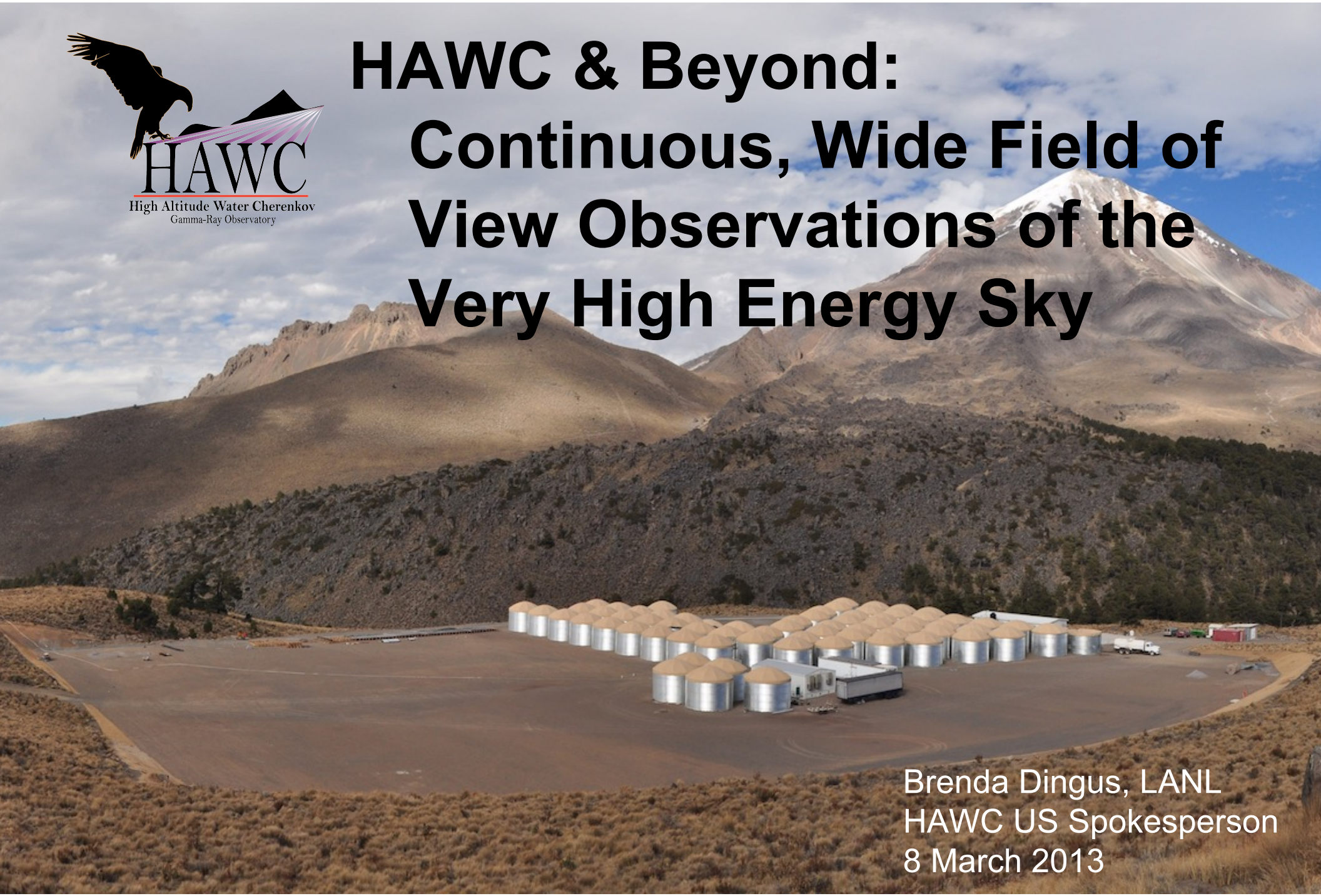


HAWC & Beyond: Continuous, Wide Field of View Observations of the Very High Energy Sky

Brenda Dingus, LANL
HAWC US Spokesperson
8 March 2013

High Energy (Astro) Physics

Unique HEP studies of:

- Higher energy particles than LHC
- Intense magnetic (>10^{12} Gauss) and gravitational (black hole event horizon) fundamental forces
- Rare process requiring billions of years

Observational, NOT Experimental Science

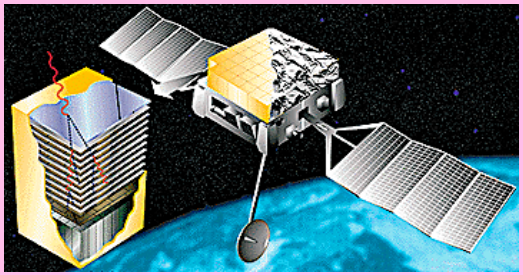
- Discerning HEP phenomena requires understanding the "astronomy" of the high energy emission from these sources
- Opportunity to discover the unexpected

Requires HEP expertise to build detectors

Gamma-Ray Detectors

Wide Field of View,
Continuous Operations

TeV Sensitivity



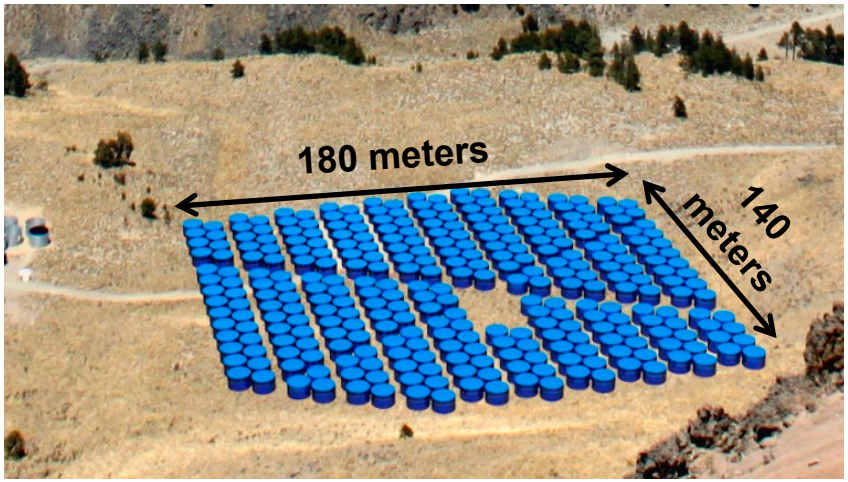
Fermi
AGILE
EGRET

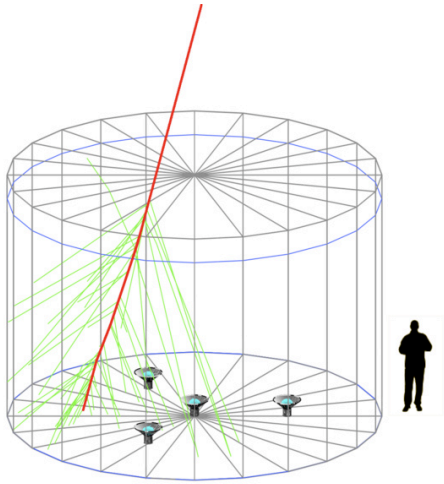
HAWC
ARGO
Milagro
Tibet ASγ

VERITAS
HESS
MAGIC

HAWC Design

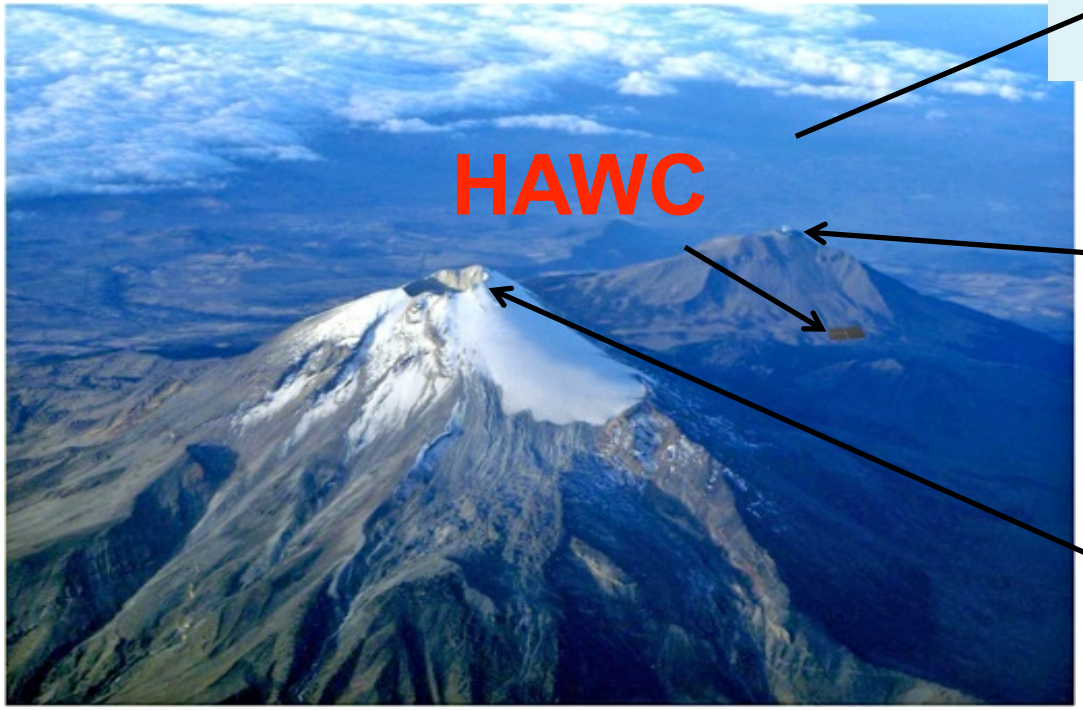
300 close packed water tanks (7.3m dia x 4.5 m deep of 200,000 liters) each with 4 upward facing photomultiplier tubes at the bottom





HAWC Site Location in Mexico

- High Altitude Site of 4100 m with temperate climate and existing infrastructure
- 17 R.L. of atmospheric overburden vs 27 R.L. at sea level
- Latitude of 19 deg N



Large Millimeter Telescope (50m dia. dish)

Pico de Orizaba 5600 m (18,500')

The HAWC Collaboration

- Los Alamos National Laboratory
- University of Maryland
- University of Wisconsin
- University of Utah
- Univ. of California, Irvine
- Michigan State University
- George Mason University
- University of New Hampshire
- Pennsylvania State University
- University of New Mexico
- Michigan Technological University
- NASA/Goddard Space Flight Center
- Georgia Institute of Technology
- University of Alabama
- The Ohio State University
- Colorado State University
- University of California Santa Cruz

