PROCEEDINGS OF SCIENCE

Highlights from the VERITAS AGN Observation Program

Wystan Benbow* **for the VERITAS Collaboration**†
Center for Astrophysics | Harvard & Smithsonian, 60 Garden St, Cambridge, MA, 02180, USA
E-mail: wbenbow@cfa.harvard.edu

VERITAS is one of the world's most sensitive detectors of astrophysical VHE (E $>$ 100 GeV) gamma rays. This array of four 12-m imaging atmospheric-Cherenkov telescopes has operated for ∼12 years, and ∼6,000 hours of observations have been targeted on active galactic nuclei (AGN). Approximately 300 AGN have been observed with VERITAS, and 39 are detected. Most of these detections are accompanied by contemporaneous, broadband observations, which enable detailed studies of the underlying jet-powered processes. Recent highlights from the VERITAS AGN observation program and scientific results are presented.

36th International Cosmic Ray Conference -ICRC2019-
July 24th - August 1st, 2019
Madison, WI, U.S.A.

*Speaker.
†https://veritas.sao.arizona.edu/

PoS(ICRC2019)632

1. Introduction

AGN comprise about one-third of the VHE sky catalog and they are the most numerous class of identified VHE γ-ray emitter. There are 78 VHE-detected AGN as of *ICRC2019* [1], and $\sim$75% of these objects have Northern declinations ($\delta > 0°$). Accordingly they are prime targets for Northern VHE observatories such as VERITAS [2]. The observed emission from VHE AGN is dominantly non-thermal and is characterized by a double-humped spectral energy distribution (SED) that spans the entire broadband spectrum. This radiation is highly variable at all wavelengths, and correspondingly most modern efforts to probe their underlying processes require contemporaneous multi-wavelength (MWL) observations. The VHE γ-ray emission in AGN is generally produced by accretion-powered jets in a compact region near their central, supermassive black hole. Decades after this VHE emission was first discovered, its origin remains debated, although processes involving leptonic particles (e.g. synchrotron self-Compton models) are typically favored over ones focusing on contributions from hadronic particles.

Blazars, objects whose jets are pointed close to the line of sight towards Earth, form the dominant class ($\sim$95%) of VHE AGN. Four nearby ($z < 0.022$) FR-I radio galaxies are also detected in the VHE band. However, these objects are not strongly misaligned and it is debated whether another two relatively nearby VHE AGN are radio galaxies or blazars. Among the 72 VHE AGN that are certainly blazars, a majority (62) are BL Lac objects; the rest (7) are either Flat Spectrum Radio Quasars (FSRQs) or have uncertain blazar sub-classification (3). The detected BL Lac objects are further sub-classified based on the location of their lower-energy SED peak, and 51 are high-frequency-peaked (HBLs), 8 are intermediate-frequency-peaked (IBLs) and 2 are low-frequency-peaked (LBLs). Unfortunately the defining characteristic of BL Lac objects (i.e. the absence of features in their optical spectra) implies difficulties in measuring their redshift. The VHE blazar catalog currently covers a redshift range from $z = 0.030$ to $z = 0.954$, but at least $\sim$20% of the objects have uncertain redshift. Only $\sim$20% of the catalog has $z > 0.3$ and more than 50% have $z < 0.2$. While energetics requirements certainly contribute to general proximity of the VHE AGN catalog, the attenuation of VHE photons in a distance- and energy-dependent manner by the extragalactic background light is also a major effect [18].

Empirically there are two qualities that typically characterize VHE AGN and this drives the design of the VERITAS AGN Program (radio galaxies and blazars). First and foremost, their observed VHE flux is almost always variable. About one-third of VHE AGN are only detected during short-duration flares, and major AGN outbursts are the defining characteristic of the VHE field for many (see, e.g., [7]). However, it is also important to note that particularly notable episodes of rapid (minute-scale), large-scale (factor of 100) flux variations are very rare and most VHE flux variations are of the order of a factor of 2-3. In general the time-scales observed for these milder variations depends on the average VHE flux. They can be as long as an observing season, but only brighter objects show such variations on shorter time scales and this is very likely an instrument-sensitivity effect. The VERITAS AGN Program therefore attempts to identify and follow-up on VHE AGN flares, noting that variations of even a factor $2-3$ can be very interesting for some targets. The other important empirical quality is that the observed photon spectra of VHE AGN are often soft ($\Gamma_{obs} \sim 3-5$), and very few VHE AGN are detected above 1 TeV. While this can be related to the higher-energy SED peak location, it is also in part due to EBL-absorption effects. In

