VERITAS & Gammapy

Samantha Wong, for the VERITAS Collaboration | Gammapy user call | May 15, 2025 | samantha.wong2@mail.mcgill.ca

Overview

1. Introduction to VERITAS
    a. Instrument
    b. Traditional analysis
2. VERITAS science with Gammapy (so far)
3. Integrating VERITAS with gammapy
    a. DL3 validation procedure
    b. Ring background method
    c. Significance distributions
4. “VERITAS with gammapy” tutorial and public data release

Introduction to VERITAS

Introduction to VERITAS

- 4 x 12m IACTs located at the Fred Lawrence Whipple Observatory in southern Arizona, USA (31° N)
- First light in 2007, with performance upgrades in 2009 (array configuration) and 2012 (PMT upgrade)
- ~80 collaboration members + 55 associate members

Specifications:

- 3.5° FoV
- Energy range: 85 GeV to >30 TeV (spectral reconstruction starts at 100 GeV)
- Angular resolution: 0.08 deg at 1 TeV, 0.13 deg at 200 GeV (68% containment radius)
- Energy resolution: 17% at 1 TeV
- Sensitivity: 10% Crab in 25 min, 1% Crab in 24h

Learn more about VERITAS: https://veritas.sao.arizona.edu/

VERITAS analysis

VEGAS

Flasher analysis
- Relative pixel timing
- Relative pixel gain

Data calibration
- Pixel noise calculations
- Retrieve run information from DB

Calibration Application
- Combine flasher + data
- Hillas parameterization

Shower reconstruction
- Array-level reconstruction
- Mean-scaled parameters based on templates of typical gamma ray images
- Energy calculations

Event Selection
- Gamma/Hadron separation
- Background estimation

Results Extractor
- Significance calculations
- Sky maps
- Flux calculations
- Spectrum

EventDisplay

Evndisp
- Pixel noise calculations
- Relative pixel timing
- Trace integration, image cleaning, parametrization, stereo reconstruction

MSCW energy
- Calculate energy, mean scaled width, mean scaled length from lookup tables

Anasum
- Gamma/hadron separation
- Background estimation

Additional scripts
- Significance calculations
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V2DL3

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V2DL3

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VERITAS science with Gammapy

VERITAS science with gammapy

Multiwavelength Investigation of γ-ray Source MGRO J1908+06 Emission Using *Fermi*–LAT, VERITAS, and HAWC

THE VERITAS COLLABORATION

A. ACHARYYA,[1] C. B. ADAMS,[2] P. BANGALE,[3] J. T. BARTKOSKE,[4] W. BENBOW,[5] J. H. BUCKLEY,[6] J. L. CHRISTIANSEN,[7] A. J. CHROMEY,[5] A. DUERR,[4] M. ERRANDO,[6] A. FALCONE,[8] Q. FENG,[4] G. M. FOOTE,[3] L. FORTSON,[9] A. FURNISS,[10] W. HANLON,[5] D. HANNA,[11] O. HERVET,[12] C. E. HINRICHS,[13] J. HOLDER,[3] T. B. HUMENSKY,[14] W. JIN,[15] P. KAARET,[16] M. KERTZMAN,[17] D. KIEDA,[4] T. K. KLEINER,[18] N. KORZOUN,[3] S. KUMAR,[19] M. J. LANG,[20] M. LUNDY,[11] G. MAIER,[18] C. E MCGRATH,[21] M. J. MILLARD,[16] J. MILLIS,[22] C. L. MOONEY,[3] P. MORIARTY,[20] R. MUKHERJEE,[23] W. NING,[15] R. A. ONG,[15] N. PARK,[24] M. POHL,[25] E. PUESCHEL,[26] J. QUINN,[21] P. L. RABINOWITZ,[6] K. RAGAN,[11] D. RIBEIRO,[9] E. ROACHE,[5] J. L. RYAN,[15] I. SADEH,[18] L. SAHA,[5] G. H. SEMBROSKI,[27] R. SHANG,[23] M. SPLETTSTOESSER,[12] A. K. TALLURI,[9] J. V. TUCCI,[28] J. VALVERDE,[29] V. V. VASSILIEV,[15] A. WEINSTEIN,[30] D. A. WILLIAMS,[12] S. L. WONG,[11] J. WOO,[31]