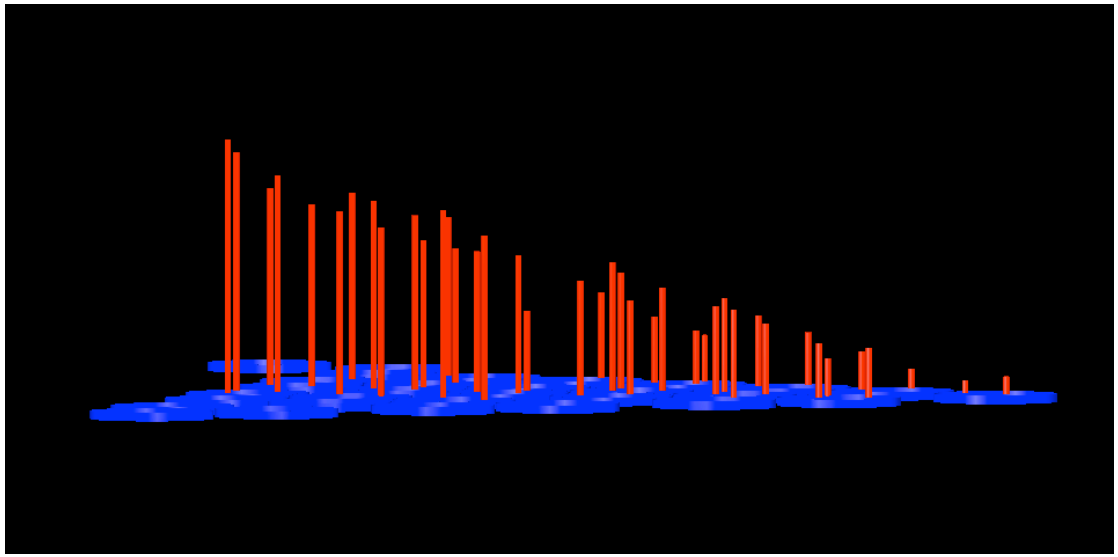
- Instituto Nacional de Astrofísica Óptica y Electrónica (INAOE)
- Universidad Nacional Autónoma de México (UNAM)
  - Instituto de Física
  - Instituto de Astronomía
  - Instituto de Geofisica
  - Instituto de Ciencias Nucleares
- Benemérita Universidad Autónoma de Peubla
- Universidad Autónoma de Chiapas
- Universidad Autónoma del Estado de Hidalgo
- Universidad de Guadalajara
- Universidad Michoacana de San Nicolás de Hidalgo
- Centro de Investigacion y de Estudios Avanzados
- Universidad de Guanajuato

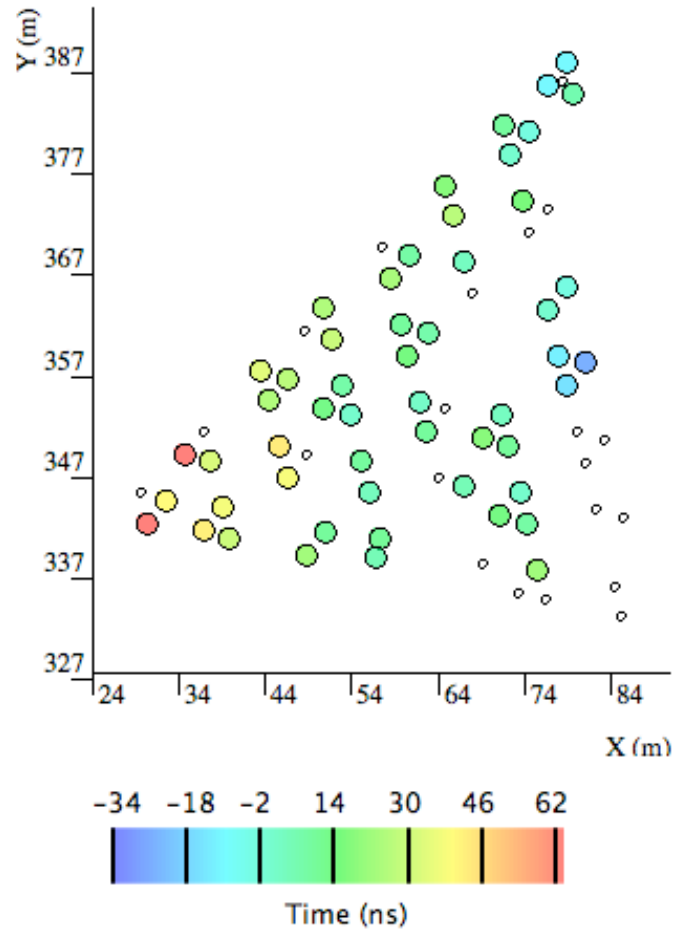
145 Members

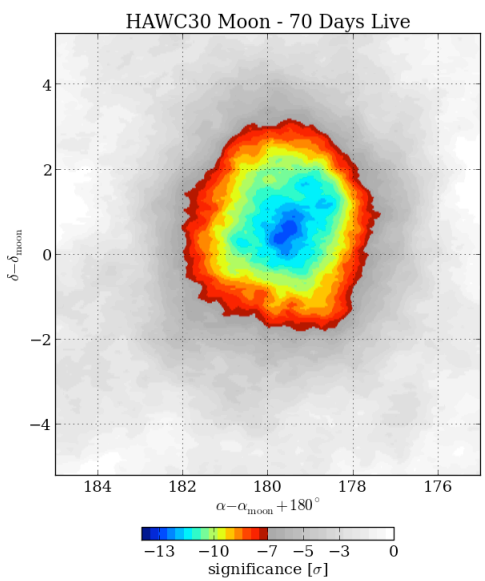
USA

Mexico

HAWC-30 Completed Sept 2012







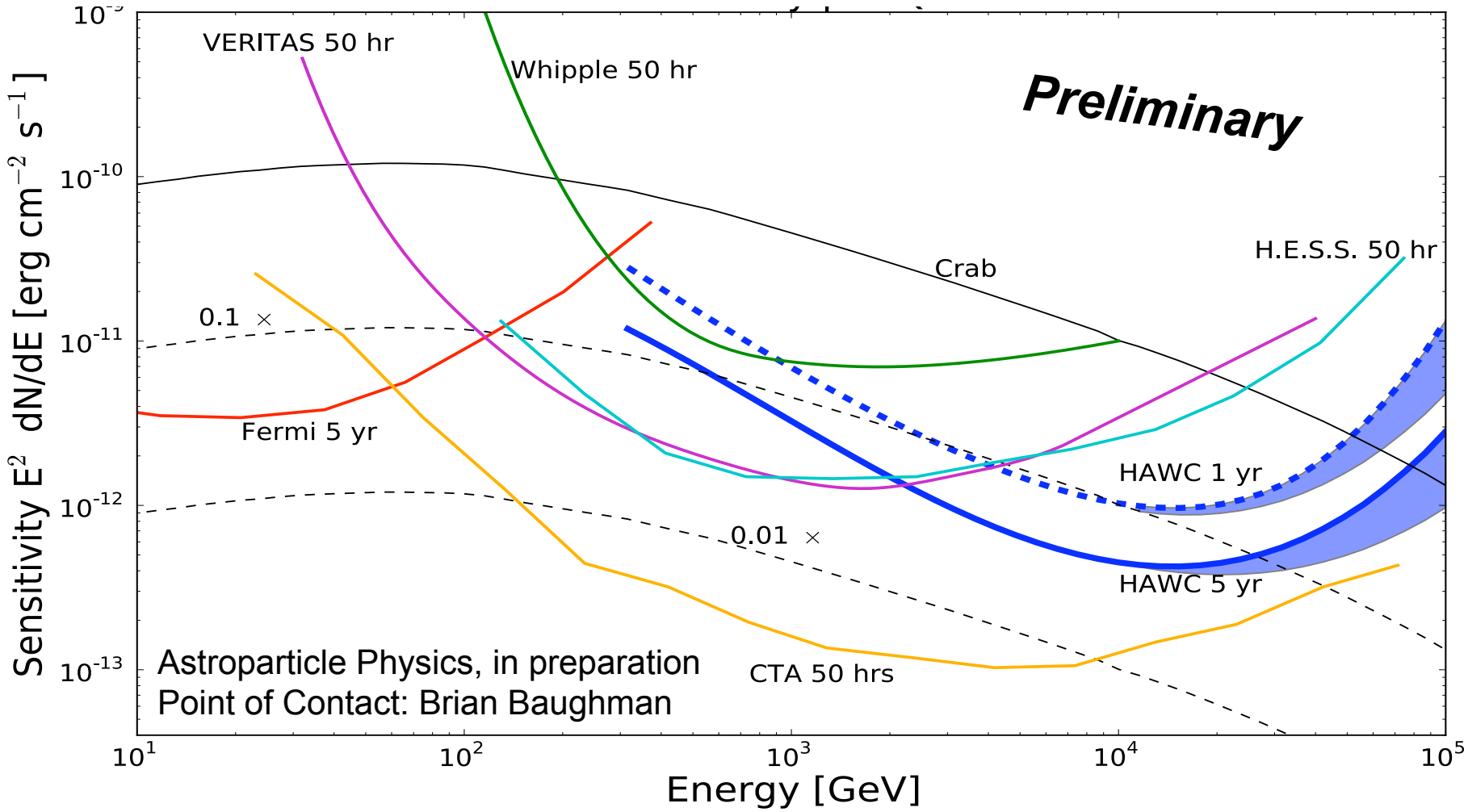
HAWC 30 Events and
Observation of cosmic-ray shadow
of Moon with 70 days of data

HAWC Science Soon

Feb 2011:	Beginning of Construction funding of 12M USD (split between NSF, DOE, and CONACYT)
Sept 2012:	Installation of 30 Water Cherenkov Detectors (WCDs)
Aug 2013:	Continuous operation of 100 WCDs with sensitivity to detect Crab in < 1 week
Aug 2014:	Construction complete with 300 WCDs with sensitivity to detect Crab in < 1 day

HAWC Differential Sensitivity

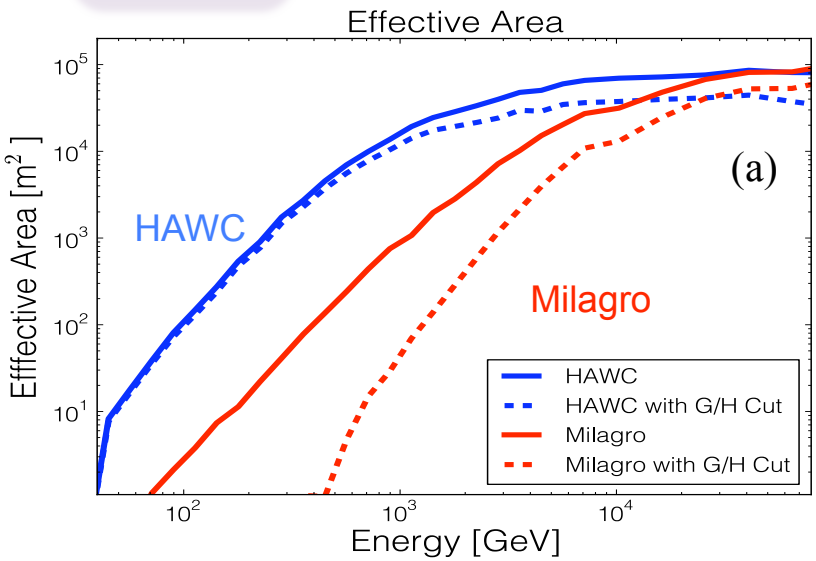
(Flux per ¼ decade for 5 σ detection)

