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VERITAS OBSERVATIONS OF A VERY HIGH ENERGY γ-RAY FLARE FROM THE BLAZAR 3C 66A

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ABSTRACT

The intermediate-frequency peaked BL Lacertae (IBL) object 3C 66A is detected during 2007–2008 in VHE (very high energy; $E > 100$ GeV) γ rays with the VERITAS stereoscopic array of imaging atmospheric Cherenkov telescopes. An excess of 1791 events is detected, corresponding to a significance of 21.2 standard deviations (σ), in these observations (32.8 hr live time). The observed integral flux above 200 GeV is 6% of the Crab Nebula's flux and shows evidence for variability on the timescale of days. The measured energy spectrum is characterized by a soft power law with photon index $\Gamma = 4.1 \pm 0.4_{\rm stat} \pm 0.6_{\rm sys}$. The radio galaxy 3C 66B is excluded as a possible source of the VHE emission.

Key words: BL Lacertae objects: individual (3C 66A) – galaxies: active – gamma rays: observations

1. INTRODUCTION

Wills & Wills (1974) first identified 3C 66A as a quasi-stellar object (QSO) using optical observations. It was subsequently classified as a BL Lacertae (BL Lac) object based on its significant optical and X-ray variability (Maccagni et al. 1987). BL Lac objects are characterized by a double-humped spectral energy distribution (SED) and are further classified according to the location of the lower energy hump, usually interpreted as synchrotron emission from relativistic electrons. Perri et al. (2003) locate the synchrotron peak between 10^{15} and 10^{16} Hz. Therefore, 3C 66A is classified as an intermediate-frequency peaked BL Lac object (IBL). To date, the majority of BL Lac objects detected at VHE (very high energy; $E > 100$ GeV) are high-frequency peaked BL Lac objects (HBLs). Only one other IBL, W Comae, has been detected above 100 GeV (Acciari et al. 2008).

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Table 1

Selection Cuts Applied to the Data for the Soft Cuts as well as the Standard Cuts[a]. Also shown are the results of the VERITAS observations of 3C 66A using both the standard analysis cuts and soft spectrum cuts.

Cuts	θ[a] (deg^2)	Size[b] (DC)	E_{th}[c] (GeV)	On[d]	Off[e]	Alpha[f]	Excess[g]	Sig. (σ)
Soft	< 0.020	> 200	120	7257	31201	0.1752	1791	21.1
Std.	< 0.013	> 400	170	1258	5282	0.1400	518	16.0

Notes.

[a] All other cuts outside of those shown here are the same.

[b] The photoelectron to digital count ratio is approximately four.

[c] Post-cuts energy threshold derived using a spectral index of 4.1.

[d] Number of on-source events passing cuts.

[e] Number of off-source events passing cuts.

[f] Normalization for the off-source events.

[g] Observed excess.

During states of high flux, continuum emission from the jet is dominant and overshadows the few emission lines from the rest of the galaxy. Blazars have few, if any, detectable emission lines, which makes determining the redshift difficult even under the best conditions. Based on a single line, interpreted as Mg II, 3C 66A was determined to be at a redshift of $z = 0.444$ (Miller et al. 1978). In addition to this, Lanzetta et al. (1993) identified a weak Lyα line corroborating these results. Since both measurements rely on a single line, the redshift of this BL Lac object is considered uncertain. Finke et al. (2008) recently derived a lower limit of $z = 0.096$. The determination of the redshift is crucial to understanding this source at VHE due to the effect of the extragalactic background light (EBL; Hauser & Dwek 2001). VHE γ rays are absorbed via pair production interactions with the infrared component of the EBL ($\gamma_{\rm vhe}\gamma_{\rm ebl} \rightarrow e^+e^-$; Gould & Schréder 1967). At VHE energies, this absorption causes a decrease in the observed flux and a softening of the observed spectrum. One can calculate an optical depth ($\tau(z, E)$) based on an EBL density model, the redshift, and the γ-ray energy. The optical depth can be used to calculate the flux corrected for extragalactic absorption from the observed flux at a given energy ($F_{\rm int} = e^{\tau(z,E)} F_{\rm obs}$). Without an accurate measure of the redshift, an accurate photon spectrum intrinsic to the blazar cannot be calculated or modeled.