THE HAWC COLLABORATION

R. ALFARO,[32] C. ALVAREZ,[33] J.C. ARTEAGA-VELÁZQUEZ,[34] D. AVILA ROJAS,[32] R. BABU,[35] E. BELMONT-MORENO,[32] A. BERNAL,[36] K.S. CABALLERO-MORA,[33] T. CAPISTRÁN,[36] A. CARRAMIÑANA,[37] S. CASANOVA,[38] J. COTZOMI,[39] S. COUTIÑO DE LEÓN,[40] E. DE LA FUENTE,[41] D. DEPAOLI,[42] N. DI LALLA,[43] R. DIAZ HERNANDEZ,[37] M.A. DUVERNOIS,[40] C. ESPINOZA,[32] K.L. FAN,[19] K. FANG,[40] N. FRAIJA,[36] J.A. GARCÍA-GONZÁLEZ,[44] F. GARFIAS,[36] M.M. GONZÁLEZ,[36] J.A. GOODMAN,[19] S. GROETSCH,[35] S. HERNÁNDEZ-CADENA,[32] J. HINTON,[42] D. HUANG,[19] F. HUEYOTL-ZAHUANTITLA,[33] A. IRIARTE,[36] S. KAUFMANN,[45] D. KIEDA,[46] J. LEE,[47] H. LEÓN VARGAS,[32] A.L. LONGINOTTI,[36] G. LUIS-RAYA,[45] K. MALONE,[48] J. MARTÍNEZ-CASTRO,[49] J.A. MATTHEWS,[50] P. MIRANDA-ROMAGNOLI,[51] J.A. MORALES-SOTO,[34] E. MORENO,[39] M. MOSTAFÁ,[52] L. NELLEN,[53] E.G. PÉREZ-PÉREZ,[45] C.D. RHO,[47] D. ROSA-GONZÁLEZ,[37] H. SALAZAR,[39] A. SANDOVAL,[32] M. SCHNEIDER,[19] J. SERNA-FRANCO,[32] Y. SON,[47] R.W. SPRINGER,[46] O. TIBOLLA,[45] K. TOLLEFSON,[54] I. TORRES,[37] R. TORRES-ESCOBEDO,[55] R. TURNER,[35] F. UREÑA-MENA,[37] E. VARELA,[39] X. WANG,[35] H. ZHOU,[55]

THE *Fermi*–LAT COLLABORATION

J. EAGLE,[56] S. KUMAR,[57]

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(VERITAS COLLABORATION)

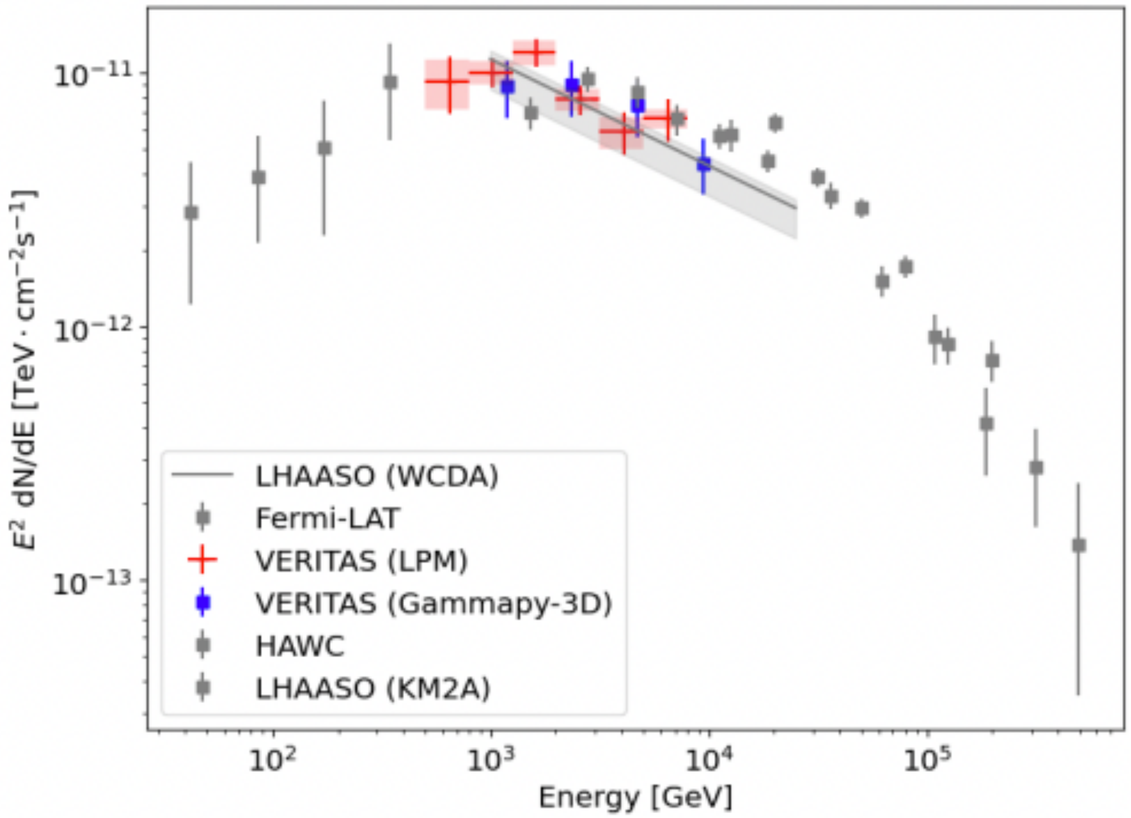
JON KWONG,[31] KAYA MORI,[30] CHARLES J. HAILEY,[30,31] SAMAR SAFI-HARB,[32] SHUO ZHANG[33] AND NAOMI TSUJI[34]

(*XMM-Newton* COLLABORATION)

SILVIA MANCONI,[35,36] FIORENZA DONATO[37] AND MATTIA DI MAURO[38]

VERITAS science with gammapy

Multiwavelength Investigation of γ-ray Source MGRO J1908+06 Emission Using *Fermi*–LAT, VERITAS, and HAWC