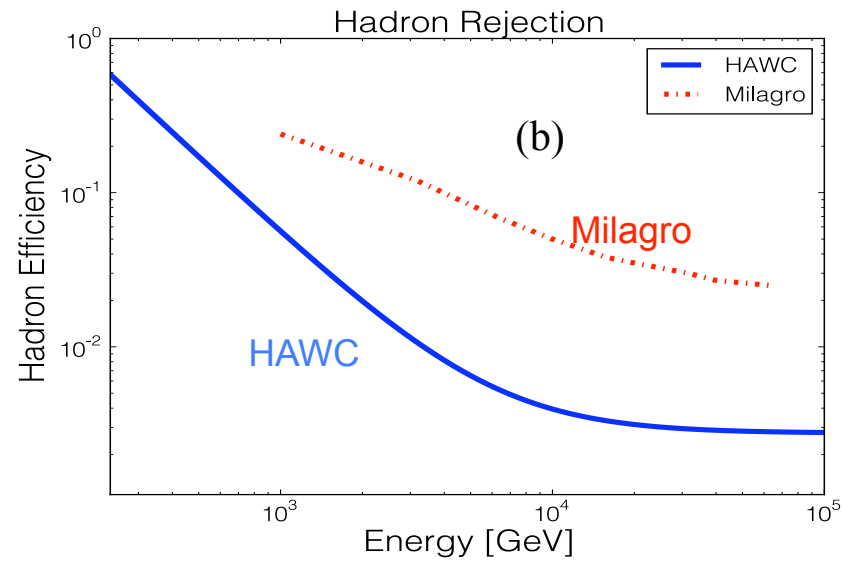


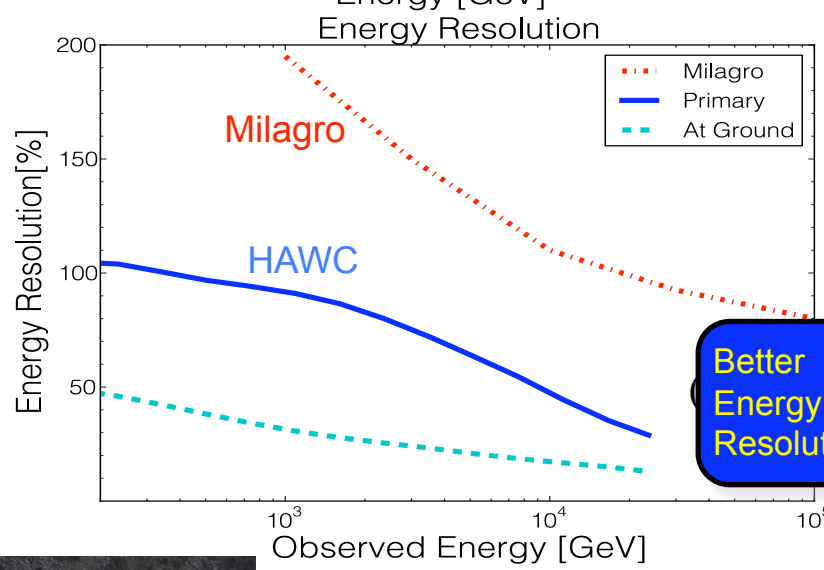
HAWC Performance

Much Better Low Energy Response

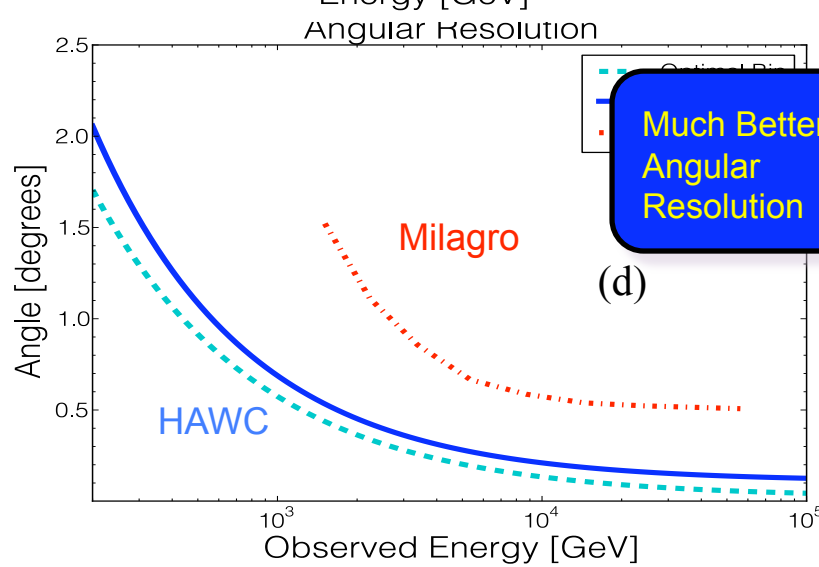
Much Better Background Rejection







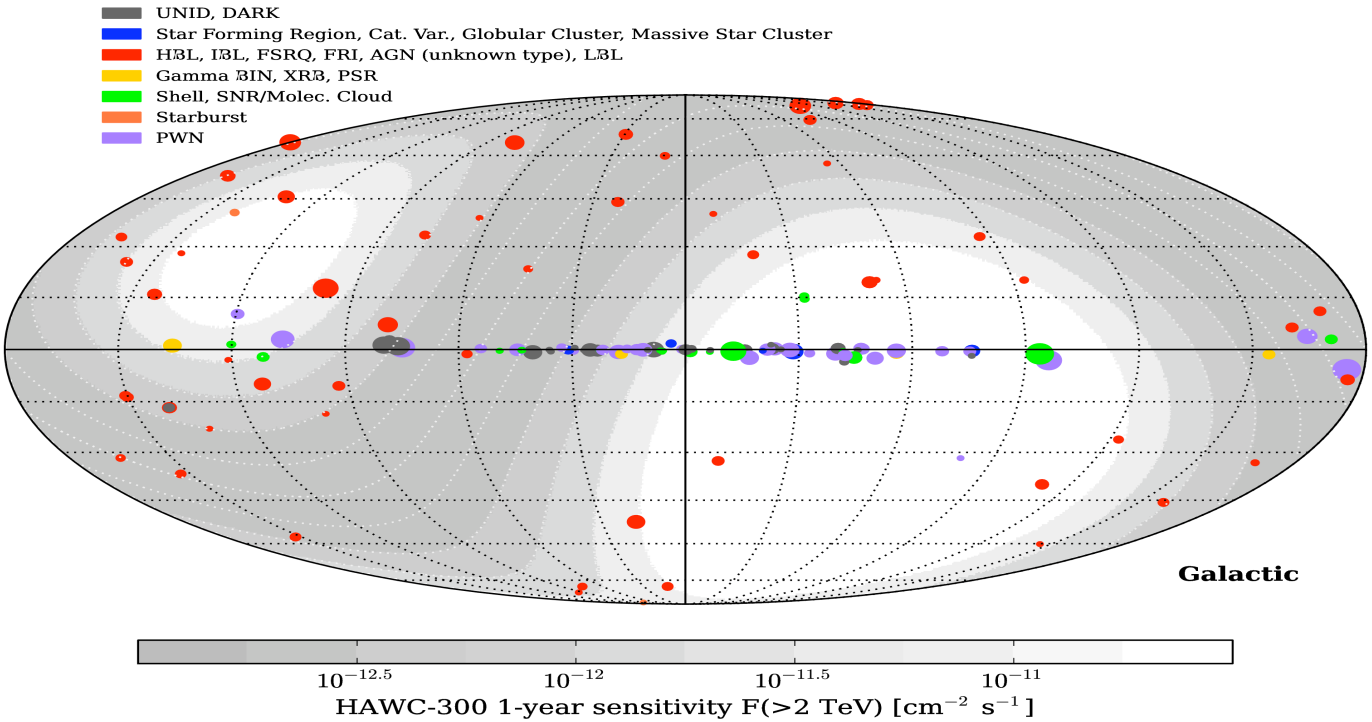
Better Energy Resolution



Much Better Angular Resolution

HAWC's Field Of View

Known sources are shown, but most of the high latitude sky has not been observed at TeV energies

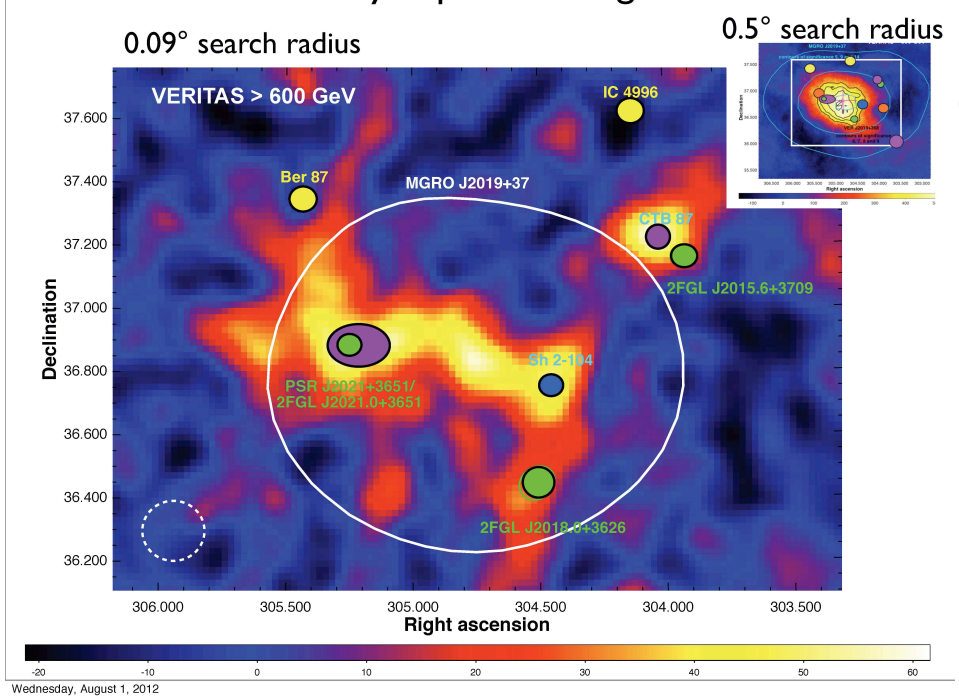


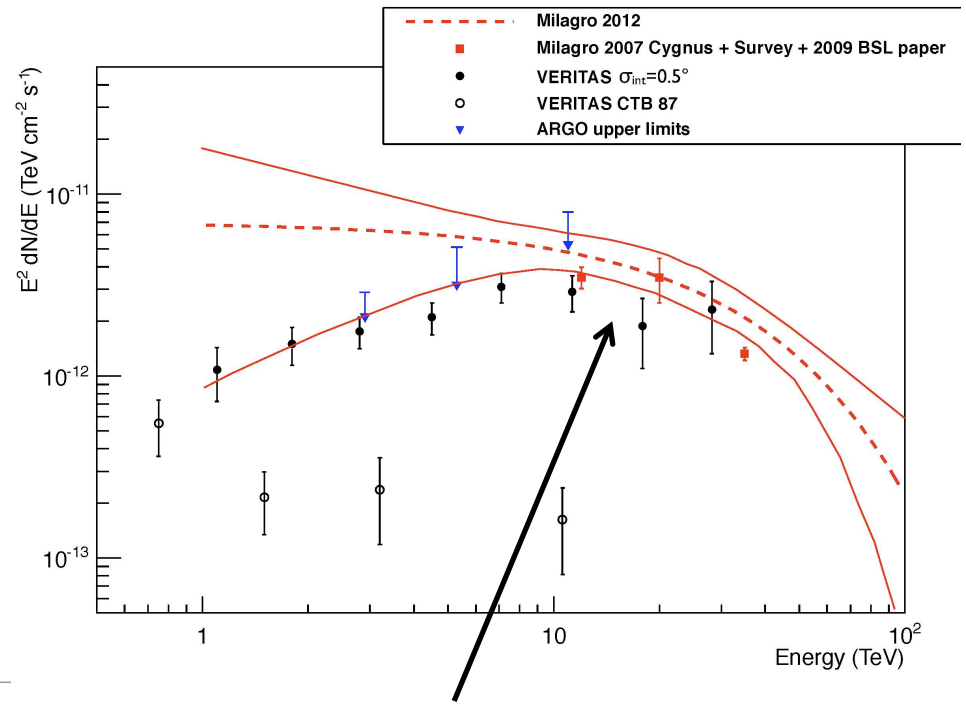
Sources from TeVCAT.uchicago.edu
plotted by Segev BenZvi

