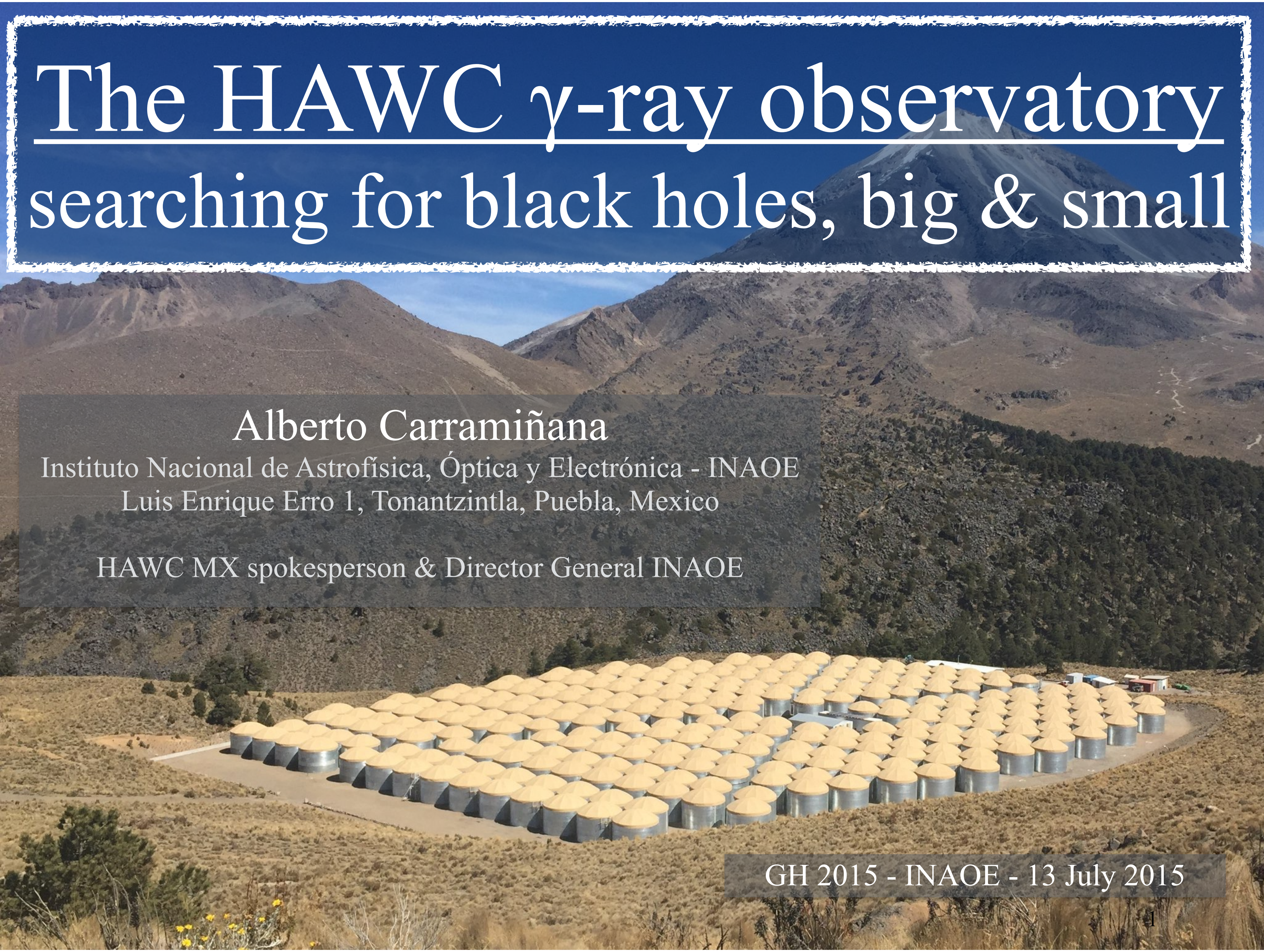
The HAWC γ-ray observatory

searching for black holes, big & small



Alberto Carramiñana

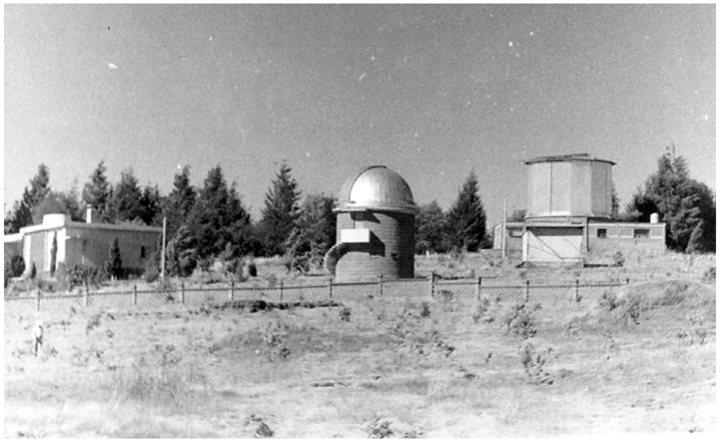
Instituto Nacional de Astrofísica, Óptica y Electrónica - INAOE