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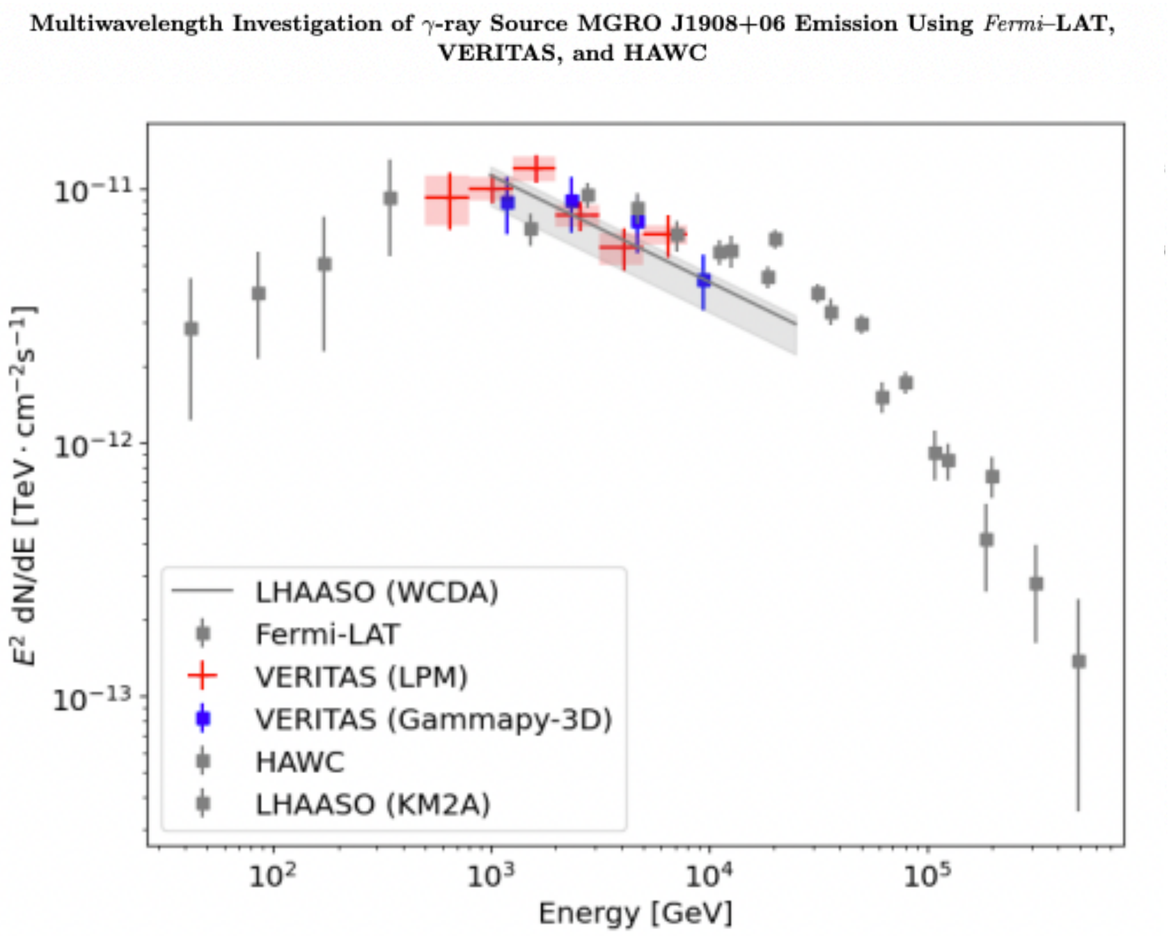
(VERITAS collaboration)

