

*Vulcano Workshop 2016*

*The High Altitude  
Water Cherenkov  
Observatory*



**PennState**  
Eberly College of Science



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# Outline

Introduction & Motivation 1

The HAWC Observatory 2

Preliminary first results 3

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# Introduction

- 2<sup>nd</sup> generation water Cherenkov
- Wide instantaneous field of view (2 sr)
- High duty cycle (> 90%)
- Large area (22,000 m<sup>2</sup>)



# Scientific Motivation

- Constrain the **origin of cosmic rays** by measuring gamma-ray spectra to 100 TeV.
- Probe **particle acceleration** in astrophysical jets with **wide field of view, high duty factor** observations.
- Explore **new physics** with an **unbiased survey** of the TeV sky.

# The HAWC Collaboration



# The HAWC Observatory



300 - 7 m x 5 m steel Water Cherenkov Detectors  
(a.k.a. tanks) with 4 PMTs at 4,100 m a.s.l. in Mexico



# Water Cherenkov Detectors



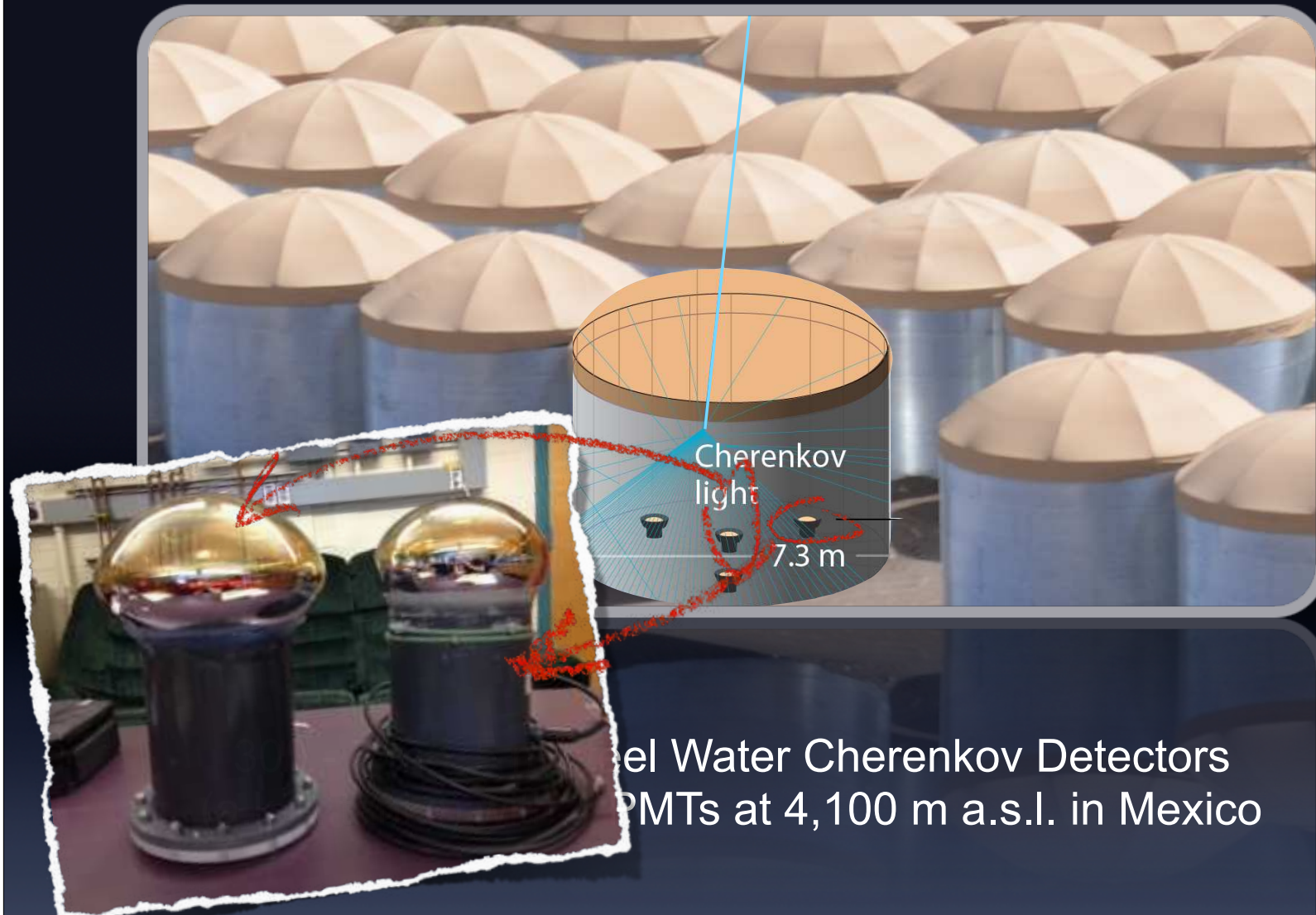
300 - 7 m x 5 m steel Water Cherenkov Detectors  
(a.k.a. tanks) with 4 PMTs at 4,100 m a.s.l. in Mexico

# Water Cherenkov Detectors



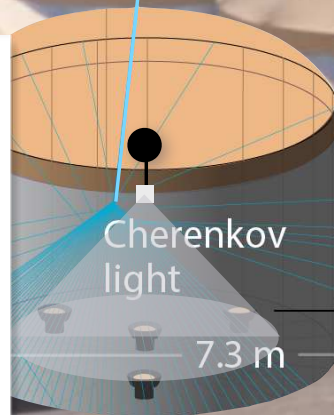
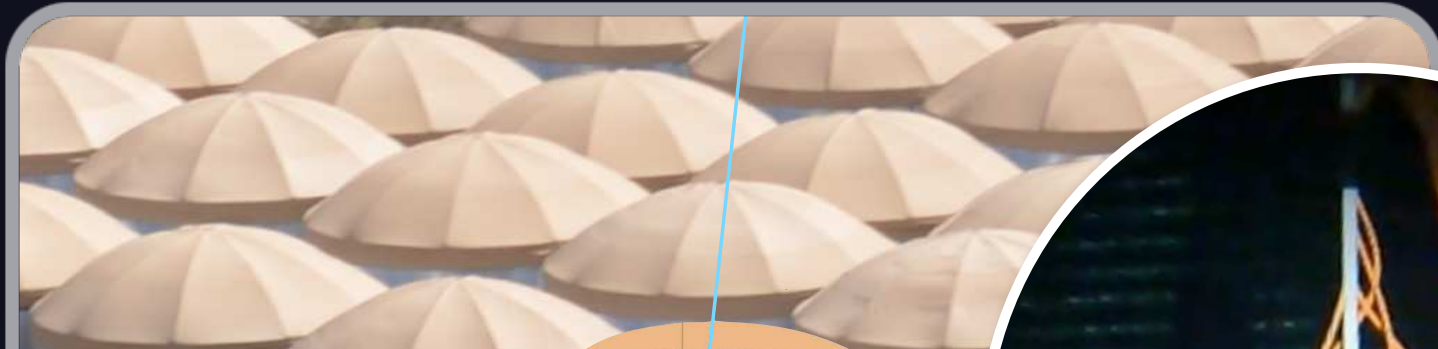
300 - 7 m x 5 m steel Water Cherenkov Detectors  
(a.k.a. tanks) with 4 PMTs at 4,100 m a.s.l. in Mexico

# Water Cherenkov Detectors



Water Cherenkov Detectors  
PMTs at 4,100 m a.s.l. in Mexico

# Water Cherenkov Detectors



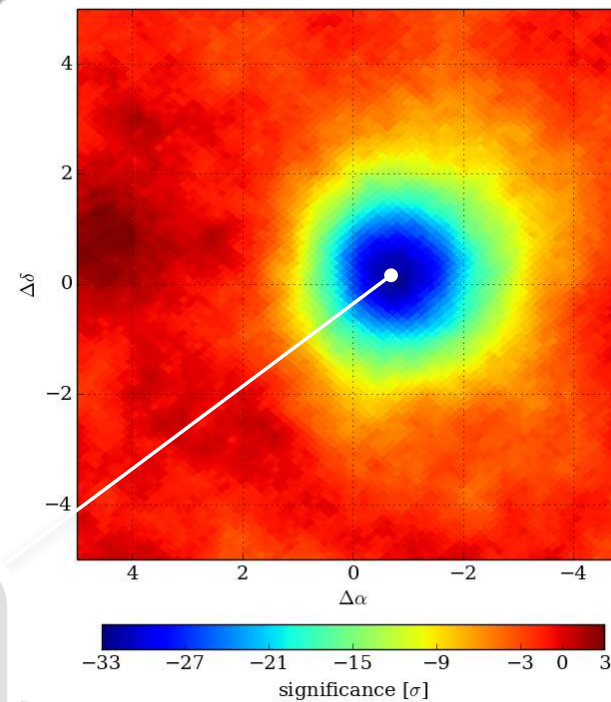
ation system

# Water Cherenkov Detectors

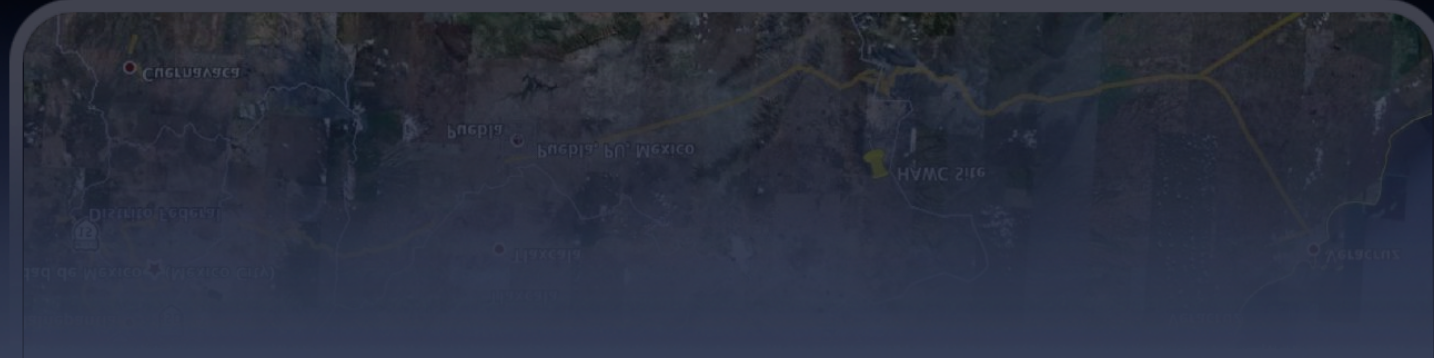
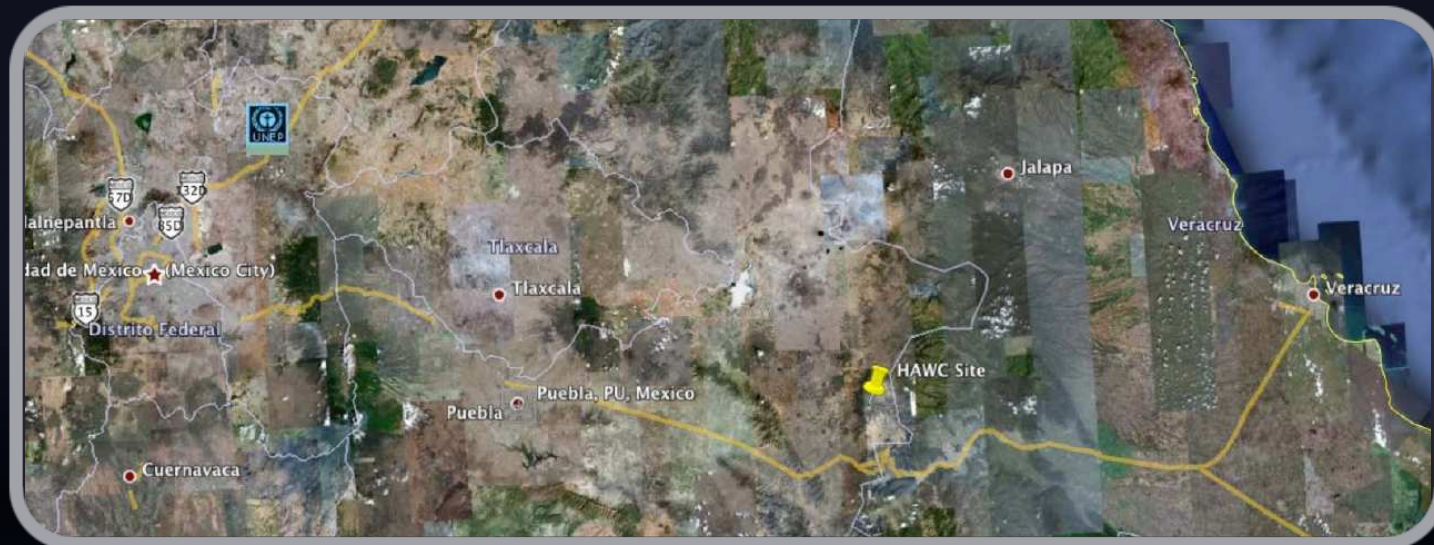
Effect of the laser calibration on the observation of the shadow of the Moon

- deflection matches 2 TeV median energy
- angular resolution < shadow width of  $1.2^\circ$
- position verifies pointing