The EGRET source 3EG J0222+4253, detected at an integral flux between $(12.1 \pm 3.9) \times 10^{-8}$ and $(25.3 \pm 5.8) \times 10^{-8}$ photons cm^{-2} s^{-1}, is associated with 3C 66A (Hartman et al. 1999). Measurements of the spectrum indicated that the spectral index of 2.01 ± 0.14 was influenced by the nearby pulsar PSR 0218+42, which is also inside the EGRET error box. A detailed study of the energy-dependent position of the EGRET source shows that the highest energy photons are coming from the BL Lac object and thus the spectrum is thought to continue out to the VHE band (Kuiper et al. 2000). A re-analysis of the EGRET data by Nandikotkur et al. (2007) finds a harder spectral index of 1.95 ± 0.14 and a flux above 100 MeV of $(17.7 \pm 2.8) \times 10^{-8}$ photons cm^{-2} s^{-1}. Recently, the Fermi Gamma-Ray Space Telescope also reported a detection of 3C 66A, contemporaneous with VHE data taken by VERITAS in the 2008–2009 season, at a higher flux than previously reported by EGRET (Tosti 2008).

There have been several attempts to detect 3C 66A in VHE γ rays. The Crimean Astrophysical Observatory reported a 5.1σ detection above 900 GeV at an average integral flux of 2.4×10^{-11} cm^{-2} s^{-1} (Stepanyan et al. 2002). Additionally, both the Whipple 10 m telescope (Horan et al. 2004) and HEGRA

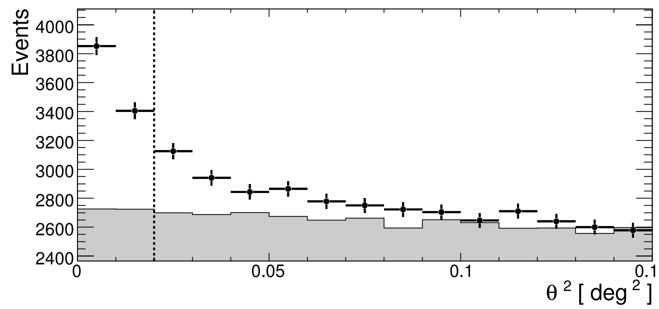

Figure 1. Distribution of θ^2 for on-source events (points) and normalized off-source events (shaded region) from observations of 3C 66A. The dashed line represents the cut on θ^2 applied to the data.

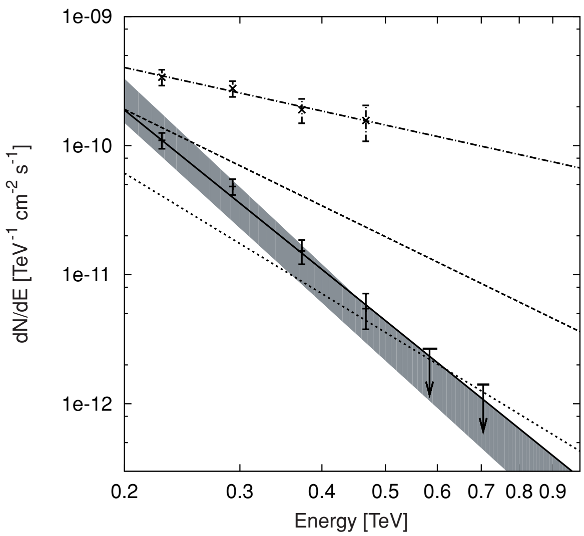

Figure 2. Energy spectrum of 3C 66A shown as solid points. The spectrum is well fitted by a power law with index $\Gamma = 4.1 \pm 0.4_{\rm stat} \pm 0.6_{\rm sys}$ (solid line). The shaded area outlines the systematic error in the spectral index. Using the models of Franceschini et al. (2008) and assuming a redshift of $z = 0.444$, the de-absorbed spectral index is calculated to be 1.1 ± 0.4 showing that the very steep measured spectrum could be due to the distance of 3C 66A. This de-absorbed spectrum is shown as a dashed-dotted line and points. The MAGIC spectrum with index $\Gamma = 3.1$ from Aliu et al. (2009) is shown as a dotted line. The Crab Nebula's spectrum divided by 10 is also shown for comparison (dashed line).