Luis Enrique Erro 1, Tonantzintla, Puebla, Mexico

HAWC MX spokesperson & Director General INAOE

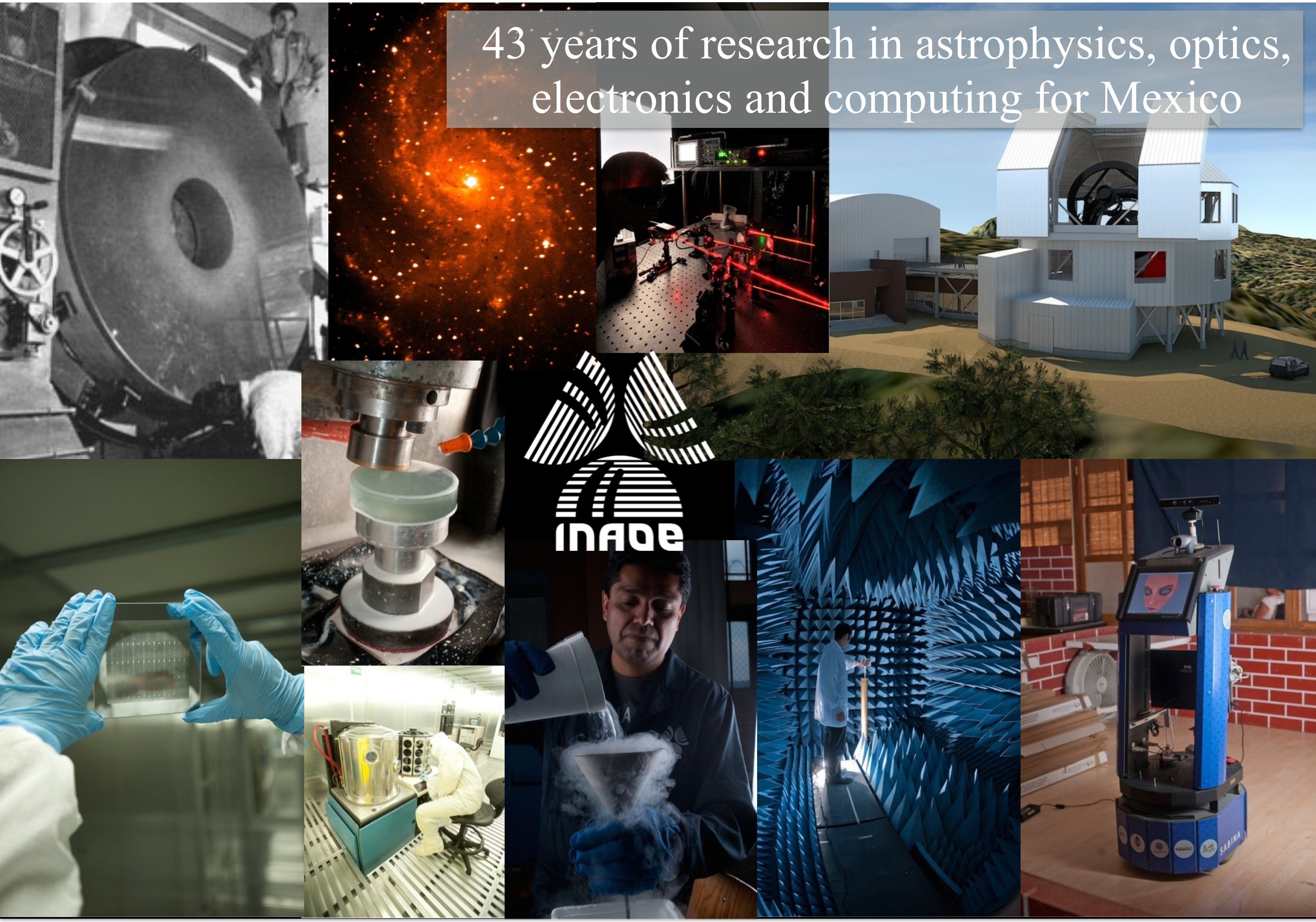
GH 2015 - INAOE - 13 July 2015

Instituto Nacional de Astrofísica, Óptica y Electrónica



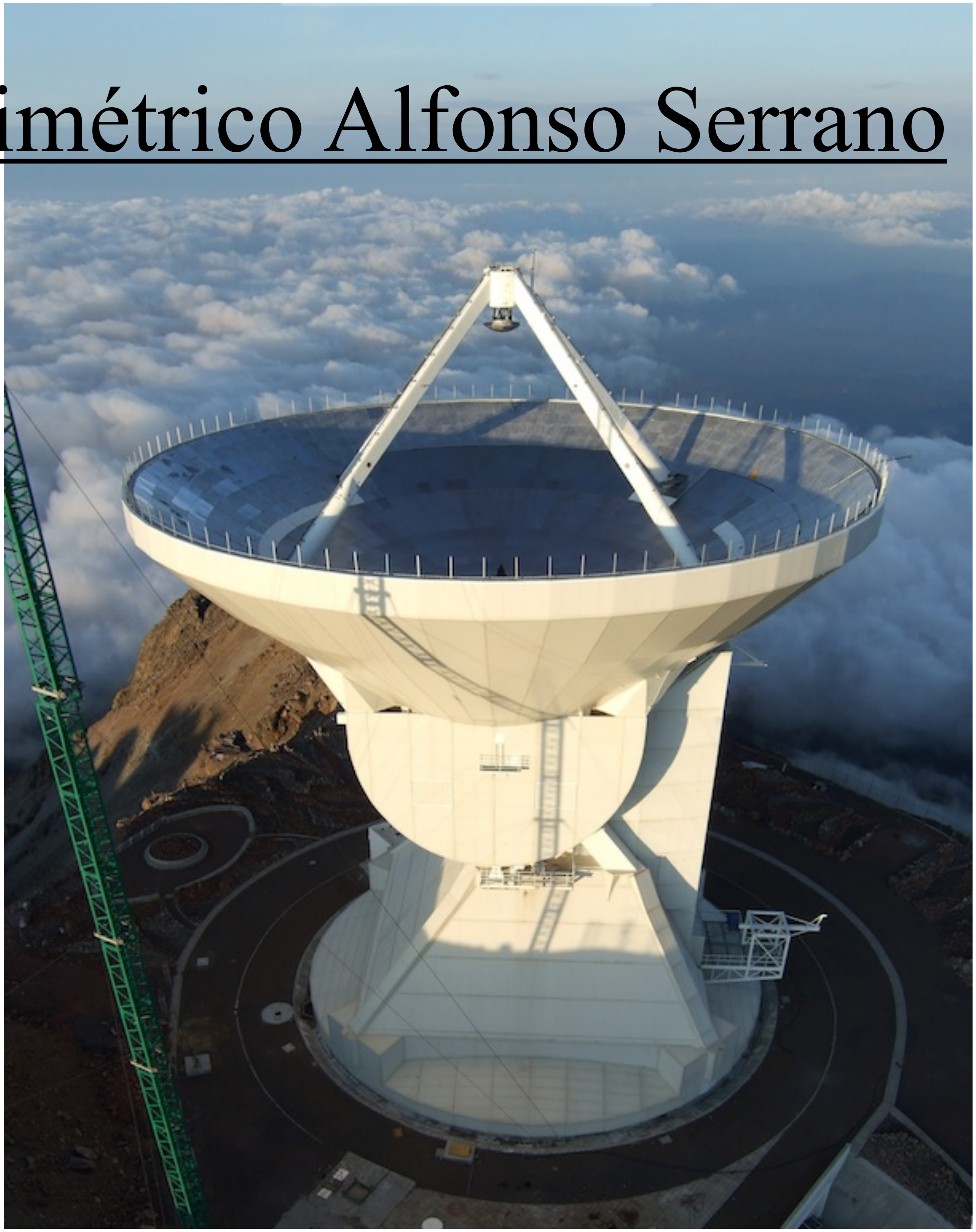
- The Observatorio Astrofísico Nacional de Tonantzintla (OAN-Ton), Puebla, was founded in 1942 by Luis Enrique Erro.
- Tonantzintla was the site of the discovery of HH objects (& Ton blue galaxies, flare stars…).
- In 1971 Guillermo Haro transformed the OAN-Ton into INAOE.
- INAOE was created with the project of establishing the Cananea observatory - today Observatorio Astrofísico Guillermo Haro, operational since 1988.