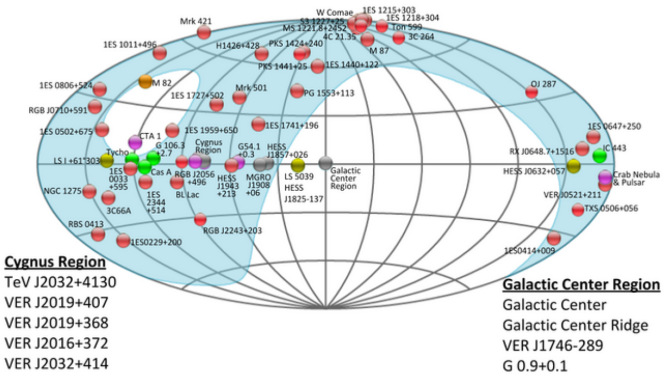

Figure 1: The VERITAS sky catalog in Galactic coordinates. The blue region is the sky visible to VERITAS at zenith angles <35°. Different astrophysical classes are shown with different colored markers. The red circles are AGN.

most cases, the harder the VHE spectrum is, and the higher energy to which it reaches, the more interesting the target becomes scientifically. Therefore the VERITAS AGN Program also focuses on hard spectrum VHE blazars and generating statistics above above 1 TeV.

In general, the goal of the VERITAS program is to make precision measurements of VHE AGN spectra and their variability patterns. It necessarily leverages contemporaneous MWL observations from both ground- and space-based facilities, in particular the FLWO 48" optical telescope and Swift XRT/UVOT. Since transitioning from an emphasis on expanding the VHE AGN catalog in ∼2010, the program has focused on long-term studies of known VHE AGN population in a manner that emphasizes the regular search for, and intense observation of, major flaring episodes. From 2013-2018, the program sampled each Northern VHE AGN (∼56), but in 2018 it was streamlined again to more heavily focus on more intense studies of a few (∼22) targets. Independent of any successful flare identification, the regular sampling of each VHE AGN built high-statistics data sets to enable fully-constrained modeling of each VHE AGN's SED (see, e.g., [9]), and the ongoing sampling continues to improve these. The various long-term MWL light curves should also allow for flux and spectral correlation studies that may indicate commonalities in the origin of each AGN's emission. In generating a large sample of precision VHE AGN spectra, the VERITAS AGN program is also useful for generating a variety of cosmological measurements such as constraints on the the density of the EBL [18] and the strength of the intergalactic magnetic field (IGMF) [10].

2. VERITAS AGN Program

VERITAS is the world's most sensitive observatory between ∼85 GeV and ∼30 TeV and it is regularly used to study the Northern sky during ∼10-month seasons (September – July). It began full operations in 2007 at the F. L. Whipple Observatory in Arizona, USA (31° 40' N, 110° 57' W, 1.3 km a.s.l.), and it achieved its present sensitivity following a series of upgrades completed in Summer 2012. The array of Cherenkov telescopes can be used to detect an object with ∼1% Crab Nebula flux (1% Crab) in less than 25 hours, and spectra can be generated above ∼100 GeV. For most measurements, the systematic errors are ∼0.1 on the photon index (Γ) and ∼20% on the flux.