telescope array (Aharonian et al. 2000) observed 3C 66A and reported upper limits of $<0.35 \times 10^{-11}$cm^{-2} s^{-1} (99.9% confidence; above 350 GeV) and $<1.4 \times 10^{-11}$cm^{-2} s^{-1} (99% confidence; above 630 GeV), respectively. STACEE reported several upper limits between <1.0 and $<1.8 \times 10^{-10}$ cm^{-2} s^{-1} above 150–200 GeV depending on the source spectrum (Bramel et al. 2005). Recently, MAGIC reported a 5.4σ detection of VHE emission above 150 GeV from observations in September to December 2007 coincident with 3C 66B. They exclude 3C 66A as the source of the VHE emission at an 85% confidence level (Aliu et al. 2009).

2. VERITAS DETECTOR AND OBSERVATIONS

The VERITAS detector is an array of four 12 m diameter imaging atmospheric Cherenkov telescopes located in southern Arizona (Weekes et al. 2002). Designed to detect emission from astrophysical objects in the energy range from 100 GeV to greater than 30 TeV, VERITAS has an energy resolution of $\sim$15% and an angular resolution (68% containment) of $\sim$0$^\circ\!\!.$1 per event. A source with a flux of 1% of the Crab Nebula is detected in $\sim$50 hr of observations while a 5% Crab Nebula flux

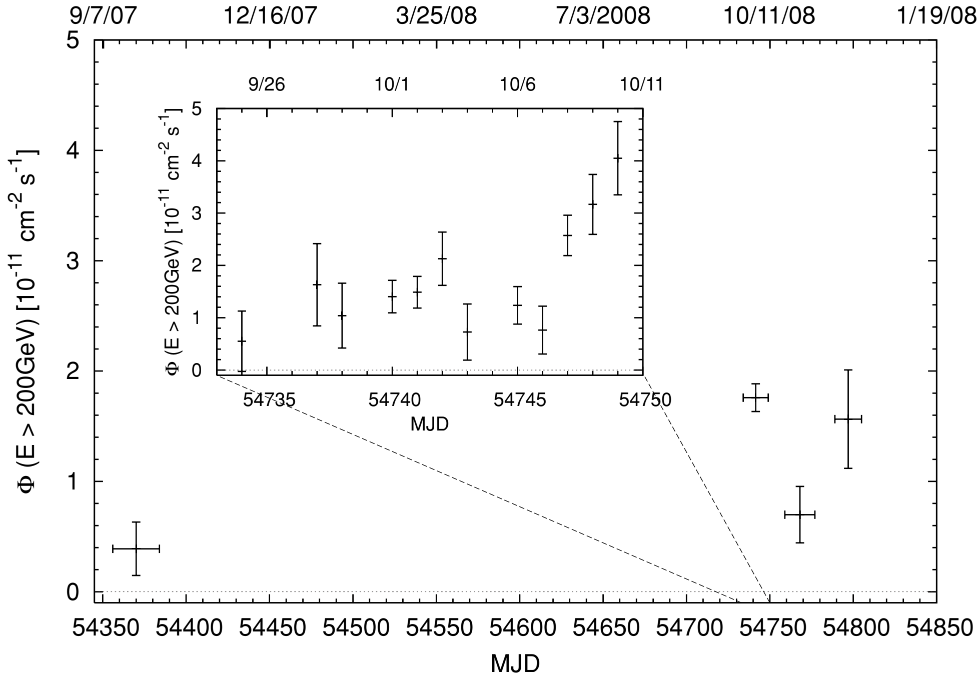

Figure 3. Light curve binned by dark period (the time between two full moons) for the full data set from 3C 66A. These data indicate night-by-night variability for the second dark period (MJD 54734 through 54749) but not within any of the other dark periods. The inset details this dark period binned by night when the flare occurred.

source is detected in ∼2.5 hr. The field of view of the VERITAS telescopes is 3°.5. For more details on the VERITAS instrument and technique, see Holder et al. (2008).