43 years of research in astrophysics, optics, electronics and computing for Mexico



Gran Telescopio Milimétrico Alfonso Serrano

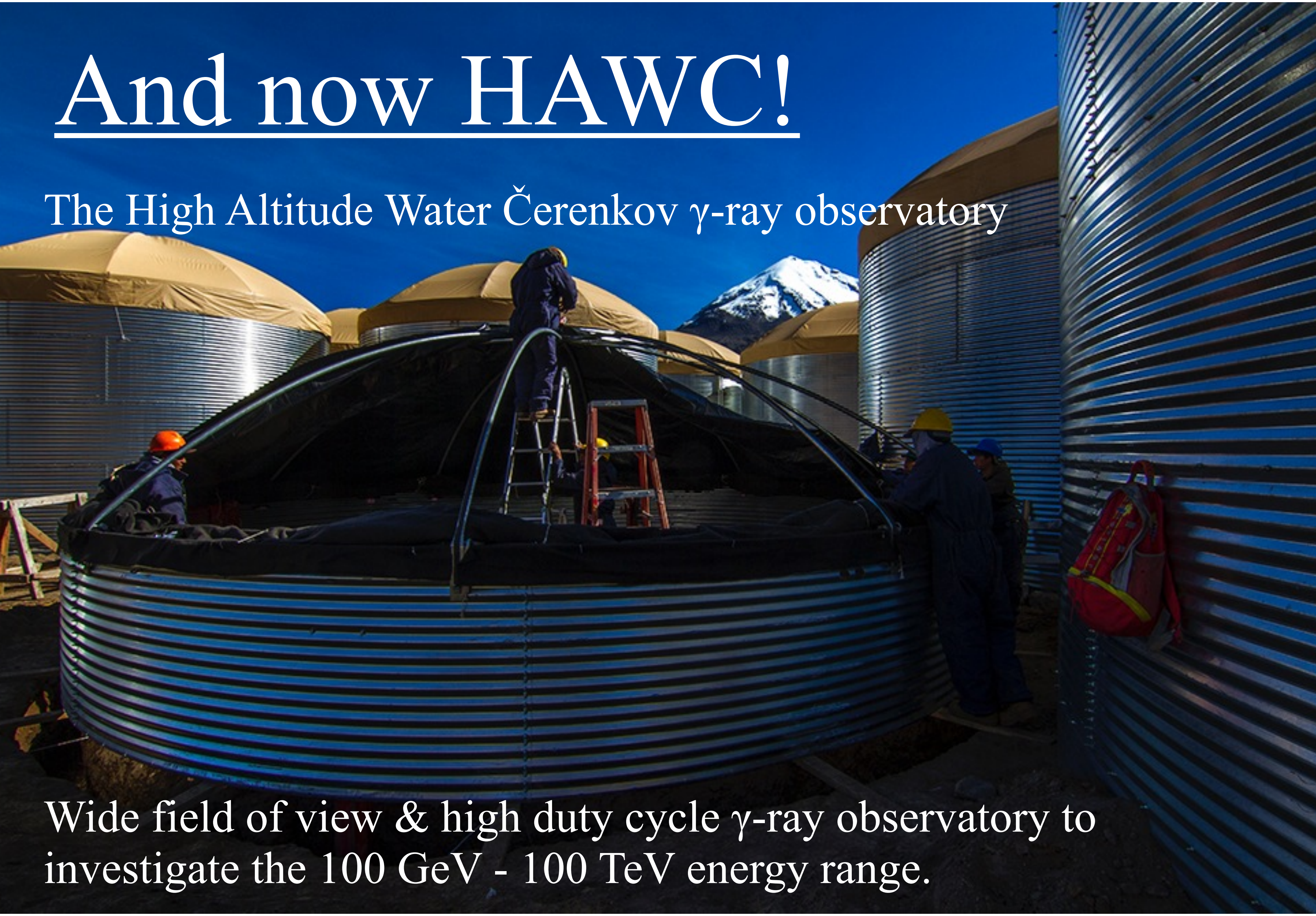
- The Large Millimeter Telescope Alfonso Serrano (LM/GTM).
- Twenty year collaboration between INAOE and UMASS, Amherst, to construct and operate the largest single dish mm telescope in the world: a 50m antenna for observations in the 0.8 - 4.0 mm band.
- Installed at the top of Sierra Negra at 4593m.
- Operational since May 2013 with a functional aperture of 32m.




