-IR, the spectral slope does not change much. There is no hint of a J-band flux excess due to the contribution of the Hα emission line even in the faintest states. This means that BLR emission is undetected in our observations. Data are compatible with a shift of the synchrotron peak towards higher energies when the flux increases, as shown by the model fits.

5.1.3 0716+714

The near-IR data from the GASP indicate a steep spectrum, which appears steeper in faint states (see also Villata et al. 2008). In contrast, the 2MASS spectrum is flat. IRAS data likely belong to a fainter state.

5.1.4 0735+178

By shifting in νFν the same log-parabola model, we obtained reasonable fits of two different brightness states traced by SDSS and WISE data, respectively.
Figure 8. Near-IR light curves of the GASP-WEBT FSRQs. Blue squares indicate data from Campo Imperatore, red diamonds those from Teide.
Figure 9. Near-IR light curves of the GASP-WEBT FSRQs. Blue squares indicate data from Campo Imperatore, red diamonds those from Teide.

Table 3. Mean fractional variation of the near-IR flux densities, $f_i$, average de-reddened colour indices $(J - H)$ and $(H - K)$ with their standard deviations ($\sigma$) and their mean fractional variations $f_{J-H}$ and $f_{H-K}$ for the BL Lacs in the GASP target list.

| IAU name | $f_J$ | $f_H$ | $f_K$ | $(J - H)$ | $(H - K)$ | $f_{J-H}$ | $f_{H-K}$ |
|----------|-------|-------|-------|-----------|-----------|-----------|-----------|
| 0219+428 | 0.39  | 0.38  | 0.37  | 0.70 (0.04) | 0.74 (0.04) | –         | –         |
| 0235+164 | 1.50  | 1.44  | 1.39  | 1.07 (0.09) | 0.98 (0.07) | 0.07      | 0.05      |
| 0716+714 | 0.49  | 0.35  | 0.33  | 0.83 (0.04) | 0.89 (0.04) | –         | –         |
| 0735+178 | 0.24  | 0.27  | 0.27  | 0.86 (0.05) | 0.83 (0.05) | 0.04      | 0.05      |
| 0829+046 | 0.23  | 0.22  | 0.22  | 0.88 (0.03) | 0.85 (0.05) | –         | –         |
| 0851+202 | 0.39  | 0.41  | 0.45  | 0.89 (0.05) | 0.91 (0.05) | 0.04      | 0.01      |
| 0954+658 | 0.45  | 0.41  | 0.40  | 0.90 (0.04) | 0.93 (0.05) | –         | –         |
| 1101+384 | 0.27  | 0.26  | 0.27  | 0.77 (0.02) | 0.25 (0.03) | –         | –         |
| 1219+285 | 0.32  | 0.33  | 0.31  | 0.72 (0.03) | 0.75 (0.05) | –         | 0.05      |
| 1652+398 | 0.01  | 0.01  | 0.01  | 0.81 (0.01) | 0.40 (0.01) | –         | –         |
| 1807+698 | 0.08  | 0.08  | 0.07  | 0.83 (0.01) | 0.66 (0.04) | –         | –         |
| 2155−304 | 0.20  | 0.20  | 0.21  | 0.61 (0.02) | 0.80 (0.01) | –         | –         |
| 2200+420 | 0.39  | 0.38  | 0.39  | 0.83 (0.04) | 0.79 (0.04) | –         | 0.01      |
| 2344+514 | 0.09  | 0.09  | 0.10  | 0.75 (0.05) | 0.33 (0.03) | 0.04      | –         |

Table 4. Mean fractional variation of the near-IR flux densities, $f_i$, average de-reddened colour indices $(J - H)$ and $(H - K)$ with their standard deviations ($\sigma$) and their mean fractional variations $f_{J-H}$ and $f_{H-K}$ for the FSRQs in the GASP target list.