VERITAS observed 3C 66A for 14 hr from September 2007 through January 2008 (hereafter, the 2007–2008 season). From September through November 2008 (hereafter, the 2008–2009 season), a further 46 hr of data were taken. In total, 180 twenty-minute exposures were made, where 109 exposures passed selection criteria which remove data with poor weather (based on infrared sky-temperature measurements) or with hardware-related problems. Data collection frequently occurred during poor weather conditions causing the lower selection throughput demonstrated here. In total, the 2007–2008 season resulted in 4.7 hr live time and the recent 2008–2009 season produced 28.1 hr live time. The average zenith angle was 17°.3. All data were taken on moonless nights in the "wobble" mode where the telescopes are pointed away from the source by ±0°.5 to allow for simultaneous background estimation (Berge et al. 2007).

3. ANALYSIS METHODS

Prior to event selection and background subtraction, the shower images are calibrated and cleaned as described in Cogan (2006) and Daniel et al. (2008). Several noise-reducing event-selection cuts are made at this point, including rejecting those events where only the two closest spaced telescopes participated in the trigger. Following the calibration and cleaning of the data, the events are parameterized using a moment analysis (Hillas 1985). From this moment analysis, the scaled parameters are calculated and used for event selection (Aharonian et al. 1997; Krawczynski et al. 2006). The event selection cuts are optimized a priori using the data taken on the Crab Nebula, scaling the background and excess rates to account for a weaker source. These selection criteria are termed the "standard cuts." Since 3C 66A is possibly very distant and the observed spectrum is expected to be soft, a modified "soft cuts" applies a further a priori optimization of increasing the θ^2 cut (the angular distance squared from the position of 3C 66A and the reconstructed shower direction) and decreasing the size cut (the number of photoelectrons in an event) for sources with a soft spectrum (see Table 1). Unless stated otherwise, the "soft cuts" were used to generate the results presented in this Letter.

The reflected-region model (Berge et al. 2007) is used for background subtraction. The total number of events in the on-source region is then compared to the total number of events in the more numerous off-source regions, scaled by the ratio (called α) of the solid angles, to produce a final excess.

4. VERITAS RESULTS

An excess of 1791 events is observed from the direction of 3C 66A (7257 on events, 31201 off events with an off-source normalization ratio α of 0.1752). The excess corresponds to a statistical significance of 21.1σ using Equation (17) from Li & Ma (1983). The distribution of θ^2 is shown in Figure 1. The shape of the excess is consistent with that expected from a point source (68% containment in 0°.16). Since lower energy events are more poorly reconstructed and this data set is dominated by low-energy events, the θ^2 distribution is wider than that of a harder spectrum source. Table 1 details the results using soft cuts as well as standard cuts. Note that the use of two different sets of cuts has an associated trials factor of 2, which has negligible impact on the significance.

Using the soft cuts, the differential energy spectrum over the energy range ∼200 GeV to ∼500 GeV is determined and is shown in Figure 2. The best fit of a power law to these data yields an index $\Gamma = 4.1 \pm 0.4_{\rm stat} \pm 0.6_{\rm sys}$ with a χ^2 of 1.94 for 2 degrees of freedom. An alternative analysis chain confirms this very soft spectrum. Note that there were 1431 excess events detected during the flaring period from MJD 54740 through MJD 54749, which accounts for 80% of the total. Thus, while the spectrum calculated here is for the full data set, it is dominated by the flare. Assuming this power-law spectrum, the observed integral flux for the full data set above 200 GeV is $(1.3 \pm 0.1) \times 10^{-11}$