Pico de Orizaba
“Citlaltepetl”
5610m (18,400 ft)
Sierra Negra
“Tliltepetl”
4582m (15,000 ft)
Latitude 19ºN, Longitude = 97ºW.
In the Mexican state of Puebla
2hr drive East of Mexico City

And now HAWC!

The High Altitude Water Čerenkov γ-ray observatory

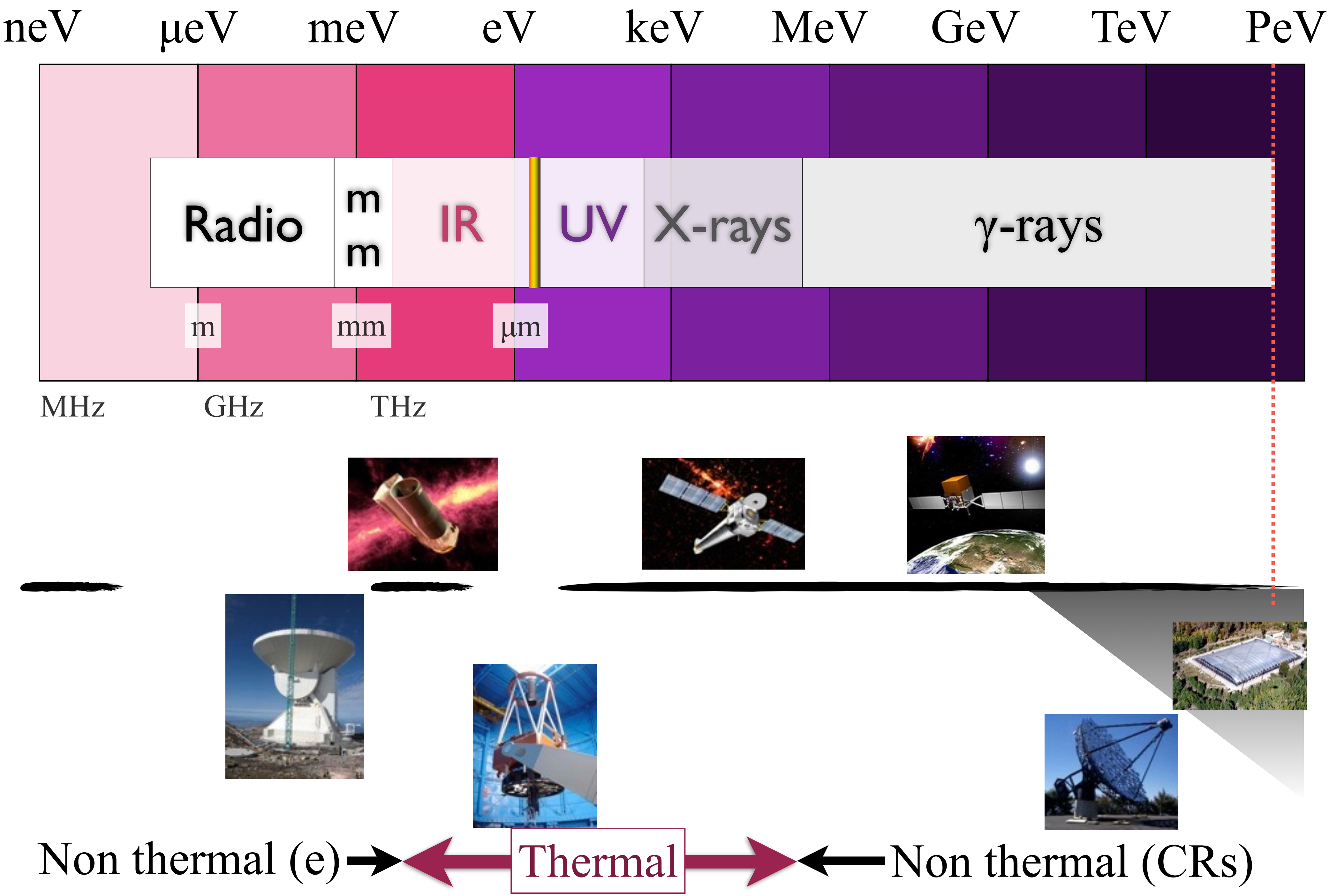


Wide field of view & high duty cycle γ-ray observatory to investigate the 100 GeV - 100 TeV energy range.

