

2008-08-20

## VERITAS discovery of > 200 GeV gamma-ray emission from the intermediate-frequency-peaked BL Lacertae object W Comae

P. T. Reynolds

*Department of Physical Sciences, Cork Institute of Technology, Bishopstown, Cork, Ireland*

et al

Follow this and additional works at: <https://sword.cit.ie/dptphysciart>



Part of the [External Galaxies Commons](#), and the [Stars, Interstellar Medium and the Galaxy Commons](#)

### Recommended Citation

Acciari, V.A., Aliu, E., Beilicke, M., Benbow, W., Böttcher, M., Bradbury, S.M., Buckley, J.H., Bugaev, V., Butt, Y., Celik, O., Cesarini, A., Ciupik, L., Chow, Y.C.K., Cogan, P., Colin, P., Cui, W., Daniel, M.K., Ergin, T., Falcone, A.D., Fegan, S.J., Finley, J.P., Finnegan, G., Fortin, P., Fortson, L.F., Furniss, A., Gall, D., Gillanders, G.H., Grube, J., Guenette, R., Gyuk, G., Hanna, D., Hays, E., Holder, J., Horan, D., Hui, C.M., Humensky, T.B., Imran, A., Kaaret, P., Karlsson, N., Kertzman, M., Kieda, D.B., Konopelko, A., Krawczynski, H., Krennrich, F., Lang, M.J., LeBohec, S., Lee, K., Maier, G., McCann, A., McCutcheon, M., Moriarty, P., Mukherjee, R., Nagai, T., Niemiec, J., Ong, R.A., Pandel, D., Perkins, J.S., Petry, D., Pohl, M., Quinn, J., Ragan, K., Reyes, L.C., Reynolds, P.T., Roache, E., Rose, H.J., Schroedter, M., Sembroski, G.H., Smith, A.W., Steele, D., Swordy, S.P., Toner, J.A., Vassiliev, V.V., Wagner, R., Wakely, S.P., Ward, J.E., Weekes, T.C., Weinstein, A., White, R.J., Williams, D.A., Wissel, S.A., Wood, M. and Zitzer, B. (2008). VERITAS Discovery of >200 GeV Gamma-Ray Emission from the Intermediate-Frequency-Peaked BL Lacertae Object W Comae. *The Astrophysical Journal*, 684(2), pp.L73–L77. Available at: <https://iopscience.iop.org/article/10.1086/592244> [Accessed

## VERITAS DISCOVERY OF >200 GeV GAMMA-RAY EMISSION FROM THE INTERMEDIATE-FREQUENCY-PEAKED BL LACERTAE OBJECT W COMAE

V. A. ACCIARI,<sup>20,1</sup> E. ALIU,<sup>23</sup> M. BEILICKE,<sup>2,30</sup> W. BENBOW,<sup>1</sup> M. BÖTTCHER,<sup>26</sup> S. M. BRADBURY,<sup>4</sup> J. H. BUCKLEY,<sup>2</sup> V. BUGAEV,<sup>2</sup> Y. BUTT,<sup>24</sup> O. CELIK,<sup>6</sup> A. CESARINI,<sup>1,21</sup> L. CIUPIK,<sup>7</sup> Y. C. K. CHOW,<sup>6</sup> P. COGAN,<sup>12</sup> P. COLIN,<sup>11</sup> W. CUI,<sup>8</sup> M. K. DANIEL,<sup>4,27</sup> T. ERGIN,<sup>3</sup> A. D. FALCONE,<sup>22</sup> S. J. FEGAN,<sup>6</sup> J. P. FINLEY,<sup>8</sup> G. FINNEGAN,<sup>11</sup> P. FORTIN,<sup>14</sup> L. F. FORTSON,<sup>7</sup> A. FURNISS,<sup>17</sup> D. GALL,<sup>8</sup> G. H. GILLANDERS,<sup>21</sup> J. GRUBE,<sup>13</sup> R. GUENETTE,<sup>12</sup> G. GYUK,<sup>7</sup> D. HANNA,<sup>12</sup> E. HAYS,<sup>5,1</sup> J. HOLDER,<sup>23</sup> D. HORAN,<sup>5</sup> C. M. HUI,<sup>11</sup> T. B. HUMENSKY,<sup>10</sup> A. IMRAN,<sup>9</sup> P. KAARET,<sup>18</sup> N. KARLSSON,<sup>7</sup> M. KERTZMAN,<sup>15</sup> D. B. KIEDA,<sup>11</sup> A. KONOPELKO,<sup>8,29</sup> H. KRAWCZYNSKI,<sup>2</sup> F. KRENNRICH,<sup>9</sup> M. J. LANG,<sup>21</sup> S. LEBOHEC,<sup>11</sup> K. LEE,<sup>2</sup> G. MAIER,<sup>12</sup> A. MCCANN,<sup>12</sup> M. MCCUTCHEON,<sup>12</sup> P. MORIARTY,<sup>20</sup> R. MUKHERJEE,<sup>14</sup> T. NAGAI,<sup>9</sup> J. NIEMIEC,<sup>9,28</sup> R. A. ONG,<sup>6</sup> D. PANDEL,<sup>18</sup> J. S. PERKINS,<sup>1</sup> D. PETRY,<sup>25</sup> M. POHL,<sup>9</sup> J. QUINN,<sup>13</sup> K. RAGAN,<sup>12</sup> L. C. REYES,<sup>10</sup> P. T. REYNOLDS,<sup>19</sup> E. ROACHE,<sup>1</sup> H. J. ROSE,<sup>4</sup> M. SCHROEDTER,<sup>9</sup> G. H. SEMBROSKI,<sup>8</sup> A. W. SMITH,<sup>1,4</sup> D. STEELE,<sup>7</sup> S. P. SWORDY,<sup>10</sup> J. A. TONER,<sup>1,21</sup> V. V. VASSILIEV,<sup>6</sup> R. WAGNER,<sup>5</sup> S. P. WAKELY,<sup>10</sup> J. E. WARD,<sup>13</sup> T. C. WEEKES,<sup>1</sup> A. WEINSTEIN,<sup>6</sup> R. J. WHITE,<sup>4</sup> D. A. WILLIAMS,<sup>17</sup> S. A. WISSEL,<sup>10</sup> M. WOOD,<sup>6</sup> AND B. ZITZER<sup>8</sup>