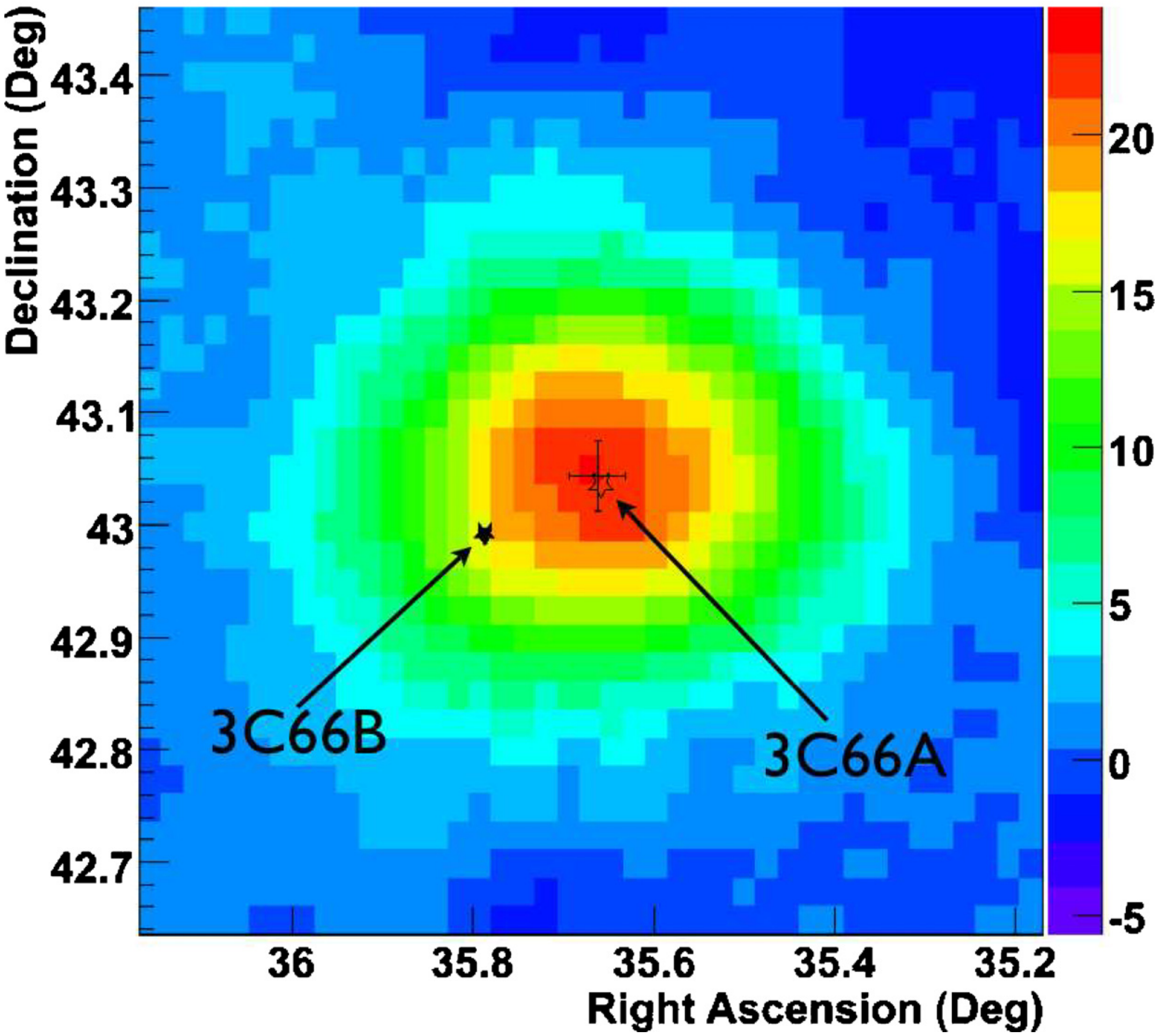

Figure 4. Smoothed significance map of 3C 66A. The location of 3C 66A is shown as an open star and 3C 66B as the closed star. The cross is the fit to the excess VHE emission resulting in a localization of $2^{h}22^{m}41\overset{s}{.}6 \pm 1\overset{s}{.}7 \pm 6\overset{s}{.}0$, $43°02'35''.5 \pm 21'' \pm 1'30''$. These data strongly favor 3C 66A as the source of the γ-ray emission at a significance level of 4.3σ. Note that the bins are highly correlated due to an integration over angular space.