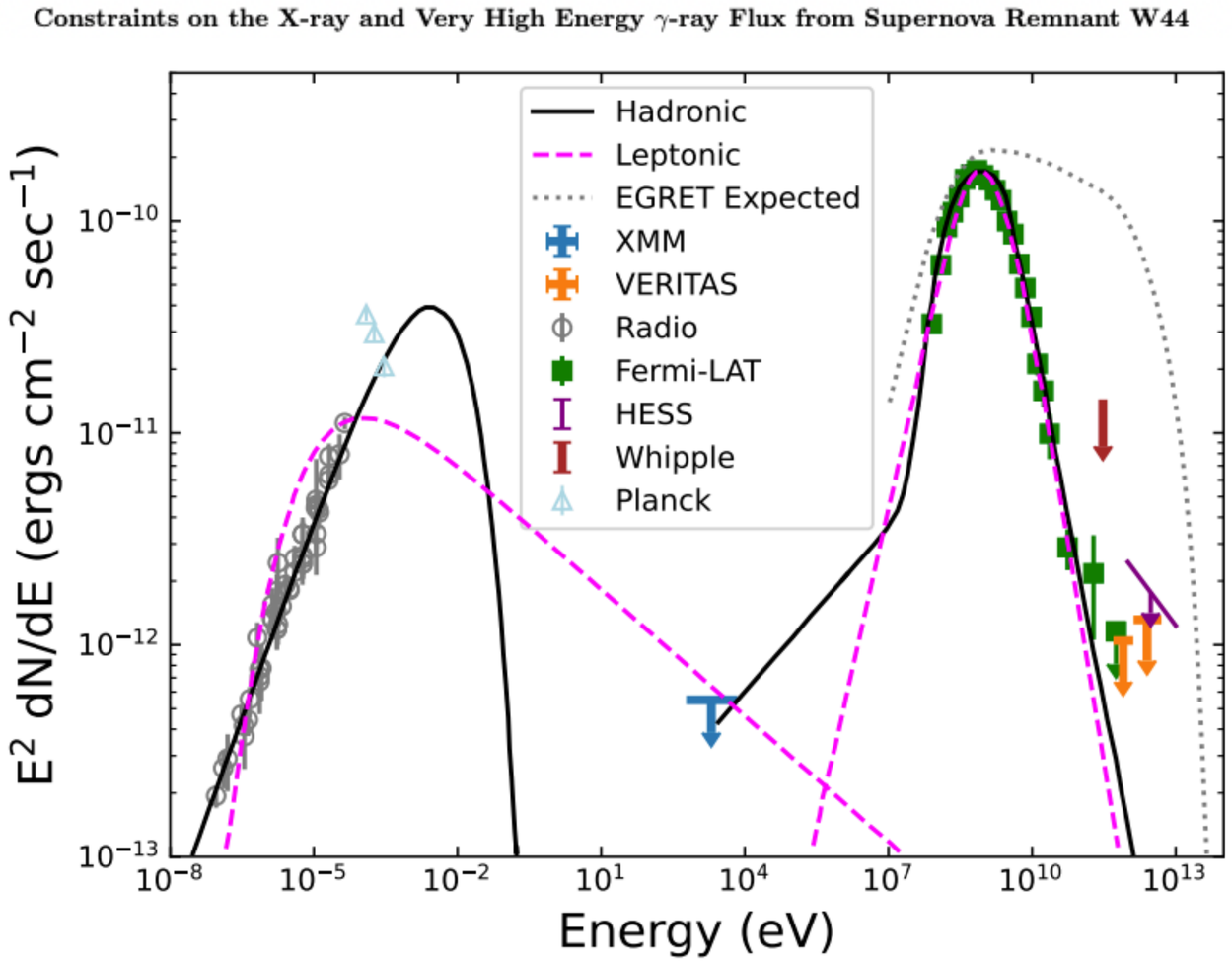
Jon Kwong,[31] Kaya Mori,[30] Charles J. Hailey,[30,31] Samar Safi-Harb,[32] Shuo Zhang[33] And Naomi Tsuji[34]

(*XMM-Newton* collaboration)

Silvia Manconi,[35,36] Fiorenza Donato[37] And Mattia Di Mauro[38]

VERITAS science with gammapy





VERITAS science with gammapy

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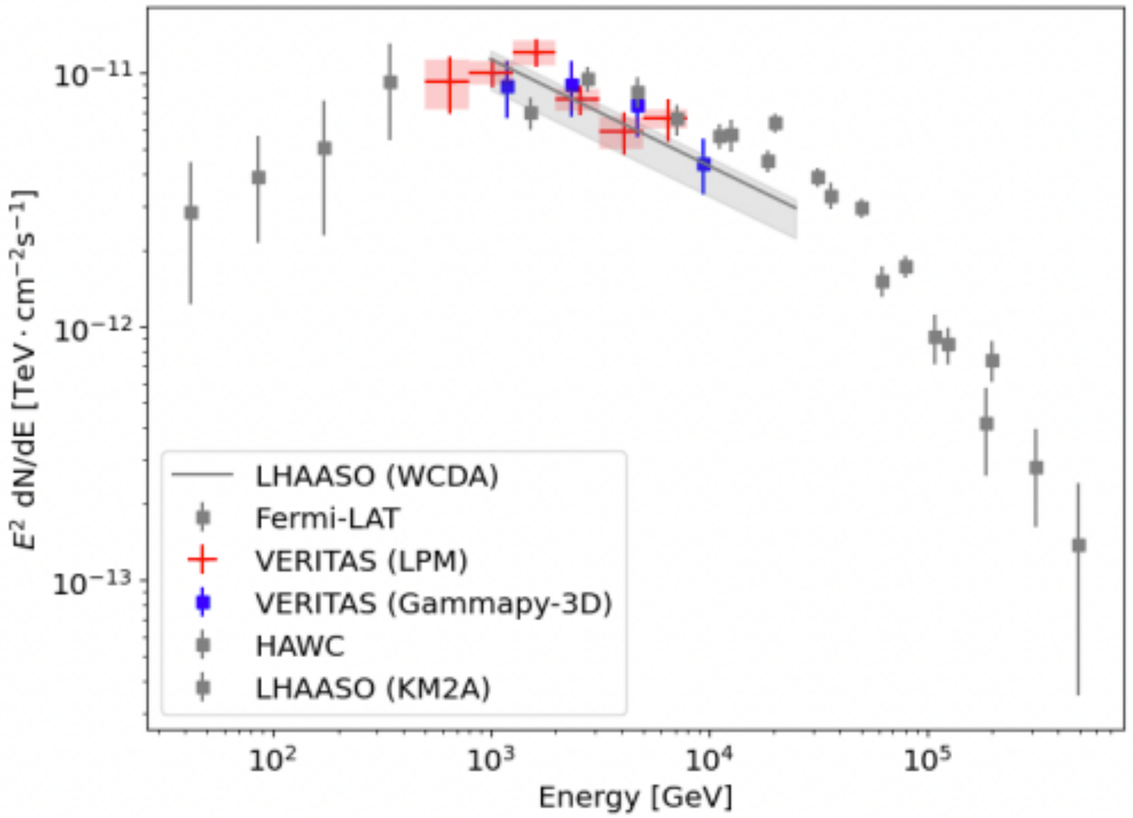