Received 2008 June 16; accepted 2008 August 4; published 2008 August 20

### ABSTRACT

We report the detection of very high energy  $\gamma$ -ray emission from the intermediate-frequency-peaked BL Lacertae object W Comae ( $z = 0.102$ ) by VERITAS. The source was observed between 2008 January and April. A strong outburst of  $\gamma$ -ray emission was measured in the middle of March, lasting for only 4 days. The energy spectrum measured during the two highest flare nights is fit by a power law and is found to be very steep, with a differential photon spectral index of  $\Gamma = 3.81 \pm 0.35_{\text{stat}} \pm 0.34_{\text{sys}}$ . The integral photon flux above 200 GeV during those two nights corresponds to roughly 9% of the flux from the Crab Nebula. Quasi-simultaneous *Swift* observations at X-ray energies were triggered by the VERITAS observations. The spectral energy distribution of the flare data can be described by synchrotron self-Compton (SSC) or external Compton (EC) leptonic jet models.

*Subject headings:* BL Lacertae objects: individual (W Comae) — gamma rays: observations

### 1. INTRODUCTION

The blazars detected at very high energies (VHE;  $E > 100$  GeV) by ground-based imaging atmospheric Cerenkov telescopes (IACTs) are extreme objects in the active galactic nucleus (AGN) population. Typically these sources show core-dominated emission, and they are characterized by rapid variability and strong broadband continuum emission ranging from the radio band to the X-ray band. Multiwavelength data on blazars reveal that their spectral energy distribution (SED) is characterized by two broad, well-separated “humps” arising from synchrotron (low energy) and inverse Compton (IC) or hadronic emission (high energy). Blazars are categorized into different subclasses based on the frequencies at which these emission components reach a maximum. Flat-spectrum radio qua-

sars (FSRQs) and low-frequency-peaked BL Lac objects (LBLs) are generally seen to have low-frequency, synchrotron peaks in the IR/optical regime, whereas high-frequency-peaked BL Lac objects (HBLs) exhibit peaks in the X-ray band, in several cases at energies of  $\sim 100$  keV or higher. Intermediate-frequency-peaked BL Lac objects (IBLs) bridge the gap between LBLs and HBLs. The properties of the broad subclasses of blazars, the luminosity-versus-frequency trends, and possible physical explanations are discussed by Ghisellini & Tavecchio (2008).

Gamma rays are an important component of the SED of blazars; the integral power in the  $\gamma$ -ray wave band is comparable to or higher than that in the rest of the electromagnetic spectrum (from radio to X-rays). There are 65 blazars detected

<sup>1</sup> Fred Lawrence Whipple Observatory, Harvard-Smithsonian Center for Astrophysics, Amado, AZ 85645.

<sup>2</sup> Department of Physics, Washington University, St. Louis, MO 63130.

<sup>3</sup> Department of Physics, University of Massachusetts, Amherst, MA 01003.

<sup>4</sup> School of Physics and Astronomy, University of Leeds, Leeds LS2 9JT, UK.

<sup>5</sup> Argonne National Lab., 9700 S. Cass Ave., Argonne, IL 60439.