Dedicated laser calibration system

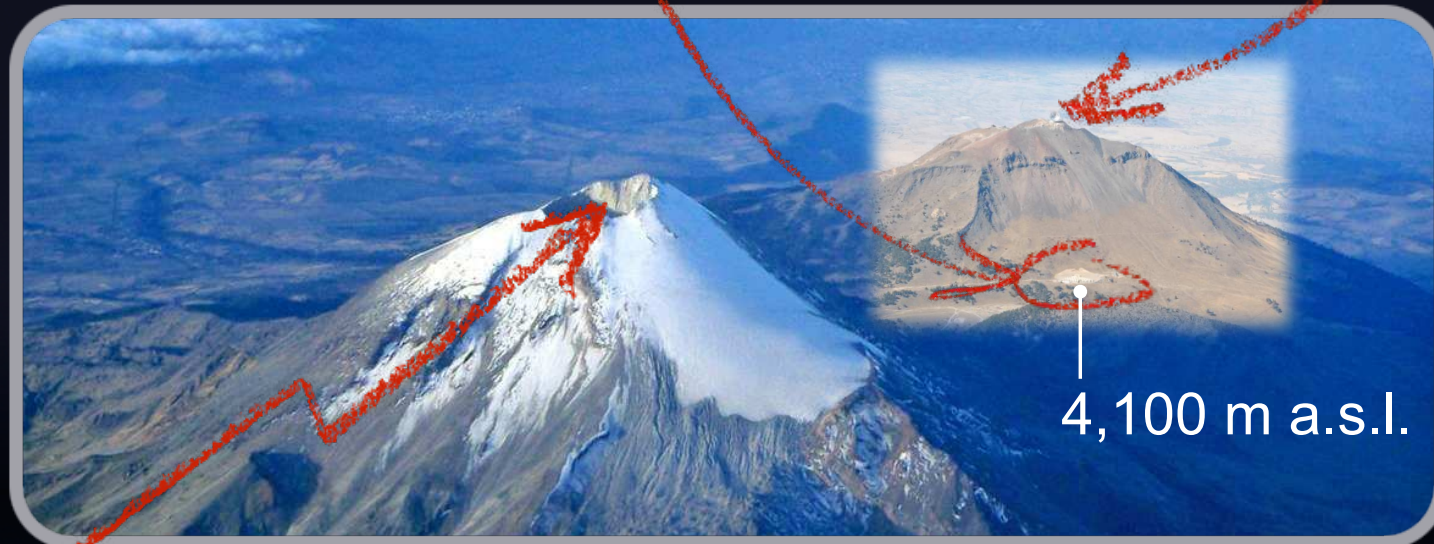


# HAWC site



# HAWC site

LMT (4,600 m)



4,100 m a.s.l.

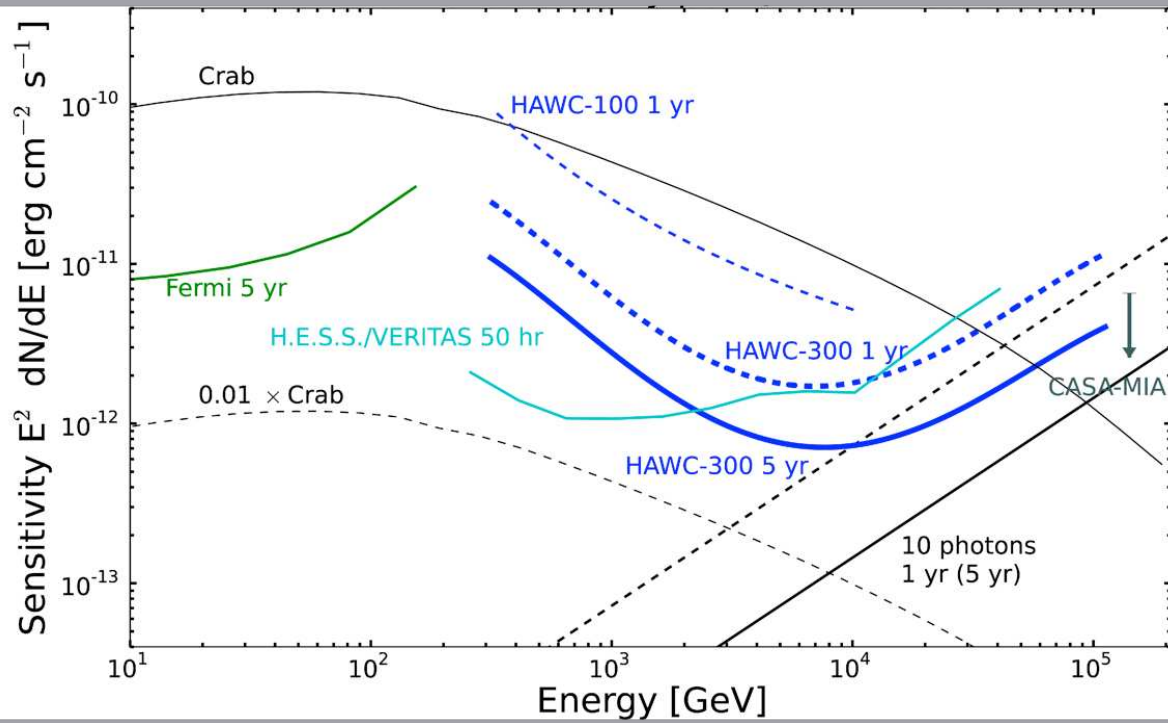
Pico de Orizaba (18,500 ft)

# working at the HAWC site



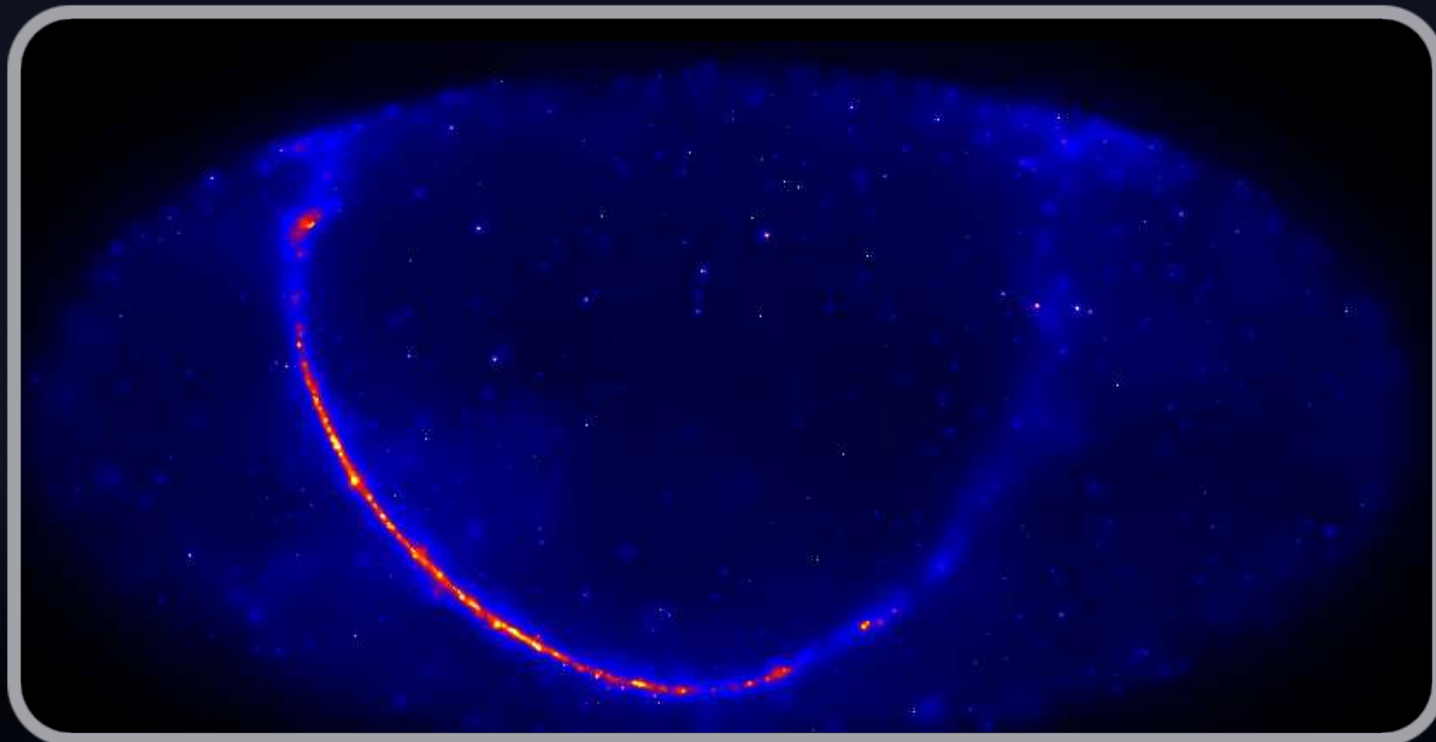


# Design improvements



**x15 more sensitive than Milagro**

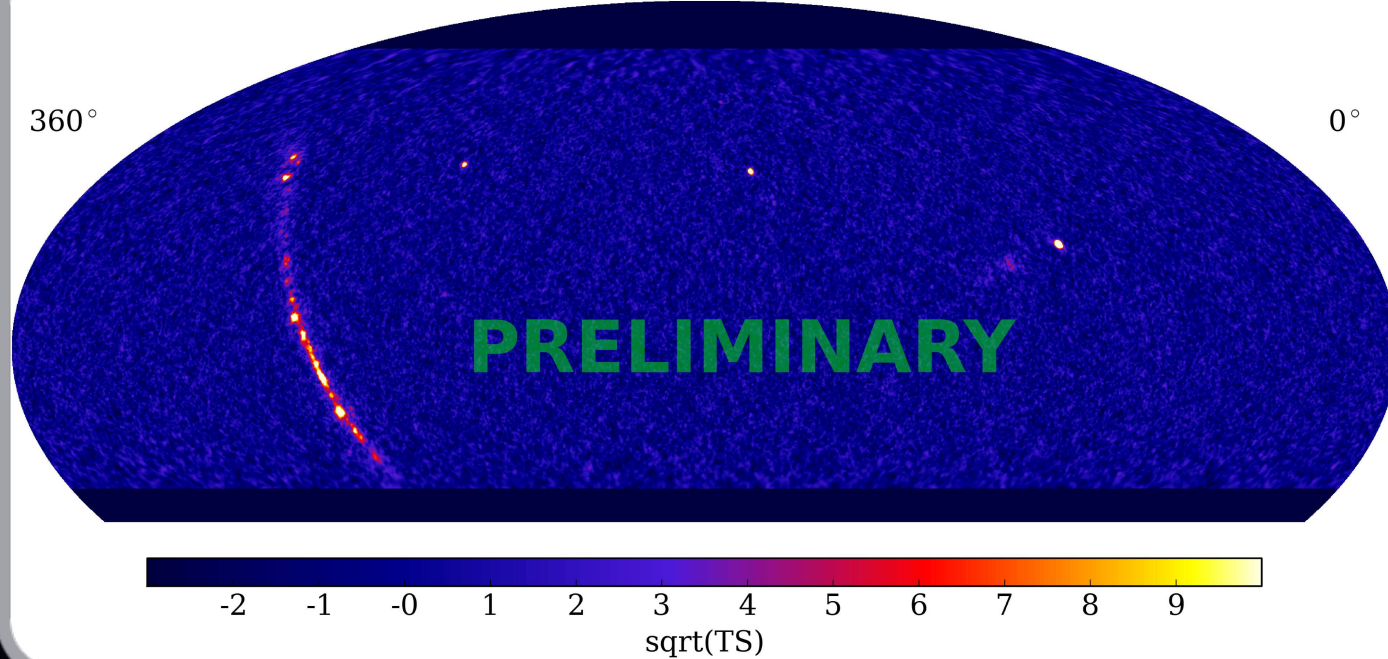
# Design improvements



Fermi-LAT sky smoothed map  
 $E > 50$  GeV (Pass 8 - 6 years of data)  
(courtesy of M. Ajello)

# Design improvements

Equatorial all sky map, point source search, spectral index -2.7



Fermi-LAT sky smoothed map  
 $E > 50$  GeV (Pass 8 - 6 years of data)  
(courtesy of M. Ajello)

Preliminary HAWC smoothed map  
 $E > 300$  GeV ( $\sim 1$  year of data)  
Full array