| IAU name | $f_J$ | $f_H$ | $f_K$ | $(J - H)$ | $(H - K)$ | $f_{J-H}$ | $f_{H-K}$ |
|----------|-------|-------|-------|-----------|-----------|-----------|-----------|
| 0420−014 | 1.00  | 1.01  | 0.89  | 0.88 (0.08) | 0.97 (0.09) | 0.07      | 0.07      |
| 0528+134 | 0.55  | 0.65  | 0.64  | 0.63 (0.16) | 0.90 (0.09) | 0.23      | 0.08      |
| 0827+243 | 0.85  | 0.87  | 0.93  | 0.58 (0.12) | 0.89 (0.15) | 0.19      | 0.16      |
| 0836+710 | 0.47  | 0.60  | 0.65  | 0.63 (0.13) | 0.83 (0.13) | 0.20      | 0.13      |
| 1156+295 | 0.73  | 0.68  | 0.69  | 0.88 (0.08) | 0.90 (0.11) | 0.08      | 0.11      |
| 1226+023 | 0.04  | 0.06  | 0.05  | 0.81 (0.04) | 1.15 (0.04) | 0.03      | 0.02      |
| 1253−055 | 0.57  | 0.58  | 0.59  | 0.91 (0.09) | 0.94 (0.07) | 0.09      | 0.05      |
| 1510−089 | 0.33  | 0.33  | 0.31  | 0.90 (0.06) | 1.02 (0.07) | 0.04      | 0.05      |
| 1611+343 | 0.24  | 0.23  | 0.32  | 0.85 (0.08) | 0.64 (0.16) | 0.08      | 0.23      |
| 1633+382 | 0.64  | 0.63  | 0.58  | 0.90 (0.11) | 0.94 (0.07) | 0.12      | 0.05      |
| 1641+399 | 0.38  | 0.40  | 0.40  | 0.98 (0.05) | 0.94 (0.07) | 0.03      | 0.05      |
| 1739+522 | 0.21  | 0.24  | 0.26  | 0.87 (0.09) | 0.72 (0.18) | 0.09      | 0.23      |
| 2230+114 | 1.12  | 1.27  | 1.25  | 0.59 (0.17) | 0.86 (0.18) | 0.28      | 0.20      |
| 2251+158 | 1.10  | 1.31  | 1.32  | 0.60 (0.30) | 0.87 (0.18) | 0.49      | 0.19      |
Figure 10. Near-IR colour–colour plots for the GASP-WEBT BL Lacs. Data have been corrected for Galactic extinction. Blue squares indicate data from Campo Imperatore, red diamonds those from Teide. The black cross indicates the point obtained from the 2MASS catalogue.

5.1.5 0829+046

The model fit accounts for a bright state marked by SDSS, 2MASS and the lowest IRAS data points.

5.1.6 0851+202

The lower model fit reproduces the WISE and 2MASS SED and its shape also agrees with the SDSS spectrum. The upper model is
obtained by shifting vertically the previous one and goes through the scattered IRAS data.

5.1.7 0954+658

As in the case of 0716+714, the near-IR data from the GASP show a steep spectrum, in contrast with the 2MASS spectral slope.

5.1.8 1101+384

This is an HBL, whose synchrotron peak lies in the X-ray band, with impressive frequency shifts (Pian et al. 1998). According to Nilsson et al. (2007), the host galaxy has a magnitude $R = 13.18 \pm 0.05$ and contributes up to $\sim 10$ mJy (for a 10 arcsec aperture radius and good seeing conditions) to the source photometry. The 2MASS data are from the All-Sky Extended Source Image Server and show a faint state of the source. An infrared excess is visible in the IRAS data suggesting thermal emission from dust, as pointed out by Impey & Neugebauer (1988). We then interpreted the SED as a superposition of a jet spectrum, host galaxy contribution and a blackbody dust component with temperature of about 23 K. The model fit presented in Fig. 12 goes through the 2MASS and IRAS data.

Figure 11. As in Fig. 10 but for the GASP-WEBT FSRQs.
Figure 12. SED of the GASP-WEBT BL Lacs. Data from ISO (red circles), IRAS (triangles), Spitzer (plus signs and crosses), WISE (squares), 2MASS (diamonds) and SDSS (asterisks) are shown. The green circles represent the results of the GASP near-IR monitoring at the Campo Imperatore and Teide observatories. The optical spectrum of 1807+698 by Buttiglione et al. (2009) is also plotted. Contributions from the synchrotron (dashed line) and host galaxy (solid line) emission are displayed in blue. In the cases of 3C 66A and Mrk 421, thermal dust emission is added, which is modelled as a blackbody (blue dot–dashed line). The black line represents the sum of all components.
Figure 13. SED of the GASP-WEBT FSRQs. Data from ISO (red circles), IRAS (triangles), Herschel (stars), Spitzer (plus signs and crosses), WISE (squares), 2MASS (diamonds) and SDSS (asterisks) are shown. The green circles represent the results of the GASP near-IR monitoring at the Campo Imperatore and Teide observatories. The optical spectrum of 1226+023 by Buttiglione et al. (2009) as well as near-IR-to-UV SEDs of 1510−089, 1633+382 and 2251+158 already published in papers by the GASP-WEBT Collaboration are also plotted. Contributions from the synchrotron (dot–dashed line) and QSO-like (solid line) emission are displayed in blue. The latter is derived from the SWIRE QSO1 templates, but when a brighter disc is required, a blackbody component is added. In these cases, we show in grey both the QSO1 template (solid line) and the blackbody (dashed line). The model fit to the 3C 273 SED requires further dust emission, obtained by adding another blackbody component (grey dotted line). The black line represents the sum of all components.
5.1.9 1219+285