<sup>6</sup> Department of Physics and Astronomy, University of California, Los Angeles, CA 90095.

<sup>7</sup> Astronomy Department, Adler Planetarium and Astronomy Museum, Chicago, IL 60605.

<sup>8</sup> Department of Physics, Purdue University, West Lafayette, IN 47907.

<sup>9</sup> Dept. of Physics and Astronomy, Iowa State University, Ames, IA 50011.

<sup>10</sup> Enrico Fermi Institute, University of Chicago, Chicago, IL 60637.

<sup>11</sup> Physics Department, University of Utah, Salt Lake City, UT 84112.

<sup>12</sup> Physics Department, McGill University, Montreal, QC H3A 2T8, Canada.

<sup>13</sup> School of Physics, University College Dublin, Belfield, Dublin, Ireland.

<sup>14</sup> Department of Physics and Astronomy, Barnard College, Columbia University, New York, NY 10027.

<sup>15</sup> Department of Physics and Astronomy, DePauw University, Greencastle, IN 46135-0037.

<sup>16</sup> Department of Physics, Grinnell College, Grinnell, IA 50112-1690.

<sup>17</sup> Santa Cruz Institute for Particle Physics and Department of Physics, University of California, Santa Cruz, CA 95064.

<sup>18</sup> Department of Physics and Astronomy, University of Iowa, Van Allen Hall, Iowa City, IA 52242.

<sup>19</sup> Department of Applied Physics and Instrumentation, Cork Institute of Technology, Bishopstown, Cork, Ireland.

<sup>20</sup> Department of Life and Physical Sciences, Galway-Mayo Institute of Technology, Dublin Road, Galway, Ireland.

<sup>21</sup> Physics Department, National University of Ireland, Galway, Ireland.

<sup>22</sup> Department of Astronomy and Astrophysics, Penn State University, University Park, PA 16802.

<sup>23</sup> Department of Physics and Astronomy, Bartol Research Institute, University of Delaware, Newark, DE 19716.

<sup>24</sup> Smithsonian Astrophysical Observatory, Cambridge, MA 02138.

<sup>25</sup> Max Planck Institute for Extraterrestrial Physics (MPE), Giessenbachstrasse, 85748 Garching, Germany.

<sup>26</sup> Department of Physics and Astronomy, Astrophysical Institute, Clippingier 339, Ohio University, Athens, OH 45701-2979.

<sup>27</sup> Current address: Department of Physics, Durham University, South Road, Durham DH1 3LE, UK.

<sup>28</sup> Current address: Instytut Fizyki Jadrowej PAN, ul. Radzikowskiego 152, 31-342 Kraków, Poland.

<sup>29</sup> Current address: Physics Department, Pittsburg State University, 1701 South Broadway, Pittsburg, KS 66762.

<sup>30</sup> Corresponding author; beilicke@physics.wustl.edu.

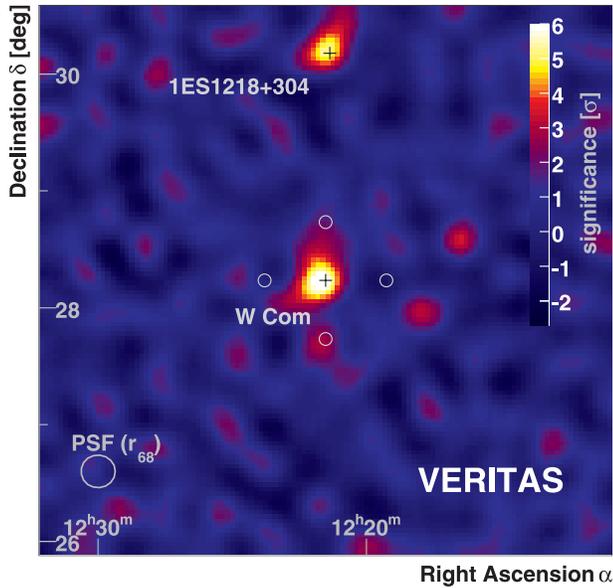


FIG. 1.—Sky map of significances of the whole data set (standard cuts; oversampling radius of  $0.15^\circ$ ). The background is estimated using the ring background model (Berge et al. 2007). The excess  $\sim 2^\circ$  north of W Com (*cross*) corresponds to 1ES 1218+304 (*cross*) and demonstrates the capability of VERITAS to detect sources at the edge of the field of view of the camera. The telescope tracking positions in wobble mode (*open circles*) and the angular resolution (PSF) are indicated as well.

at MeV/GeV energies by the EGRET instrument on board the *Compton Gamma Ray Observatory* (CGRO) (Mattox et al. 2001; Hartman et al. 1999) and several of the other EGRET sources also have likely blazar counterparts. Ground-based IACTs have established  $\sim 20$  blazars as emitters of VHE  $\gamma$ -radiation.<sup>31</sup> While the blazars detected at MeV/GeV energies tend to be largely FSRQs (and some LBLs), almost all VHE blazars belong to the class of HBLs, the only exceptions being the LBLs BL Lacertae (Albert et al. 2007a), S5 0716+71 (Teshima 2008), and the FSRQ 3C 279 (Teshima et al. 2007).