# Deployment status



From 2011 to 2015

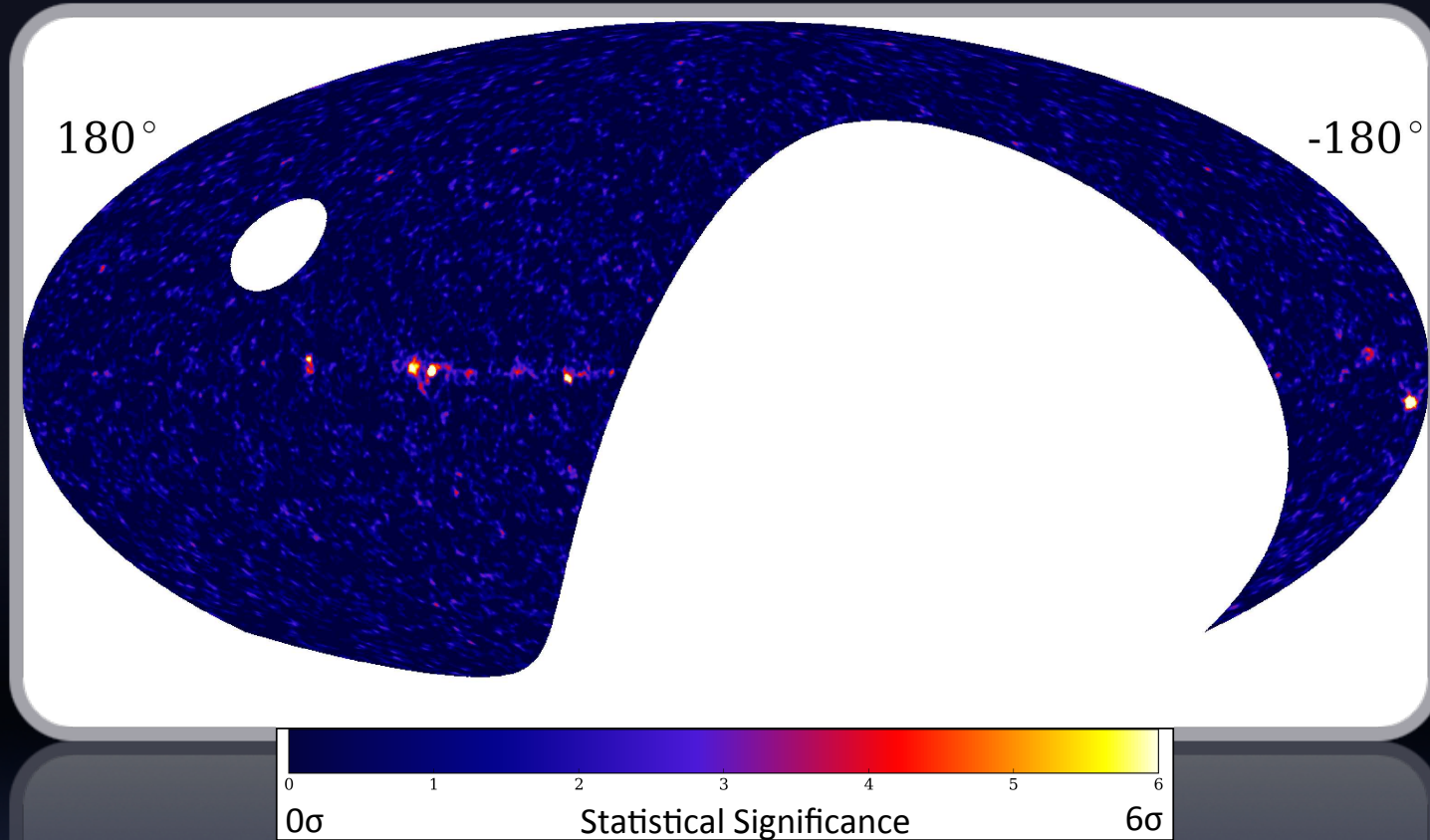
# Deployment status



From 2011 to 2015

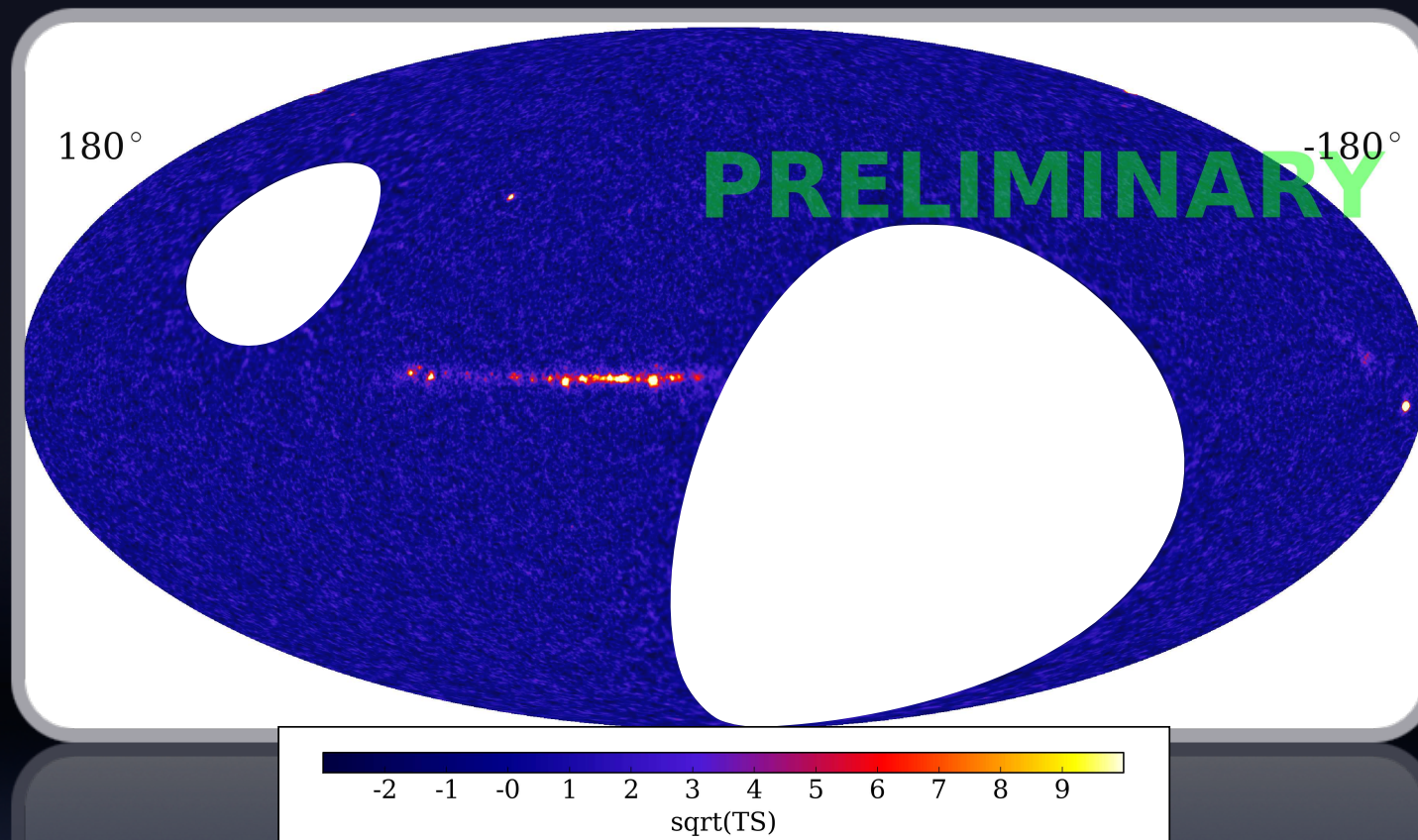
# *First Results*

# Milagro — 8-year TeV sky survey ( $17\sigma$ Crab)



## Multi-TeV sky

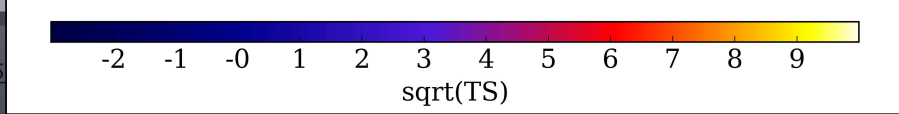
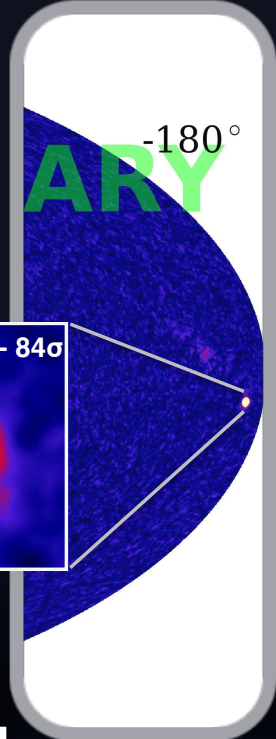
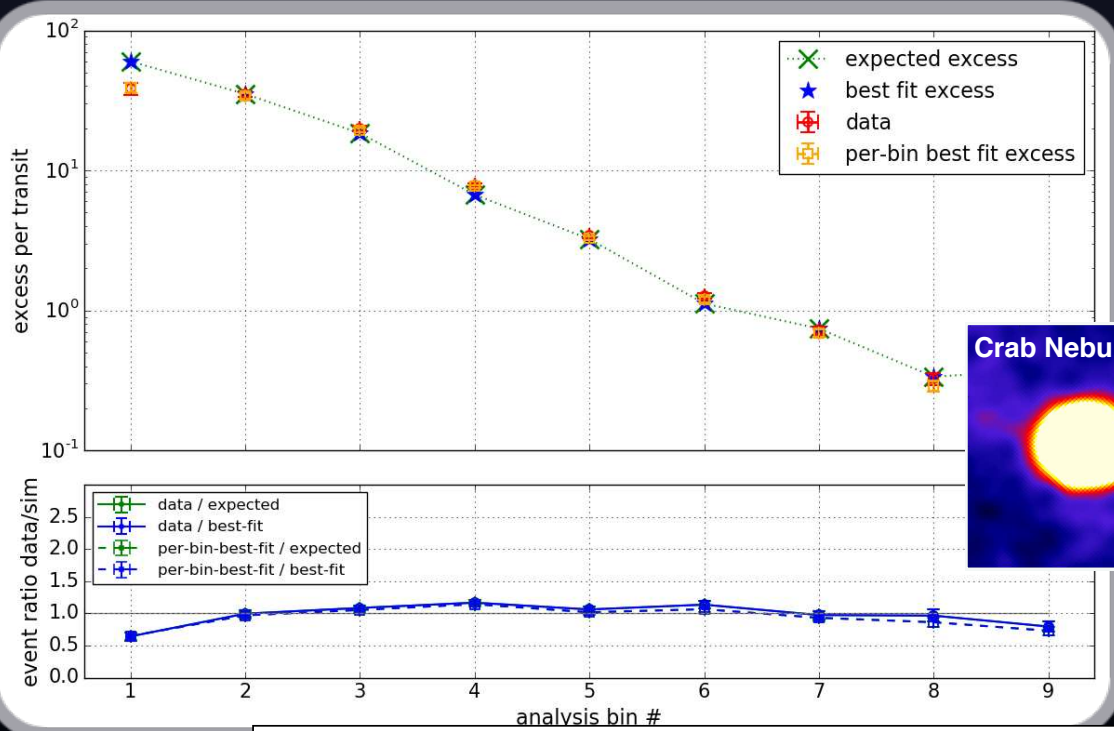
HAWC — 340-day TeV sky survey ( $>80\sigma$  Crab)