HAWC: Highest Energy Sources

VERITAS 75 hour deep observation confirmed the angular extent and spectrum that was detected by Milagro

VERITAS skymap with Milagro contour

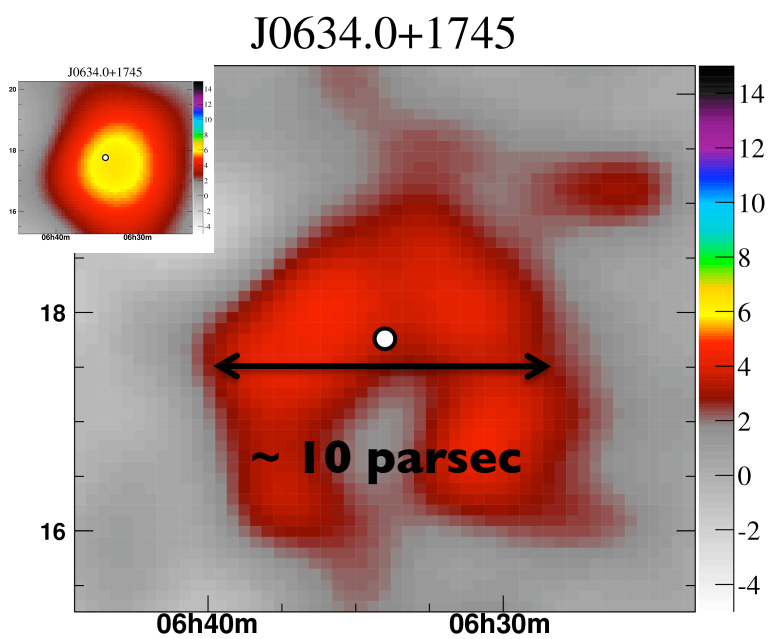




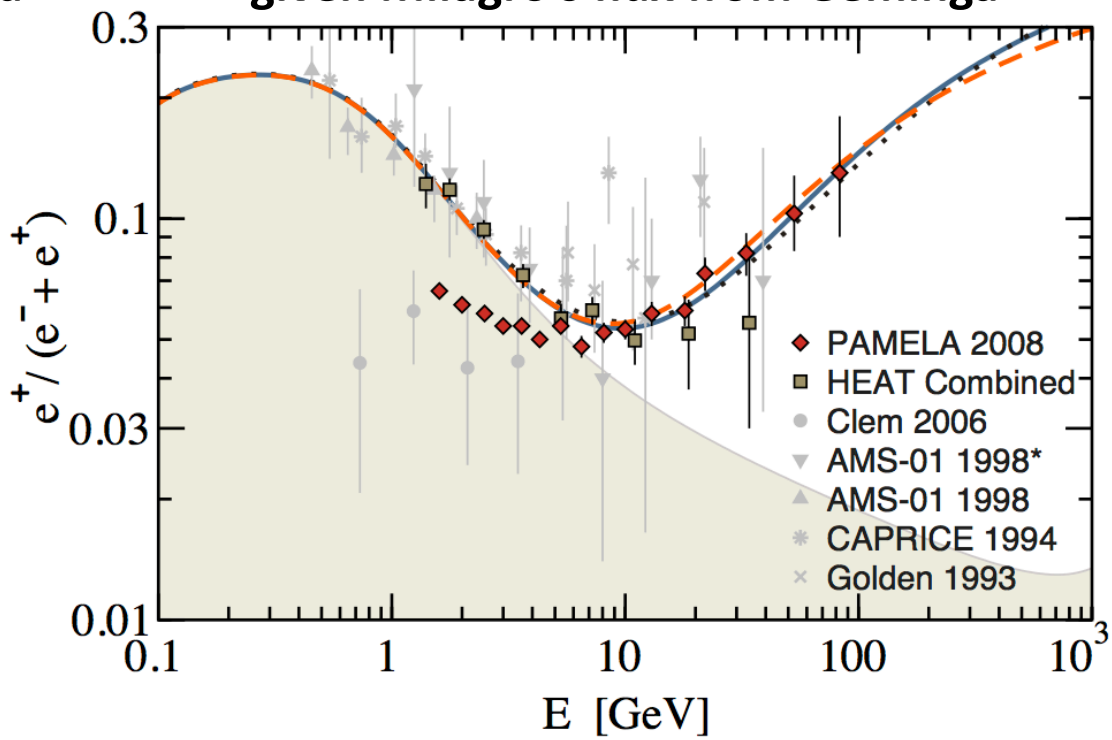
HAWC will likely discover new higher energy peaked sources.

HAWC: Extended Sources

Milagro's Detection of an extended excess coincident with Geminga



PAMELA's positron excess is well fit given Milagro's flux from Geminga



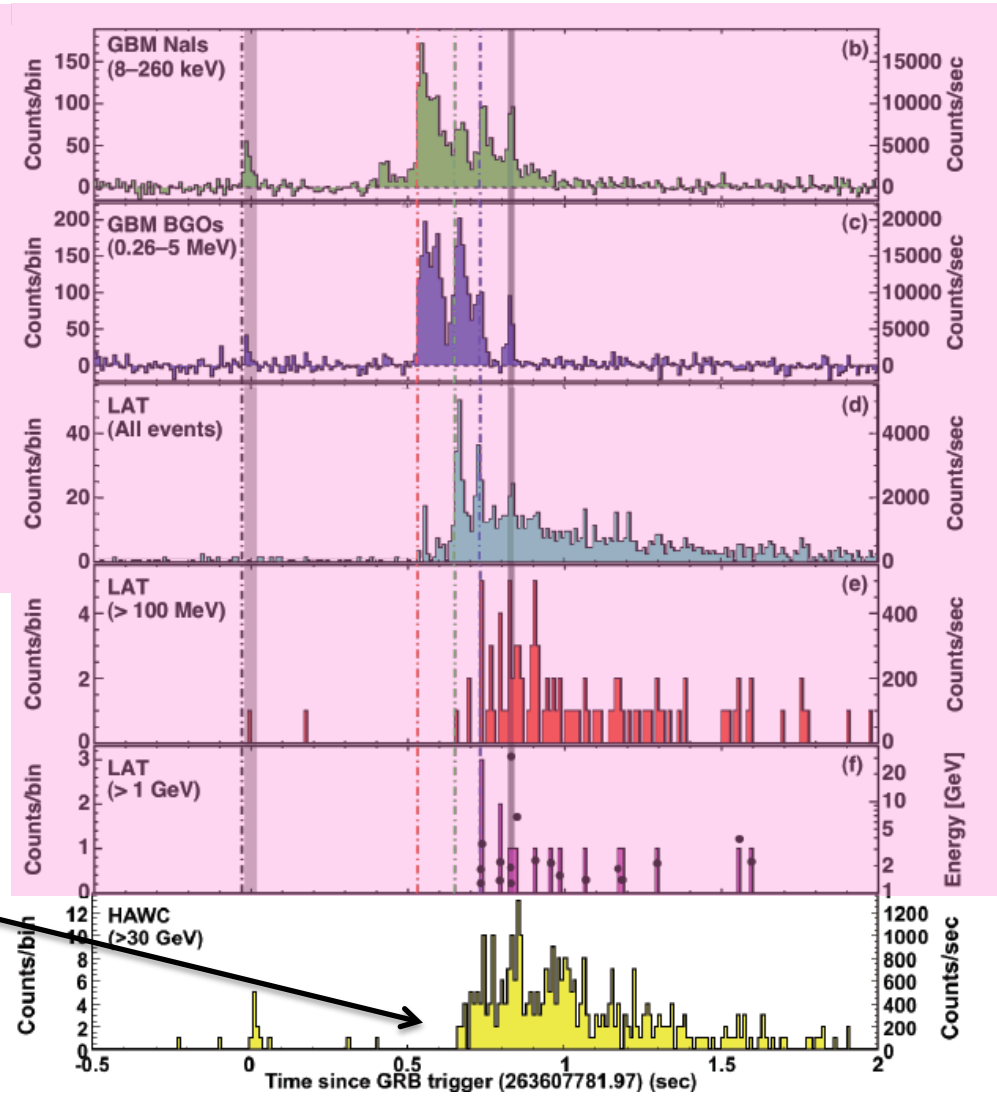
Yüksel, Kistler, Stanev PRL 2009

HAWC will detect Geminga with >50σ to measure spectra and map diffusion near source.

HAWC: Transient Sources

Fermi observation of GRB090510, z=0.9

- Highest Observed Energy was 33 GeV with 16 γ-rays >1 GeV
- Constrained Lorentz Invariance at the Plank Mass scale

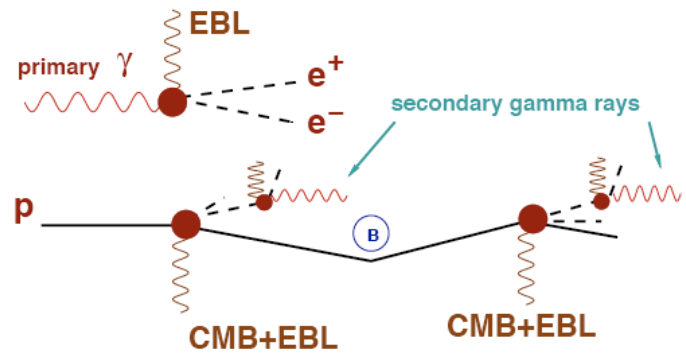


HAWC would detect this GRB if it occurred in FOV

HAWC: Distant Sources

- ~40 known TeV AGN, yet most of the extragalactic sky has not been surveyed.
- TeV spectra from distant sources probes:
  - Cosmology of Extragalactic Background Light
  - Sources of UHECR
  - Intergalactic Magnetic Field
  - Axion Like Particles

    $\gamma \rightarrow a \rightarrow \gamma$ (Hooper & Serpico, PRL, 2007)