The IBL W Comae (W Com) at a redshift of  $z = 0.102$  has long been an object of interest for VHE observatories. W Com was discovered at radio frequencies (Browne 1971) and later detected at X-ray energies by the *Einstein* Imaging Proportional Counter in 1980 June (Worrall & Wilkes 1990). Data taken with the *BeppoSAX* satellite in 1998 (Tagliaferri et al. 2000) clearly showed that the transition between the low- and high-energy peaks in the SED occurs around  $\sim 4$  keV. In 1998 April–May an exceptional optical outburst was detected from W Com showing rapid variability on timescales of hours (Massaro et al. 1999).

At  $\gamma$ -ray energies, W Com was detected by EGRET in the 100 MeV to 10 GeV band (Hartman et al. 1999) and in a reanalysis of the data up to 25 GeV (Dingus & Bertsch 2001). Due to its rather hard EGRET spectrum (photon spectral index  $\alpha = 1.73 \pm 0.18$ ), with no sign of spectral cutoff (Hartman et al. 1999), the source became even more interesting for VHE observations. However, W Com was not detected by the Whipple IACT above 300 GeV in 1993/1994 (Kerrick et al. 1995) and 1995/1996/1998 (Horan et al. 2004), nor by the solar heliostat Cerenkov telescope STACEE (Scalzo et al. 2004). In

<sup>31</sup> See for example *TeVCat* (S. Wakely & D. Horan 2007; available online at <http://tevcats.uchicago.edu>).

this Letter we report the discovery of VHE  $\gamma$ -ray emission from W Com with VERITAS.

## 2. VERITAS AND SWIFT OBSERVATIONS AND RESULTS

VERITAS consists of four 12 m diameter IACTs and is located at the base camp of the Fred Lawrence Whipple Observatory (FLWO) in southern Arizona at an altitude of 1280 m. It detects the Cerenkov light emitted by an extensive air shower (initiated by a VHE  $\gamma$ -ray photon or cosmic-ray entering the Earth’s atmosphere) using a 499 pixel photomultiplier camera located in the focal plane of each telescope. The array is sensitive to  $\gamma$ -rays in the energy range from  $\sim 100$  GeV to  $\sim 30$  TeV. Observations are performed in moonless nights in the “wobble” mode of operation, where the telescopes are pointed to positions offset by  $\pm 0.5^\circ$  (alternating in direction) with respect to the source position, to allow for a simultaneous background estimation. More details about VERITAS, the data calibration, and the analysis techniques can be found in Acciari et al. (2008).

Only shower images which pass certain quality cuts are considered in the event reconstruction (image size  $\geq 500$  digital counts [dc],<sup>32</sup> distance between the image center of gravity and the center of the camera  $\leq 1.43^\circ$ ). The  $\gamma$ /hadron separation cuts used in this analysis are based on the width and length of the recorded images (Acciari et al. 2008) and were optimized a priori on Crab Nebula data for a source with a flux at the 5% level of the Crab Nebula. We refer to these as “standard cuts.” An event is considered to fall into the signal (ON) region if the squared angular distance  $\Delta\theta^2$  between the reconstructed event direction and the W Com position is less than  $0.0125 \text{ deg}^2$ . The background is estimated from different regions of equal size positioned at the same radial distance from the camera center as the ON region (Berge et al. 2007). This background model, referred to as the “reflected region model,” is used unless otherwise stated. Since the energy spectrum of W Com is found to be very steep (see below) a second set of cuts (optimized on Crab Nebula data for low energies of  $E \leq 200$  GeV) is used to derive the energy spectrum and the light curve. These a posteriori cuts are referred to as “soft cuts” in this Letter and use an image size  $\geq 250$  dc and an angular distance to the source position of  $\Delta\theta^2 \leq 0.02 \text{ deg}^2$ . All results obtained with the soft cuts are in good agreement with the ones obtained using the standard cuts.