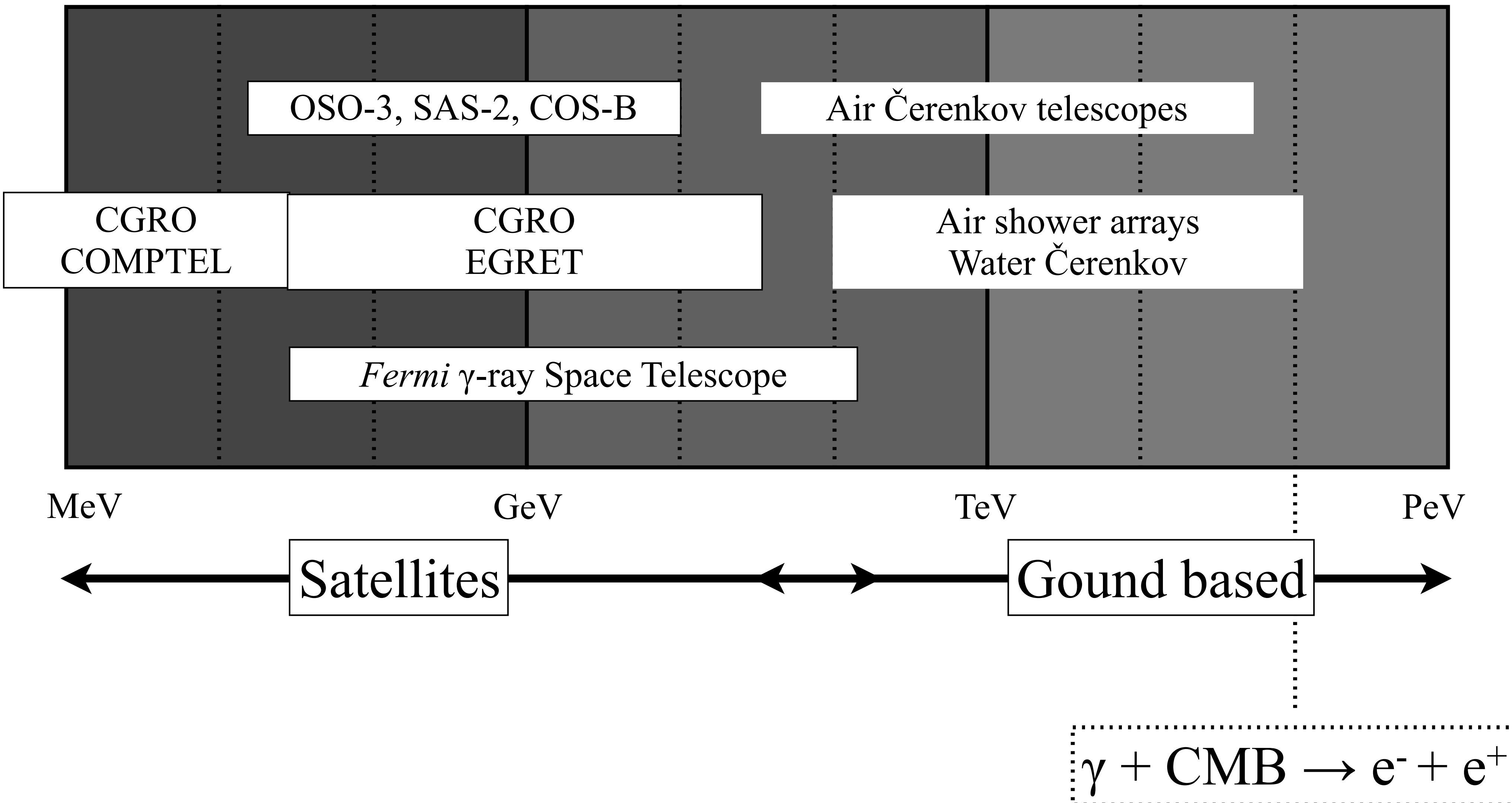
The HAWC Collaboration

High Altitude Water Cherenkov Gamma-Ray Observatory

Mexico		**United States**	
Instituto Nacional de Astrofísica, Óptica y Electrónica	(INAOE)	University of Maryland	(UMD)
Universidad Nacional Autónoma de México		Los Alamos National Laboratory	(LANL)
Instituto de Astronomía UNAM	(IA-UNAM)	Colorado State University	(CSU)
Instituto de Ciencias Nucleares UNAM	(ICN-UNAM)	George Mason University	(GMU)
Instituto de Física UNAM	(IF-UNAM)	Georgia Institute of Technology	(GATECH)
Instituto de Geofísica UNAM	(IG-UNAM)	Michigan State University	(MSU)
Benemérita Universidad Autónoma de Puebla	(BUAP)	Michigan Technological University	(MTU)
Instituto Politécnico Nacional		Pennsylvania State University	(PSU)
Centro de Investigación y Estudios Avanzados	(CINVESTAV)	NASA GSFC	
Centro de Investigación en Cómputo - IPN	(CIC-IPN)	University of California Santa Cruz	(UCSC)
Universidad Autónoma de Chiapas	(UNACH)	University of California Irvine	(UCI)
Universidad Autónoma del Estado de Hidalgo	(UAEH)	University of New Hampshire	(UNH)
Universidad de Guadalajara	(UdG)	University of New Mexico	(UNM)
Universidad Michoacana de San Nicolás de Hidalgo	(UMSNH)	University of Rochester	(UR)
Universidad Politécnica de Pachuca	(UPP)	University of Utah	(UU)
		University of Wisconsin	(UW)


neV
μeV
meV
eV
keV
MeV
GeV
TeV
PeV
Radio
m m
IR
UV
X-rays
γ-rays
m
mm
μm
MHz
GHz
THz
Non thermal (e)
Thermal
Non thermal (CRs)

The γ-ray band



Sr

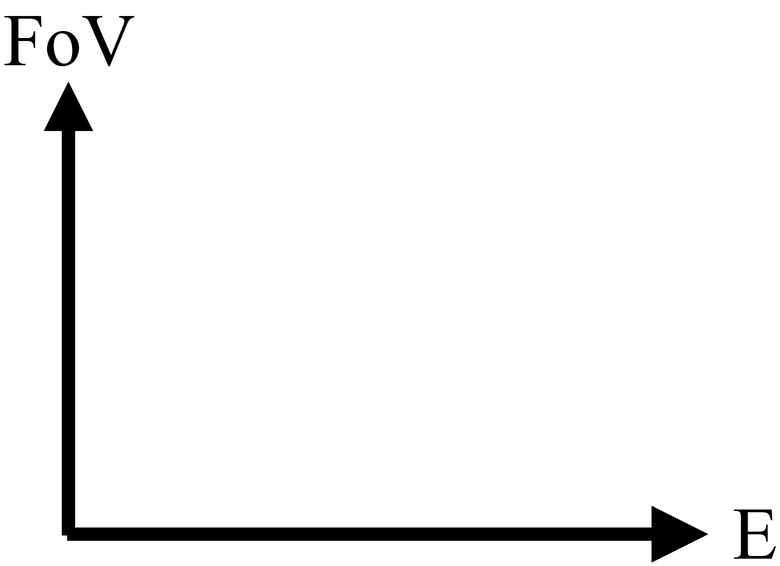
Pair production telescopes
0.1 - 100 GeV
Space based: small effective area
Background free
Large f.o.v. and high duty cycle