AGN	z	Type	$\log_{10}(\nu_{\rm synch})$ [Hz]	TeV FoM
M 87	0.004	FR I	−−	−−
NGC 1275	0.018	FR I	−−	−−
3C 264†	0.022	FR I	−−	−−
Mrk 421	0.030	HBL	16.3	39.8
Mrk 501	0.034	HBL	17.9	12.6
1ES 2344+514	0.044	HBL	17.7	1.58
1ES 1959+650	0.047	HBL	17.0	20.0
1ES 1727+502	0.055	HBL	17.0	3.16
BL Lac	0.069	IBL	14.3*	−−
1ES 1741+196	0.084	HBL	17.8	1.00
W Comae†	0.102	IBL	14.8*	−−
RGB J0521.8+2112†	0.108	IBL	15.1	5.01
RGB J0710+591†	0.125	HBL	18.1	3.98
H 1426+428	0.129	HBL	18.1	3.98
B2 1215+30	0.131	IBL	15.1	2.51
S3 1227+25†	0.135	IBL	15.0	3.98
1ES 0806+524†	0.138	HBL	15.9	3.16
1ES 0229+200	0.140	HBL	18.5	2.00
1ES 1440+122†	0.163	IBL	17.2	1.26
RX J0648.7+1516†	0.179	HBL	16.6	1.58
1ES 1218+304	0.182	HBL	16.8	3.16
RBS 0413†	0.190	HBL	17.3	1.00
1ES 1011+496	0.212	HBL	16.2	3.98
MS 1221.8+2452	0.218	HBL	16.1	1.26
1ES 0414+009	0.287	HBL	17.9	3.16
OJ 287†	0.306	BL Lac	13.9*	−−
TXS 0506+056	0.337	Blazar	15.3*	−−
1ES 0502+675†	0.341	HBL	17.9	3.98
PKS 1222+216	0.432	FSRQ	−−	−−
1ES 0033+595	0.467	HBL	18.9*	−−
PKS 1424+240†	0.604	IBL	15.0	7.94
Ton 599†	0.7247	FSRQ	−−	−−
PKS 1441+25	0.939	FSRQ	−−	−−
3C 66A†	$0.33 < z < 0.41$	IBL	15.6*	−−
1ES 0647+250	?	HBL	16.8	3.16
PG 1553+113	$0.43 < z < 0.50$	HBL	15.6	7.94
HESS J1943+213	?	HBL	18.1	2.00
RGB J2056+496†	?	Blazar	−−	−−
RGB J2243+203†	?	HBL	15.1	1.58

Table 1: The 39 AGN (25 HBL, 5 IBL, 3 FSRQs, 3 unclassified blazars, and 3 radio galaxies) detected with VERITAS. This catalog has grown by 3, 5, 7, 13, and 22 AGN since each of the previous 5 ICRCs, respectively. The 16 blazars discovered at VHE by VERITAS are marked with a dagger. The classifications are taken from TeVCat, and the synchrotron peak frequencies and TeV Figures of Merit are from [14]; the frequencies marked with an asterisk are from [16].

The VERITAS collaboration has acquired a total of ∼14,600 h of full-scale observations, averaging ∼930 h of good-weather observations each season during "dark time" (moon illumination <30%), and since 2012, ∼150 h during periods of "bright moonlight" (i.e. >30% illumination). The bright-moon data has comparable sensitivity to dark-time observations with only slightly higher threshold (e.g. 250 GeV) [11], and are useful for selected AGN targets.

Given VERITAS's Northern Hemisphere location, AGN observations are naturally a significant component of its data taking (∼50%). As of July 2019, these data comprise a total of ∼6,100h (∼425 h per year) of good-weather dark time and ∼1,000h (∼170 h per year) of good-weather, bright-moon time. The dark time is typically split ∼90% to blazars, primarily BL Lac objects, and ∼10% to radio-galaxies. The bright-moon time for AGN is devoted almost entirely to BL Lac objects, with recent (>2017) observations split ∼45% to candidates for new VHE discoveries, and ∼55% to known VHE blazars, particularly those with hard VHE spectra. This marks a shift from prior seasons where the split was 65% / 35%, respectively. AGN comprise 62% of the VERITAS source catalog (shown in Figure 1), and Table 1 lists the 39 AGN detected by VERITAS.

The VERITAS AGN program is based on regular monitoring observations of the Northern VHE catalog to self-identify VHE flaring episodes for immediate MWL target-of-opportunity (ToO) follow-up. The monitoring program's minimum sample duration will detect ∼10% Crab flux, and the observation cadence ranges from daily to weekly. While any monitoring observation could fortuitously catch a short-duration, bright flare (e.g. BL Lac in 2017 [4]), in general the concept is to identify long-lasting, bright states for initiating intense campaigns. Naturally the VERITAS monitoring observations are supplemented with coordinated data at lower energy to assist with triggering and to ensure that long-term contemporaneous MWL data sets exist for the monitored AGN. From 2013-18, every VHE AGN was monitored by VERITAS, and some AGN have been monitored continuously since ∼2010. Over a long period, even the lowest level monitoring significantly increased the data set for each object. In 2018, the program was streamlined based on each target's existing VHE variability profile (e.g. from the VERITAS data), its possibilities for external triggers (e.g. from *Fermi*-LAT or FACT), and its perceived scientific importance. This streamlining from 59 to 22 targets enables much deeper, legacy exposures on particularly interesting objects during what are likely to be the final years of VERITAS operations.