VERITAS observed W Com from 2008 January to April for a total of 39.5 hr (dead-time corrected) after run quality selection. The zenith-angle range of the observations was  $3^\circ$ – $45^\circ$  with an average of  $19^\circ$ , corresponding to an analysis energy threshold<sup>33</sup> of 260 GeV (standard cuts) and 180 GeV (soft cuts). In the entire data set, 111 excess events (543 ON events and 432 normalized OFF events, normalization  $\alpha = 0.111$ ) are detected from the direction of W Com using the standard cuts, corresponding to a statistical significance of 4.9 standard deviations ( $4.9 \sigma$ ), calculated following Li & Ma (1983). The sky map showing W Com and the known VHE blazar 1ES 1218+304<sup>34</sup> (Albert et al. 2006; Fortin et al. 2007) located in the same field of view of the dedicated W Com observations is shown in Figure 1. The mean position of the W Com excess

<sup>32</sup> The photomultiplier pulses are integrated within a time window of 24 ns duration. One digital count corresponds to approximately 5 photoelectrons.

<sup>33</sup> The energy threshold is defined as the energy corresponding to the peak detection rate for a Crab-like spectrum.

<sup>34</sup> A significant VHE  $\gamma$ -ray excess was recorded from 1ES 1218+304 during the dedicated W Com observations, which will be addressed in a forthcoming paper.

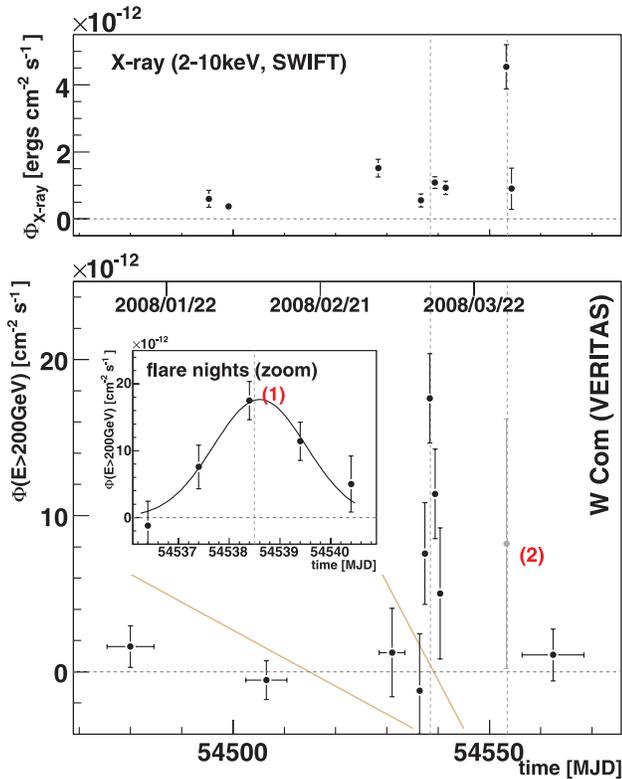


FIG. 2.—*Bottom panel:* The light curve  $I(E > 200 \text{ GeV})$  is shown (soft cuts; assuming a spectral shape of  $dN/dE \propto E^{-\Gamma}$  with  $\Gamma = 3.8$ ). Each flux point corresponds to one observation period (defined by  $\sim 3$  weeks of operation between two full-moon phases), with the exception of the flare around MJD 54,538 (*label 1*) for which a night-by-night binning is used (see inset for details; the fitted model light curve is described in the text). *Top panel:* The X-ray flux as measured by *Swift* for the same time period. The vertical lines are shown for easier comparison. The simultaneous VERITAS/*Swift* measurements around MJD 54,553.3 (*label 2*) during a high X-ray flux level is discussed in the text.

is derived by fitting a 2D Gaussian function to the uncorrelated excess sky map and is found to be compatible within errors with the nominal position of W Com.

Almost the entire excess from W Com ( $>70\%$ ) is recorded during a strong flare, which occurred during four nights in the middle of March (Swordy 2008) (see Fig. 2). The measured excess of the whole corresponding observation period—modified Julian date (MJD) 54,528.4 to 54,540.4—corresponds to a statistical significance of  $6.3 \sigma$  (standard cuts; 85 excess events) and  $8.6 \sigma$  (soft cuts; 275 excess events). Correcting for eight trials (four observations periods and two sets of cuts) results in  $5.9$  and  $8.3 \sigma$ , respectively. No statistically significant excess is measured in the remaining data set. A fit of a constant function to the whole night-by-night light curve (January to April) results in a probability of constant emission of  $2.1 \times 10^{-4}$ . In order to estimate the timescale of the flux variations the light curve of the flare nights (see inset of Fig. 2) is modeled by the function  $\Phi(t) = \Phi_0 \exp[-(t - t_0)^2/\sigma_t^2]$  with the flare occurring at  $t_0 = 54,538.6 \pm 0.2$  MJD with the characteristic timescale of  $\sigma_t = 1.29 \pm 0.28$  days. No significant flux variations are measured within individual nights.