All sky survey & monitoring
Transients (AGN, GRB)
Diffuse emission

Extensive air-shower arrays
100 GeV - 100 TeV
Good background rejection
Large f.o.v. and high duty cycle

Partial sky survey & monitoring
Extended sources
Transients (AGN, GRB)
Highest energies

Deg

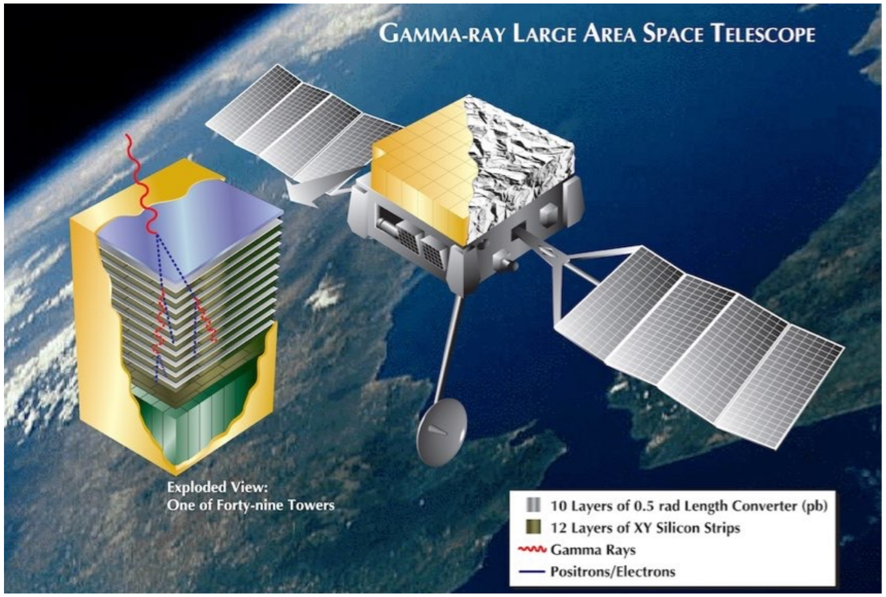


Atmospheric Cherenkov Telescopes
50 GeV - 100 TeV
Large effective area
Excellent background rejection
Small f.o.v. and low duty cycle

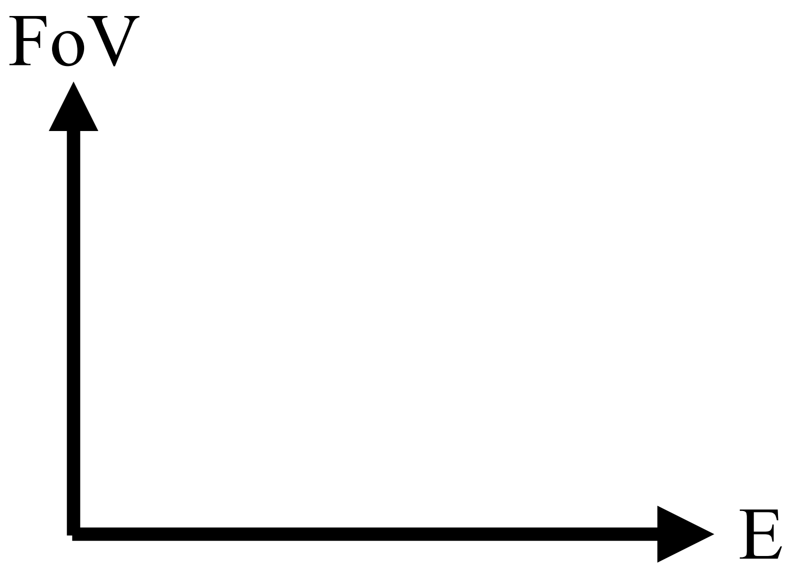
Detailed study of known sources
Deep surveys of limited regions
High resolution spectra

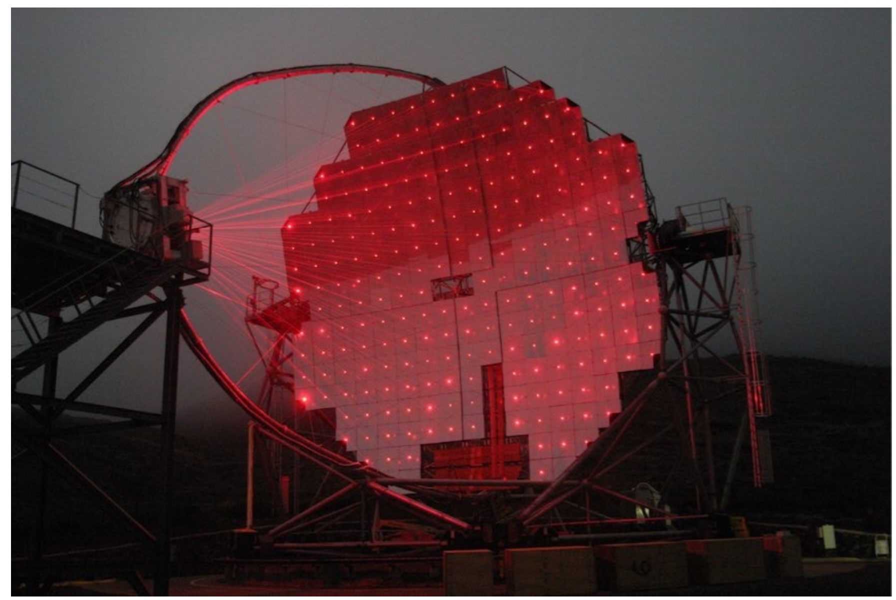
GeV | **TeV**

Sr



Deg





GeV TeV

The HAWC detector

Second generation WC γ-ray observatory - built from MILAGRO experience.