The Spitzer data, from Malmrose et al. (2011), were acquired in 2007 June–July (plus signs) and 2008 January (crosses); observations with the different instruments (IRS, IRAC and MIPS) are not simultaneous and this explains the discontinuities of the spectra. The model fit peaks in the z band.

5.1.10 1652+398

This is another HBL, whose near-IR–optical spectrum shows a strong host galaxy signature. The host brightness is $R = 11.92 \pm 0.06$ (Nilsson et al. 2007); its contribution in Fig. 12 is $\sim 12$ mJy, in agreement with the contaminating flux estimate within an aperture radius of 7.5 arcsec.

5.1.11 1807+698

In Fig. 12, data from the ISO by Haas et al. (2004) and the spectrum from Buttiglione et al. (2009) are also included. The model fit accounts for the WISE and faintest IRAS and ISO data. It requires an important contribution from the host galaxy.

5.1.12 2155−304

This is the most southern among the GASP sources. The synchrotron peak of the model fit falls in the UV.

5.1.13 2200+420

This is one of the most studied sources by the GASP-WEBT (see e.g. Villata et al. 2002; Raiteri et al. 2013, and references therein). The host galaxy has $R = 15.5 \pm 0.02$ (Scarpa et al. 2000), and affects the source photometry in the near-IR and optical bands, especially in faint states.

5.1.14 2344+514

This is the third HBL in the GASP sample. Its near-IR–optical spectrum is dominated by the host galaxy, whose brightness is $R = 13.90 \pm 0.06$ (Nilsson et al. 2007). In Fig. 12, we show a fit to the faint state traced by the 2MASS data. The jet contribution is superposed to a host galaxy contribution corresponding to the contaminating flux entering an aperture radius of 3 arcsec when the FWHM is 3 arcsec.

5.2 Flat spectrum radio quasars

5.2.1 0420−014

The near-IR data from the GASP indicate a steep spectrum, with a flux excess in J band during faint states. Indeed, the source redshift implies a contribution from the Hγ emission line in this band, as shown by the SWIRE TQSO1 template. The lack of medium or far-infrared data in a low state prevents us to derive information on the torus emission.

5.2.2 0528+134

The near-IR spectra traced by both 2MASS and GASP data in faint states reveal a concave shape, suggesting the transition from a spectrum dominated by jet emission to a spectrum dominated by QSO-like emission. The Hα and Hβ emission lines affect the K- and H-band fluxes, respectively. Modelling the near-IR spectrum with a log-parabola plus the SWIRE TQSO1 template would overproduce the mid-infrared flux detected by WISE because of the prominent infrared contribution from the dust torus. This implies that the IR/optical flux ratio of the QSO-like contribution in this source must be smaller. We thus combined the disc+BLR component of the TQSO1 template at $\lambda < 11000$ Å (rest frame) with the torus component of the BQS01 template at $\lambda \geq 11000$ Å. The result is shown in Fig. 13 as a grey solid line. However, this composite template cannot explain the curvature of the near-IR spectrum at intermediate flux levels, which requires a brighter disc. We thus added a blackbody component (grey dashed line in Fig. 13) to the composite template to obtain a final QSO-like contribution (blue solid line) that, once added to the jet emission (dot–dashed blue line), can produce a reasonable fit (black solid line) to the observing data. This implies a softening of the optical spectrum with increasing flux, confirming the guess by Palma et al. (2011).

