# Limits on the Emission of Gamma Rays from M31 (The Andromeda Galaxy) with HAWC

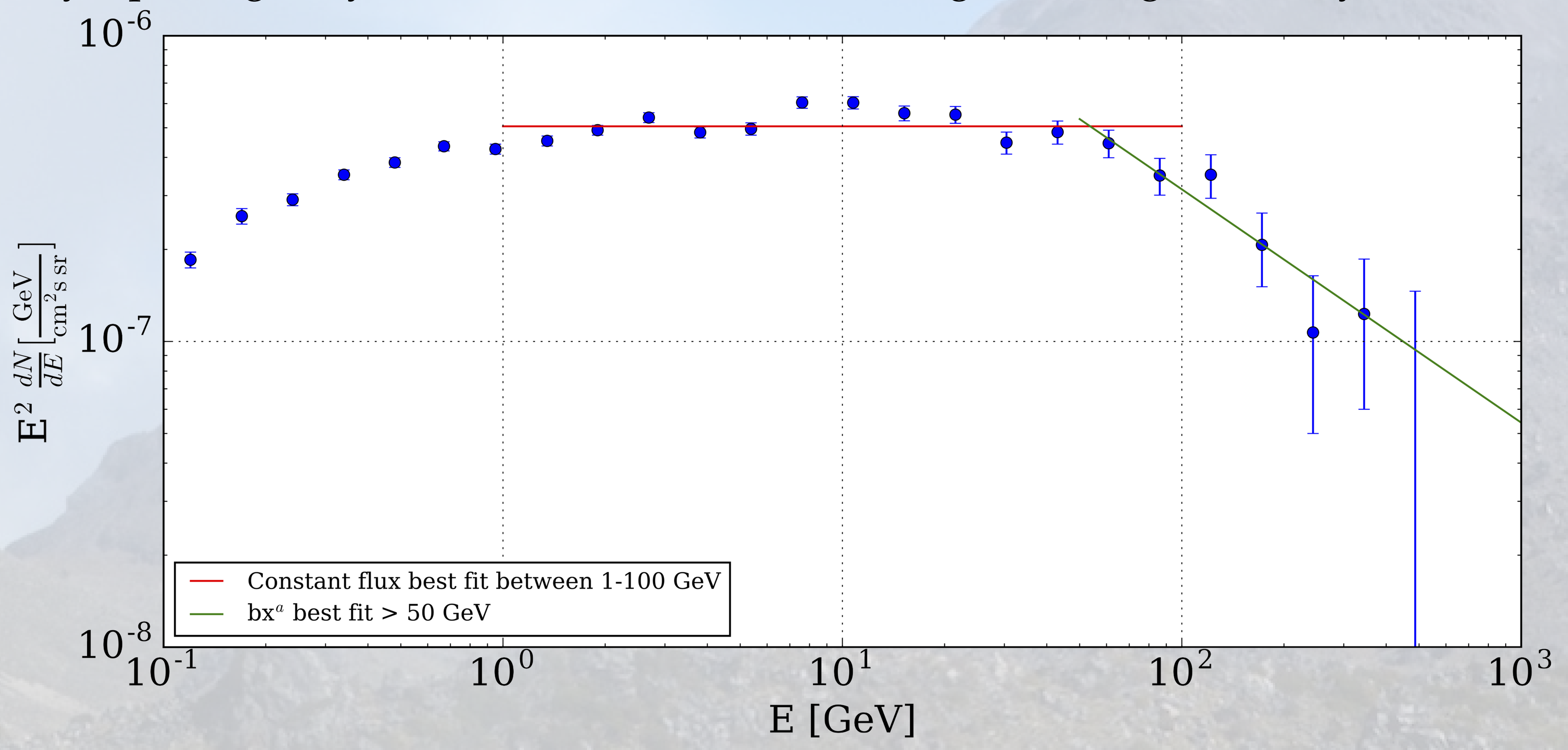
Ryan Rubenzahl[1], Segev BenZvi[1], Joshua Wood[2]

[1]Department of Physics and Astronomy, University of Rochester, Rochester, NY, USA
[2]Department of Physics and WIPAC, University of Wisconsin-Madison, Madison, WI, USA