Located in Sierra Negra at higher altitude 4100m and lower latitude 19ºN

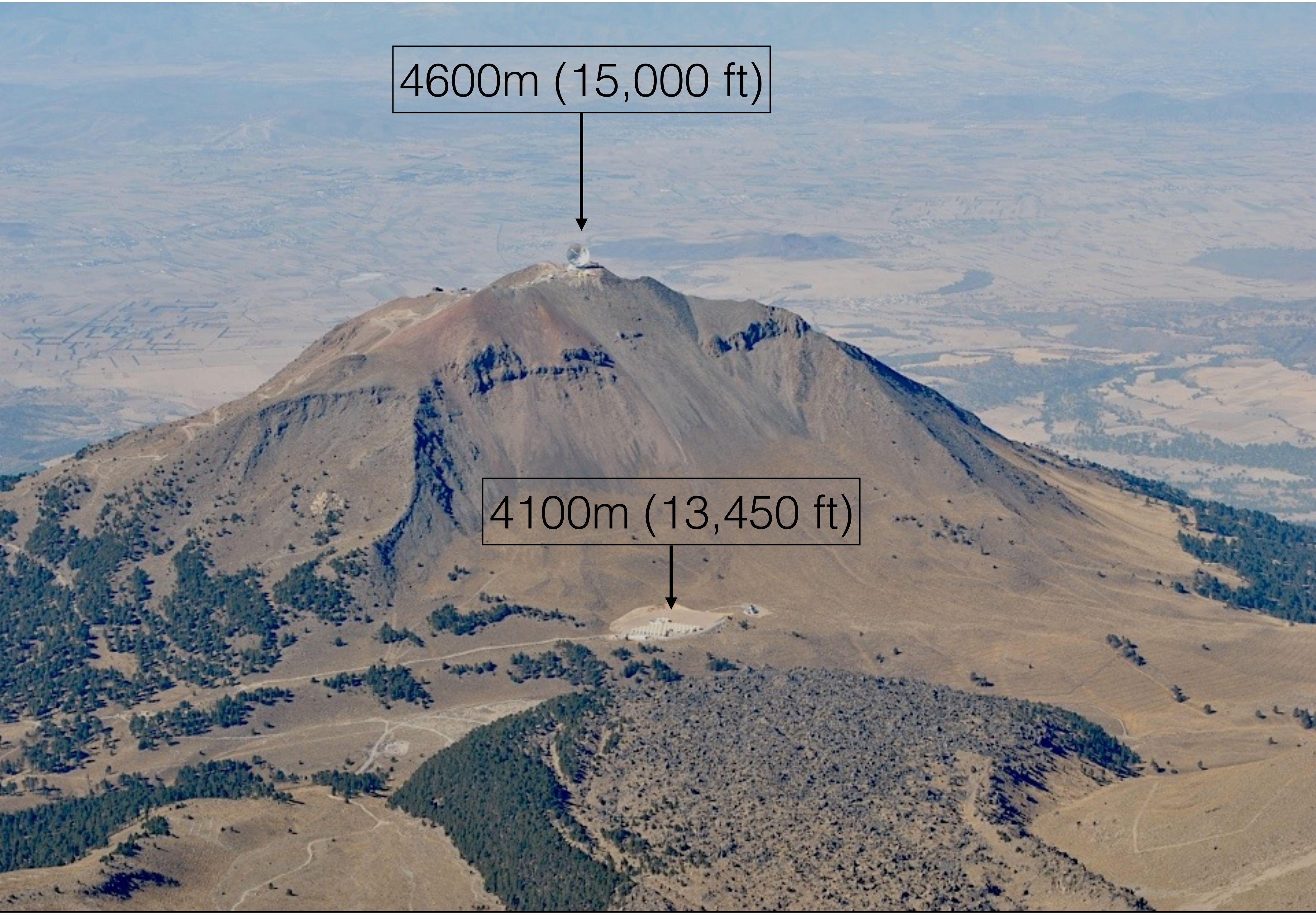
- 4 × larger dense sampling region (22,000m^2)
- 10 × larger muon detection area (22,000m^2)
- Optical isolation of detector elements
- 15 × more sensitive than Milagro

Energy range 100 GeV - 100 TeV :: also cosmic-ray detector.

FOV: 1/6 of the sky instantaneous => scans 2/3 of all sky each sidereal day.