Multi-TeV sky

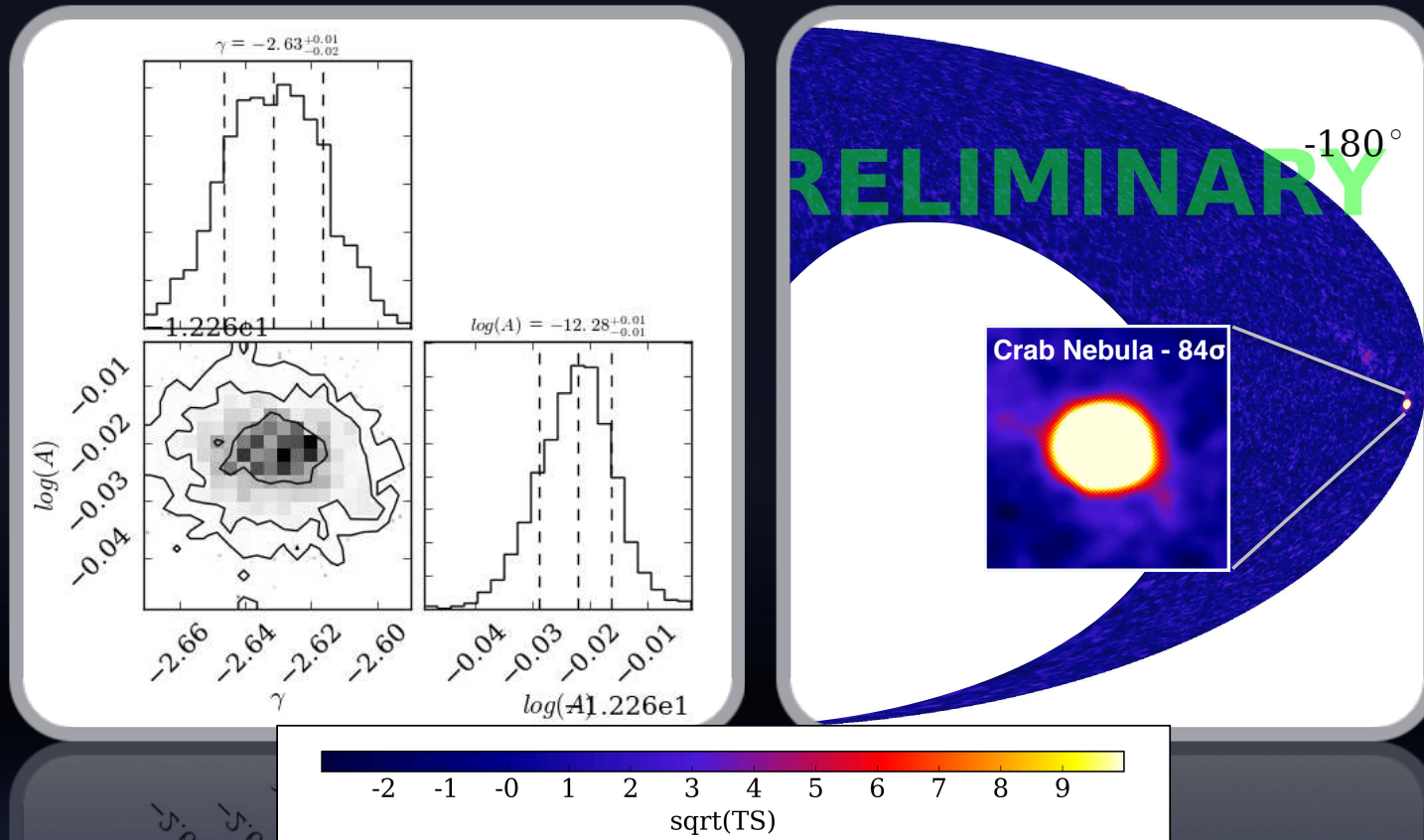


# HAWC — 340-day TeV sky survey ( $>80\sigma$ Crab)



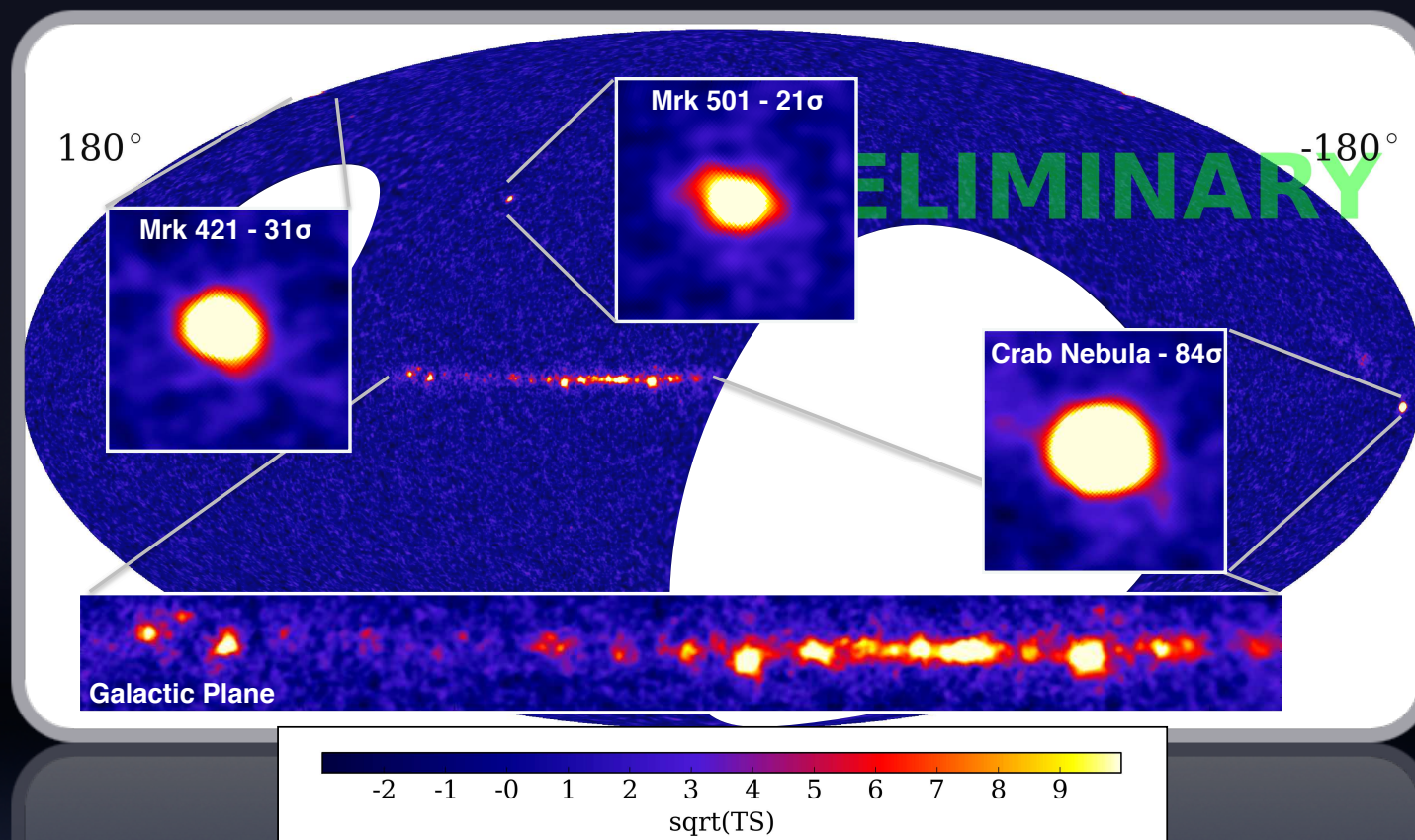
Multi-TeV sky

# HAWC — 340-day TeV sky survey ( $>80\sigma$ Crab)



## Multi-TeV sky

# HAWC — 340-day TeV sky survey ( $>80\sigma$ Crab)



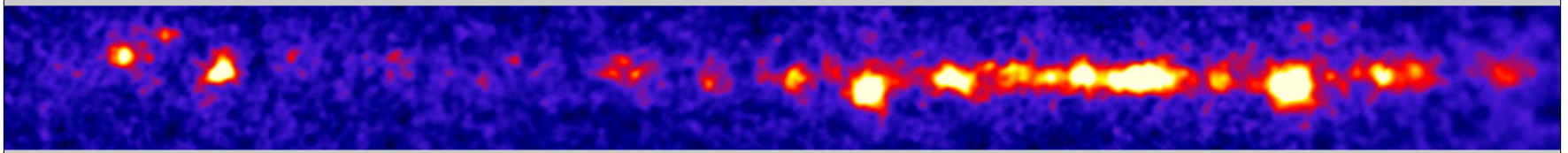
## Multi-TeV sky

# from Milagro to HAWC



- Inner Galaxy: Milagro (8 years) vs. 1<sup>st</sup> year of HAWC

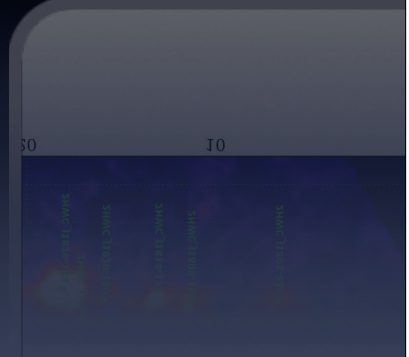
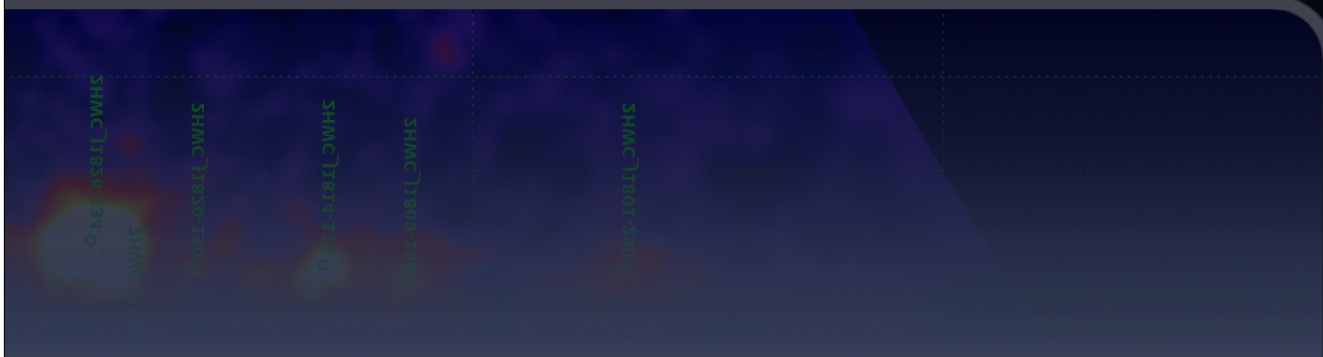
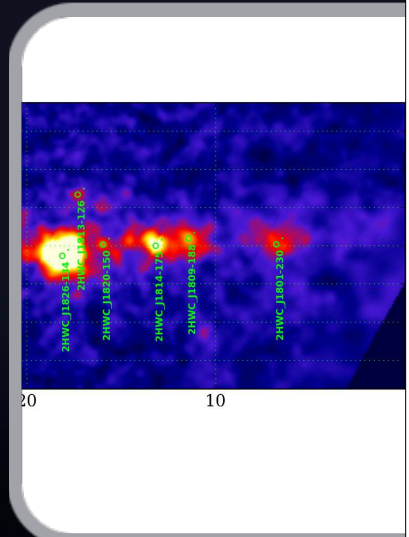
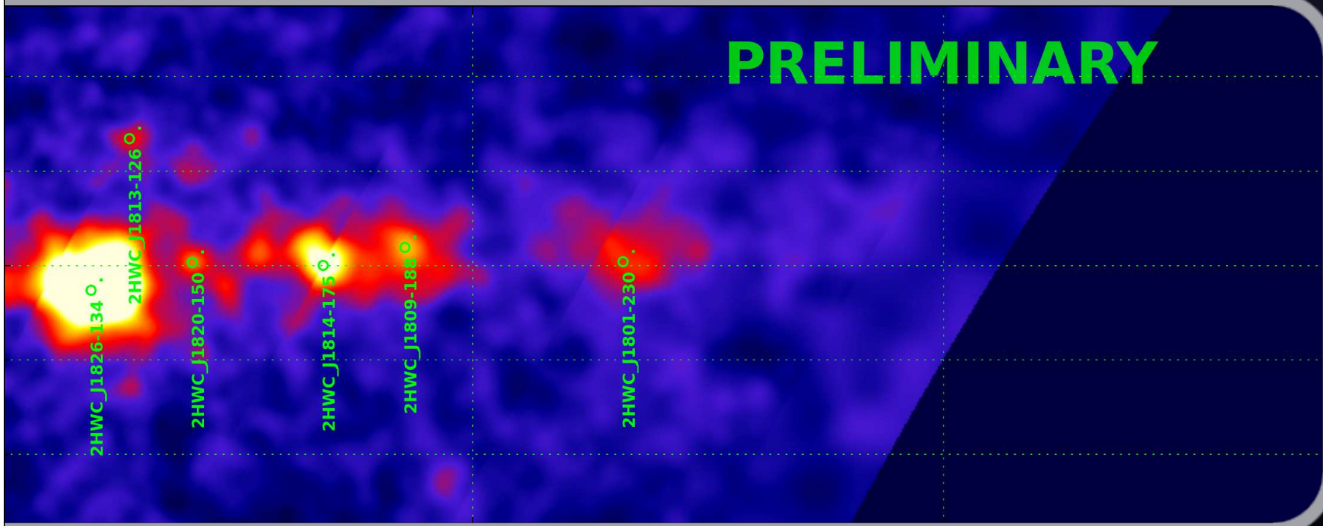
# from Milagro to HAWC

