Final Report

Project Title - EXPANDING THE DISCOVERY POTENTIAL OF VERITAS VIA MOONLIGHT OBSERVATIONS

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Recipient Organization: Smithsonian Astrophysical Observatory
Street Address: 60 Garden Street, Cambridge MA 02138

Principal Investigator: Wystan R. Benbow
Address: 60 Garden Street, MS-20, Cambridge MA 02138
Telephone: (617) 496-7597
e-mail: wbenbow@cfa.harvard.edu

DOE/Office of Science Program Officer: Dr. Kathleen Turner
DOE/Office of Science Technical Program Manage Contact: High Energy Physics

VERITAS Collaborating Institutions:

Iowa State University* (Dr. Frank Krennich)
Purdue University* (Dr. John Finley)
Washington University* (Dr. James Buckley)
University of Chicago (Dr. Scott Wakely)
U.C.L.A. (Dr. Rene Ong)
University of Utah (Dr. David Kieda)
McGill University, Canada (Dr. David Hanna)
University College, Dublin (Dr. John Quinn)
*These institutions are supported separately by DOE via Base Grants

The full VERITAS Collaboration is listed at: http://veritas.sao.arizona.edu/about-veritas-mainmenu-81/newpeople

Introduction:

This grant partially supported the base research efforts of the Smithsonian Astrophysical Observatory (SAO), Very-High-Energy (VHE; E > 100 GeV) gamma-ray research group from 8/1/09 to 7/31/14. This report focuses of the final 3-years of support from this grant, with particular emphasis on the results from the final year. The SAO group's research efforts primarily involve the VERITAS project, and is headed by the PI, Dr. Wystan Benbow, who received no salary support from the funding. Dr. Benbow is the VERITAS Project Scientist, is also the PI of all grants for the VERITAS' site-operations, and also was PI for VERITAS' construction funding (via separate DOE, NSF and SAO awards).

Overall this grant partially supported the salary and benefits of 3 post-doctoral researchers: Dr. Nicola Galante, Dr. Matteo Cerruti and Dr. Anna Barnacka, as well as their travel and some travel of the PI, some materials related to their research program, and publication expenses for the research group. In the final year of support, only Dr. Cerruti's and Dr. Barnacaka's salary and benefits were supported. Other salary / benefits, travel, etc., were supported via separate grants.

During the project period, the SAO gamma-ray group carried out a wide-range of research efforts, but focused on VHE observations of extragalactic sources with VERITAS. Indeed, the SAO group led or co-lead nearly all VERITAS extragalactic working groups. These extragalactic observations of nature's most powerful particle accelerators have implications for both fundamental physics and astrophysics, and form the core of the VERITAS fundamental physics program. Overall the observing program was centered on three themes:

1. **Particle Physics and Fundamental Laws**
   - What is the nature of dark matter? What is the mass of dark matter particles? What are the annihilation channels?
   - What is the distribution of dark matter in the Galactic halo?
   - What are the constraints on physical laws at energies well beyond the reach of terrestrial accelerators, from TeV to Planck scales (Lorentz invariance violation)?
   - Search for evaporating primordial black holes.
   - Search for axion-like particles.
2. **Cosmology**
   - Constraining the epoch of re-ionization and the history of star and galaxy formation through γ-ray opacity measurements ($\gamma_{TeV} + \gamma_{EBL} \rightarrow e^+ + e^-$).
   - Study of cosmic rays in starburst galaxies & ultra-luminous infrared galaxies; Study of the origin of cosmic rays observed at Earth.
   - Study of galaxy clusters and large scale structure formation shocks.
   - Were intergalactic magnetic fields seeded by primordial magnetic fields?
3. **Black Holes**
   - Active Galactic Nuclei (AGNs): How do super-massive black holes launch relativistic jets and how does AGN accretion work?
   - How are AGN jets structured and how do AGN influence their environments?
   - How do AGN jets accelerate particles? How do the jets of GRBs differ from AGNs?
   - Do AGNs or Gamma Ray Bursts (GRBs) accelerate UHE cosmic rays?