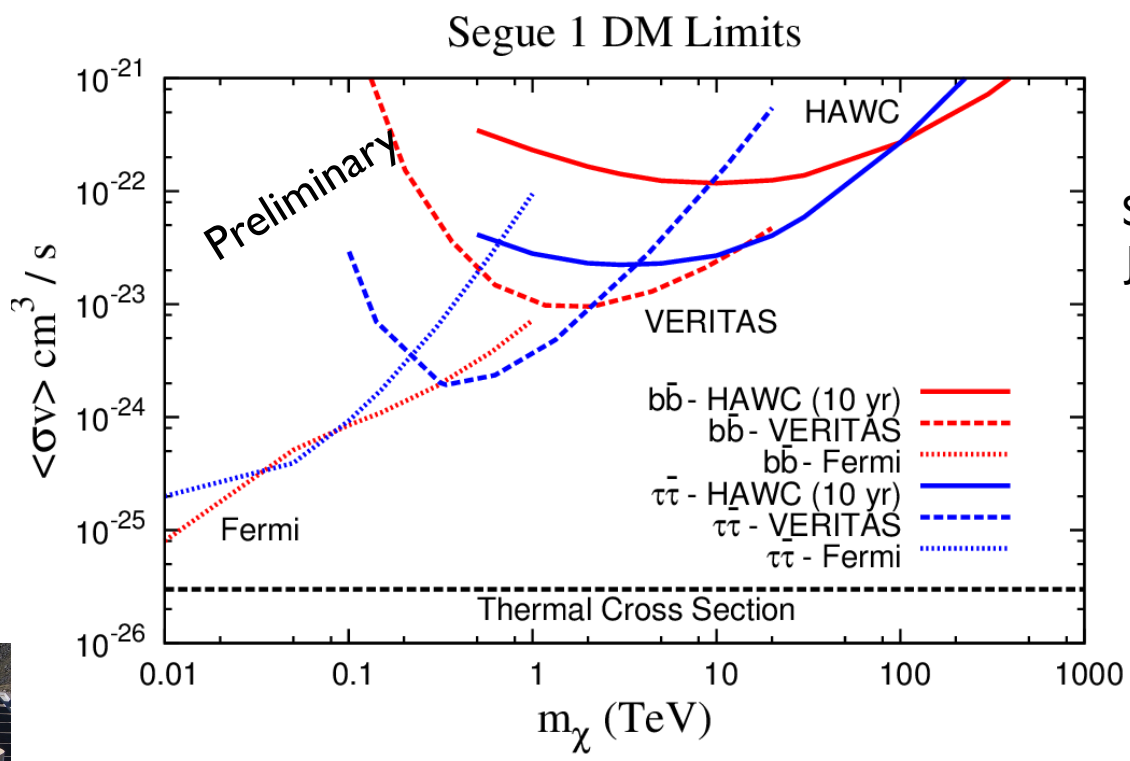
Essey, Kalashev, Kusenko, Beacom, PRL 2010

HAWC will survey the extragalactic sky, measure multi-TeV spectra and it's variability, and enable multimessenger observations through prompt notification of flaring activity.

HAWC: Dark Matter

- Satellite galaxies have large Mass, but small Luminosity and are thus dark matter rich

  - Recently higher M/L galaxies have been found by Sloan Deep Survey
  - HAWC will observe all M/L galaxies in half the sky, *even if L=0*
  - HAWC has sensitivity to higher mass WIMPS



See Talk by John Pretz

HAWC: Cosmic Rays

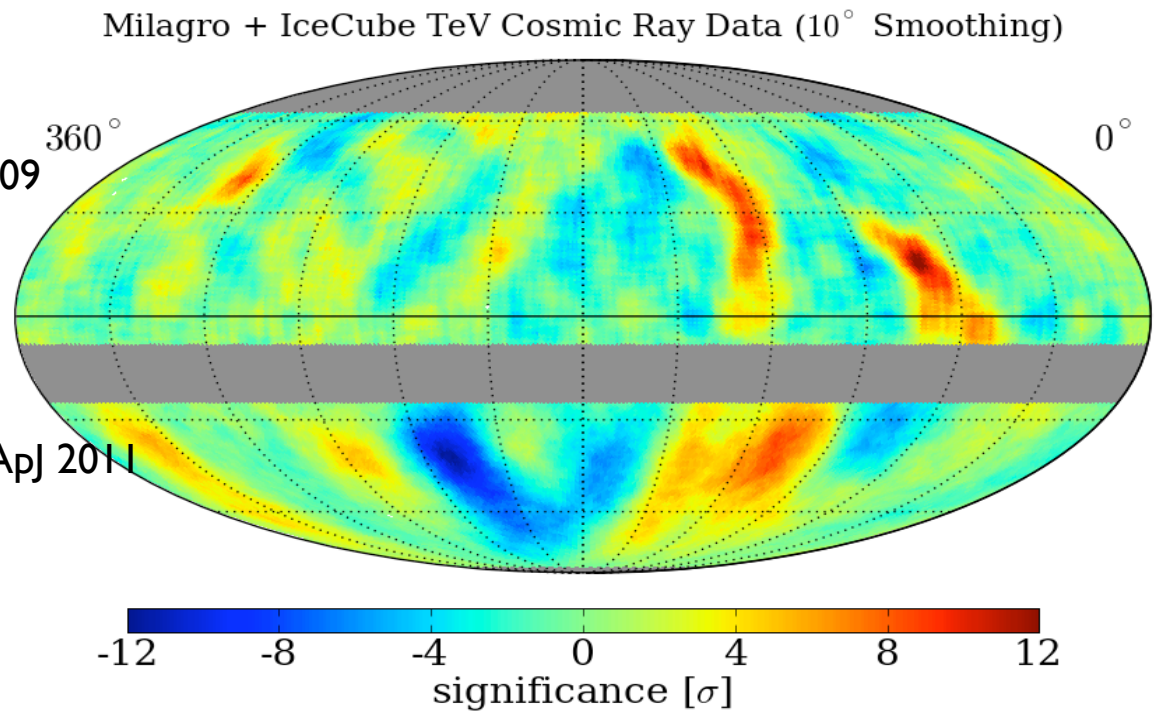
Unexpected Anisotropy of 10 TeV Cosmic Rays

- Gyroradius of 10TeV proton in 1μG field is 0.01parsecs=2000 AU
- Localized excesses of hadronic cosmic rays observed by multiple detectors

Propagation of cosmic rays is NOT understood

Abdo, et al. PRL, 2009

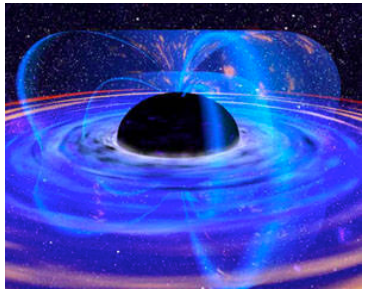
R. Abbasi, et al., ApJ 2011



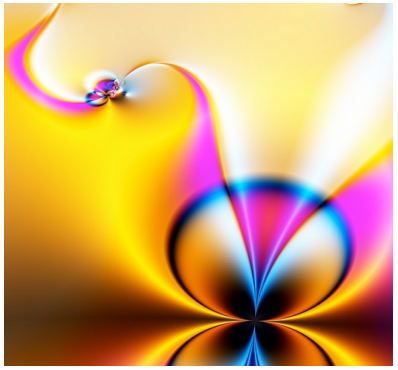
HAWC will measure spectrum of excesses and to lower energies.

HAWC: Exotic Physics

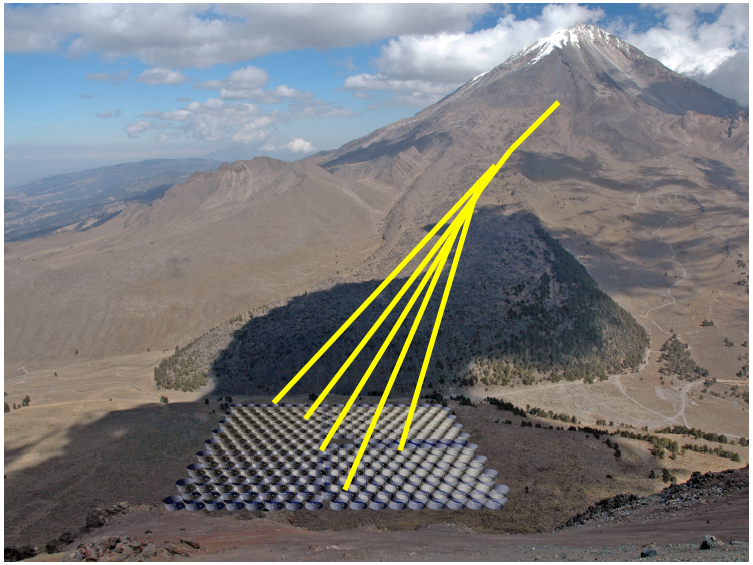
- Primordial Black Hole Evaporation
  - Burst of TeV gamma-rays



- Direct Detection of SUSY Q-balls and Monopoles
  - Massive particles produced in the early Universe
  - Pass through HAWC in 100s of microseconds
  - Deposit ~ 1 GeV every few meters depending on the cross section

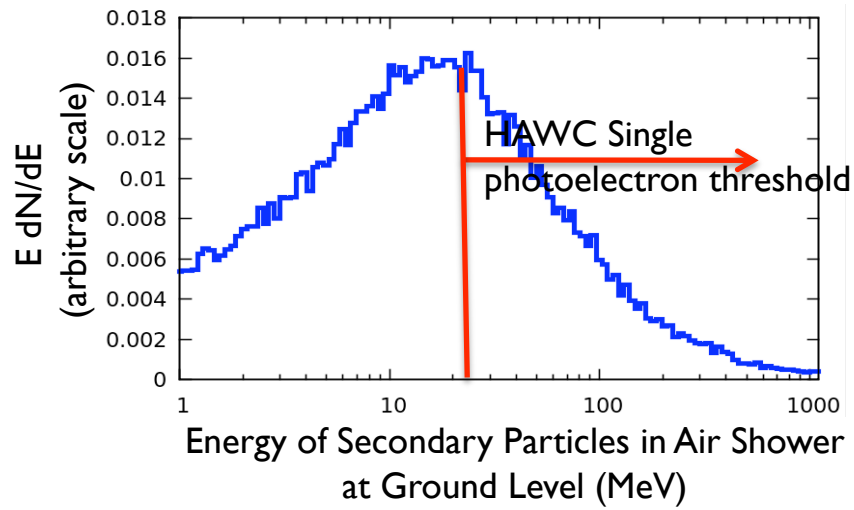


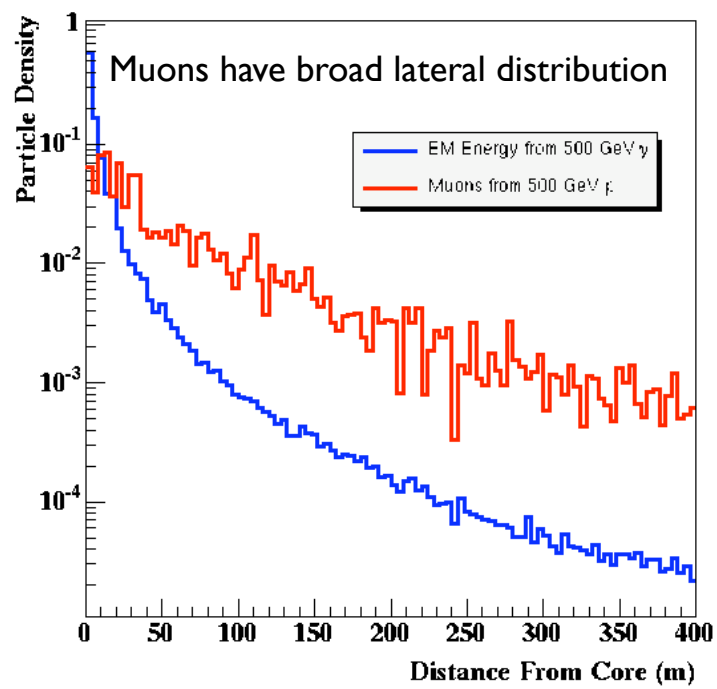
- Tau neutrinos
  - Interact in mountain to produce nearly horizontal air showers