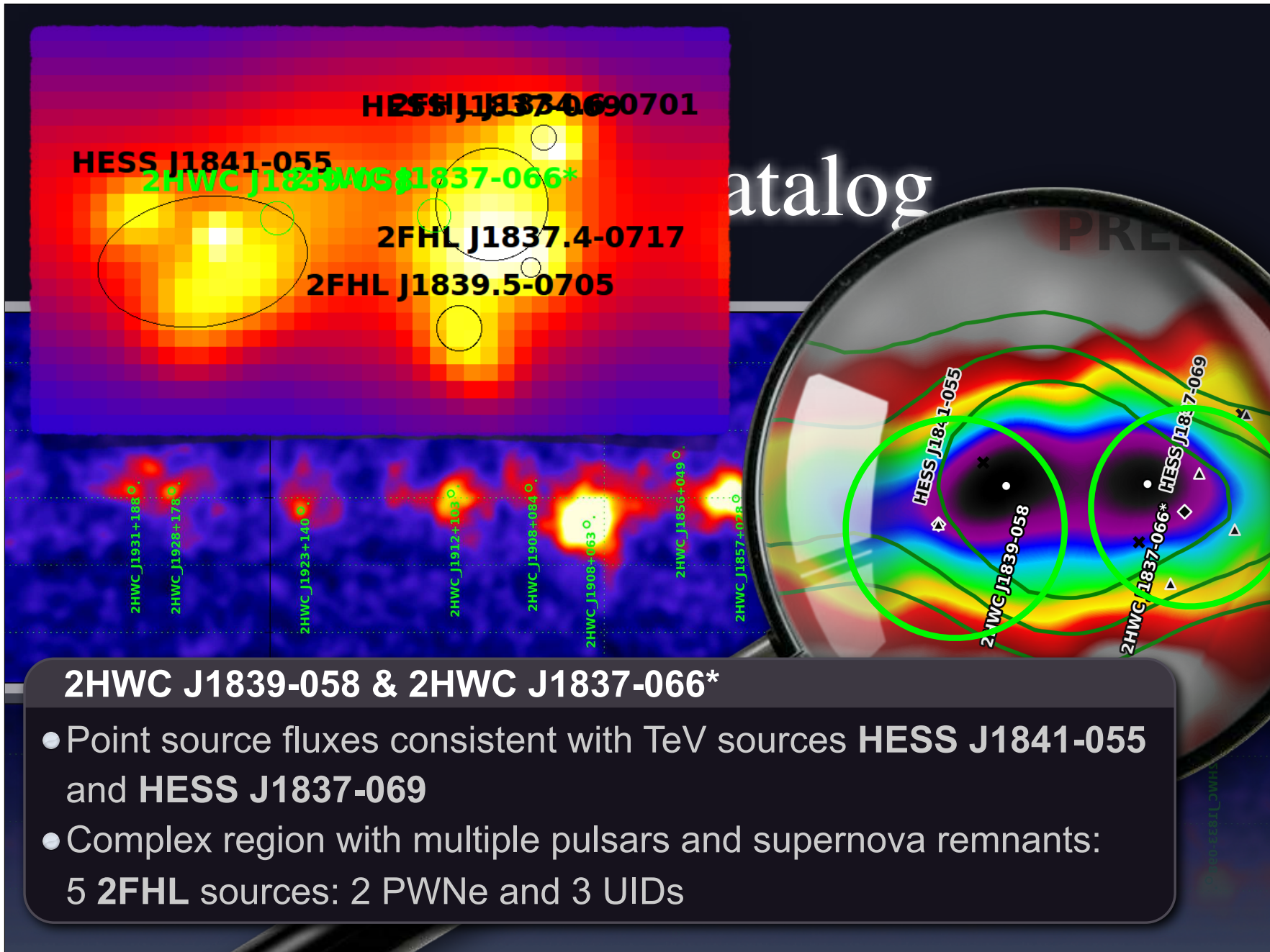


- Inner Galaxy: Milagro (8 years) vs. 1<sup>st</sup> year of HAWC

# first year catalog

PRELIMINARY





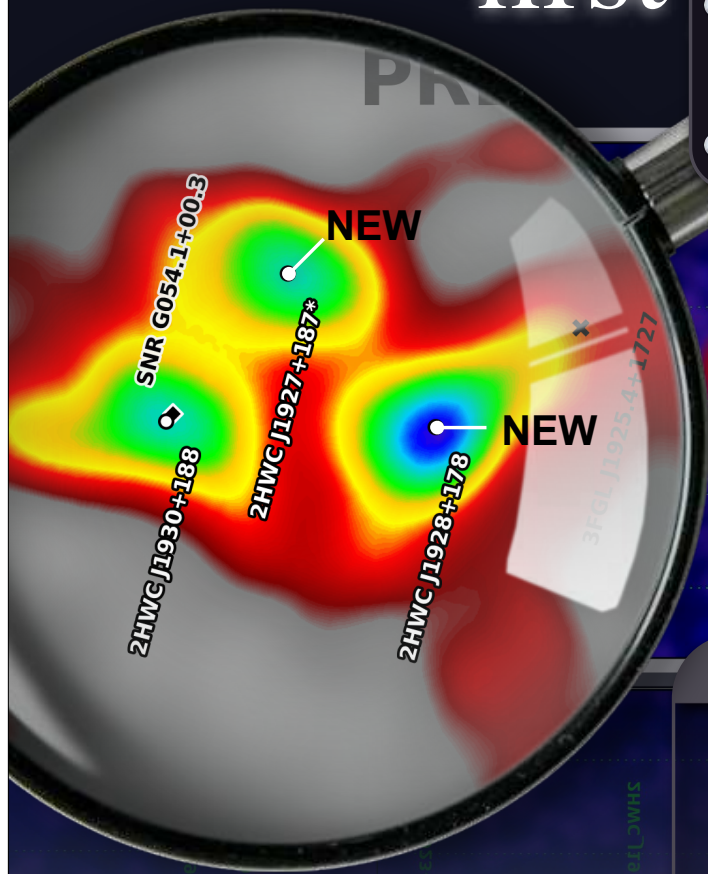
atalog

PRE

**2HWC J1839-058 & 2HWC J1837-066\***

- Point source fluxes consistent with TeV sources **HESS J1841-055** and **HESS J1837-069**
- Complex region with multiple pulsars and supernova remnants:  
5 **2FHL** sources: 2 PWNe and 3 UIDs

first



### 2HWC J1930+188

- coincident with VER J1930+188
- SNR G54.1+00.3 — PSR J1930+1852
- TeV emission was reported to be point-like and likely from PWN
- nearby molecular CO cloud

### 2HWC J1927+187\*

- associated with 2HWC J1930+188?
- ongoing analysis on spatial morphology

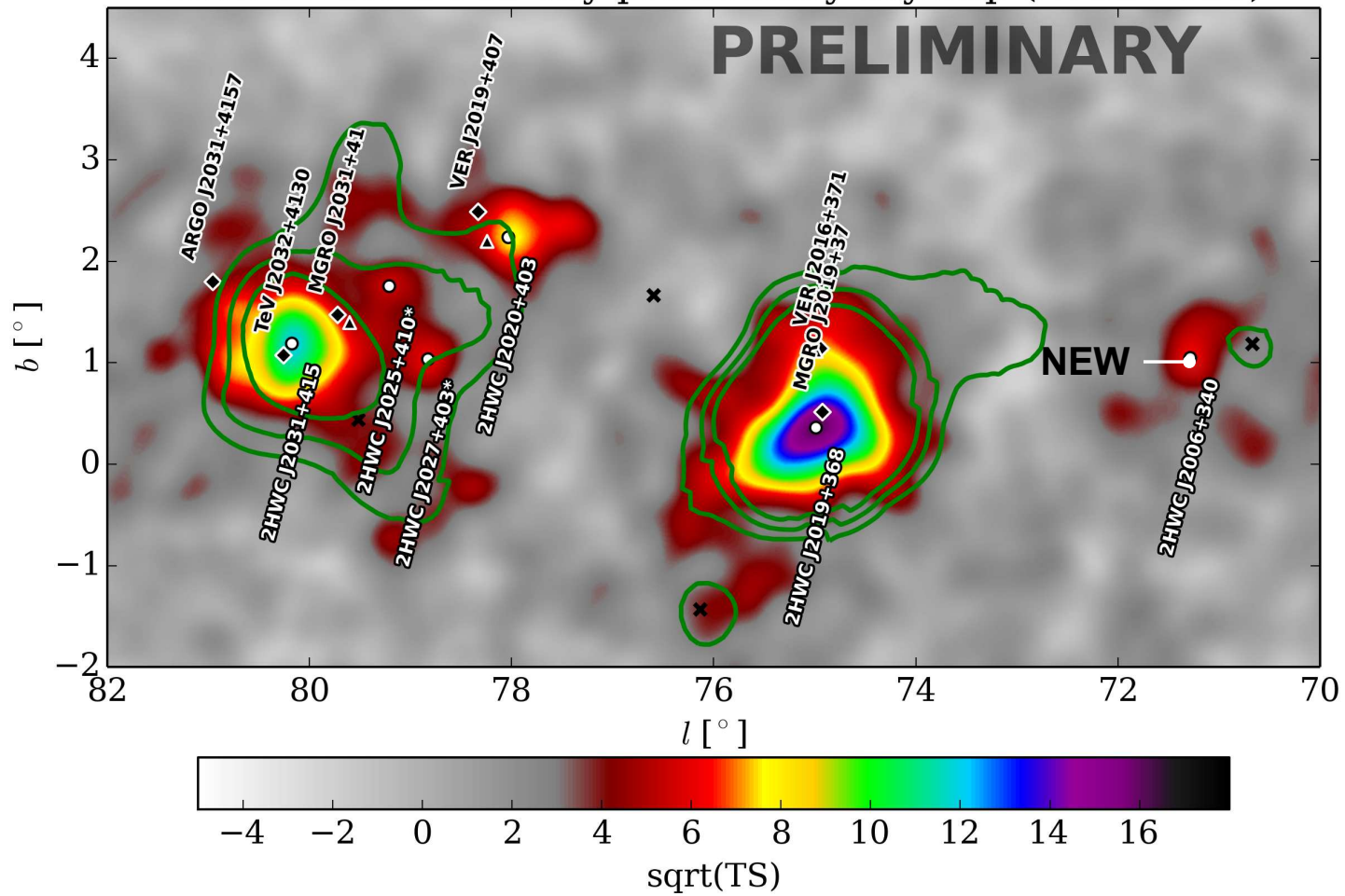
### 2HWC J1928+178

- coincident with PSR J1928+1746
- tail towards unidentified source 3FGL J1925.4+1727
- VERITAS pt-src upper limit  $\sim 1.4\%$  of Crab

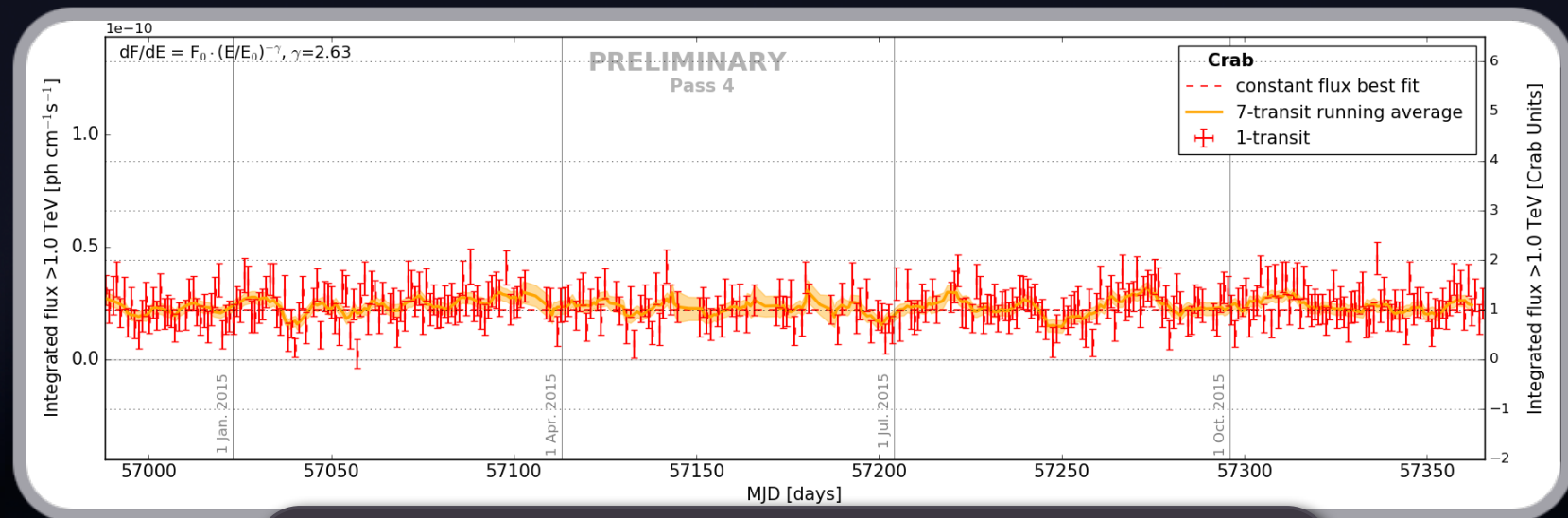
PRELIMINARY



HAWC Pass 4 341-day preliminary skymap (2014-2015)