Project Status:

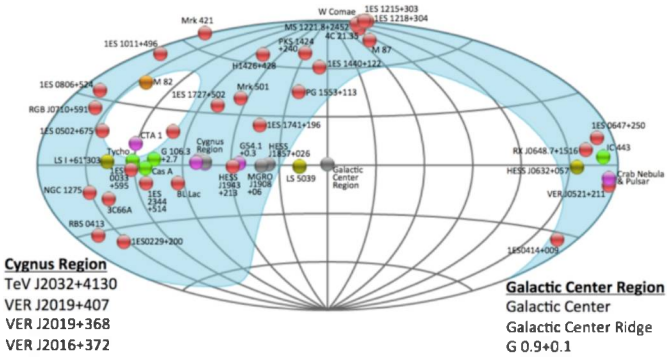
In July 2014, VERITAS completed its seventh year of operations with its full four-telescope array. It remains the most-sensitive very-high-energy (VHE; E > 100 GeV) gamma-ray observatory in the Northern Hemisphere, and it should remain so through the decade. In Summer 2012, a major upgrade of the VERITAS array was completed on-budget and on-time, with effectively no loss of observation time. Observations with the VERITAS array remain routine. Due to its upgrade VERITAS now detects objects twice as fast as when it began full-scale operations and has a 40% lower energy

threshold, allowing its science goals to be accomplished more quickly and enabling fresh looks at topics previously addressed by VERITAS.

Figure 1: *The VERITAS array of imaging atmospheric-Chereknov telescopes in Arizona.*

During the 2013-14 observing season VERITAS acquired ~1450 hours of data; this is 600 h more than anticipated when the project was built and more than 350 h more than the average of the first 5 seasons. This improvement is due to the development of a unique capability for VERITAS to observe during all periods of moonlight. This development was led by the SAO group and was funded by (and is the title of) this award. Initially this effort expanded the typical data yield of VERITAS by ~250 h / year. These data are now viewed as scientifically useful as any other VERITAS data. In early 2012, the moonlight capability of VERITAS was again expanded via special observing techniques (either running with reduced high-voltage / gain on the PMTs, or with special light-reducing filters) that allow operation during all phases of the moon. This new capability increased the data yield by another ~350 h in 2013-14 (~250 h in 2012-13). While these new data have higher energy threshold, limiting their utility, this enables studies of unique transient phenomena whenever needed, and frees up further time for other programs (e.g. indirect dark matter detection). The moonlight data is dominantly used for extragalactic observations, which are the SAO group's area of research focus.

Figure 2: *Left) The VERITAS sky catalog in Galactic coordinates. The different colored objects represent different classes of sources and the blue region is that visible to VERITAS.*



As of July 31, 2014, the VERITAS collaboration of ~100 scientists (1/3 faculty, 1/3 post-doc, 1/3 graduate student), and ~35 associate members, had reported the detection of 50 astrophysical sources of very high energy (VHE; E>100 GeV) gamma rays with the array (see Figure 2). Of these, approximately half were source discoveries and the object belong to 8 different source classes. These sources represent about one-third of the entire VHE catalog, and several new sources have yet to be released. The VERITAS collaboration has published >200 articles, including 66 refereed journal articles

(as of July 31, 2014), and has produced more than 40 PhD theses. Approximately 49 journal articles are currently in preparation or have been submitted. The VERITAS collaboration continues to maintain a major presence at international conferences, and has released more than 20 Astronomer's Telegrams to disseminate results rapidly. As the leading group in VERITAS, SAO has played a major role in all of these results.

Summary of Recent Publications:

A total of 16 VERITAS journal articles were published since the previous technical report for this project (covering until April 2013). Dr. Benbow, Dr. Cerruti, Dr. Barnacka, as well as other members of the SAO gamma-ray group (Dr. T. Weekes, Dr. M. Schroedter, Dr. P. Fortin, Dr. N. Galante, Mr. E. Roache; support via site-operations, NASA or SAO funding), are signatories of these articles; all include an explicit acknowledgement of the Department of Energy Office of Science support. These articles, whose author lists are alphabetical, are given in References 36 to 51.