$\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ (6% of the Crab Nebula's flux). By comparison, the 2007–2008 season yielded a significance of 2.6σ at a lower average flux above 200 GeV of $(3.9 \pm 1.6) \times 10^{-12}$ photons $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, which is 26% of the flux seen in 2008–2009. Figure 3 shows the integral flux above 200 GeV from 3C 66A for each dark period (the time between two full moons). The highest flux seen from 3C 66A occurred on MJD 54749. A significant variability is seen only during the dark period spanning September 25 through October 10 (shown in the inset of Figure 3), with a χ^2 probability of 0.009% for a fit to a constant flux. No statistically significant evidence for variability is seen within any of the individual nights. Fits of a constant to the nightly flux in any other dark period do not yield a χ^2 probability less than 10%.

The radio galaxy 3C 66B lies in the same field of view as 3C 66A at a separation of $0\overset{\circ}{.}12$ and is also a plausible source of VHE radiation (Tavecchio & Ghisellini 2008). With the recent detection of VHE emission from the 3C 66A/B region by MAGIC (Aliu et al. 2009) favoring 3C 66B as the source and excluding 3C 66A at an 85% confidence level, it is important to determine which of these objects is the source of the emission reported here. Thus, a two-dimensional Gaussian shape was fitted to the uncorrelated excess of γ rays, yielding a position of $2^{h}22^{m}41\overset{s}{.}6 \pm 1\overset{s}{.}7$, $43°02'35''.5 \pm 21''$, with an additional systematic angular uncertainty of $90''$. The systematic error has been confirmed via optical pointing monitors which are mounted to each telescope. This rules out 3C 66B as the source of the VHE emission reported here at a significance level of 4.3σ. 3C 66A lies $0\overset{\circ}{.}01$ from the fit position while 3C 66B lies $0\overset{\circ}{.}13$ away and the total error on the fit is $0\overset{\circ}{.}03$ (see Figure 4). In addition to fitting the full data set, fits were made to the data divided into high (>300 GeV) and low (<300 GeV) energy bands under the assumption that the high-energy emission might originate from 3C 66B, while the low-energy emission might come from 3C 66A (see Tavecchio & Ghisellini 2008). The fit to the position did not deviate from the measurement using the full data set. Correlated variability studies utilizing optical, VHE, and HE (30 MeV to 100 GeV) bands are underway to verify 3C 66A as the source of VHE γ rays and will be the subject of a future paper. Further restricting the VERITAS data to observations contemporaneous with MAGIC in September to December 2007, we calculate an upper limit, assuming the reported MAGIC spectrum of $\Gamma = 3.10$, on the flux above 300 GeV from 3C 66B to be 1.8×10^{-12} photons $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

at the 99% confidence level based on ∼5 hr of data. MAGIC reported an integral flux based on a ∼50 hr exposure above 150 GeV of $(7.3 \pm 1.5) \times 10^{-12}$ photons cm^{-2} s^{-1} for their full data set (approximately 1.7×10^{-12} photons cm^{-2} s^{-1} above 300 GeV). Unfortunately, it is not possible to calculate a spectrum from the 2007–2008 season data due to low statistics. Although VERITAS is more sensitive (∼2×) than MAGIC the brief (∼5 hr) exposure on the 3C 66A/B region in 2007 does not enable a clear determination of which object was the source of VHE emission in 2007. However, based on the MAGIC flux, VERITAS expects ∼700 excess events at the location of 3C 66B in the full data set, whereas only ∼300 are detected and the latter is consistent with expectations for spill over from 3C 66A due to the VERITAS point-spread function (PSF). Therefore, if the MAGIC claims of VHE emission from 3C 66B are correct, it must have been considerably brighter in 2007 than 2008, and similarly 3C 66A must have been considerably brighter in 2008 than 2007.