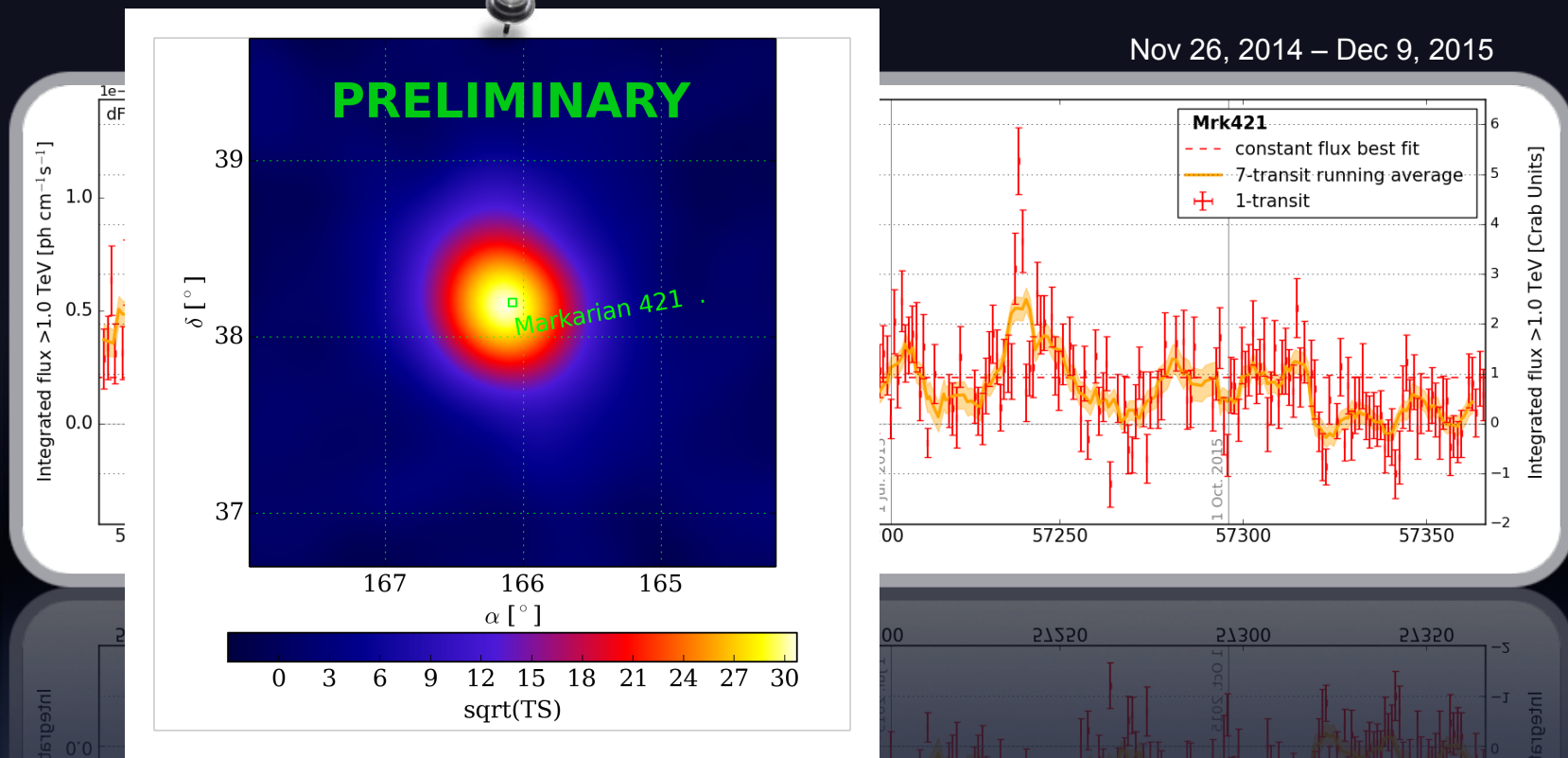
# transient searches



## Crab

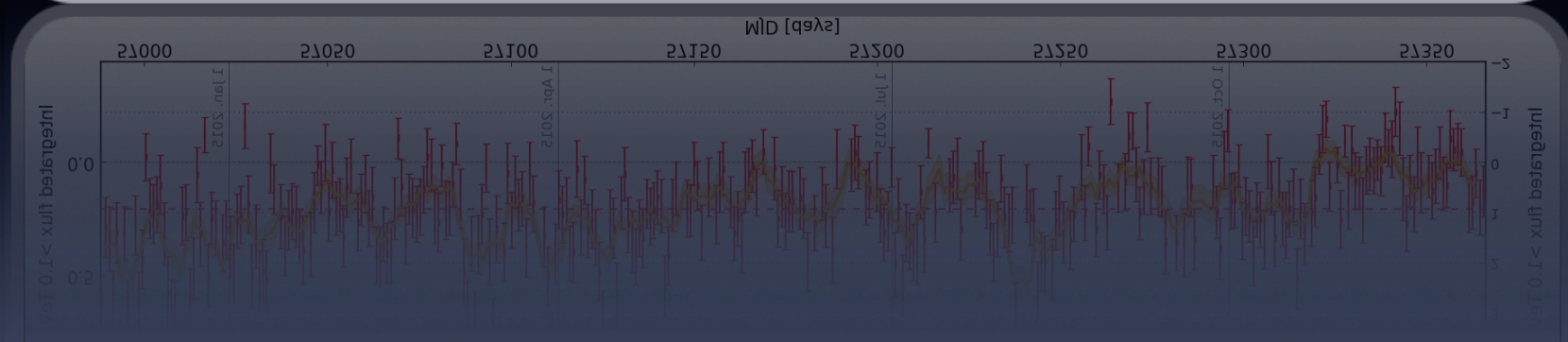
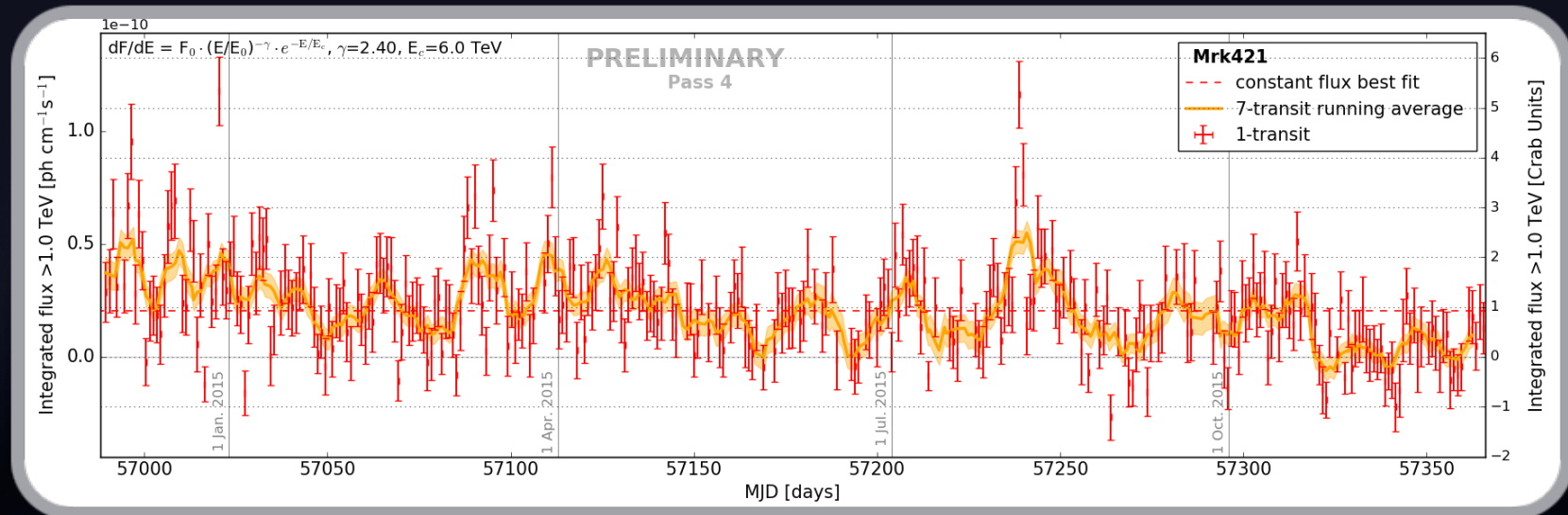
- Pass 4 data from 26 Nov 2014 to 9 Dec 2015
- >80 $\sigma$  in 315 transits
- lightcurve binned in sidereal day
- consistent with constant flux

# AGN flares with HAWC

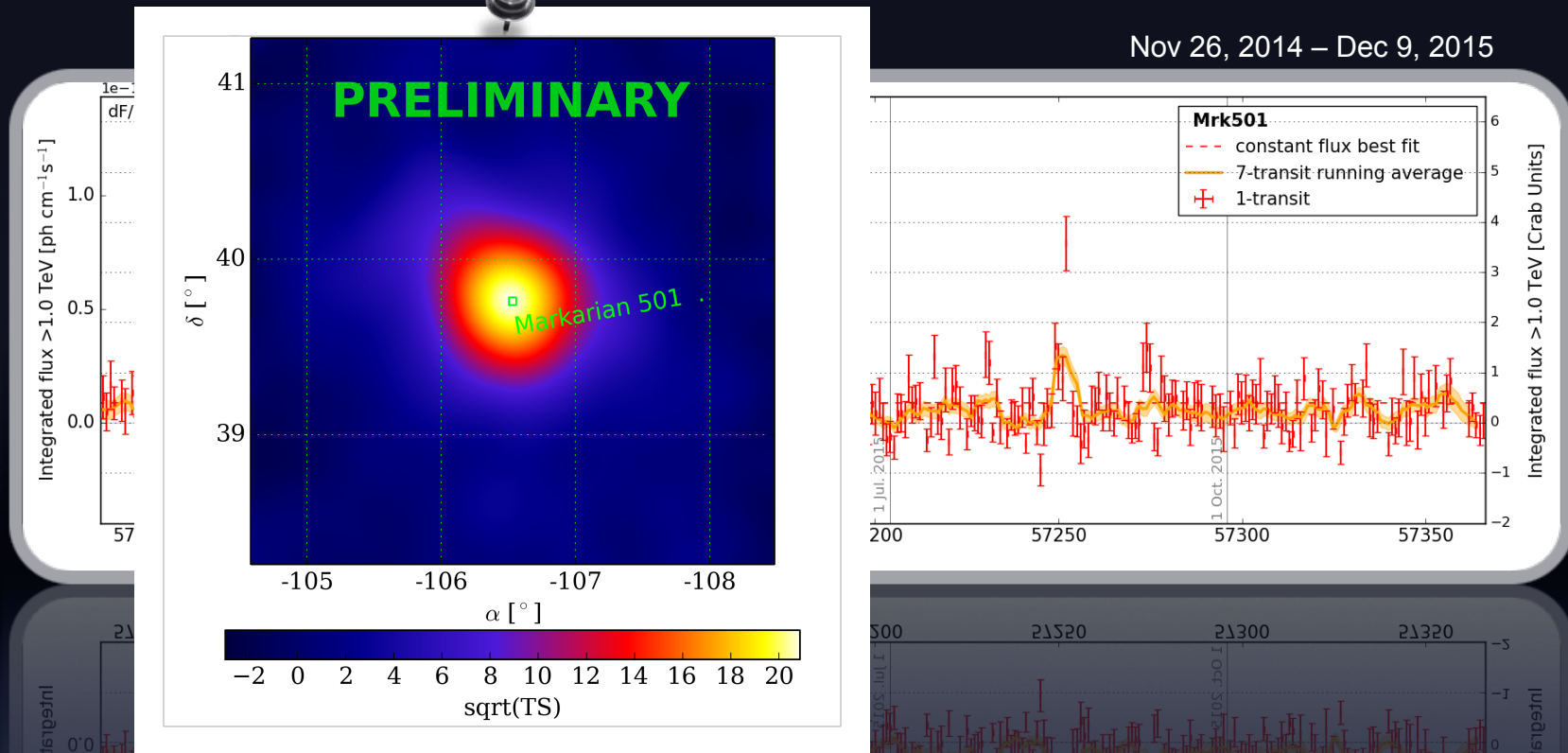


# AGN flares with HAWC

Nov 26, 2014 – Dec 9, 2015

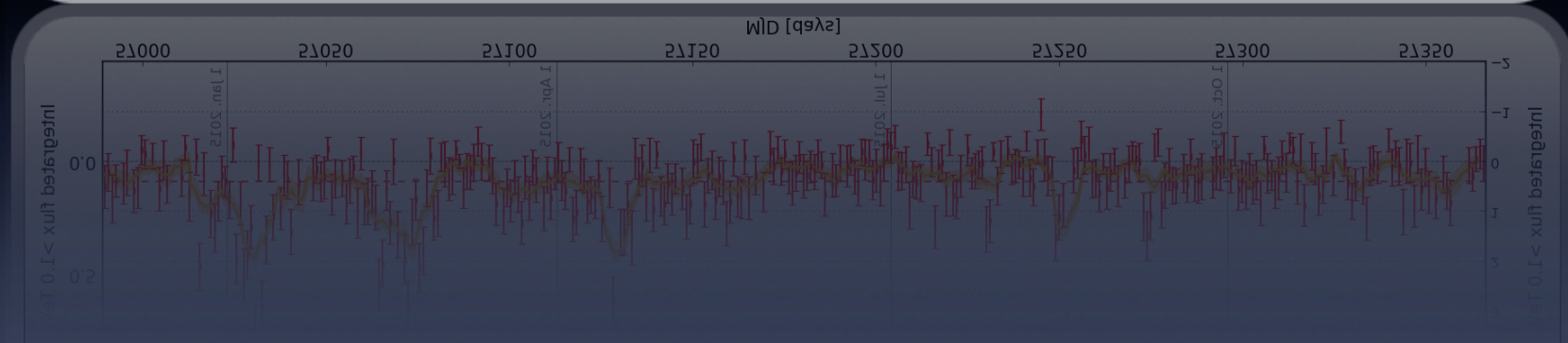
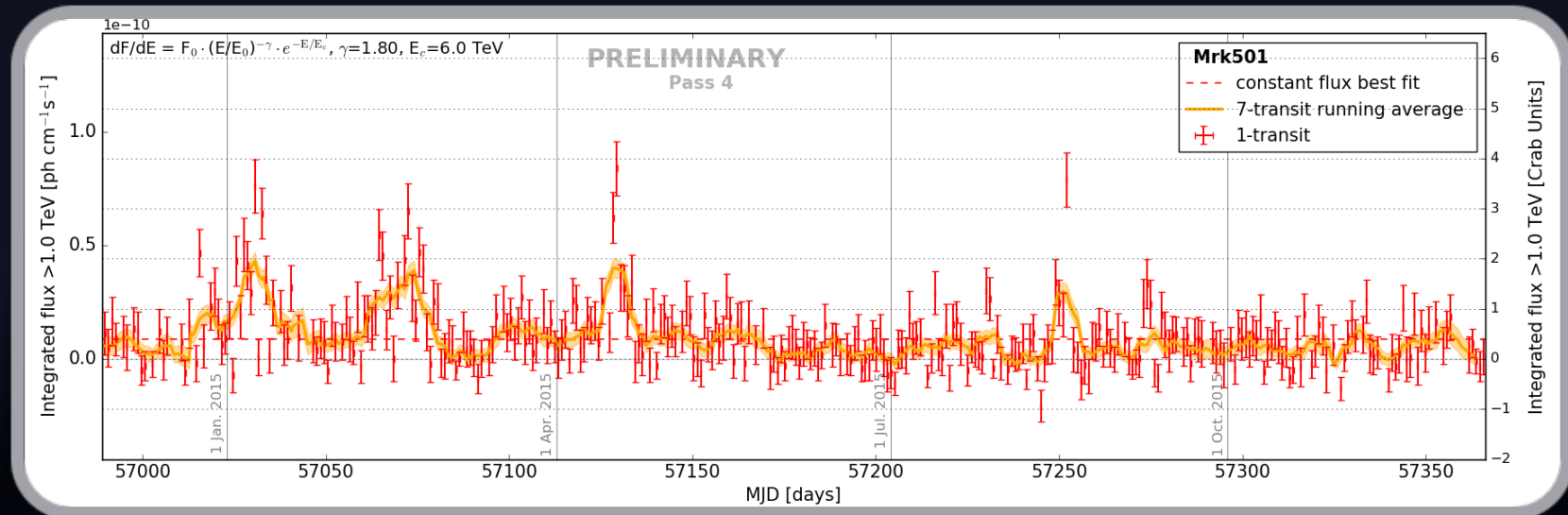