A differential energy spectrum is derived for the two highest flare nights. The spectrum is shown in Figure 3 and is well fit ( $\chi^2/\text{dof} = 2.9/3$ ) by a power-law function  $dN/dE = I_0(E/400 \text{ GeV})^{-\Gamma}$ , with  $I_0 = (2.00 \pm 0.31_{\text{st}}) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1} \text{ TeV}^{-1}$  and  $\Gamma = 3.81 \pm 0.35_{\text{st}}$ . The integral photon flux above 200 GeV

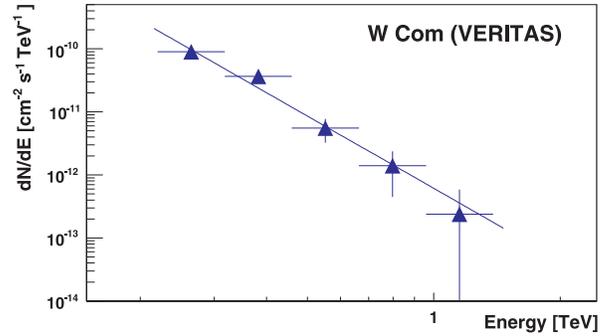


FIG. 3.—Differential energy spectrum of W Com (soft cuts), derived from the two highest flare nights: label 1 in Fig. 2. The parameters of the fitted power-law function (*line*) are summarized in the text.

is calculated to be  $\Phi_{E > 200 \text{ GeV}} = (1.99 \pm 0.07_{\text{st}}) \times 10^{-11} \text{ cm}^{-2} \text{ s}^{-1}$ , corresponding to 9% of the flux measured from the Crab Nebula above the same energy. The systematic errors on the normalization constant and the photon index for this low-energy regime are estimated to be  $\Delta I_0/I_0 = 25\%$  and  $\Delta\Gamma/\Gamma = 9\%$ , respectively.

Simultaneous *Swift* observations of W Com were performed for a total duration of 11.6 hr. *Swift* comprises a UV instrument UVOT and X-ray instruments XRT and BAT (Gehrels et al. 2004). Data reduction and calibration are performed with the HEASoft 6.4 package<sup>35</sup> and the xrtpipeline tool. All energy spectra are fit with an absorbed power law using XSPEC 12.4. A Galactic column density of  $N_{\text{H}} = 1.88 \times 10^{20} \text{ cm}^2$  was assumed (Dickey & Lockman 1990). No significant deviation from a power-law spectral shape is found within the limited statistics. UVOT observations were taken over the six photometric bands of *V*, *B*, *U*, *UVW1*, *UVM2*, and *UVW2* (Poole et al. 2008). The uvotsource tool is used to extract counts, correct for coincidence losses, apply background subtraction, and calculate the source flux. The source fluxes are dereddened using the interstellar extinction curve in Fitzpatrick (1999).

The light curve of the X-ray flux is shown in Figure 2 (*top panel*). No change in spectral slope could be detected when comparing results for individual nights. An X-ray flux at a level roughly 4 times higher than the flux observed during the VHE flare was observed around MJD 54,553.3 (see Fig. 2, *top panel*). VERITAS also observed W Com during this night for  $\sim 40$  minutes but the data do not pass the standard quality selection.<sup>36</sup> Nevertheless, since the VERITAS data (MJD 54,553.3) are simultaneous with the X-ray flare the flux derived from these data (including an additional 50% systematic error) is shown for reference in Figure 2 (*label 2*). The 99.9% c.l. upper limit (assuming an underestimation of the count rates by 50%) is calculated to be  $\sim 2$  times higher than the peak flux measured during the VHE flare. Although no detailed conclusions can be drawn, a linear X-ray/TeV flux correlation does not seem likely.

### 3. MODELING AND DISCUSSION

The VERITAS data taken at MJD 54,538.4 and 54,539.4 are used to model the SED of W Com (see Fig. 4) together with the simultaneous *Swift* XRT/UVOT (MJD 54,539.4) and optical

<sup>35</sup> See <http://heasarc.gsfc.nasa.gov/lheasoft/>.

<sup>36</sup> Showing a cosmic-ray trigger rate  $\sim 27\%$  lower than expected due to nonoptimal weather conditions—with the maximum allowed deviation being 20%.