5. SUMMARY & CONCLUSION

VERITAS has observed the IBL 3C 66A for a total of 32.8 hr good-quality live time from September 2007 through November 2008, resulting in the detection of VHE γ rays with a statistical significance of 21.1σ. The average integral flux above 200 GeV is $(1.3 \pm 0.1) \times 10^{-11}$ cm^{-2} s^{-1} (6% of the Crab Nebula's flux). The differential energy spectrum is well fitted by a soft power law with index $\Gamma = 4.1 \pm 0.4_{\mathrm{stat}} \pm 0.6_{\mathrm{sys}}$ between 200 and 500 GeV.

It is thought that the redshift of 3C 66A is $z = 0.444$ but this measurement is based upon a single, poorly detected line (Miller et al. 1978). A definitive measurement of the redshift is needed to determine the intrinsic spectrum of 3C 66A, corrected for EBL absorption. The extreme distance of 3C 66A, if true, will allow modelers to probe the evolution of the EBL with redshift. Assuming the current redshift measurement of $z = 0.444$, we calculate a de-absorbed spectrum based on the EBL models of Franceschini et al. (2008) which are based upon recent measurements from the optical to the submillimeter. The original spectrum along with the corrected spectrum can be seen in Figure 2. While this is not a definitive calculation of the intrinsic spectrum, due to the uncertainties in the redshift measurement and in the modeling of the EBL, it illustrates that the steepness of the measured spectrum could be due to the distance of 3C 66A.

The initial announcement of a detection of VHE emission from 3C 66A (Swordy 2008) prompted several other groups and instruments to also observe this object (Tosti 2008; Larionov et al. 2008). In addition, the Fermi Gamma-Ray Space Telescope detected 3C 66A at a level higher than that reported by EGRET. The *Swift* observatory also monitored 3C 66A over this time period, in the X-ray and UV bands. A future paper by the Fermi Collaboration, VERITAS Collaboration, and multiwavelength partners will describe these results and provide details on correlated variability as well as a broadband SED for the 2008 data set.

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REFERENCES

Acciari, V. A., et al. 2008, ApJL, 684, L73
Aharonian, F. A., Hofmann, W., Konopelko, A. K., & Völk, H. J. 1997, Astropart. Phys., 6, 343
Aharonian, F. A., et al. 2000, A&A, 353, 847
Aliu, E., et al. 2009, ApJL, 692, L29
Berge, D., Funk, S., & Hinton, J. 2007, A&A, 466, 1219
Bramel, D. A., et al. 2005, ApJ, 629, 108
Cogan, P. 2006, PhD thesis School of Physics, Univ. College Dublin
Daniel, M. K., et al. 2008, Proc. 30th ICRC, Merida Mexico, ed. R. Caballero, J. C. D'Olivo, G. Medina-Tanco, L. Nellen, F. A. Sánchez, & J. F. Valdés-Galicia, 3, 1325
Finke, J. D., Shields, J. C., Böttcher, M., & Basu, S. 2008, A&A, 477, 513
Franceschini, A., Rodighiero, G., & Vaccari, M. 2008, A&A, 487, 837
Gould, R. J., & Schréder, G. P. 1967, Phys. Rev., 155, 1408
Hartman, R. C., et al. 1999, ApJS, 123, 79
Hauser, M. G., & Dwek, E. 2001, ARA&A, 39, 249
Hillas, A. M. 1985, Proc. 19th ICRC, NASA Goddard Flight Center, ed. F. C. Jones, 445
Holder, J., et al. 2008, Proc. 4th Int. Meeting on High Energy Gamma-Ray Astronomy, 657
Horan, D., et al. 2004, ApJ, 603, 51
Krawczynski, H., Carter-Lewis, D. A., Duke, C., Holder, J., Maier, G., Le Bohec, S., & Sembroski, G. 2006, Astropart. Phys., 25, 380
Kuiper, L., Hermsen, W., Verbunt, F., Thompson, D. J., Stairs, I. H., Lyne, A. G., Strickman, M. S., & Cusumano, G. 2000, A&A, 359, 615
Lanzetta, K. M., Turnshek, D. A., & Sandoval, J. 1993, ApJS, 84, 109
Larionov, V. M., et al. 2008, ATel, 1759, 1
Li, T.-P., & Ma, Y.-Q. 1983, ApJ, 272, 317
Maccagni, D., Garilli, B., Schild, R., & Tarenghi, M. 1987, A&A, 178, 21
Miller, J. S., French, H. B., & Hawley, S. A. 1978, in Pittsburgh Conf. BL Lac Objects, ed. A. M. Wolfe, 176
Nandikotkur, G., Jahoda, K. M., Hartman, R. C., Mukherjee, R., Sreekumar, P., Böttcher, M., Sambruna, R. M., & Swank, J. H. 2007, ApJ, 657, 706
Perri, M., et al. 2003, A&A, 407, 453
Stepanyan, A. A., Neshpor, Y. I., Andreeva, N. A., Kalekin, O. R., Zhogolev, N. A., Fomin, V. P., & Shitov, V. G. 2002, Astron. Rep., 46, 634
Swordy, S. P. 2008, ATel, 1753, 1
Tavecchio, F., & Ghisellini, G. 2008, arXiv:0811.1883
Tosti, G. 2008, ATel, 1759, 1
Weekes, T. C., et al. 2002, Astropart. Phys., 17, 221
Wills, B. J., & Wills, D. 1974, ApJ, 190, L97