Beyond HAWC: Increase Sensitivity

- Increase photodetection efficiency for lower energies
  - Winston Cones
  - Large Area Photodetectors
  - Liquid Scintillator
- Larger Area Array
  - Sensitivity proportional to Area, NOT sqrt(Area) due to background rejection

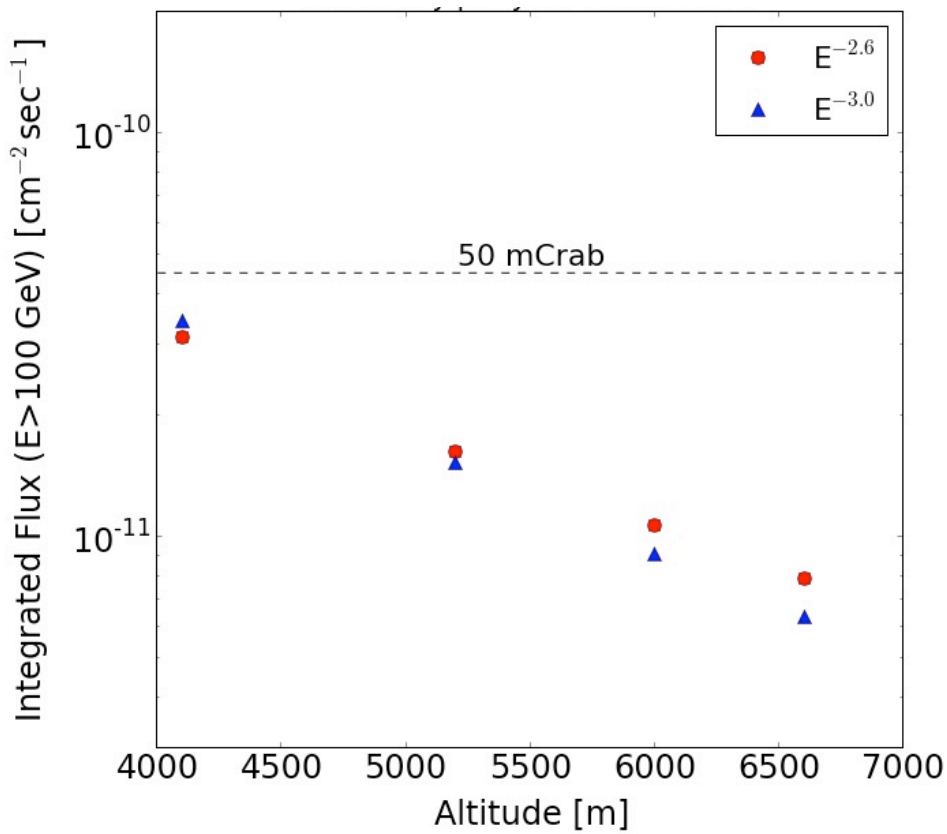




	HAWC 150m x 150m	HAWC(100k m^2) 300m x 300m
Deep Survey Sensitivity (4 years)	20mCrab	4-5mCrab
Instantaneous sensitivity ($\sigma/\sqrt{hr}$) ~	~3	12-15

Beyond HAWC: Lower Energy

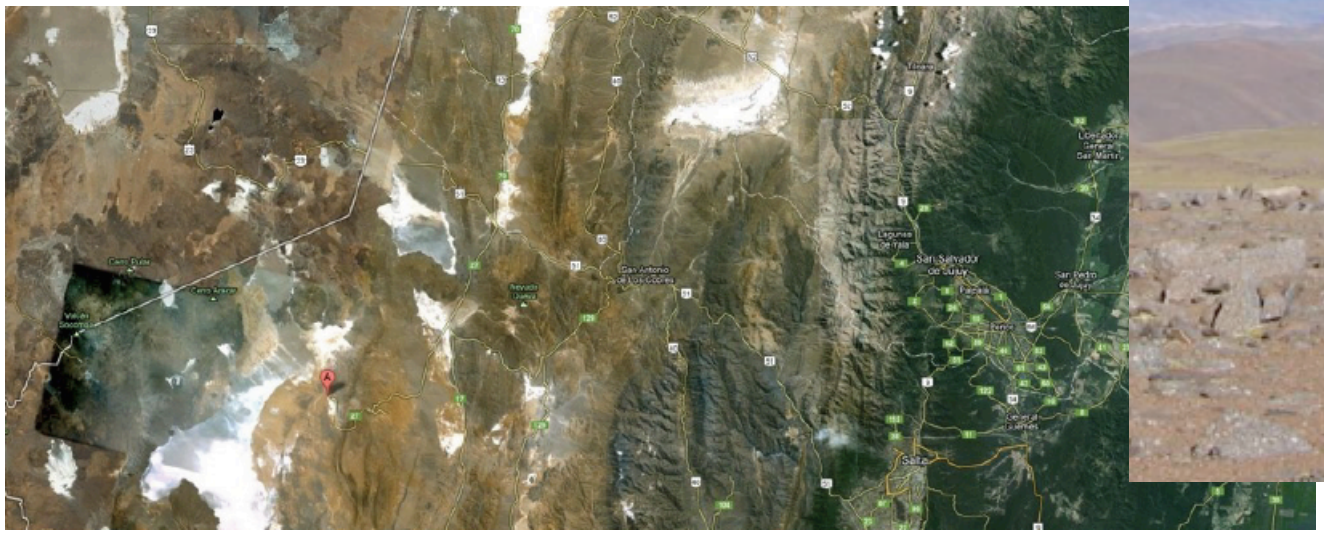
- Same detector at a higher altitude has increased sensitivity especially at lower energies
- Factor of 4 increase in sensitivity between ALMA and HAWC altitude

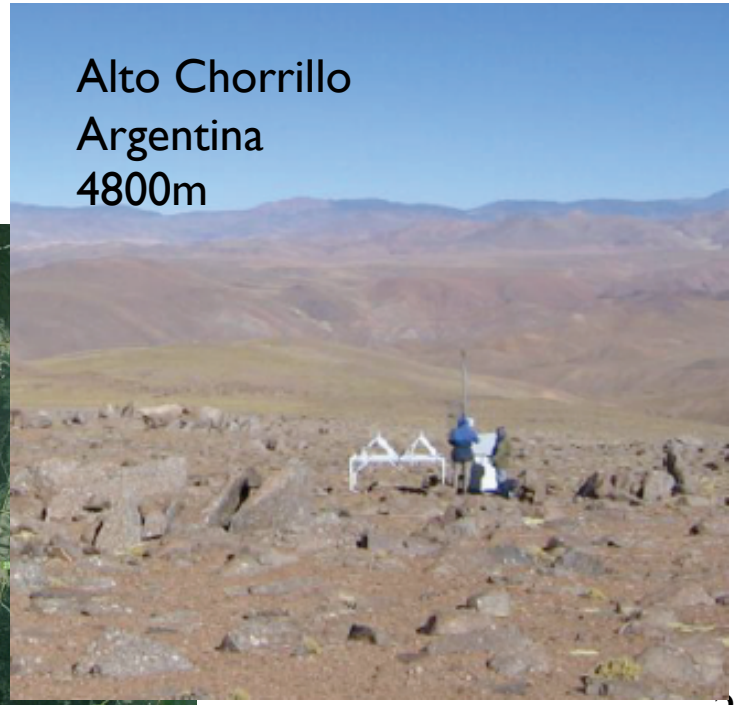


Sensitivity for one year of observation of an array of 900 tanks with 900 PMTs at different altitudes

Beyond HAWC: Southern Site

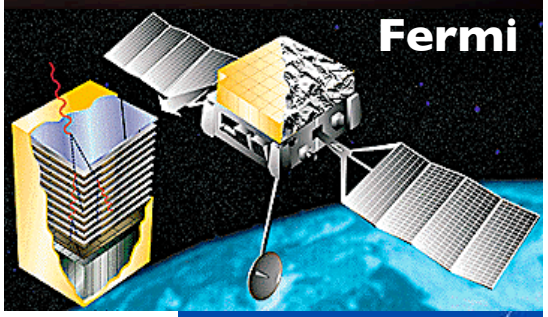
- Discovering rare transient events requires full sky coverage
  - GRB finder for Advanced LIGO, which will detect all neutron binary coalescence with z<0.5
  - AGN flares & GRBs as distant probes of high energy physics (e.g. Lorentz invariance and axions)
- Galactic Center
- TeV Source finder for CTA south

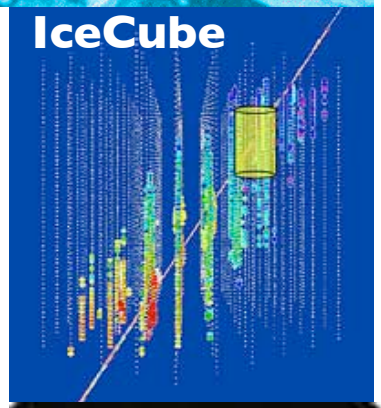




HAWC & Particle Astrophysics

- Complements TeV atmospheric Cherenkov telescopes (which have <3 degree field of view and <10% duty factor)
  - Identifies new and flaring sources for follow up observation of morphology and sub TeV spectra
  - Extends TeV spectra to higher energies
  - Detects diffuse gamma-ray emission from the Galactic plane
- Complements GeV All Sky Survey
  - Monitors 1000s of Fermi sources at higher energies
- Complements TeV neutrino observations
  - Identifies new and flaring TeV sources to improve the sensitivity and interpretation of blind searches
- Complements Advanced LIGO
  - Simultaneous observations of nearby, short GRBs from ns-ns inspiral





BACKUP

Distinguishing Fundamental Physics from Gamma Ray Astrophysics

Lorentz Invariance OR Astro Particle Acceleration

- Observe many, flaring extragalactic sources
- Resolve distance vs source mechanisms

Axions or UHECRs or Cosmology OR Astro High E Cut-offs

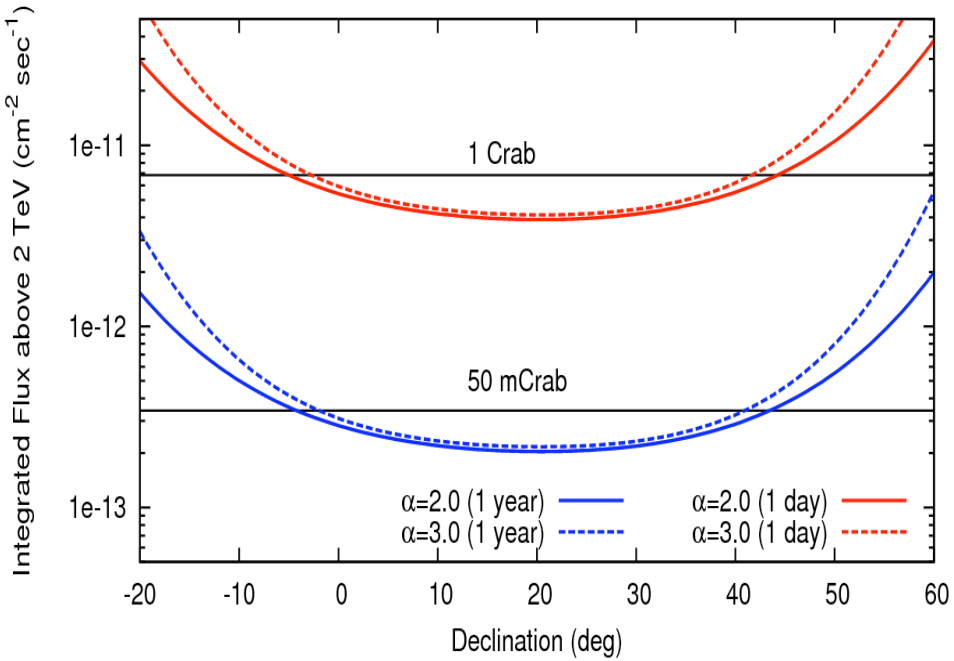
- Measure the highest energy spectra of AGN
- Multiwavelength observations to determine emitted TeV spectra