The detection of the Fermi Bubbles suggests that spiral galaxies such as the Milky Way can undergo active periods. Using gamma-ray observations we can investigate the possibility that such structures are present in other nearby galaxies. We have analyzed the region around the Andromeda Galaxy (Messier Catalog M31) for signs of bubble-like emission using TeV gamma-ray data recorded by the High-Altitude Water Cherenkov Observatory. We fit a model consisting of two 6 kpc bubbles symmetric about and perpendicular to the M31 galactic plane and assume a power-law distribution for the gamma-ray flux. We compare the emission from these bubble regions to that expected from structures similar to the Fermi Bubbles found in the Milky Way. No significant emission was observed. We report upper limits on the TeV flux from Fermi Bubble structures in M31.

## Introduction

The "Fermi Bubbles" are two large spherical regions of gamma-ray emission above and below the Galactic Plane [1]. The flux has been observed between 100 MeV and 300 GeV and is described by a power law with a cutoff above 100 GeV [2], though the spectrum is also fit by a broken power law with a break at 50 GeV (see figure below). The origin of the bubbles is not understood, and at present only the Milky Way is the only spiral galaxy observed with extended regions of gamma-ray emission.

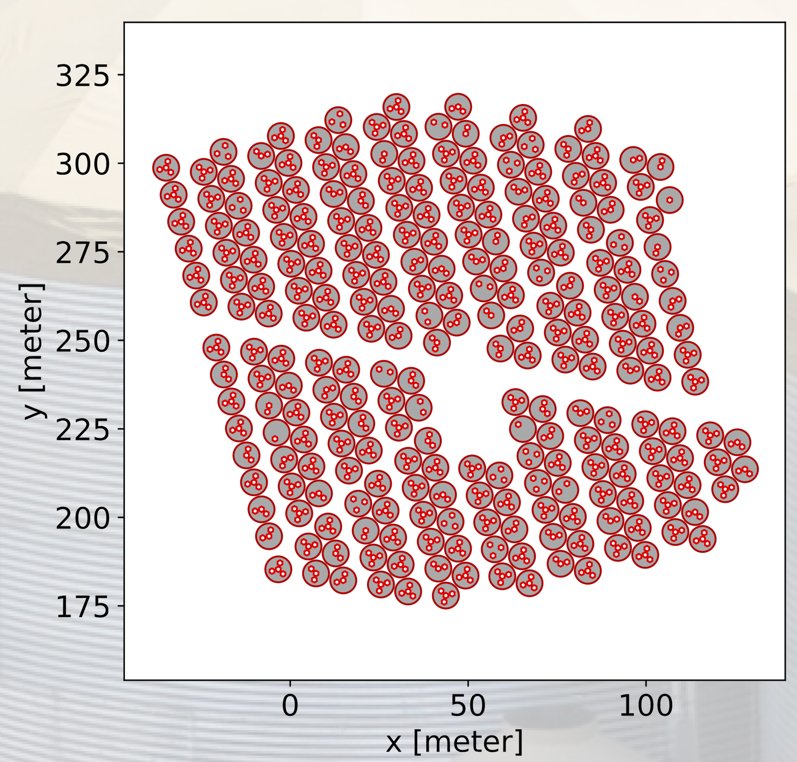


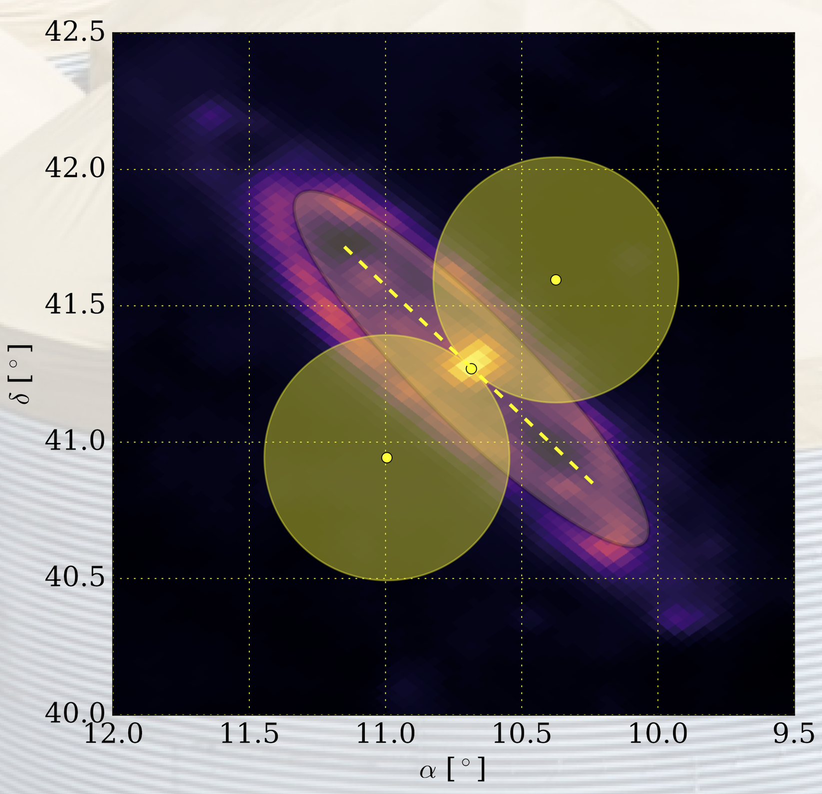

However, a recent analysis of Fermi-LAT data suggests that M31, the Andromeda Galaxy, contains two $6.0 - 7.5$ kpc circular regions of gamma-ray emission [3]. Like the Fermi Bubbles in our own Galaxy, these regions are oriented perpendicular to the plane of M31 and are symmetric about its galactic nucleus.

At TeV energies, VERITAS observed M31 for 54 hours but has not found emission from the galactic plane or the region around its galactic nucleus [4]. While VERITAS is quite sensitive to point sources, the spatial extent of M31 (roughly $3° \times 1°$) makes it a challenging target for pointed telescopes. The High-Altitude Water Cherenkov (HAWC) Observatory is well-suited to observe very spatially extended targets. We report observations of M31 with HAWC using 760 days ($\sim$ 25 months) of data recorded since November 2014.

## Observing M31 with HAWC

The HAWC Observatory (below left) is an air shower array covering 22,000 m$^2$ in Sierra Negra, Mexico. The array contains 296 water Cherenkov detectors with 4 photomultipliers per detector. Using the timing of hits from charged particles in an air shower, gamma rays can be reconstructed with a typical angular resolution of 1° at 1 TeV and 0.2° above 10 TeV.