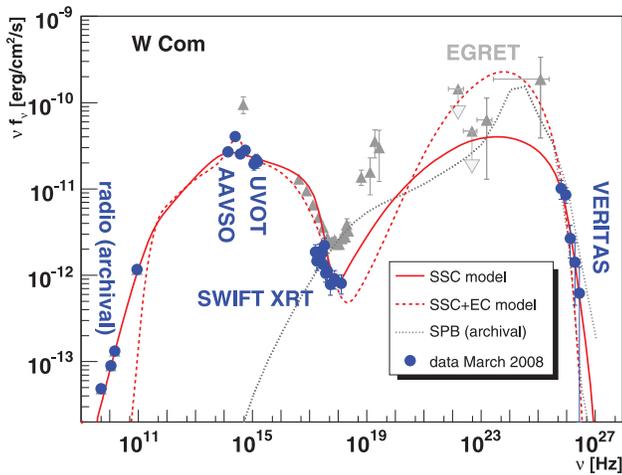


FIG. 4.—Quasi-simultaneous SED of W Com, including the VERITAS flare data (MJD 54,538.4 and 54,539.4; see Fig. 3), the *Swift* XRT/UVOT data (MJD 54,539.4), and the *V*- and *I*-band data (MJD 54,540) from AAVSO (J. Bedient 2008, private communication). The radio data are nonsimultaneous and the same as in Böttcher et al. (2002b). Details of the SSC and SSC+EC model fits (see legend) are described in the text. The hadronic SPB model curve 1 from Böttcher et al. (2002b) is shown for reference. Archival data (optical, X-ray, and 1998 EGRET data) are shown as gray points for comparison; see references in Böttcher et al. (2002b).

AAVSO data (MJD 54,540; J. Bedient 2008, private communication), as well as archival radio data. The following model curves are corrected for  $\gamma\gamma$  absorption by the extragalactic background light according to the “best fit” model of Kneiske et al. (2004). The SED can be fit by a simple one-zone SSC model, using the equilibrium version of the code of Böttcher & Chiang (2002a). Here an ad hoc nonthermal electron injection spectrum with particle index  $q$  and total particle injection luminosity  $L_{\text{inj}}$  is balanced self-consistently with radiative cooling from synchrotron and Compton emission. The best fit to the SED is shown in Figure 4 as a solid line. The parameters of the fit are  $\gamma_1 = 450$ ,  $\gamma_2 = 4.5 \times 10^5$ ,  $q = 2.2$ ,  $L_{\text{inj}} = 2.8 \times 10^{45} \text{ erg s}^{-1}$ , a magnetic field of  $B = 0.007 \text{ G}$ , a Doppler factor of  $\delta = 30$ , and a size of the emission region of  $R = 10^{17} \text{ cm}$ . The wide separation of the SED peaks, together with the very low X-ray flux, require an unusually low magnetic field in order to allow for sufficiently high particle Lorentz factors to produce the observed VHE  $\gamma$ -ray flux. The ratio between the magnetic and electron energy density is  $\sigma = 1.3 \times 10^{-3}$ . The light crossing time  $\tau = R/(c \times \delta) \approx 1.3$  days matches the timescale observed in the VHE flare (compare Fig. 2), but it is relatively large compared with the extremely rapid VHE variability on timescales of 2–10 minutes seen in other TeV blazars at higher flux levels (Albert et al. 2007b; Aharonian et al. 2007).

The SED was also fit by a self-consistent model that contains both SSC emission and an EC component, similar to the model of Inoue & Takahara (1996). The external photons are assumed as steady-state blackbody radiation peaking in the near-infrared (radius 1800 Schwarzschild radii, 0.4% of the Eddington luminosity). The particles are accelerated by diffusive shock acceleration and the maximum electron Lorentz factor  $\gamma_{\text{max}}$  is determined by competition between acceleration and radiative cooling. As for the SSC fit, a cooling break in the electron spectrum is assumed to occur at the energy where the cooling time becomes shorter than the light crossing time of the emis-

sion region. Finally, we assume that the electron distribution has some minimum Lorentz factor  $\gamma_{\text{min}}$  from some unknown injection process. The power-law slope of the electron spectrum (without the cooling break) is parameterized by  $dN/dE \propto E^{-s}$ , where the free parameter  $s$  is expected to vary between 2.3 (for canonical first-order Fermi ultrarelativistic shock acceleration) and 2.0 (for canonical nonrelativistic first-order Fermi acceleration by a strong shock).

A reasonably good fit (see Fig. 4) is obtained taking  $B = 0.3 \text{ G}$ ,  $\delta = \Gamma = 30$ ,  $\sigma = 1.0$  (assuming equipartition),  $\gamma_{\text{min}} = \Gamma = 30$ , and  $R = 1.76 \times 10^{16} \text{ cm}$ . To match the inferred shape of the electron spectrum, rather inefficient particle acceleration is invoked with an electron spectrum with index  $s = 2.0$ . For this choice of parameters, the model gives an acceleration time (equal to the cooling time) at the maximum electron energy of 7.2 minutes. Assuming that the emission region of radius  $R$  is comoving with the jet, the light crossing time for these parameters is  $\tau = 330$  minutes. This value is closer to the typical variability timescales of other VHE blazars and consistent with our observed light curve.