While the primary focus of the VERITAS AGN program is performing deep / timely measurements of the known VHE sources, ∼40% of the AGN program was devoted to the discovery and follow-up observations of new VHE AGN between 2017-19. Most of these observations were either ToO observations triggered by one of our MWL partners or regular observations of targets from a list of selected candidates. Recently, our discovery candidates include AGN with a weak excess (>3σ) in large, archival VERITAS exposures, and those remaining in a comprehensive list of Northern objects with only limited exposures (<4 h). The comprehensive target list was generated in 2016, and included all the X-ray brightest HBLs in the 2WHSP catalog (i.e. objects with a "TeV Figure of Merit" > 1.0) [14], all the hardest ($\Gamma_{2FHL} < 2.8$) AGN in the *Fermi*-LAT 2FHL (>50 GeV) catalog [6], and all targets previously selected for VERITAS [12, 13].

ToO observations are the highest priority of the VERITAS AGN program. Historically, these data average ∼25% of the AGN dark-time yield each season and the percentages were 26% and only 6% in the 2017-18 and 2018-19 seasons, respectively. These observations include attempts to discover and/or follow-up on new VHE sources, and efforts to harness the potential of bright flares in known VHE AGN. Almost all VERITAS FSRQ observations are taken via ToO campaigns.

3. Recent Highlights

TXS 0506+056 is currently one of the most important objects in multi-messenger astronomy. Prior to the 2017-18 season, this *Fermi*-LAT detected blazar was on the VERITAS discovery target list because of its hard MeV-GeV spectrum. It appears in both the 2FHL (>50 GeV) and 3FHL (>10 GeV) [8] catalogs, and it was relatively bright (F(>50 GeV) ∼ 4% Crab) for a non-VHE-detected object. However, because its redshift ($z = 0.337$) was not yet measured and its synchrotron peak location ($10^{15.3}$ Hz) was unremarkable, it was a low-priority object, and only ∼1 h of VERITAS data were taken in 2016. On Sept. 22, 2017, IceCube detected a ∼290-TeV neutrino from a direction consistent with the γ-ray blazar, leading to a global follow-up campaign [3]. Prompt observations of TXS 0506+056 with VERITAS and MAGIC initially did not yield detections. However, follow-up observations eventually revealed the blazar to be in an elevated γ-ray emission state. This was initially seen by *Fermi*-LAT, and later MAGIC discovered VHE emission. Upper limits were measured by several other VHE instruments, including VERITAS, in ∼2 weeks of follow-up observations, likely due to short term variations. VERITAS carried out extended long-term follow-up observations of the blazar (∼35 h from September 23, 2017 to February 8, 2018) leading to a detection [5] at a significance of 5.8 standard deviations (σ), albeit at lower flux than detected by MAGIC. The average flux observed from TXS 0506+056 was F(>110 GeV) = $(8.9 \pm 1.6) \times 10^{-12}$ cm^{-2} s^{-1}, or 1.6% of the Crab Nebula flux, and the observed photon index is $\Gamma = 4.8 \pm 1.3$.

The correlation of the high-energy neutrino with the gamma-ray flare of TXS 0506+056 is statistically significant at the level of 3σ, and could indicate that blazar jets accelerate cosmic rays to at least several PeV. It also suggests that blazars are a source of very-high-energy cosmic rays, and therefore contribute significantly to the cosmic neutrino flux observed by IceCube. Naturally, the observation of further correlations of high-energy neutrinos with gamma-ray flares in blazars are required to solidify this conclusion and this will be a major effort for VERITAS in the future. This detection also impacts future neutrino follow-up strategies with VERITAS, as the potential γ-ray counterparts may be active over time periods of weeks or months, requiring multiple exposures.

Ton 599 is an FSRQ at redshift $z = 0.7247$. It is a known, variable MeV-GeV γ-ray emitter, but its *Fermi*-LAT spectrum ($\Gamma_{3FGL} = 2.1$) softens considerably at higher energy. It does not appear in the 2FHL (>50 GeV) catalog, and the extrapolation of its 3FHL (>10 GeV) spectrum ($\Gamma_{3FHL} = 3.0$) to the VHE band (F(>200 GeV) ∼ 0.2% Crab flux) suggests it is not normally detectable using VERITAS. Given its large redshift and unfavorable high-energy characteristics it was not observed by VERITAS prior to 2017. However in October 2017, a series of Astronomer's Telegrams reported a long-lasting, remarkably high state in the optical, infrared, X-ray and γ-ray bands. These reports initiated a series of VERITAS ToO observations when the source first became visible at reasonable zenith angles. On December 15 and 16, 2017, an excess of γ-rays, corresponding to a statistical significance of ∼10σ, was quickly (∼2 h) detected from the direction of Ton 599 (ATel #11075). The observed VHE flux is ∼12% Crab and the spectrum is very soft ($\Gamma \sim 5$). The object was detected on the same night (December 15) by MAGIC (ATel #11061) and was hence co-discovered at VHE by the two projects. Ton 599 is the third FSRQ detected by VERITAS, and is the seventh overall at VHE, and is one of the most distant VHE emitters known.