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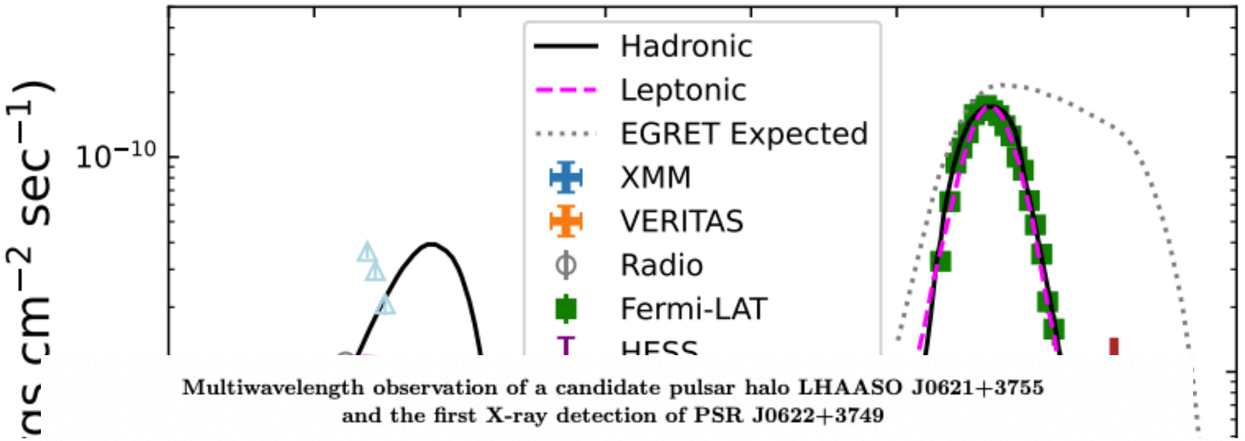

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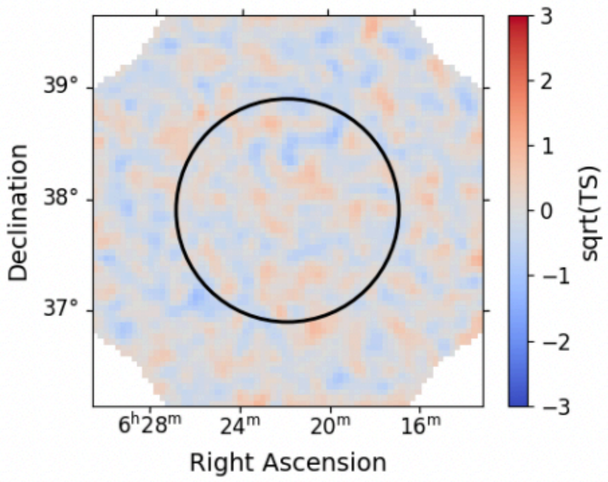
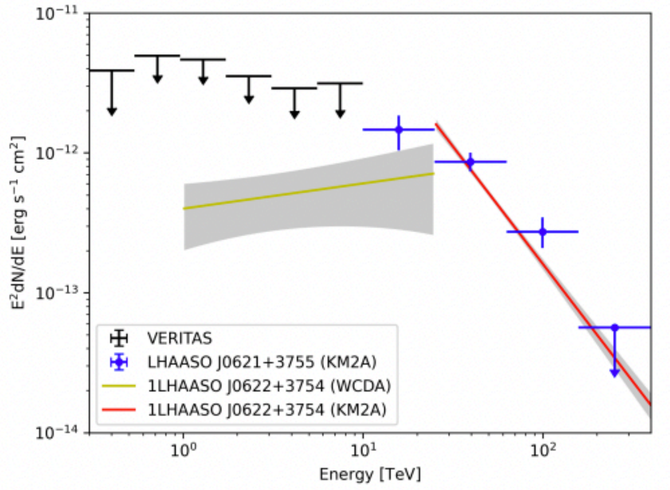




VERITAS science with gammapy

Towards open and reproducible multi-instrument analysis in gamma-ray astronomy

C. Nigro[1], C. Deil[2], R. Zanin[2], T. Hassan[1], J. King[3], J. E. Ruiz[4], L. Saha[5], R. Terrier[6], K. Brügge[7], M. Nöthe[7], R. Bird[8], T. T. Y. Lin[9], J. Aleksić[10], C. Boisson[11], J. L. Contreras[5], A. Donath[2], L. Jouvin[10], N. Kelley-Hoskins[1], B. Khelifi[6], K. Kosack[12], J. Rico[10], and A. Sinha[6]

2019
Public Crab data for joint analysis with Fermi-LAT, MAGIC, VERITAS, FACT, H.E.S.S.

VERITAS test DL3 data set for gammapy development

Wong, Samantha (Data curator)[1]; Lundy, Matthew (Data curator)[1]; Maier, Gernot (Data curator)[2]