5.2.3 0827+243

As in the 0528+134 case, the signature of a QSO-like emission contribution is already evident in the near-IR spectrum. In particular, the J-band excess is due to the contribution of the broad Hα emission line, while the Hβ line enters the SDSS z band, and the Mg II and Fe lines, giving rise to the blue bump, contribute to the flux between the r and g bands. The composite QSO1 template explains the spectral slope of the faintest NIR data points. The model presented in Fig. 13 reproduces a brightness state traced by the 2MASS and SDSS data; it requires, besides the non-thermal contribution, an enhanced disc contribution, which was obtained, as in the case of 0528+134, by adding a blackbody component to the QSO1 composite template.

5.2.4 0836+710

This is the farthest FSRQs in the GASP sample. The Hα line contributes to the K band, and the Hβ line enters the H band. Also in this case, the near-infrared data suggest that the accretion disc may be brighter than predicted by the QSO1 template.

5.2.5 1156+295

Emission from the QSO-like component is not prominent: it appears in the SDSS spectrum, which shows the clear contribution of the Mg II line in the g band. Fig. 13 displays a possible fit to the source SED at the SDSS and IRAS brightness level.

5.2.6 1226+023

The SED of 3C 273 in the infrared–optical band is known to be complex, and various authors have proposed interpretations in terms of synchrotron plus various dust components (see e.g. Törlér et al. 2006) or dust plus various synchrotron contributions (see e.g. Soldi et al. 2008). The model fit we show in Fig. 13 includes a log-parabola synchrotron component (dot–dashed blue line) superimposed to a
QSO-like emission (solid blue line) obtained from the composite QSO1 template (solid grey line), with enhanced disc (obtained by adding the dashed grey blackbody to the template) and enhanced dust around the W1 WISE band (obtained by adding the dotted grey blackbody). This latter component is responsible for the spectral break that causes the anticorrelation between $J - H$ and $H - K$ noticed in the previous section. The brightest state traced by the IRAS data can be reproduced by increasing the jet flux. Note that the 2MASS $J$-band flux is underproduced by the model, but the spectral shape of the GASP data applied to the 2MASS points would suggest a lower value. We plotted the optical spectrum (red continuous line) from Buttiglione et al. (2009) to help us model the disc emission.

5.2.7 1253–055

The near-IR spectrum of 3C 279 remains steep even in faint states, so that the presence of a QSO-like emission contribution cannot be inferred. However, evidence for thermal emission was found by Pian et al. (1999) when analysing UV data of the source at a minimum brightness level.

5.2.8 1510–089

This source is known to present noticeable spectral variations in the near-IR–optical band (e.g. D’Ammando et al. 2011). Spectral variability is also suggested from the data points in Fig. 13, including observations from Spitzer (plus and cross symbols; Malmrose et al. 2011). To help SED modelling, in the figure we reported the faintest SED by D’Ammando et al. (2011), built with near-IR and optical data from the GASP (red dots), and optical–UV data from Swift (red empty circles) acquired in 2008 March. Two model fits are then presented in the figure: one passing through the 2008 March spectrum, requiring a synchrotron peak at about log $v = 13$, while the other one reproduces a higher state involving 2MASS data, with the synchrotron peak shifted at a higher energy, in agreement with D’Ammando et al. (2011).

5.2.9 1611+343

The shape of the near-IR spectrum is explained by the contributions from the H$_\alpha$ and H$_\beta$ lines to the $H$ and $J$ fluxes, respectively. The model fit displayed in Fig. 13 reproduces reasonably well the shape of the SDSS optical spectrum. The peak of the disc emission falls in the $u$ band, which receives a contribution from the C iv] line. Mg ii and Fe lines affect the $r$ flux.

5.2.10 1633+382

A big observing effort on this source has recently been carried out by the GASP-WEBT; the results have been published by Raiteri et al. (2012). In Fig. 13, we display their faintest near-IR–UV SED, which was obtained in 2010 April (JD = 245 5296). Red dots represent ground-based data, red empty circles are from the UVOT instrument onboard Swift.\footnote{We enhanced the UVOT $v$-band flux by 10 per cent to account for calibration problems (see Raiteri et al. 2012).} The optical spectrum shows a brightness level similar to that of the SDSS. The observed flux in $u$, $b$ and $i$ bands is enhanced by the contribution from the Ly$_\alpha$, C iv], and Mg ii lines, respectively. The very hard near-IR spectrum traced by the 2MASS data points is not confirmed by the GASP data (neither those presented in this paper, nor those published in Raiteri et al. 2012), which indicate a higher flux in the K band. The model fit shown in Fig. 13 satisfactorily reproduces the WISE spectrum as well as the near-IR–optical spectrum traced by the SDSS and 2010 April data, with a QSO-like component in agreement with the $R = 17.85$ estimate given in Raiteri et al. (2012).