# AGN flares with HAWC

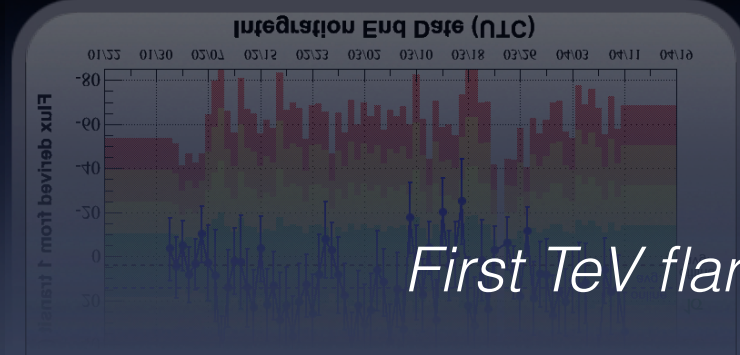
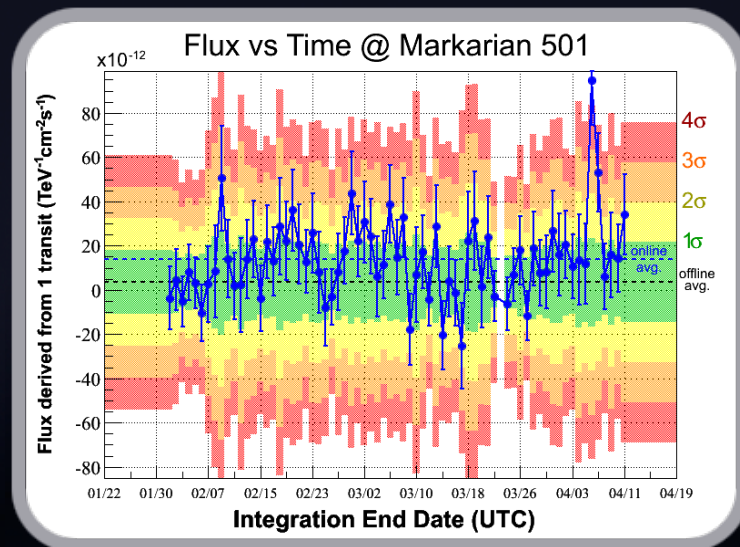


# AGN flares with HAWC

Nov 26, 2014 – Dec 9, 2015



# AGN flares with HAWC



## HAWC detection of increased TeV flux state for Markarian 501

ATel #8922; *Andrés Sandoval (IF-UNAM), Robert Lauer (UNM), Joshua Wood (UMD) on behalf of the HAWC collaboration*  
 on 7 Apr 2016; 23:38 UT  
 Credential Certification: C. Michelle Hui (c.m.hui@nasa.gov)

Subjects: Gamma Ray, TeV, VHE, Request for Observations, AGN, Blazar

Tweet Recommend 15

The HAWC Observatory measured an increased gamma-ray flux from the direction of the BL Lac Markarian 501 ( $z=0.033$ ) at the level of  $(4.88 \pm 1.05) \times 10^{-11}$  photons  $\text{cm}^{-2} \text{s}^{-1}$  above 1 TeV when averaged during the 6 hour transit over HAWC on April 6, 2016 (MJD 57484.31 - 57484.56) which is 2.2 times the average Crab flux observed by HAWC. For the following transit on April 7, 2016 (MJD 57485.30 - 57485.55), a decreased but still above-average flux of  $(2.78 \pm 0.09) \times 10^{-11}$  photons  $\text{cm}^{-2} \text{s}^{-1}$  was observed, 1.3 times the Crab flux seen by HAWC. The flux on April 6 lies 4 sigma above the average flux of  $0.89 \times 10^{-11}$  photons  $\text{cm}^{-2} \text{s}^{-1}$  that was measured for this source by HAWC during the previous year. The flux level on April 7 is 2 sigma above this average and seems to indicate a declining but on-going high flux state. All flux values are obtained from a maximum likelihood fit under the assumption of a fixed spectral shape with power law index of 1.8 and exponential cut-off at 6 TeV. These spectral parameters are the best fit results for HAWC data from Markarian 501 collected between November 2014 and December 2015. HAWC is a TeV gamma ray water Cherenkov array located in the state of Puebla, Mexico that monitors 2/3 of the sky every day with an instantaneous field of view of  $\sim 2$  sr. The HAWC contact people for this analysis are Robert Lauer (University of New Mexico, rjlauer@unm.edu) and Michelle Hui (Marshall Space Flight Center, c.m.hui@nasa.gov).

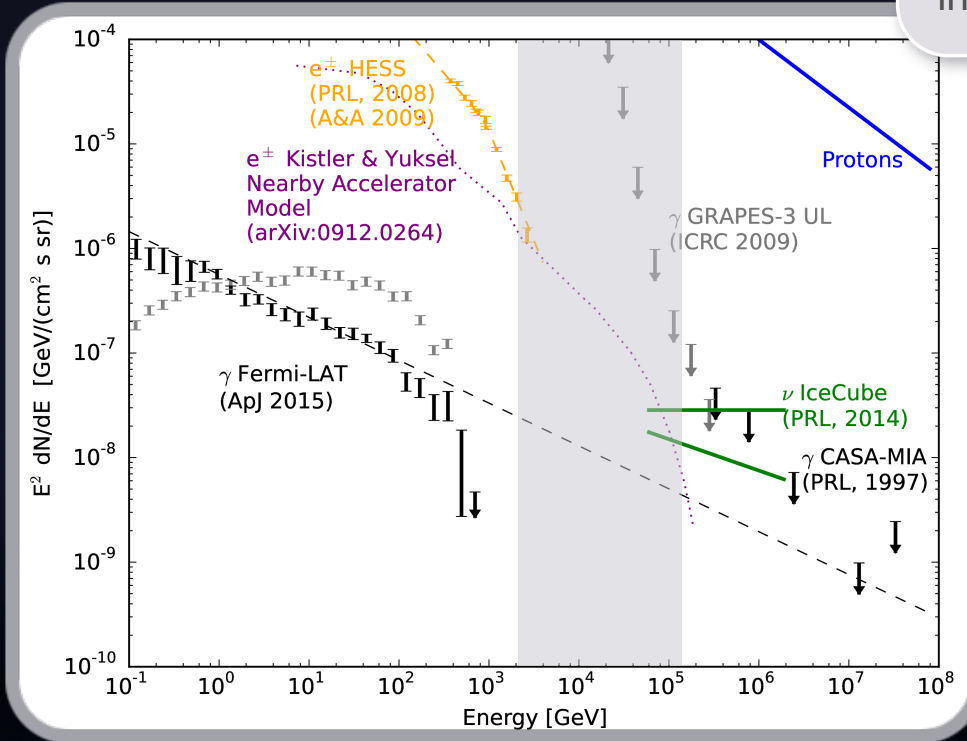
*First TeV flare alert from HAWC!*





# Isotropic Diffuse Emission

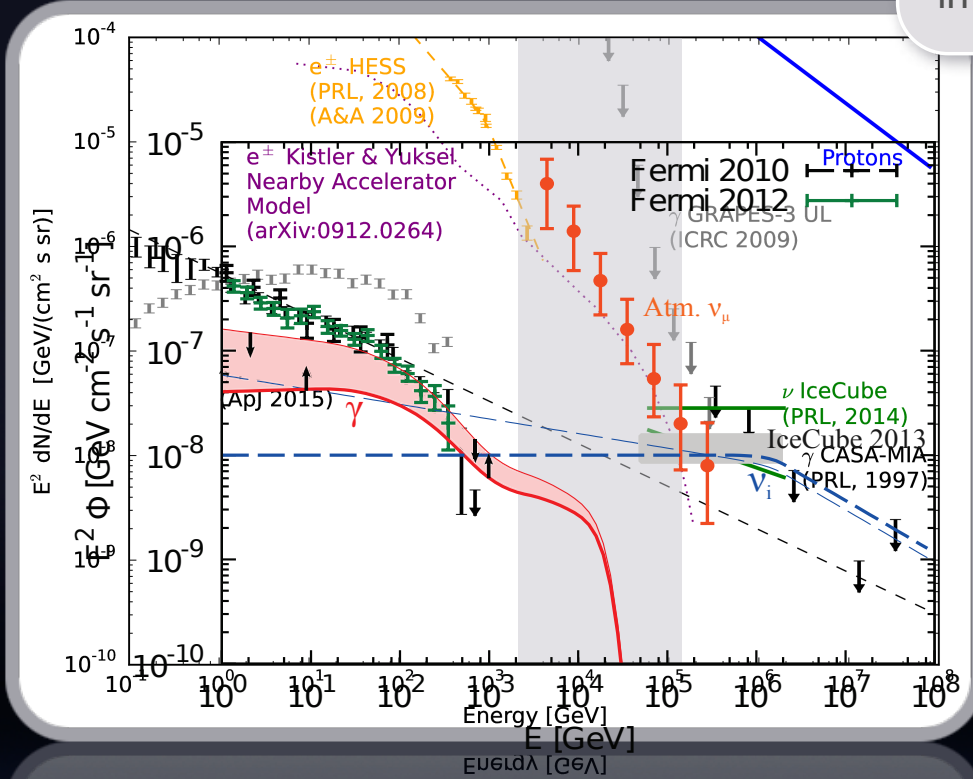
Neither measurements nor limits  
in the 10-100 TeV range