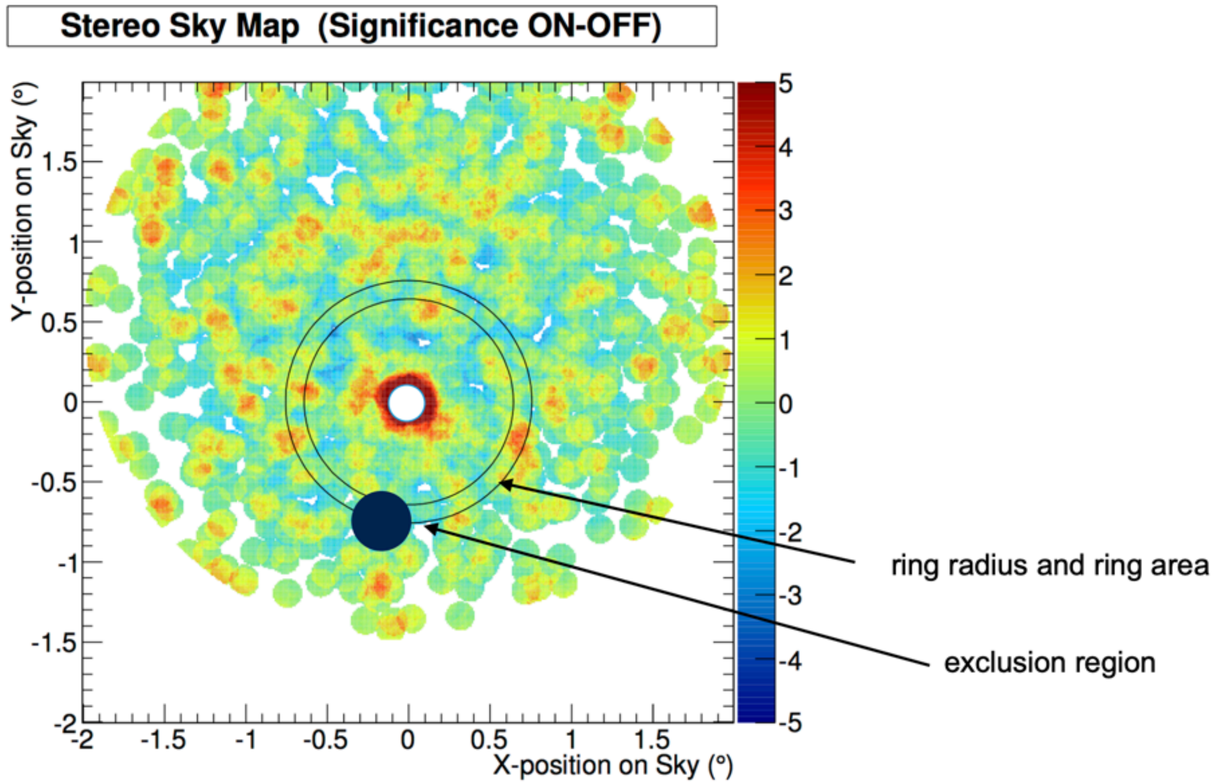
Show affiliations

Test dataset at DL3 level from VERITAS observations to be used for testing and developing the gammapy software. The dataset includes multiple observation runs targeting the Crab Nebula (runs 64080-64083) and the Segue 1 dwarf spheroidal galaxy (runs 73266, 77021, 80190, 81437).

Released under an informal data-sharing agreement between the VERITAS collaboration and the Gammapy developer team.

2025
Data release for gammapy development purposes

Ring background analysis



What is ring background?

→ OFF counts are calculated in an annular region surrounding the source

→ Ring size and location can be adjusted based on the source extension and exclusion regions

→ Backgrounds (radial acceptances) are used to normalize the acceptance of the ring to that of the source location

Why ring background?