VERITAS Highlights:

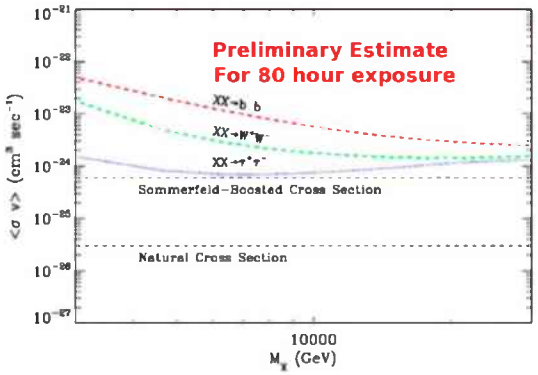
The subjects of the 16 articles published this cycle (i.e. from May 2012 to April 2013) are varied. Highlights include:

- 7 blazar-related papers. Dr. Benbow led the VERITAS blazar science working group and accordingly played a significant role in the development of the various publications. Many of these articles contain significant moonlight data.
  - The low-flux-state detection of a blazar (1ES 1959+650) during strongly a strongly varying (factor of 10) X-ray state. In the standard blazar modeling scenarios (SSC), gamma-ray flares are always accompanied by increased activity in the X-ray energy band. More complex radiation models are thus required to explain this type of event.
  - The discovery of a TeV source (VER J0521+211) by isolating clusters of gamma-ray photons above 30 GeV in the public release of the *Fermi*-LAT. The strongly variable TeV source, is relatively distant and potentially provides constraints on the extragalactic background light (EBL; cosmology) during particularly bright states. In recent months, the source again showed strong, long-lasting gamma-ray flares and was detected by the newly commissioned HAWC experiment.
  - The detection of a flaring blazar and multi-wavelength observations of the source during the flare. These data, including unprecedented TeV statistics, were used to construct the SED of B2 1215+30. A one-zone leptonic model was successfully used to model the blazar emission with typical parameters; this was not the case in earlier, lower statistics attempts.
  - The definitive compilation of the entire Whipple 10-m data sample for the blazar Mrk 421 taken over a 14-year time period. It is the longest sample for any TeV-emitting blazar, and the TeV flux varies on timescales from minutes to years with a strong correlation to observed X-ray behavior. Mkn 421 is the brightest blazar and is regularly observed with VERITAS. This article was led by SAO.
  - Deep observations of the distant, hard-spectrum blazar 1ES 0229+200 which suggest variability in the VHE band. This target is often used for intergalactic magnetic field studies (cosmology), and our result shows that this application may not be as straightforward as assumed and challenges models that attribute hard its TeV spectra to secondary γ-ray production along the line of sight. The multi-wavelength data from this blazar were modeled, using new SAO algorithms that provide a range of acceptable physical parameters, instead of one degenerate solution. This article was led by SAO.
  - Exceptionally deep VERITAS observations of the most-distant VHE emitter, PKS 1424+240, indicate a highly unusual up-turn in the spectral energy distribution above ~500 GeV, which could either indicate flaws in the current models for the EBL or even exotic physics (e.g. a signature of axion-like particles). This blazar

was discovered at VHE by SAO scientists exploiting VERITAS moonlight data in 2009.

- Multi-wavelength observations of the BL Lac object 1ES 1218+304 during a TeV flare in 2009. Data from the flare epoch in the optical, X-ray, and high-energy gamma rays are reported, and the first, strictly-simultaneous spectral energy distribution (SED) for this important blazar was presented. A typical one-zone synchrotron self-Compton (SSC) emission model could be successfully fit to the SED. The data were used to test several models of the extragalactic background light (cosmology studies).

Figure 3: *Estimates on the limits on the velocity weighted cross section for Neutralino annihilation, into several different particles, versus particle mass are shown for VERITAS observations of the Galactic Center.*