5.2.11 1641+399

The near-IR spectrum always maintains a steep slope, showing no hints of QSO-like emission. The SDSS data points suggest a spectral flattening with increasing optical flux, which is not easy to explain.

5.2.12 1739+522

The GASP observations were done during a low-brightness state and draw a near-IR spectrum that reveals flux contributions from the H$_\alpha$ and H$_\beta$ lines in the $H$ and $J$ bands, respectively. The lack of a flux excess in the $H$ band in the 2MASS data implies that the QSO-like component becomes negligible at that flux level.

5.2.13 2230+114

Marginal evidence for thermal emission was found by Impey & Neugebauer (1988) in IRAS data and tentative detection of dust was reported by Malmrose et al. (2011) analysing Spitzer data. Spitzer observed the source in two epochs: 2007 June–July (crosses in Fig. 13), and 2007 December–2008 January (plus signs). Some of these data are affected by large errors. The model fit presented in Fig. 13 aims at reproducing a high-brightness state as traced by IRAS, Spitzer and SDSS data points. The excess flux in $J$ band can be accounted for by the H$_\alpha$ line flux contribution.

5.2.14 2251+158

For this very famous blazar, many infrared data are available, as shown in Fig. 13. In particular, ISO observed the source in two epochs: 1996 December 6 (red circles) and 1997 December 18 (grey circles). According to Haas et al. (2004), these data may reveal a thermal dust bump, which however is not confirmed by the IRAS data. Spitzer spectra are from Ogle et al. (2011); the bright state was observed in 2005 July, while the low state was observed in 2006 December. Data from the IRAC detector are plotted as plus signs, those from IRS as crosses; the two instruments were not pointing at the source at the same time. Observations by Herschel on 2010 November 30–December 1 and 2011 January 8 (Wehrle et al. 2012) are shown as red stars. To better characterize the interplay between the jet and QSO-like emission, we also plotted three infrared-to-UV SEDs (small filled and empty red circles) taken from Raiteri et al. (2011). The highest and intermediate SEDs were built with GASP-WEBT and Swift data acquired during a multifrequency campaign on this source; the lowest SED is originally from Neugebauer et al. (1979). The QSO-like emission signature is best visible in this faint state, where the flux excess in the $J$/UVm2 bands is the signature of the H$_\alpha$/Ly$_\alpha$ broad emission line (see also Raiteri et al. 2008), and the spectral curvature in the optical band is due to the little blue bump. The models displayed in Fig. 13 show possible fits to the SEDs, where a jet emission component is superimposed to a QSO-like contribution with enhanced disc emission.
6 CONCLUSIONS

In this paper, we have investigated the near-IR properties of blazars. The *WISE* and 2MASS catalogues allow us to study the statistical properties of the whole class and in particular to investigate the differences between the two blazar subtypes of FSRQs and BL Lacs. The addition of the SDSS data base makes it possible to complete the information on blazar SEDs around the peak of the synchrotron emission component.

However, blazars are characterized by strong variability at all wavelengths and a deeper understanding of the blazar phenomenon can be achieved only through long-term monitoring, which is possible only for a limited number of sources.

We have thus considered the 28 blazars (14 FSRQs and 14 BL Lacs) that belong to the target list of the GASP project of the WEBT, and for which continuous monitoring was performed since the project birth in 2007. Data in the near-IR come from the Campo Imperatore and Teide observatories.

Among the blazars in the *WISE*, 2MASS and SDSS catalogues, the GASP sources are well distributed in infrared colours and redshifts, but generally have high infrared–optical fluxes, so they represent a mini-sample of bright blazars.

We have shown *JHK* light curves of these objects, revealing noticeable variability for most of them. In average, the mean fractional flux variation is greater for FSRQs than for BL Lacs, with the notable exception of AO 0235+164, which was found to be the most variable object in the considered period. Indeed, this blazar has often shown a behaviour more similar to FSRQs than to BL Lacs. We have compared variability in the three near-IR bands: while in general the BL Lacs show more variability at higher frequency, the reverse is true for FSRQs. This is the consequence of the different emission components overlapping in this band. Colour variability is very small in BL Lacs, not exceeding a few per cent. The nearly achromaticity of the near-IR emission of BL Lacs is a characteristic of the dominant synchrotron jet emission. In contrast, the larger spectral changes exhibited by FSRQs are due to the overlapping between synchrotron and quasar-like emission components.