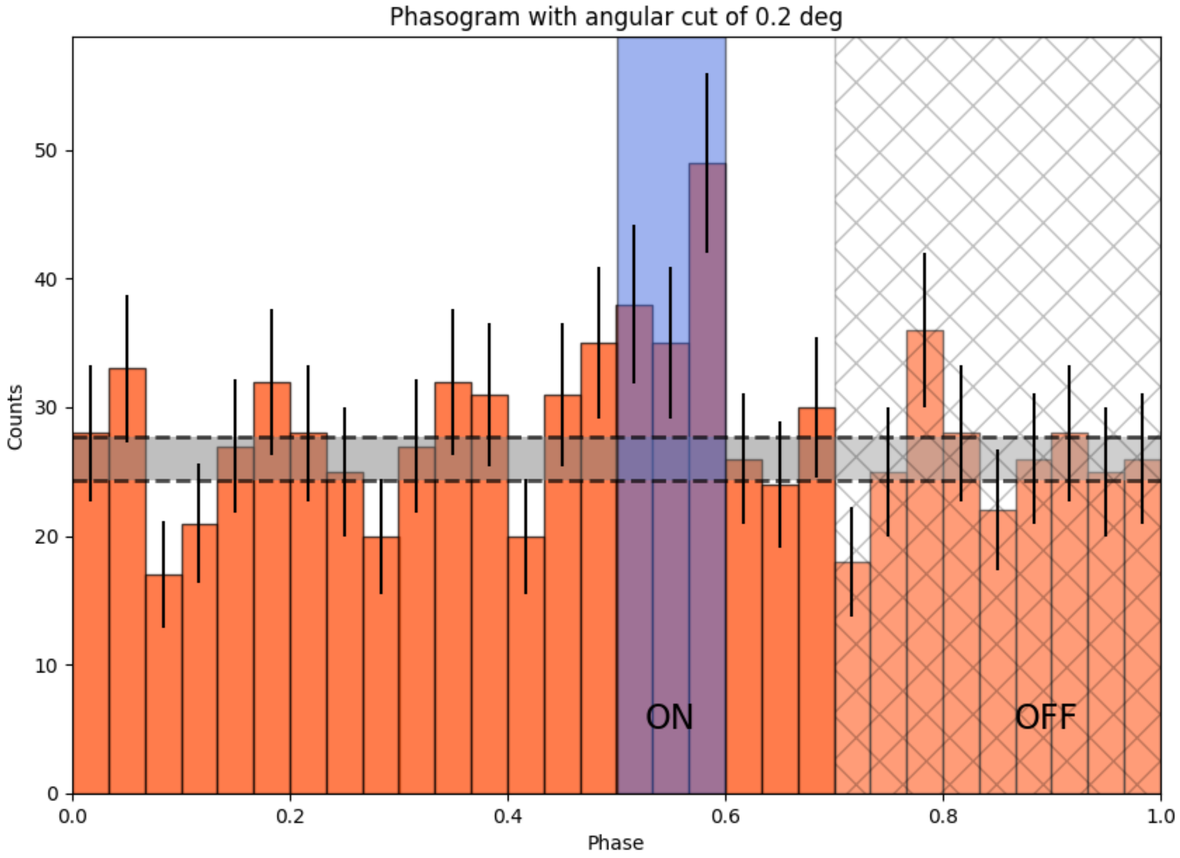
→ Allows for the analysis of extended sources or locations that can't be wobbled

→ Directly compare results with existing VERITAS packages

→ Allows us to validate full-enclosure DL3 files & backgrounds without additional complications of 3D analysis

New with Gammapy: energy-dependent acceptances

Pulsar analysis



Phase-resolved spectra are easy to make in gammapy

→ **New with Gammapy:** Easy nebula subtraction for flux estimation and spectra

Python allows integration of barycentering and phase calculations with PINT

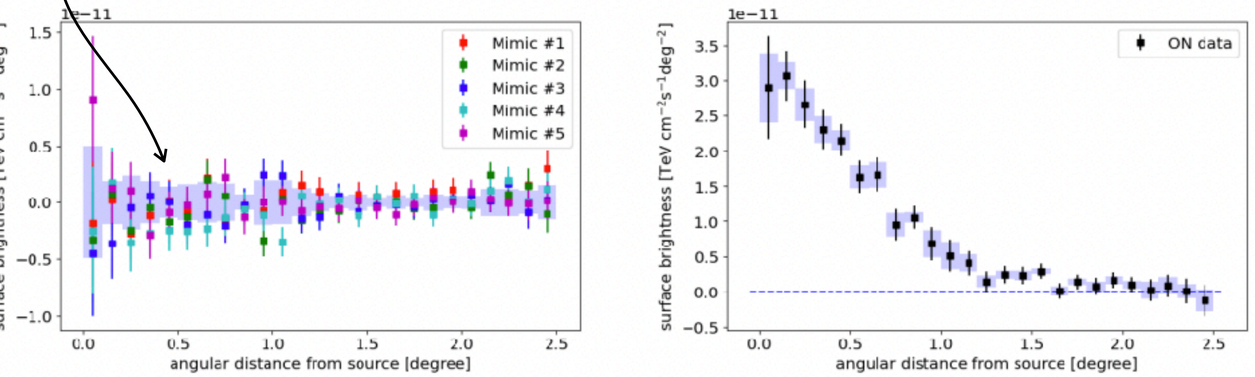
→ We modified some older Gammapy recipes to assign phases to VERITAS data

→ Other collaborations also have scripts to do this — is there any interest in making a universal up-to-date PINT script for DL3 files?

Mimic data method for extended sources

$$\sigma_{\mathrm{syst}}(x,y) = \sqrt{\frac{1}{5}\sum_{i=1}^{5}\left(\frac{D_i(x,y) - B_i(x,y)}{D_i(x,y)}\right)^2},$$

where $D_i(x,y)$ ($B_i(x,y)$) is the data (background) count in the sky map bin (x,y) in the mimic data set i.



(a) (b)

Plots from: [Multiwavelength Investigation of γ-ray Source MGRO J1908+06 Emission Using Fermi–LAT, VERITAS, and HAWC] (method described in appendix B.2.)

For extended sources, we want to quantify the uncertainties in our background estimation techniques.