The synchrotron proton blazar (SPB) model from Böttcher et al. (2002b) fitted to data of the 1998 W Com campaign is also shown for reference in Figure 4.

#### 4. SUMMARY AND CONCLUSION

VERITAS detected VHE  $\gamma$ -ray emission from W Com with a statistical significance of 4.9 standard deviations for the entire data set (2008 January–April). A strong outburst was observed in 2008 March with a statistical significance of  $>8$  standard deviations, that lasted for only 4 days. In addition to W Com, a second extragalactic source (the VHE blazar 1ES 1218+304) is detected in the same field of view, for the first time in VHE  $\gamma$ -ray astronomy.

W Com is the first VHE-detected blazar of the IBL class. The extension of the VHE catalog to the FSRQ, LBL, and IBL classes will play a major role in our understanding of blazar populations and dynamics. The quasi-simultaneous SED of W Com at the time of the VHE outburst can be modeled with a simple one-zone SSC model. However, an unusually low magnetic field of  $B = 0.007 \text{ G}$  (more than an order of magnitude lower than typically found in the modeling of other BL Lac-type blazars) and a small ratio of the magnetic field to electron energy density of  $\sigma = 1.3 \times 10^{-3}$  are required. An EC model with more natural parameters ( $B = 0.3 \text{ G}$  and  $\sigma = 1$ ) provides a good fit and could account for shorter variability timescales. Our model results agree with the expectation that for IBLs (and LBLs) the higher optical luminosity plays an important role in providing the seed population for IC scattering.

The IBL W Com will be an excellent target for future observations at GeV energies with *GLAST* and in the VHE regime with IACTs, including correlated GeV/TeV variability studies.

This research is supported by grants from the US Department of Energy, the US National Science Foundation, and the Smithsonian Institution, by NSERC in Canada, by Science Foundation Ireland, and by PPARC in the UK. We acknowledge the excellent work of the technical support staff at the FLWO and the collaborating institutions in the construction and operation of the instrument. We acknowledge the efforts of the *Swift* team for providing the UVOT/XRT observations. We thank James Bedient of the AAVSO for his *V*- and *I*-band data on W Com.

## REFERENCES

- Acciari, V. A., et al. 2008, *ApJ*, 679, 1427  
Aharonian, F., et al. 2007, *ApJ*, 664, L71  
Albert, J., et al. 2006, *ApJ*, 642, L119  
———. 2007a, *ApJ*, 666, L17  
———. 2007b, *ApJ*, 669, 862  
Berge, D., Funk, S., & Hinton, J. 2007, *A&A*, 466, 1219  
Böttcher, M., & Chiang, J. 2002a, *ApJ*, 581, 127  
Böttcher, M., Mukherjee, R., & Reimer, O. 2002b, *ApJ*, 581, 143  
Browne, I. W. A. 1971, *Nature*, 231, 515  
Dickey, J. M., & Lockman, F. M. 1990, *ARA&A*, 28, 215  
Dingus, B. L., & Bertsch, D. L. 2001, in *AIP Conf. Ser. 587, Gamma 2001: Gamma-Ray Astrophysics*, ed. S. Ritz et al. (New York: AIP), 251  
Fitzpatrick, E. L. 1999, *PASP*, 111, 63  
Fortin, P., et al. 2007, in *Proc. 30th Int. Cosmic Ray Conf. (Merida)*, preprint (arXiv:0709.3657)  
Gehrels, N., et al. 2004, *ApJ*, 611, 1005  
Ghisellini, G., & Tavecchio, F. 2008, *MNRAS*, 387, 1669  
Hartman, R. C., et al. 1999, *ApJS*, 123, 79  
Horan, D., et al. 2004, *ApJ*, 603, 51  
Inoue, S., & Takahara, F. 1996, *ApJ*, 463, 555  
Kerrick, A. D., et al. 1995, *ApJ*, 452, 588  
Kneiske, T. M., Bretz, T., Mannheim, K., & Hartmann, D. H. 2004, *A&A*, 413, 807  
Li, T., & Ma, Y. 1983, *ApJ*, 272, 317  
Massaro, E., et al. 1999, *A&A*, 342, L49  
Mattox, J. R., Hartman, R. C., & Reimer, O. 2001, *ApJS*, 135, 155  
Poole, T. S., et al. 2008, *MNRAS*, 383, 627  
Scalzo, R. A., et al. 2004, *ApJ*, 607, 778  
Swordy, S. 2008, *ATel* 1422  
Tagliaferri, G., et al. 2000, *A&A*, 354, 431  
Teshima, M., et al. 2007, in *30th Int. Cosmic Ray Conf. (Merida)*, preprint (arXiv:0709.1475)  
———. 2008, *ATel* 1500  
Worrall, D. M., & Wilkes, B. J. 1990, *ApJ*, 360, 396