We have built infrared SEDs of these sources, including the results of the GASP-WEFT near-IR monitoring plus archive and the literature data from *WISE*, 2MASS, *IRAS*, *ISO*, *Spitzer* and *Herschel*, as well as optical information from the SDSS and the literature. Although these SEDs do not contain simultaneous data, as would be desirable for these variable objects, they can nevertheless help us understand the interplay among the various emission contributions: synchrotron radiation from the jet, QSO-like emission including torus, disc, and BLR radiation and radiation from the host galaxy. We have modelled the synchrotron emission with a log-parabola, while for the host galaxy and QSO-like contributions we have adopted SWIRE templates, with the possible inclusion of blackbody components to simulate additional dust emission or enhanced disc emission. We have used single-temperature blackbodies for these additional components instead of multitemperature blackbodies or dusty galaxy templates to keep the interpretation as simple as possible.

A strong host galaxy signature has been found in the SED of Mrk 421, and especially in those of Mrk 501 and 1ES 2344+514, the three closest and high-energy-peaked BL Lacs, which were the first ones to be detected at TeV energies. At nearly the same redshift of 1ES 2344+514 lies 3C 371, which shows an important host galaxy contribution too. A bit farther, BL Lac does not show evidence of host galaxy in its SED, even if we know that the host affects the source photometry in faint states (e.g. Raiteri et al. 2013). Apart from the above cases, all other BL Lac SEDs are well fitted by a synchrotron component; the only indications for the presence of dust thermal emission are found for 3C 66A and Mrk 421, as previously reported (Impye & Neugebauer 1988).

For many FSRQs, the near-IR band signs the transition from a non-thermal, synchrotron-dominated emission to a thermal, QSO-like dominated emission. The cases of PKS 0528+134 and 4C 71.07, whose *WISE* data were acquired in very faint states, suggest that torus emission is relatively weak in FSRQs. A particularly bright disc is required to explain the SEDs of 9 out of the 14 GASP FSRQs. From the SED fits, we can derive disc luminosities at the peak of log (νLν) ~ 44.8–46.6 [erg s⁻¹], the highest values characterizing 4C 71.07, PKS 0528+134 and 4C 38.41, which are the most distant objects. For comparison, various authors analysing different QSO samples obtained mean values ranging from ~44.9 to ~45.8, with large dispersion (see Elvis et al. 2012, and references therein). Hence, our FSRQs have accretion discs with luminosities in the same range as QSO, up to the highest values. In the case of 3C 273, an extra dust contribution peaking at log ν ~ 14 [Hz] is needed to explain the near-to-medium infrared SED.

ACKNOWLEDGEMENTS

We are grateful to an anonymous referee for useful comments. This article is partly based on observations made with the telescopes IAC80 and TCS operated by the Instituto de Astrofísica de Canarias in the Spanish Observatorio del Teide on the island of Tenerife. Most of the observations were taken under the routine observation programme. The IAC team acknowledges the support from the group of support astronomers and telescope operators of the Observatorio del Teide. This work was supported by Russian RFBR foundation grant 12-02-00452. AZT-24 observations are made within an agreement between Pulkovo, Rome and Teramo observatories. This research has made use of the NASA/IPAC Infrared Science Archive, which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This publication makes use of data products from the *Wide-field Infrared Survey Explorer*, which is a joint project of the University of California, Los Angeles, and the Jet Propulsion Laboratory/California Institute of Technology, funded by the National Aeronautics and Space Administration. This publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the US Department of Energy Office of Science. The SDSS-III website is http://www.sdss3.org/. SDSS-III is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS-III Collaboration including the University of Arizona, the Brazilian Participation Group, Brookhaven National Laboratory, University of Cambridge, Carnegie Mellon University, University of Florida, the French Participation Group, the German Participation Group, Harvard University, the Instituto de Astrofísica de Canarias, the Michigan State/Notre Dame/JINA Participation Group, Johns Hopkins University, Lawrence Berkeley National Laboratory, Max Planck Institute for Astrophysics, Max Planck Institute for Extraterrestrial Physics, New Mexico State University, New York University, Ohio State University, University of Pennsylvania, University of Portsmouth, Princeton University, the Portuguese Participation Group, the与其相关的参考文献，例如邦克等人的工作，以及参考文献中的其他作品。