3C 264 is an FR-I type radio galaxy at redshift $z = 0.0216$. It is considered a more distant (∼6 times) analog to M 87, which is a well-known VHE emitter. 3C 264 is an MeV-GeV source, and the extrapolation of its 3FHL spectrum ($\Gamma_{3FHL} = 1.65$) to the VHE band (F(>200 GeV) ∼ 1.6% Crab flux) suggests it should be detectable with VERITAS. A remarkable aspect of 3C 264 is its rapidly evolving knot structure revealed by long-term Hubble Space Telescope observations [15]. Four knots can be seen in its inner jet, of which two are quasi-stationary and another two appear to be moving at superluminal speeds (7c and 1.8c, respectively). The two moving knots are expected to interact within the next ∼30 years, and this interaction could plausibly generate

PoS(ICRC2019)632

an outburst of VHE γ-rays. Given several compelling motivations, 3C 264 was observed with VERITAS for $\sim$10 h in 2017 and a weak excess was initially observed. A follow-up campaign was organized for 2018, and the source was immediately detected in an active VHE state ($\sim$1% Crab flux) in a similar data sample ($\sim$12 h) (ATel #11436). This led to the initiation of a large VERITAS campaign, and a significant MWL follow-up effort including VLA, VLBI, Chandra, HST, Swift and various ground-based optical facilities, with the hope of observing intra-jet phenomena. In total, $\sim$38 h of good-quality live-time were acquired with VERITAS on 3C 264, resulting in the detection of 9σ excess consistent with its SIMBAD position. The observed VHE flux varies on monthly time scales, and was F(>320 GeV) $\sim$ 0.6% Crab flux on average in 2018, noting that the bulk of the exposure was taken after the active state had subsided. Similar to M 87, the VHE spectrum for 3C 264 is hard with $\Gamma = 2.2 \pm 0.3$. A preliminary analysis of the MWL data shows no evidence of a knot collision, a flare in the jet microstructure, or even any significant brightening. 3C 264 will continue to be observed by VERITAS ($\sim$16 h per year) in future seasons, and the 2019 VERITAS results are consistent with those from 2018.

1ES 1218+304 is one of the most useful objects to observe with VERITAS to generate constraints on both the EBL and the IGMF due to its combination of *relatively* hard VHE spectrum, bright VHE flux (typically $\sim$5% Crab) and distant redshift ($z = 0.182$). Day-scale variability was observed from this HBL in 2009, reaching a peak of $\sim$20% Crab. Although heavily monitored with VERITAS since 2009, it has shown no major VHE flux variations. However, it began showing high activity in both the optical and X-ray bands in late 2018. VERITAS's normal monitoring began in December 2018, and in January 2019 a significant flare (>20% Crab) was observed, triggering a ToO campaign and high-cadence monitoring until April 2019. During this time, the Swift XRT also observed a historic peak in the X-ray count rate. The total good-quality VERITAS exposure is $\sim$12 h live time between MJD 58461 and 58600 MJD. An excess with significance $\sim$19σ is detected from the direction of 1ES 1218+304, corresponding an average flux of F(>150 GeV) $\sim$ 11% Crab, peaking at $\sim$23% Crab. The VHE spectrum observed during the campaign ($\Gamma \sim 3.25$) and on the flare night ($\Gamma \sim 3.09$) are consistent with prior observations. More details on the VERITAS and MWL observations of this flare can be found in these proceedings [17].

4. Conclusion

As of July 2019, the VERITAS collaboration have acquired more than 14,600 hours of scientific observations, of which $\sim$12,600 h are in good weather, and more than 6,000 of these good-weather hours are targeted on AGN. Since *ICRC2017* the array was used to acquire $\sim$1120 h and $\sim$820 h of good-weather observations in 2016-17 and 2017-18, respectively. The most recent season was particularly affected by poor weather conditions in southern Arizona. Regardless, the good weather AGN yields were strong in each season: $\sim$560 h and $\sim$450 h, respectively.