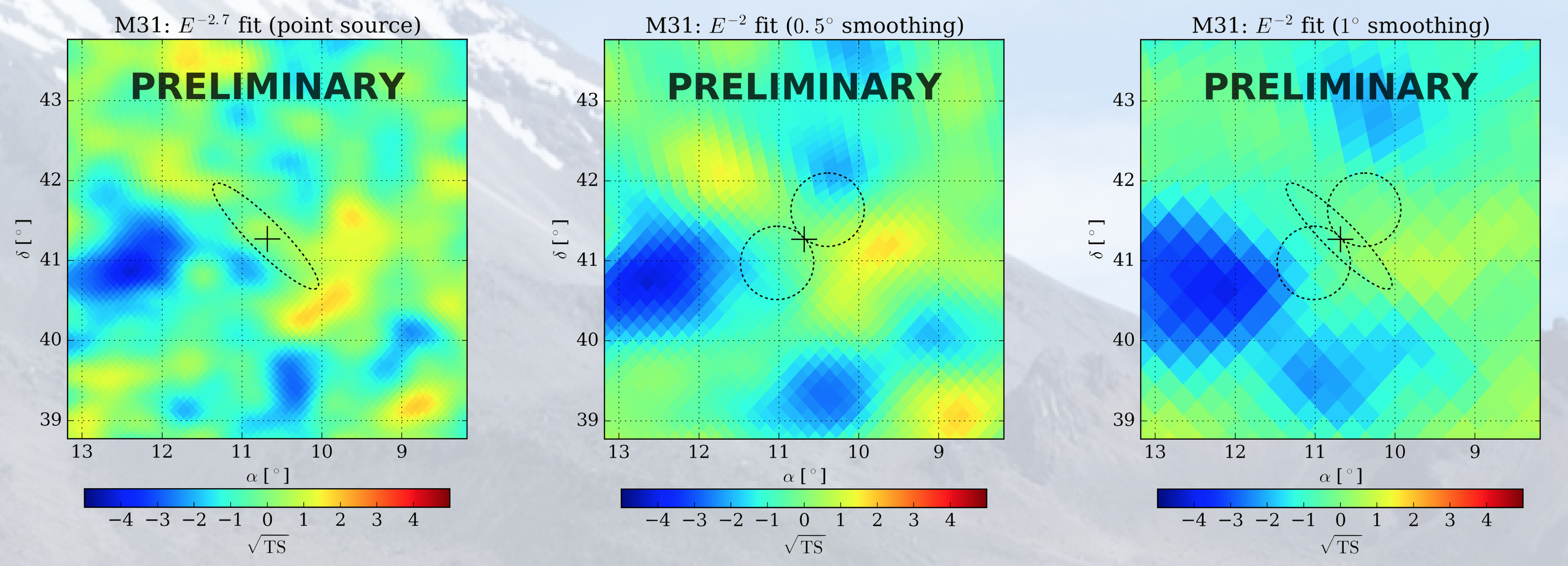


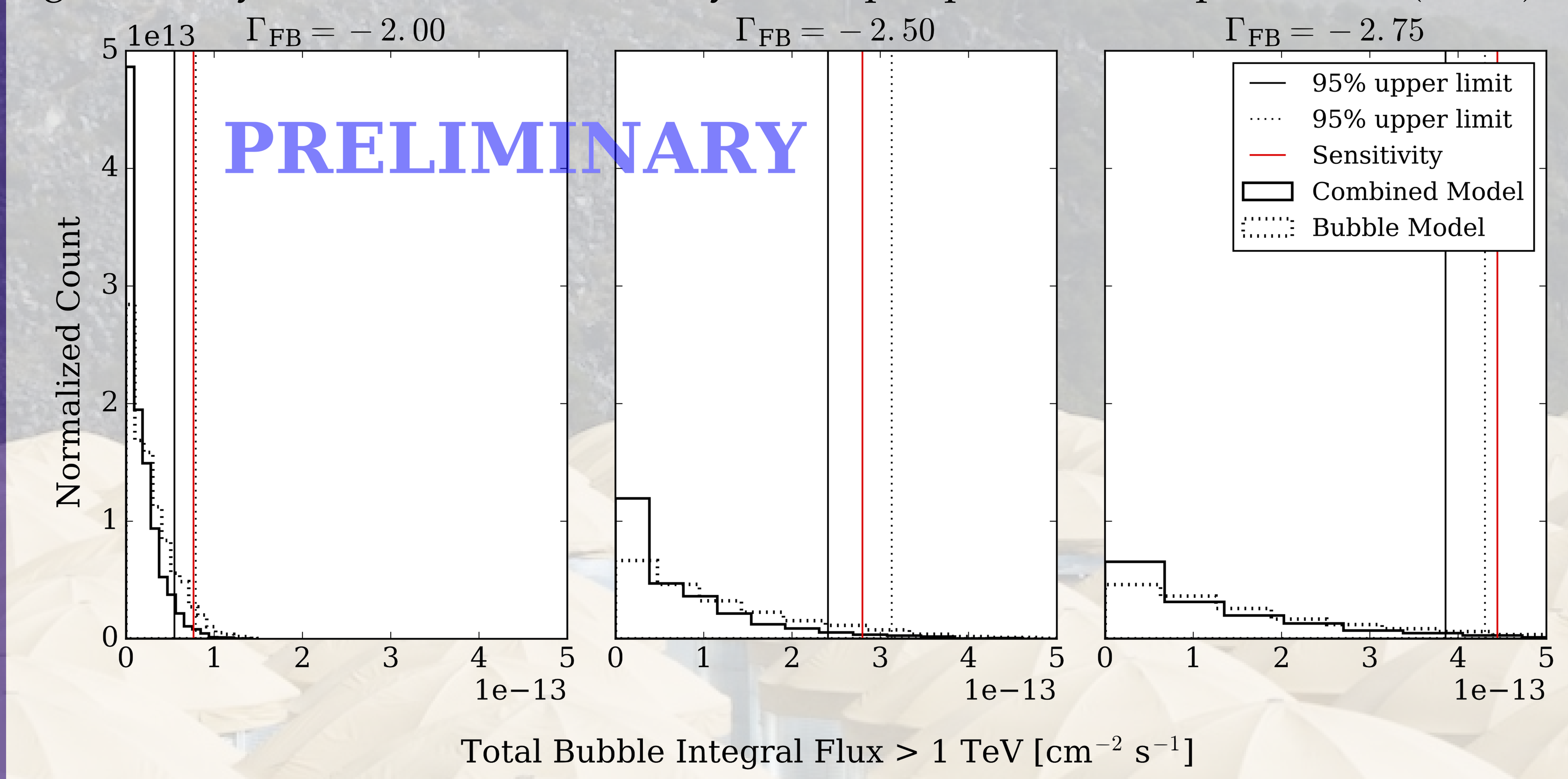

We treat the morphology of the M31 Fermi Bubbles as described in [3]. The position of the core of M31 is taken from a 100 $\mu$m infrared map (background, above right) from the IRIS (Improved Reprocessing of the IRAS Survey) database [5]. The M31 galactic disk is modeled as an ellipse inclined at 45.04° with a semimajor axis of $a = 0.9°$ and aspect ratio $b/a = 0.22$ [3]. The Fermi Bubble regions are modeled as circular disks of radius 0.45°, oriented perpendicular to (and symmetrically above and below) the galactic plane of M31. These regions comprise the model used in our fit (above right).

## Results

HAWC does not observe any significant excess in gamma ray emission from the M31 region (below). Thus for each model template, a 95% upper limit on the flux above 1 TeV is calculated.




We consider three models in this analysis: the M31 galactic disk only, two 0.45° disks at the locations of the proposed bubbles, and a combined model including both the disk and two bubbles (outlines overlaid above). To fit these models, we use the Multi-Mission Maximum Likelihood Framework (3ML) [6]. For both the M31 disk and bubble regions, we assume the gamma-ray emission is defined by a simple power law spectrum $K(E/E_0)^{\Gamma}$.




The distribution of the likelihood around the maximum is determined by a Markov Chain Monte Carlo, and the 95th percentile of the integral flux above 1 TeV is reported as a 95% UL.