1. Select gamma-ray-free mimic data (point source observations with the point sources excluded) to mimic the observation data (> 80% of the total exposure) — repeat 5x

2. Transform the RA, DEC to match the observations

3. Estimate the systematic uncertainty on the background by computing the RMS of the background-subtracted mimic data sets

Integrating VERITAS with Gammapy

VERITAS with Gammapy

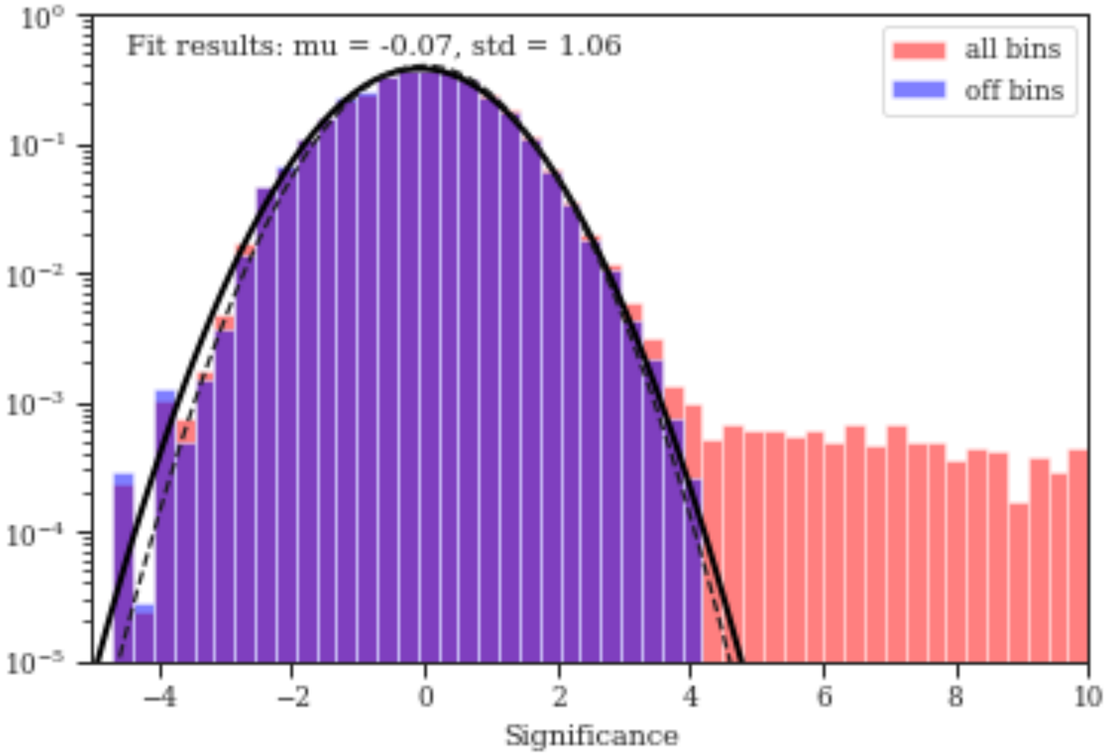
Point-like validation for both VERITAS packages → Full-enclosure DL3 validation with ring background → 3D analysis

✅ Significance & flux calculations
✅ Spectra
✅ Light curves

✅ Full-enclosure significance, counts, flux
✅ Ring background spectra
🏗️ Sky maps & significance distributions
🏗️ Extended source analysis

🏗️ Method validation for VERITAS data

Significance distributions



We've noticed significance distributions for point sources are broadened and **skewed negative by ~5%** compared to VERITAS analyses

→ Both ring background and FoV methods show this

→ We've also seen this in other collaboration results that we've seen at conferences, etc. **Has anyone else noticed this?**

VERITAS with Gammapy

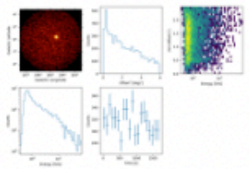
“VERITAS with Gammapy” tutorial notebook coming soon (aiming for 2.0 release)!

→ Data exploration + full VERITAS point-like significance, spectral, and light curve analyses

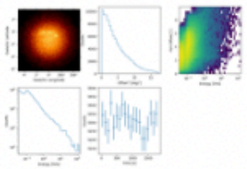
→ Release of first public dataset in gammapy-data

Data exploration

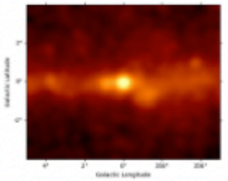
These tutorials show how to perform data exploration with Gammapy, providing an introduction to the CTA, HAWC, H.E.S.S. and Fermi-LAT data and instrument response functions (IRFs). You will be able to explore and filter event lists according to different criteria, as well as to get a quick look of the multidimensional IRFs files.



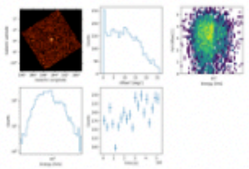
H.E.S.S. with Gammapy



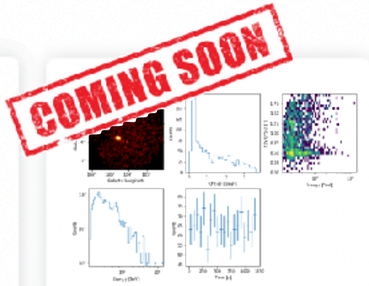
CTAO with Gammapy



Fermi-LAT with Gammapy



HAWC with Gammapy



VERITAS with Gammapy