- Results from three years (~44 h) of VERITAS large-zenith-angle observations of the Galactic Center, resulting in a strong detection (18 standard deviations) at energies above ~2.5 TeV. The discrete source of photons at the Galactic Center may have numerous potential origins; e.g., astrophysical particle acceleration or the annihilation of dark matter particles. The energy spectrum is surprisingly competitive with the deep HESS results, and is found to be compatible with various hadronic, leptonic and hybrid emission models discussed in the literature. The presence or lack of a cut-off in the gamma-ray spectrum above a few TeV can be used to constrain dark-matter annihilation models and is the subject of a manuscript in preparation. SAO's Dr. Galante led the working group coordinating this study.
- The VERITAS collaboration performed a survey of the Cygnus region of our Galaxy and one result from this was the detection of extended gamma-ray emission from an area within the radio shell of the supernova remnant SNR G78.2+2.1. Related multi-wavelength data suggest that the TeV gamma rays result from particles (leptons or nuclei) accelerated within the shock of the supernova remnant.
- The detection of a gamma-ray binary (one of only 4 known at TeV energies) or the first time since the launch of the Fermi satellite. The detailed MeV-TeV spectral energy distribution (SED) from LS I +61 303 shows a distinct cutoff in emission near 4 GeV, while the emission seen by the VERITAS observations following a simple power-law above 200 GeV. This feature may indicate that there are two distinct populations of accelerated particles producing the GeV and TeV emission.
- Upper limits from observations covering six distinct radio/X-ray states of a famous microquasar. The lack of a positive signal, especially in the states where GeV gamma rays were detected, places constraints on TeV gamma-ray production in Cygnus X-3.
- Long-term observations of a system conducted with the VERITAS and H.E.S.S. cherenkov telescopes and the Swift X-ray satellite, spanning a time range from 2004 to

2012. The variable VHE emission is correlated with that at X-ray energies, and both show a periodic behavior (period ~ 315 days). Based on these observations, we now believe this object to be a binary system; one of only 4 known in the VHE band.

- The first sensitive TeV observations during a 2-week Fermi-LAT (MeV-GeV) flare observed from the Crab Nebula. The Fermi-LAT gamma-ray flux was on average elevated by a factor of about 6, but the VERITAS data does not indicate any significant enhancement of the TeV flux during the same period, constraining emission models.
- Deep VERITAS observations of the first unidentified source of TeV photons, TeV J2032+4130. This object was initially detected in 2002 and the VERITAS observations led to its identification as a pulsar wind nebula, which is a far less exotic explanation for the gamma-ray emission from this object than published by many others.
- Deep observations of the Milagro source MGRO J1908+06, which led to the detection of extended VERITAS emission covering a region near the Fermi-LAT pulsar PSR J1907+0602, but also extending towards the supernova remnant SNR G40.5–0.5. A strange energy-dependent VHE morphology was present requiring a non-standard explanation for the overall emission
- Results from VERITAS observations of the most-intense source in the Milagro all-sky map, J2019+37. The data reveals two separate TeV emission regions that were previously unresolved. One is a faint point-like source that overlaps with CTB 87, a center-filled supernova remnant with no evidence of a shell. The second source is brighter and extended (~1º), and likely accounts for the bulk of the Milagro emission; it could be the superposition of several not-yet-resolved sources.

Other Unpublished VERITAS Highlights led by SAO:

- For the 2013-14 VERITAS observing season, the SAO group were authors on 27 proposals requesting observations from the VERITAS Time Allocation Committee, and were first authors on 16 of these. Nearly all were awarded time.
- The group also coordinated/submitted 13 other Target of Opportunity (ToO) requests to the VERITAS Time Allocation Committee in response to interesting transient phenomena. These resulting in the detection of three new VERITAS sources, as well as a number of flares which have significant implications for cosmology (i.e. the EBL, cosmic-ray line of sight studies), Lorentz-invariance violation, and the search for axion-like particles. For each of these, Dr. Benbow also triggered related ToO's at numerous other observatories (e.g. Swift, XMM, optical, MAGIC) to ensure complete broadband and temporal coverage of these interesting events. These events are all relatively new, so only preliminary results can be described.
  - One of these ToO's was resulted in the first VERITAS detection of 1ES 0033+595. The VERITAS detection is more than 10 times brighter than the archival detection, correspondingly has stronger statistics, and also has significant multi-wavelength data for modeling. The modeling of this object reveals an unique spectral energy distribution. This manuscript is being written by SAO's Dr. Barnacka.
  - Another ToO led to the first VERITAS detection of a flat spectrum radio quasar (FSRQ). The VERITAS detection is unique in that it occurred nearly 10 days after a flare was observed at slightly lower energies by the Fermi-LAT.
  - Another ToO led to the first observations of a >2 Crab flare from a blazar not detected by earlier generation instruments. Previously, all bright flares were seen from the brightest targets (i.e. those seen by weaker instruments).
  - Another two ToOs led to exceptionally high statistics being generated at multi-TeV energies for relatively distant TeV blazars. These results will enable the strongest EBL constraints in the mid-IR band.
- The SAO gamma-ray group, continues to work on data from their 2010 ToO request that resulted in the VERITAS observation of a giant flare of the blazar Mkn 421. This

historic event enables constraints on potential Lorentz-invariance violation (LIV). The latter would manifest itself in an energy-dependent speed of light, and the VERITAS observations constrain the mass-scale of such violations to a few percent of the Planck mass. The SAO group completed a standard code and simulations for VERITAS to handle LIV studies. These will be the strongest ever determined from a blazar.