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ERRATUM: "VERITAS OBSERVATIONS OF A VERY HIGH ENERGY γ-RAY FLARE FROM THE BLAZAR 3C 66A" (2009, ApJ, 693, L104)

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In the published paper, there was an error in the calculation of the blazar's intrinsic photon spectrum. The intrinsic photon spectrum was determined from the observed VERITAS spectrum by removing the effects of γ-ray absorption on the extragalactic background light (EBL) using the model of Franceschini et al. (2008). The de-absorbed photon spectrum reported in the article with a spectral index of 1.1 ± 0.4 was erroneously calculated using a redshift of $z = 0.5$, not $z = 0.444$ as stated in the text. The correct intrinsic photon index, assuming a redshift of $z = 0.444$, is 1.5 ± 0.4. The corrected Figure 2 is presented below.

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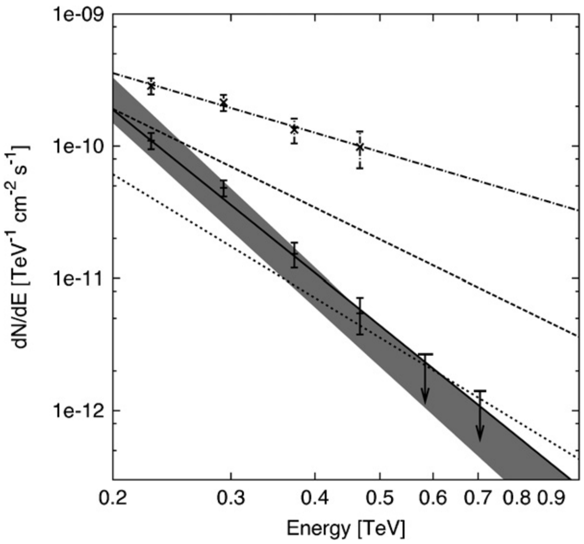

Figure 2. Energy spectrum of 3C 66A shown as solid points. The spectrum is well fitted by a power law with index $\Gamma = 4.1 \pm 0.4_{\mathrm{stat}} \pm 0.6_{\mathrm{sys}}$ (solid line). The shaded area outlines the systematic error in the spectral index. Using the models of Franceschini et al. (2008) and assuming a redshift of $z = 0.444$, the de-absorbed spectral index is calculated to be 1.5 ± 0.4 showing that the very steep measured spectrum could be due to the distance of 3C 66A. This de-absorbed spectrum is shown as a dashed-dotted line and points. The MAGIC spectrum with index $\Gamma = 3.1$ from Aliu et al. (2009) is shown as a dotted line. The Crab Nebula's spectrum divided by 10 is also shown for comparison (dashed line).

REFERENCES

Aliu, E., et al. 2009, ApJ, 629, L29

Franceschini, A., Rodighiero, G., & Vaccari, M. 2008, A&A, 487, 837