Dark Matter Annihilation OR Astro Source

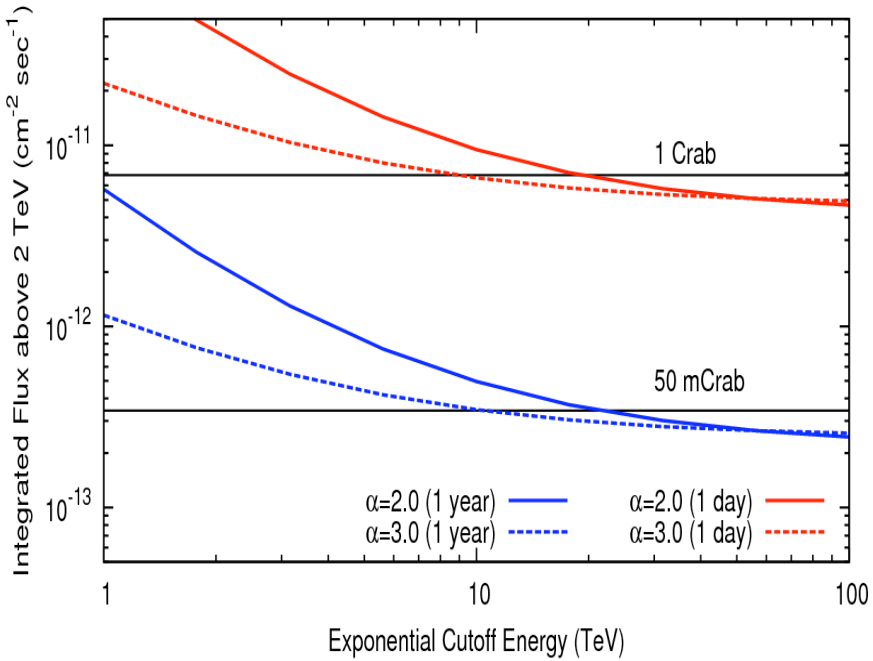
- Understand how astrophysical sources mimic WIMP signal
- Insure potential WIMP sources are not time variable

HAWC Integral Sensitivity

vs. Declination
for 1 day and1 year

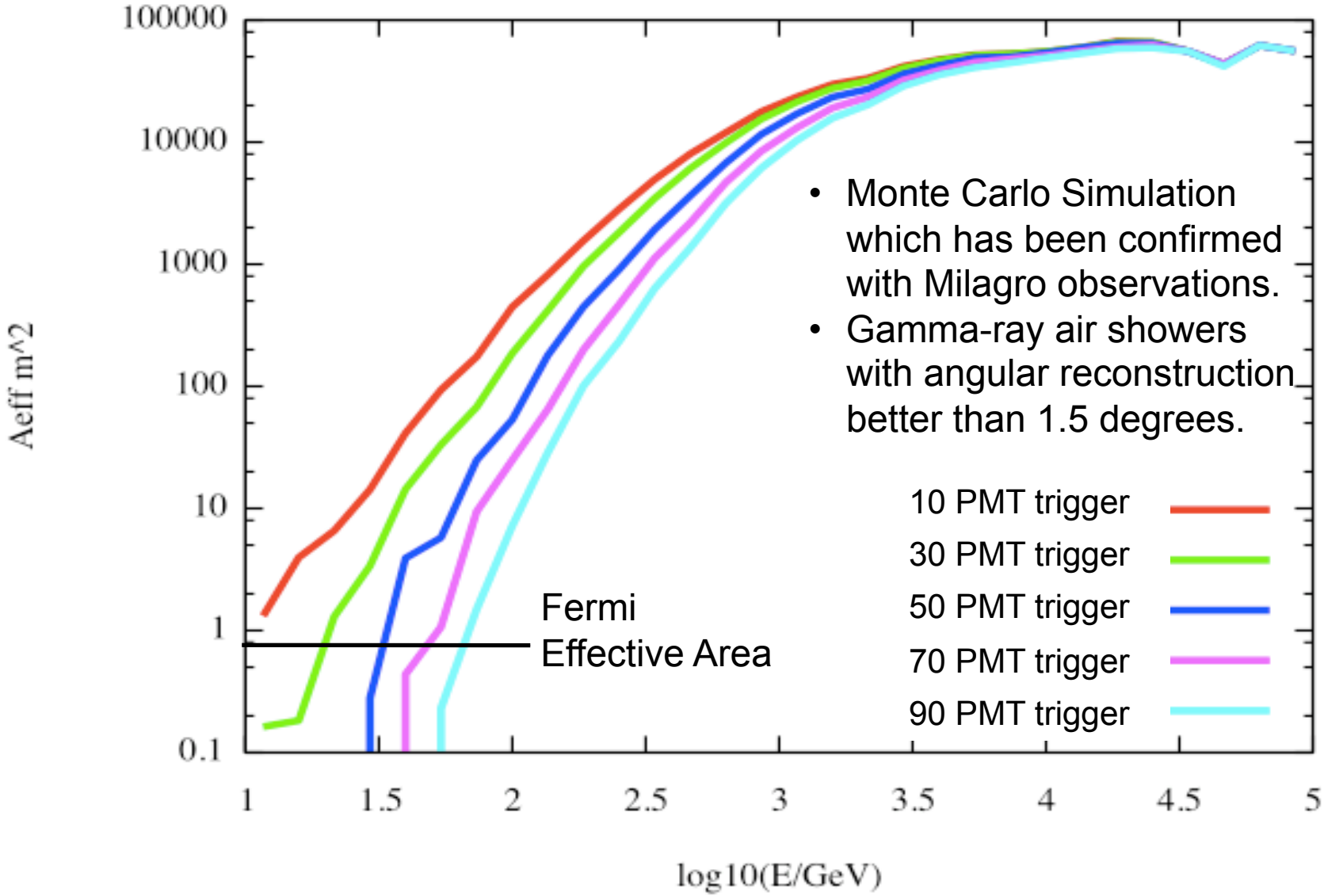


vs. High Energy Cut off
for 1 day and1 year



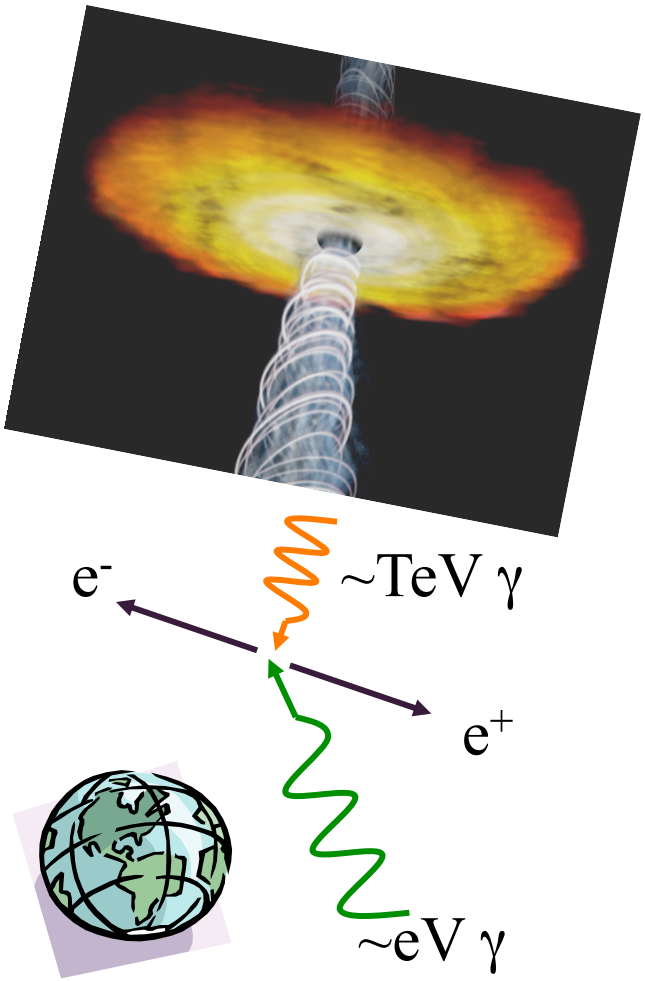
Astroparticle Physics, in preparation
Point of Contact: John Pretz

Pushing HAWC's Low Energy Response



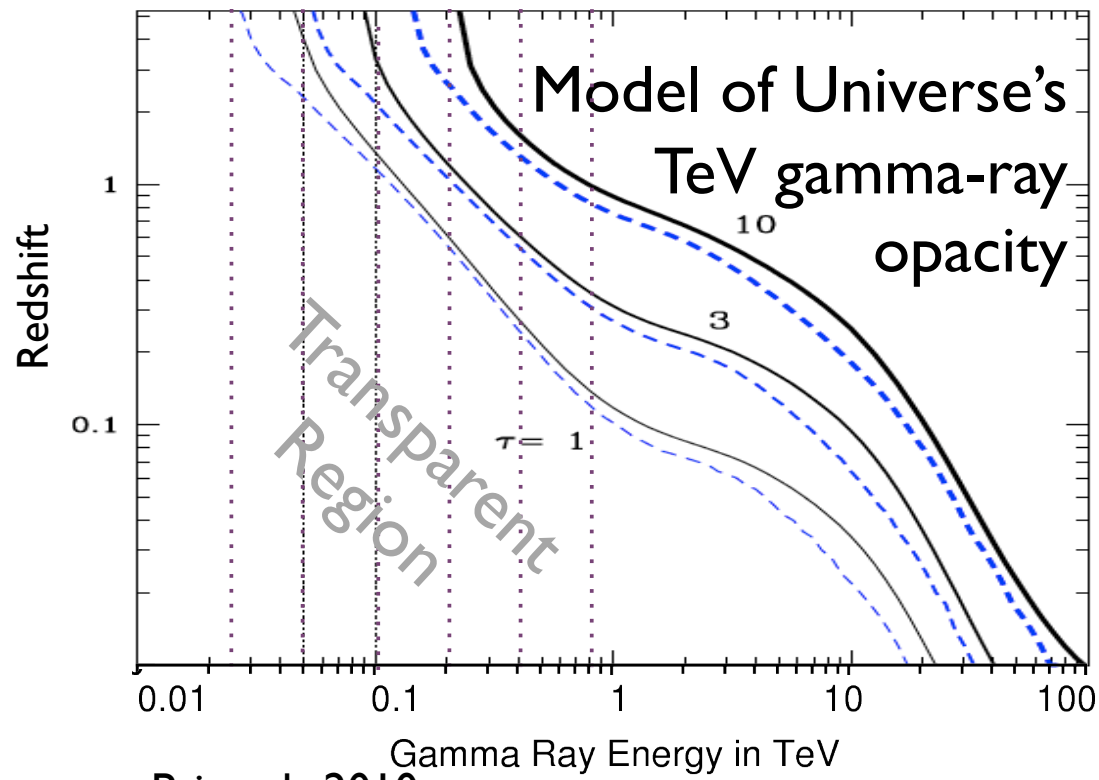
- Monte Carlo Simulation which has been confirmed with Milagro observations.
- Gamma-ray air showers with angular reconstruction better than 1.5 degrees.