- The SAO group is finishing the effort on the blazar 1ES 0502+675. This target was initially observed in the moonlight program supported by this proposal, similar to many other VERITAS blazar discoveries. Modeling of the emission initially showed that only hadronic mechanisms were possible, however further study now shows that the emission has a possible leptonic origin. This manuscript is very near submission.
- The SAO group is nearly finished with an analysis effort of 5-years of all blazar observations (nearly 1000 hours) resulting in upper limits. This massive endeavor, includes all Fermi-catalog objects in the fields of view and will be of significant benefit to the gamma-ray community. This effort is led by Dr. Cerruti.

SAO Leadership Roles in VERITAS:

During the entire project period Dr. Benbow served as VERITAS Project Scientist and sat on all major committees in the collaboration (e.g. the Science Board and the Executive Committee). In addition, the PI chaired the VERITAS Blazar Science Working group. During nearly the entire 5-year project period, Dr. Galante chaired the VERITAS Dark-matter and Extragalactic Non-blazar Science Working Group. The blazar program made significant progress in its efforts to measure the extragalactic background light (EBL) and the intergalactic magnetic field (IGMF), to constrain Lorentz invariance violation to approximately the Planck mass, to conclusively model the acceleration processes in blazars and explain the blazar sequence. Dr. Cerruti developed a new blazar modeling code that provides a range of acceptable parameters in the modeling (i.e. model parameters with error bars), instead of the previous standard of reporting one set of parameters that are part of a degenerate solution. He produced several publications (independently funded) on various blazar modeling issues. Dr. Cerruti is now the leader of all blazar modeling efforts in VERITAS and in September 2014, became chair of the VERITAS Blazar Science Working group. Among its many goals, the DM-AsPEN working group made significant progress in determining the various sources of cosmic rays, and an unprecedented effort to indirectly detect dark matter particles at TeV energies, to constrain primordial black hole evaporation, and to constrain the physical aspects of some of the largest structures in the Universe. Many VERITAS collaboration articles on these subjects remain in development.

Conclusions:

The PI would like to thank the DOE Office of Science for its generous support of his group's research efforts with this award. This award has enabled both his group and VERITAS to be unusually productive. VERITAS is less than half the size of the rival MAGIC / HESS collaborations, yet publishes at a similar rate. Despite being only ~5% of VERITAS, the SAO group is the primary author of 9%, and played a major role in another 21%, of the collaboration's manuscripts. Further, by having led two of the four major science working groups for the past ~5 years, the SAO group has directly coordinated nearly 50% of the Collaboration's published output. Finally operating and maintaining various next-day analysis and data-quality pipelines, with the support of this grant, the SAO group ensured that it has influenced every VERITAS result. Over the 5-year project period, the SAO group contributed to the VERITAS publications of 51 refereed articles, and numerous non-refereed literature. All refereed publications can be found at the end of this report. VERITAS continues to operate and is preparing the science justification for the next five years. During this last year of support, the PI authored both the Blazar and the Dark Matter Science Working Group's long-term observing plans to ensure the legacy of this award lives on. Thank you again!

Refereed publications supported by this grant:

(1) V. Acciari et al., "Simultaneous Multiwavelength Observations of Markarian 421 During Outburst", *Astrophysical Journal*, **703**, 169, 2009
(2) V. Acciari et al., "Detection of Extended VHE Gamma Ray Emission from G106.3+2.7 with VERITAS", *Astrophysical Journal Letters*, **703**, L6, 2009
(3) V. Acciari et al., "A connection between star formation activity and cosmic rays in the starburst galaxy M 82", *Nature*, **462**, 770, 2009
(4) V. Acciari et al., "VERITAS Upper Limit on the VHE Emission from the Radio Galaxy NGC 1275", *Astrophysical Journal Letters*, **706**, L275, 2009
(5) V. Acciari et al., "Multiwavelength observations of a TeV-Flare from W Com", *Astrophysical Journal*, **707**, 612, 2009
(6) V. Acciari et al., "Discovery of very high energy gamma rays from PKS 1424+240 and multiwavelength constraints on its redshift", *Astrophysical Journal Letters*, **708**, L100, 2010
(7) V. Acciari et al., "Discovery of Variability in the Very High Energy Gamma-Ray Emission of 1ES 1218+304 with VERITAS", *Astrophysical Journal Letters*, **709**, L163, 2010
(8) V. Acciari et al., "Observations of the shell-type SNR Cassiopeia A at TeV energies with VERITAS", *Astrophysical Journal*, **714**, 163, 2010
(9) V. Acciari et al., "The Discovery of γ-ray emission from the Blazar RGB J0710+591", *Astrophysical Journal Letters,* **715**, L49, 2010
(10) V. Acciari et al., "VERITAS 2008 - 2009 monitoring of the variable gamma-ray source M87", *Astrophysical Journal*, **716**, 819, 2010
(11) V. Acciari et al., "Discovery of VHE Gamma-ray Emission from the SNR G54.1+0.3", *Astrophysical Journal Letters*, **719**, L69, 2010
(12) V. Acciari et al., "VERITAS Search for VHE Gamma-ray Emission from Dwarf Spheroidal Galaxies", *Astrophysical Journal*, **720**, 1174, 2010
(13) A. Abdo et al., "Multi-wavelength Observations of Flaring Gamma-ray Blazar 3C 66A in October 2008", *Astrophysical Journal*, **726**, 43, 2011
(14) A. Abdo et al., "Insights Into the High-energy γ-ray Emission of Markarian 501 from Extensive Multifrequency Observations in the Fermi Era", *Astrophysical Journal*, **727**, 129, 2011
(15) V. Acciari et al., "Spectral Energy Distribution of Markarian 501: Quiescent State vs. Extreme Outburst", *Astrophysical Journal*, **729**, 2, 2011
(16) V. Acciari et al., "Discovery of TeV Gamma-ray Emission From Tycho's Supernova Remnant", *Astrophysical Journal Letters*, **730**, L20, 2011
(17) V. Acciari et al., "Gamma-ray observations of the Be/pulsar binary 1A0535+262 during a giant X-ray outburst", *Astrophysical Journal*, **733**, 96, 2011
(18) E. Aliu et al., "VERITAS Observations of the Unusual Extragalactic Transient Swift J164449.3+573451", *Astrophysical Journal Letters*, **738**, L30, 2011
(19) V. Acciari et al., "VERITAS Observations of the TeV Binary LSI +61 303 during 2008-2010", *Astrophysical Journal*, **738**, 3, 2011
(20) V. Acciari et al., "TeV and Multi-wavelength Observations of Mrk 421 in 2006-2008", *Astrophysical Journal*, **738**, 25, 2011
(21) V. Acciari et al., "Multiwavelength Observations of the VHE Blazar 1ES 2344+514", *Astrophysical Journal*, **738**, 169, 2011
(22) E. Aliu et al., "Detection of Pulsed Gamma Rays Above 100 GeV from the Crab Pulsar", Science, **334**, 69, 2011
(23) E. Aliu et al., "Multiwavelength Observations of the Previously Unidentified Blazar RXJ0648.7+1516", *Astrophysical Journal*, **742**, 127, 2011
(24) V. Acciari et al., "VERITAS Observations of Gamma-ray Bursts Detected by Swift", *Astrophysical Journal*, **743**, 62, 2011
(25) A. Abramowski et al., "The 2010 VHE Flare & 10 Years of Multi-Wavelength Observations of M87" *Astrophysical Journal*, **746**, 151, 2012
(26) E. Aliu et al., "VERITAS observations of day-scale flaring of M87 in April 2010", *Astrophysical Journal*, **746**, 141, 2012
(27) E. Aliu et al., "VERITAS deep observations of the dwarf spheroidal galaxy Segue 1", Physical Review D, 85, 062001, 2012
(28) E. Aliu et al., " Discovery of High-energy and Very High Energy γ-Ray Emission from the Blazar RBS 0413" *Astrophysical Journal*, **750**, 94, 2012
(29) E. Aliu et al., "VERITAS Observations of the Nova in V407 Cygni", *Astrophysical Journal*, **754**,