During the past two seasons, the VERITAS AGN program focused heavily on regular VHE and MWL monitoring of known Northern VHE AGN, and particularly emphasized immediate and intense ToO follow-up of interesting flaring events. We also maintained a program focused on the discovery of new VHE AGN, and $\sim$40% of our most recent observations had a discovery focus. The most recent AGN observations resulted in the VHE discovery of 1 radio galaxy, the co-discovery of a VHE FSRQ, the VHE detection of a BL Lac object during MWL flaring possibly associated with

PoS(ICRC2019)632

a high-energy neutrino emission, and the detection of several VHE flares. The VERITAS catalog now includes 31 BL Lac objects, 3 FSRQs, 2 unclassified blazars and 3 FR I radio galaxies.

The VERITAS collaboration plans to operate the telescope array through at least 2022 and has secured the necessary site-operations funding to do so. Although the array is now $\sim$12 years old, it continues to run well with the past two seasons each among historical bests for various technical performance benchmarks (e.g. fewest hours lost to technical issues, highest percentages of data with all telescopes operational). As the VERITAS collaboration's long-term science plan continues to prioritize AGN observations and the array continues to perform exceptionally well, we expect our long tradition of producing exciting results to continue.

This research is supported by grants from the U.S. Department of Energy Office of Science, the U.S. National Science Foundation and the Smithsonian Institution, and by NSERC in Canada. This research used resources provided by the Open Science Grid, which is supported by the National Science Foundation and the U.S. Department of Energy's Office of Science, and resources of the National Energy Research Scientific Computing Center (NERSC), a U.S. Department of Energy Office of Science User Facility operated under Contract No. DE-AC02-05CH11231. We acknowledge the excellent work of the technical support staff at the Fred Lawrence Whipple Observatory and at the collaborating institutions in the construction and operation of the instrument.

References

[1] http://tevcat.uchicago.edu/

[2] https://veritas.sao.arizona.edu/specifications

[3] M.G. Aarsten et al., *Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A*, *Science*, **361**, 1378, 2018.

[4] A. Abeysekara et al., *Multiwavelength Observations of the Blazar BL Lacertae: A New Fast TeV Gamma-Ray Flare*, *ApJ*, **856**, 95, 2018.

[5] A. Abeysekara et al., *VERITAS Observations of the BL Lac Object TXS 0506+056*, *ApJ*, **861**, L20, 2018.

[6] M. Ackermann et al., *2FHL: THE SECOND CATALOG OF HARD FERMI-LAT SOURCES*, *ApJS*, **222**, 1, 2016.

[7] F. Aharonian et al., *An Exceptional Very High Energy Gamma-Ray Flare of PKS 2155-304*, *ApJ*, **664**, L71, 2007.

[8] M. Ajello et al., *3FHL: The Third Catalog of Hard Fermi-LAT Sources*, *ApJS*, **232**, 2, 2017.

[9] E. Aliu et al., *A Three-Year MWL Study of the VHE γ-ray Blazar 1ES 0229+200*, *ApJ*, **782**, 13, 2014.

[10] S. Archambault et al., *Search for Magnetically Broadened Cascade Emission From Blazars with VERITAS*, *ApJ*, **835**, 288, 2017.

[11] S. Archambault et al., *Gamma-ray Observations Under Bright Moonlight with VERITAS Astroparticle Physics*, **91**, 34, 2017.

[12] W. Benbow, *The VERITAS Blazar Key Science Project*, *Proc. of the 31st ICRC (Lodz)*, 2009; arXiv:0908.1412.

[13] W. Benbow, *VHE Blazar Discoveries with VERITAS*, *Proc. of the 32nd ICRC (Beijing)*, 2011; arXiv:1110.0040.

[14] Y.-L. Chang et al., *2WHSP: A multi-frequency selected catalogue of high energy and very high energy γ-ray blazars and blazar candidates*, *A&A*, **598**, 17, 2017.

[15] E. Meyer et al., *A kiloparsec-scale internal shock collision in the jet of a nearby radio galaxy*, *Nature*, **521**, 495, 2015.

[16] E. Nieppola et al., *SEDs of a Large Sample of BL Lacertae Objects*, *A&A*, **445**, 441, 2006.

[17] S. O'Brien, *VERITAS Observations of 1ES 1218+304 during the 2019 VHE High State*, *Proc. of the 36th ICRC (Madison)*, 2019.

[18] E. Pueschel, *Measurement of the Extragalactic Background Light with VERITAS*, *Proc. of the 36th ICRC (Madison)*, 2019.