# connecting HAWC with IC

# Isotropic Diffuse Emission

Neither measurements nor limits  
in the 10-100 TeV range

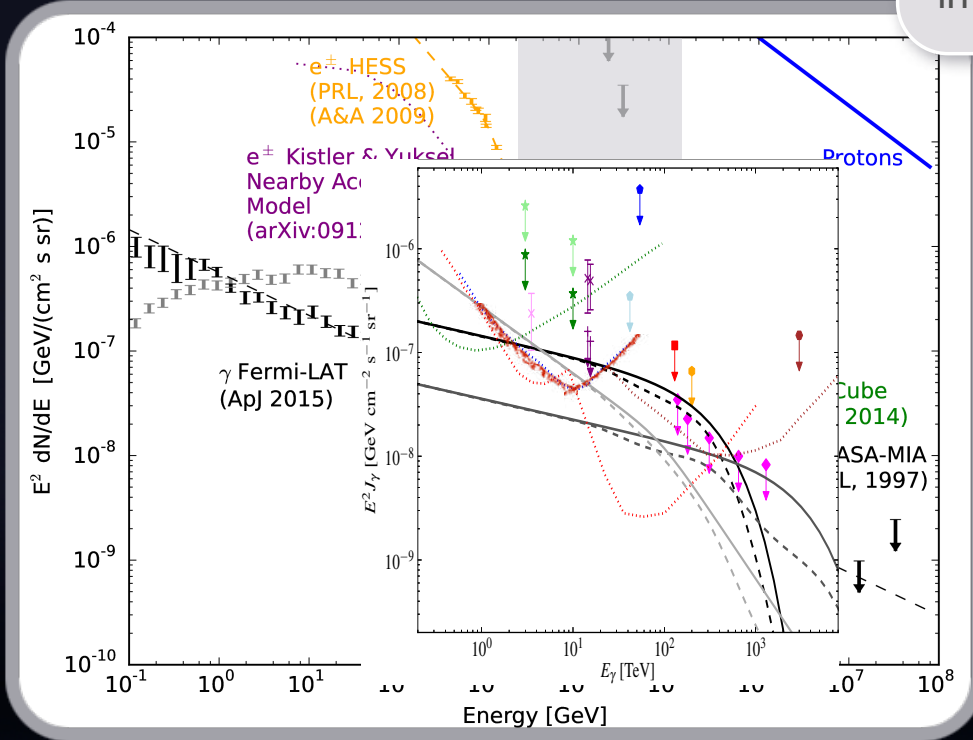


K. Murase, M. Ahlers, B.C. Lacki,  
Phys. Rev. D 88 (2013) 121301

# connecting HAWC with IC

# Isotropic Diffuse Emission

Neither measurements nor limits in the 10-100 TeV range

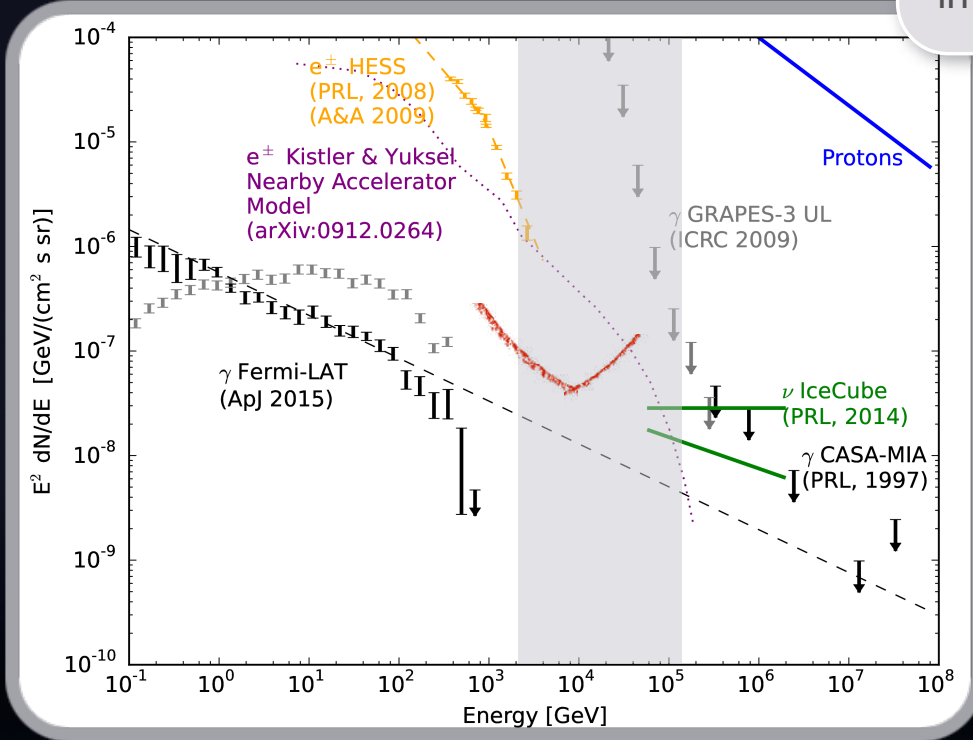


M. Ahlers, K. Murase,  
Phys. Rev. D 90 (2014) 023010

connecting HAWC with IC

# Isotropic Diffuse Emission

Neither measurements nor limits  
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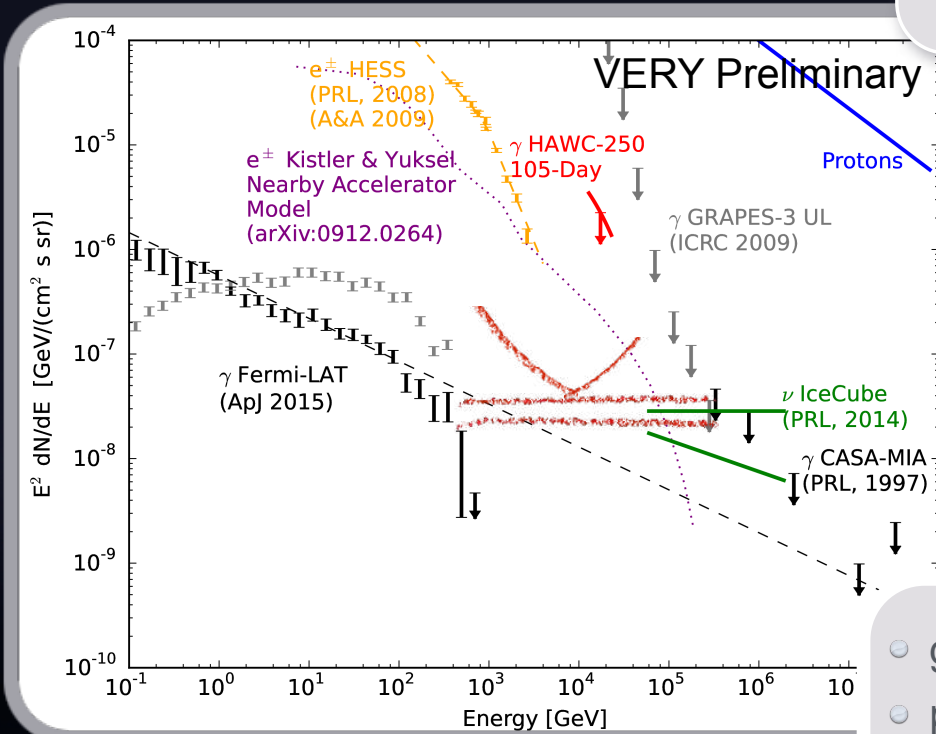


M. Ahlers, K. Murase,  
Phys. Rev. D 90 (2014) 023010

connecting HAWC with IC

# Isotropic Diffuse Emission

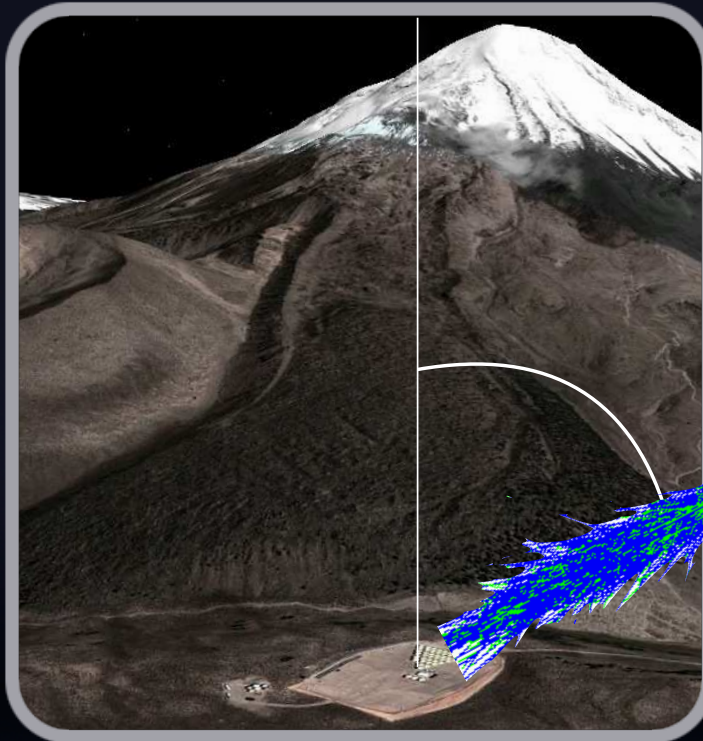
Neither measurements nor limits in the 10-100 TeV range



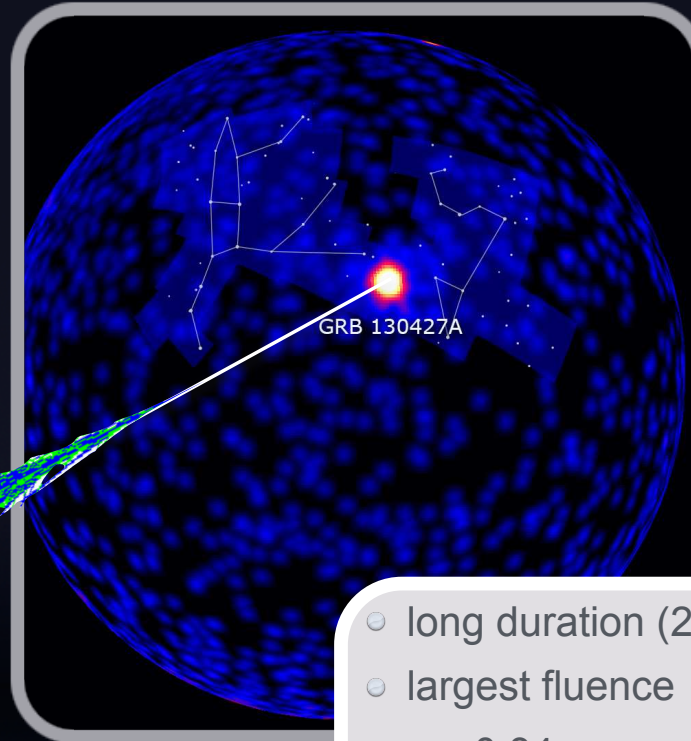
- gamma/hadron separation
- precise understanding of background efficiency

# connecting HAWC with IC

## GRB 130427A

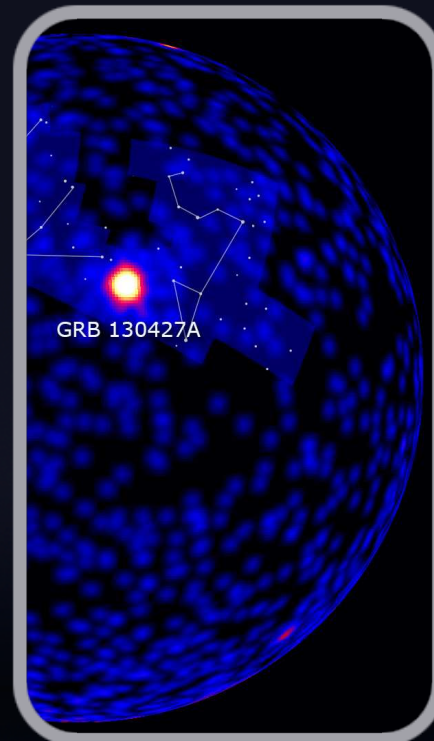
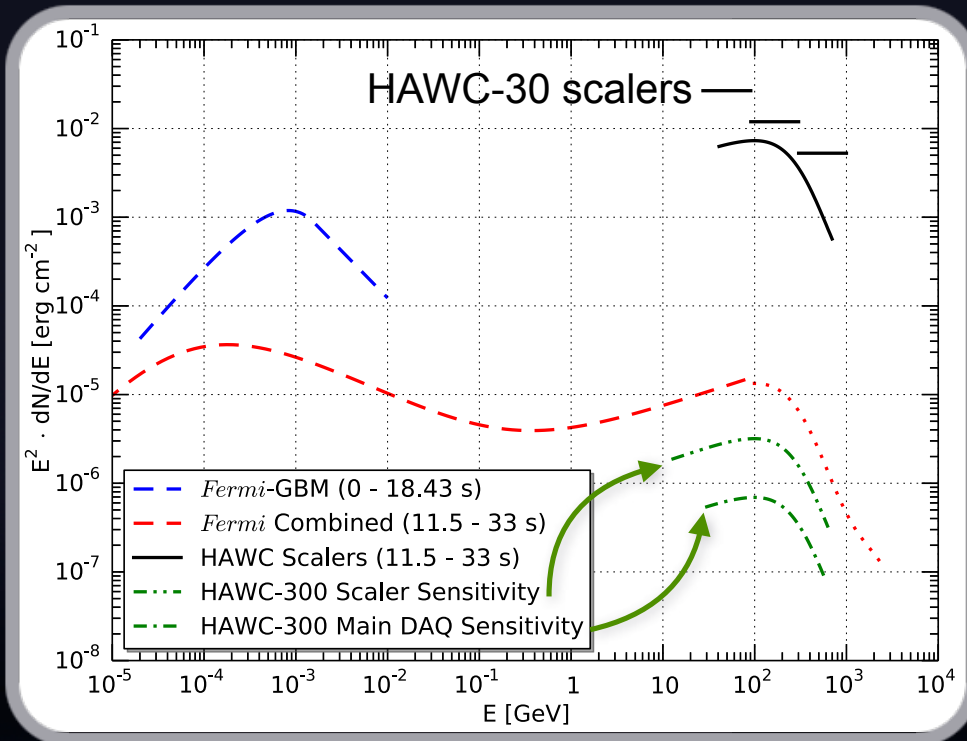


- HAWC-30
- $\theta = 57^\circ$
- only scalars DAQ up



- long duration (20 h)
- largest fluence
- $z = 0.34$
- highest energy photon (95 GeV)

# GRB 130427A



- HAWC-30
- $\theta = 57^\circ$
- only scalers DAQ up

"Search for gamma-rays from the unusually bright GRB 130427A with the HAWC Gamma-ray Observatory,"  
*The Astrophysical Journal*, Volume 800 (2015) Number 2, p78

# Outlook

## Other results

- Dark matter, extended regions, Cosmic rays, ...
- EBL, solar physics, ...

## Multi-wavelength physics

- MoUs with IceCube, IACTs, etc
- AMON
- HAWC alerts

## Enhancements

- Array of Outriggers

## Future Experiment

- Southern Observatory





*Thank you very much*