77, 2012
(30) E. Aliu et al., " Multiwavelength Observations of the AGN 1ES 0414+009 with VERITAS, Fermi-LAT, Swift-XRT, and MDM", *Astrophysical Journal*, **755**, 118, 2012
(31) T. Arlen et al., "Constraints on Cosmic Rays Magnetic Fields and Dark Matter from Gamma-ray Observations of the Coma Cluster of Galaxies with VERITAS and *Fermi*", *Astrophysical Journal*, **757**, 123, 2012
(32) E. Aliu et al., "VERITAS Observations of Six Bright Hard-Spectrum Fermi-LAT Blazars", *Astrophysical Journal*, **759**, 102, 2012
(33) E. Aliu et al., "Search for a correlation between very-high-energy gamma rays and giant radio pulses in the Crab pulsar", *Astrophysical Journal*, **760**, 136, 2012
(34) T. Arlen et al., "Rapid TeV Gamma-ray Flaring of BL Lacertae", *Astrophysical Journal*, **762**, 92, 2013
(35) E. Aliu et al., "Discovery of TeV Gamma-ray Emission from CTA 1 by VERITAS", *Astrophysical Journal*, **764**, 38, 2013
(36) E. Aliu et al., "Discovery of TeV Gamma-ray Emission Toward Supernova Remnant SNR G78.2+2.1", *Astrophysical Journal*, **770**, 93, 2013
(37) E. Aliu et al., "Multiwavelength Observations and Modelling of 1ES 1959+650", *Astrophysical Journal*, **775**, 3, 2013
(38) S. Archambault et al., "Discovery of a New TeV Gamma-ray Source: VER J0521+211", *Astrophysical Journal,* **776,** 69, 2013
(39) E. Aliu et al., "Multiwavelength Observations of The TeV Binary LS I +61 303 with VERITAS, Fermi-LAT and Swift-XRT During a TeV Outburst", *Astrophysical Journal,* **779,** 88, 2014
(40) E. Aliu et al., "Long term observations of B2 1215+30 with VERITAS", *Astrophysical Journal,* **779,** 92, 2013
(41) S. Archambault et al., "VERITAS Observations of the Microquasar Cygnus X-3", *Astrophysical Journal,* **779,** 150, 2013
(42) E. Aliu et al., "Long-term TeV and X-ray observations of the Gamma-ray Binary HESS J0632+057", *Astrophysical Journal,* **780**, 168, 2014
(43) E. Aliu et al., "A search for enhanced very-high-energy gamma-ray emission from the March 2013 Crab Nebula flare", *Astrophysical Journal Letters,* **781,** L11, 2014
(44) V. Acciari et al., "Observation of Markarian 421 in TeV gamma rays over a 14-year time span", Astroparticle Physics, **54**, 1, 2014
(45) E. Aliu et al., "A Three-Year Multi-Wavelength Study of the Very High Energy gamma-ray Blazar 1ES 0229+200", *Astrophysical Journal,* **782,** 13, 2014
(46) E. Aliu et al., "Observations of the unidentified gamma-ray source TeV J2032+4130 by VERITAS", *Astrophysical Journal,* **783**, 16, 2014
(47) S. Archambault et al., "Deep Broadband Observations of the Distant Gamma-ray Blazar PKS 1424+240", *Astrophysical Journal Letters,* **785,** L16, 2014
(48) E. Aliu et al., "Investigating the TeV Morphology of MGRO J1908+06 with VERITAS", *Astrophysical Journal,* **787**, 166, 2014
(49) E. Aliu et al., "Spatially Resolving the Very High Energy Emission From MGRO J2019+37 with VERITAS", *Astrophysical Journal,* **788,** 78, 2014
(50) S. Archambault et al., "Test of Models of the Cosmic Infrared Background with Multi-wavelength Observations of the Blazar 1ES 1218+30.4 in 2009", *Astrophysical Journal,* **788,** 158, 2014
(51) A. Archer et al., "Very-high Energy Observations of the Galactic Center Region by VERITAS in 2010–2012 ", *Astrophysical Journal,* **790,** 149, 2014