## Conclusions

A search using 25 months of data from HAWC has found no significant emission from M31. Using IRIS templates for emission from the disk [5] and bubble templates from a GeV fit to Fermi-LAT data [3], we have computed flux upper limits on emission from the galactic disk and bubble regions. The upper limits are two orders of magnitude higher than the flux of $\gamma$ rays from the Fermi Bubbles in the Milky Way (extrapolated to TeV energies and normalized to the distance to M31), but are at the current sensitivity limit of HAWC. This analysis represents the first systematic study of very extended emission from M31 above 1 TeV.

## References

[1] Meng Su, Tracy R. Slatyer, and Douglas P. Finkbeiner. In: *Astrophys. J.* 724 (2010), pp. 1044–1082. DOI: 10.1088/0004-637X/724/2/1044. arXiv: 1005.5480 [astro-ph.HE].

[2] M. Ackermann et al. In: *Astrophys. J.* 793.1 (2014), p. 64. DOI: 10.1088/0004-637X/793/1/64. arXiv: 1407.7905 [astro-ph.HE].

[3] M. S. Pshirkov, V. V. Vasiliev, and K. A. Postnov. In: *Mon. Not. Roy. Astron. Soc.* 459.1 (2016), pp. L76–L80. DOI: 10.1093/mnrasl/slw045. arXiv: 1603.07245 [astro-ph.HE].

[4] Ralph Bird. In: *PoS* ICRC2015 (2016), p. 851. arXiv: 1508.07195 [astro-ph.HE].

[5] Marc-Antoine Miville-Deschenes and Guilaine Lagache. In: *Astrophys. J. Suppl.* 157 (2005), pp. 302–323. DOI: 10.1086/427938. arXiv: astro-ph/0412216 [astro-ph].

[6] Giacomo Vianello et al. In: *Proceedings of 34th ICRC*. 2015. arXiv: 1507.08343 [astro-ph.HE].

HAWC Gamma-Ray Observatory
www.hawc-observatory.org