Extragalactic γ-ray Absorption



$$I = I_o\, e^{-\tau}$$

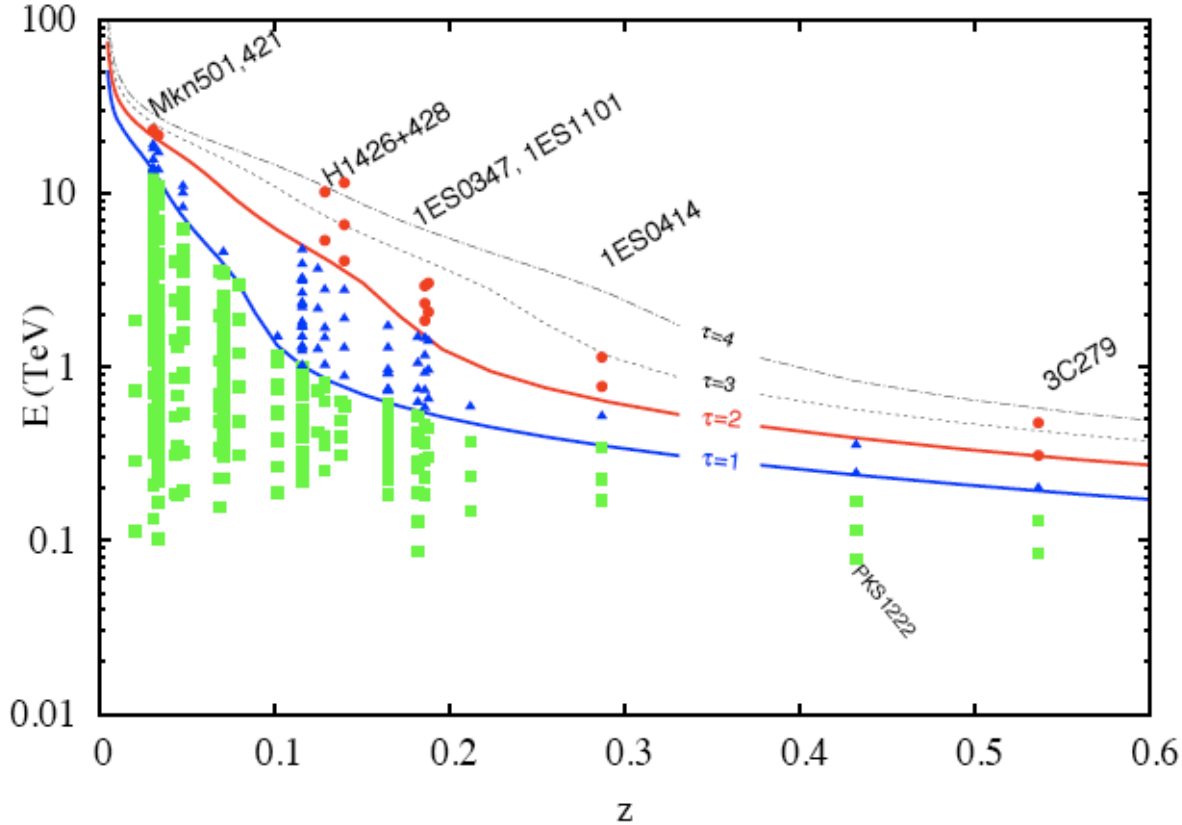
- High energy gamma rays pair produce with the infrared to UV extragalactic background light (EBL)
- EBL not well constrained by direct measurements due to foreground light
- EBL is constrained by galaxy and star formation history



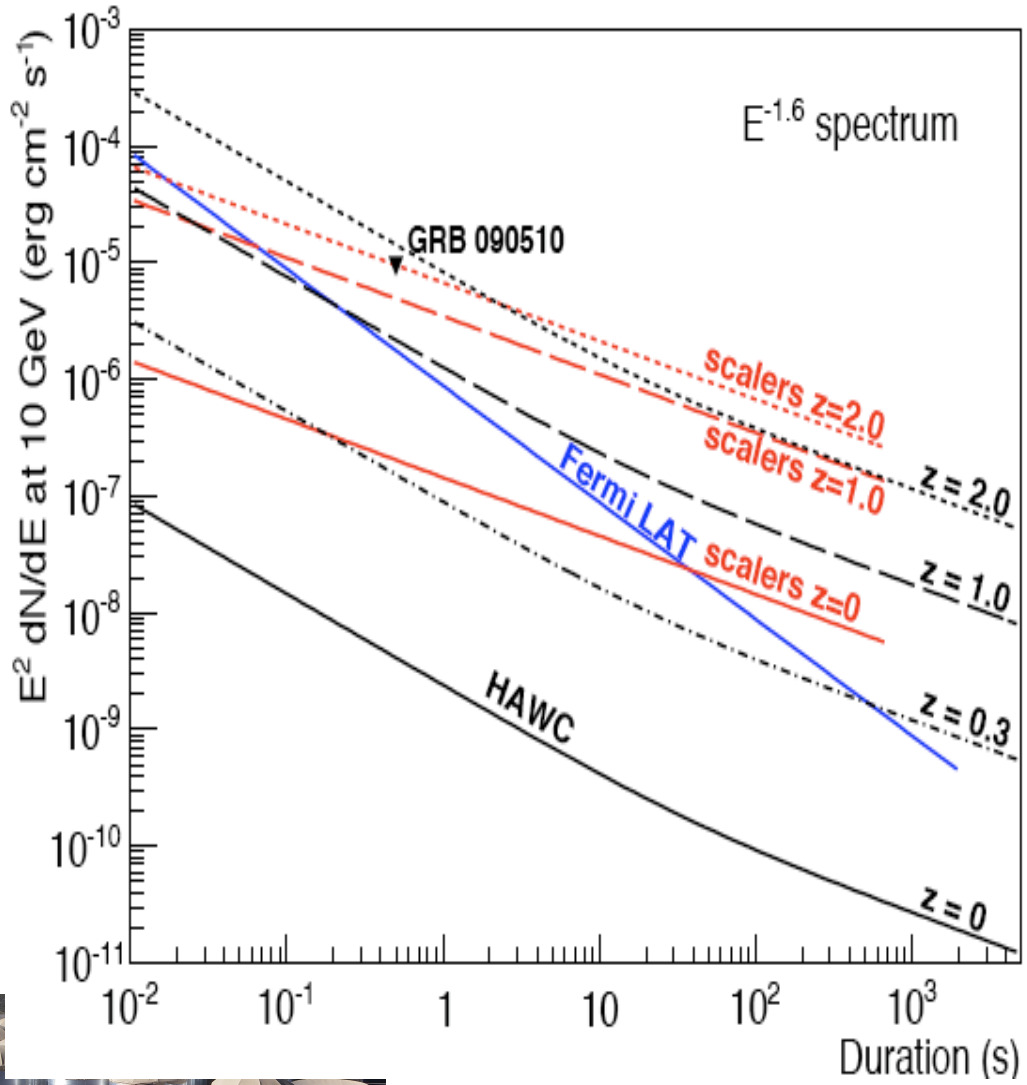
Primack, 2010

"High E Spectra of AGN" Problem

- AGN are unexpectedly observed at high energies where the predicted optical depth is high



HAWC: Transients

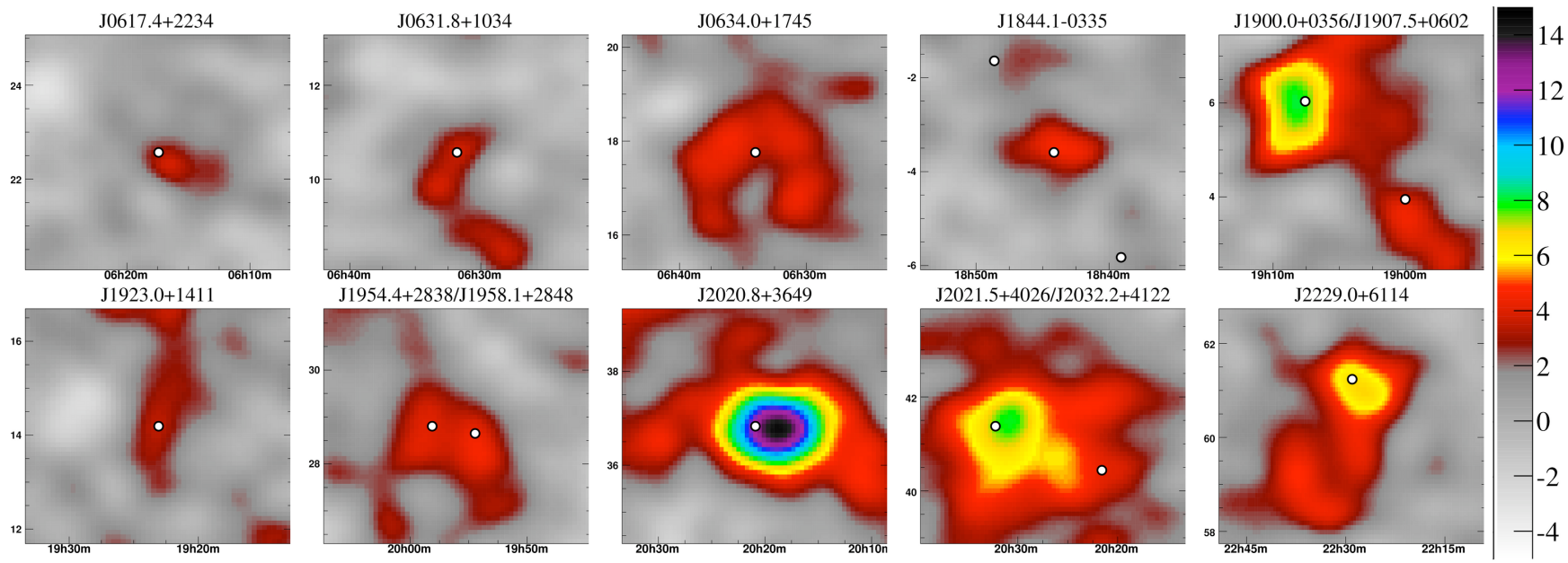


- Fermi LAT sensitivity assumes 1 gamma-ray > 10 GeV
- Scaler sensitivity uses sum of single photoelectron rates in individual PMTs to observe shortest and most distant transients
- Assume cutoff due to Extragalactic Background Light (Gilmore, 2009)

Abeysekara et al., Astroparticle Physics, 2011
Point of Contact: Ignacio Taboada

See Posters of Ian Wisher and Dmitry Zaborov

Milagro Significance for Fermi GeV Bright Sources



Abdo et al., ApJ Lett 2009

Bright GeV pulsars are coincident with TeV emission.

HAWC will observe Galactic GeV sources with the same significance as Fermi.