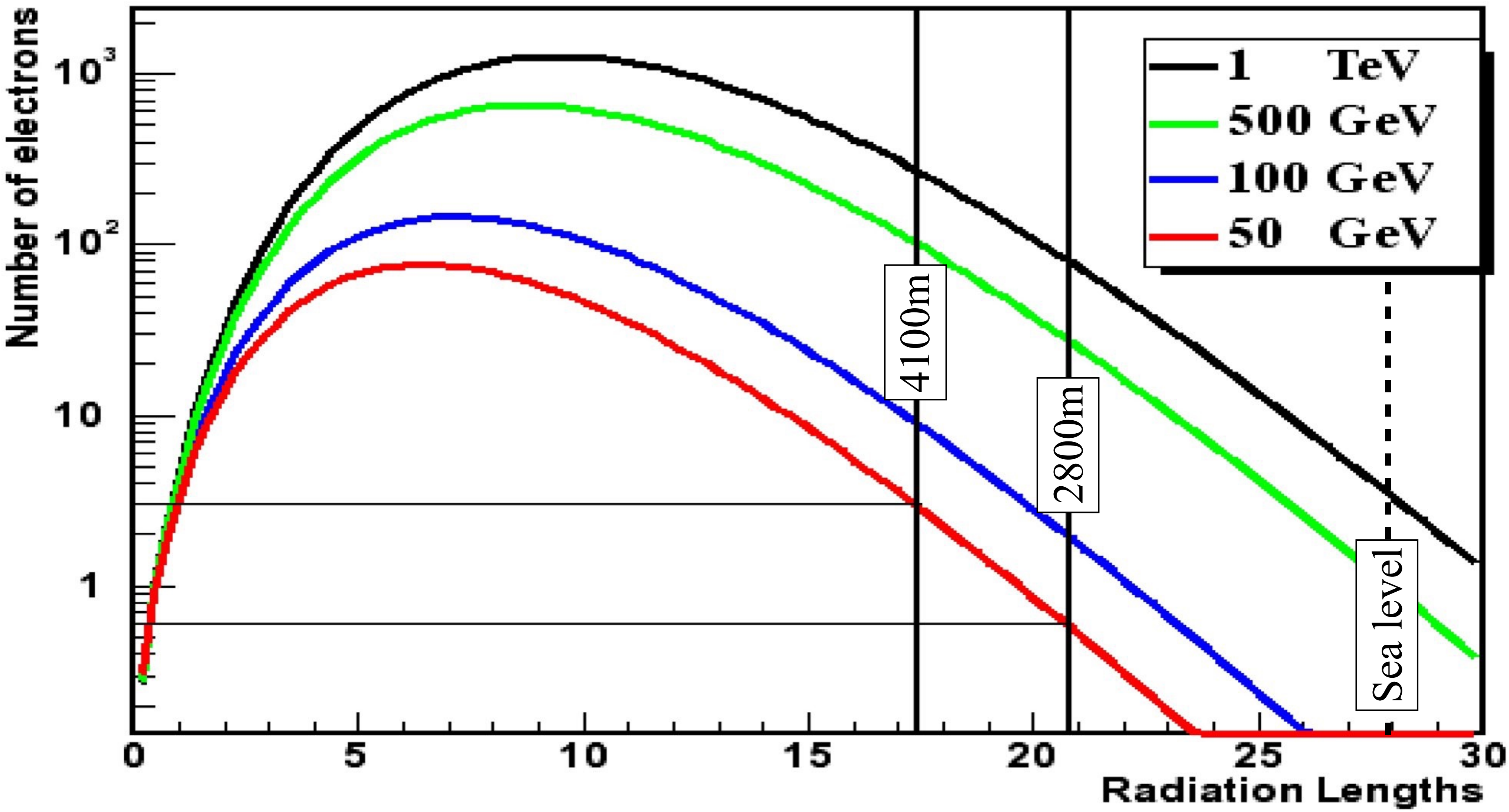
HAWC science

- Partial all-sky mapping:
  - deep mapping of 2/3 of the sky and of 2/3 Galactic plane.
  - Cosmic-ray anisotropies.
- γ-ray transient sources: AGNs, GRBs, PBHs, Galactic transients, Galactic Center.
- Mapping and characterizing extended γ-ray sources: SNR, PWN, diffuse.
- Solar events; dark matter searches.
- Multiwavelength & multimessenger synergies.



4600m (15,000 ft)
4100m (13,450 ft)

The atmosphere is part of the detector

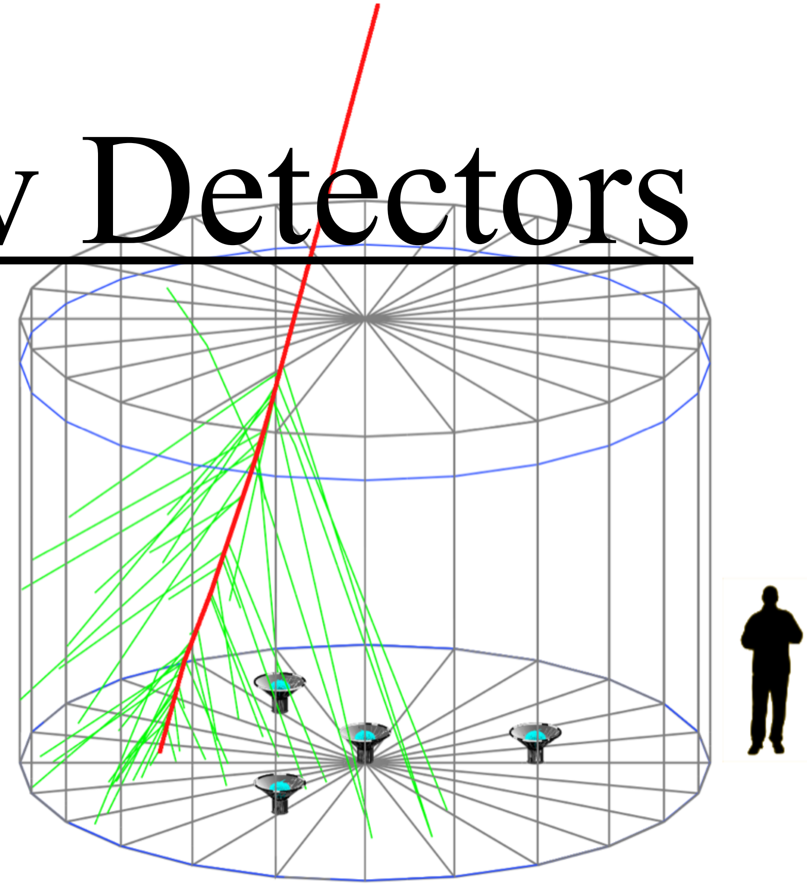


HAWC construction

February 2012 to December 2015


Mon Apr 22 00:02:58 GMT 2013

Water Cherenkov Detectors



- Each water tank is filled with 180,000 liters of water.
- Water is treated to ensure maximum transparency.
- Each WCD has 3(8”) + 1(10”) PMT: fast response and good QE to Cherenkov light (blue to UV).
- Optical fiber for calibration.
- Each WCD is connected to the central counting house.


HAWC-100
Sept 2013

HAWC-100
Sept 2013

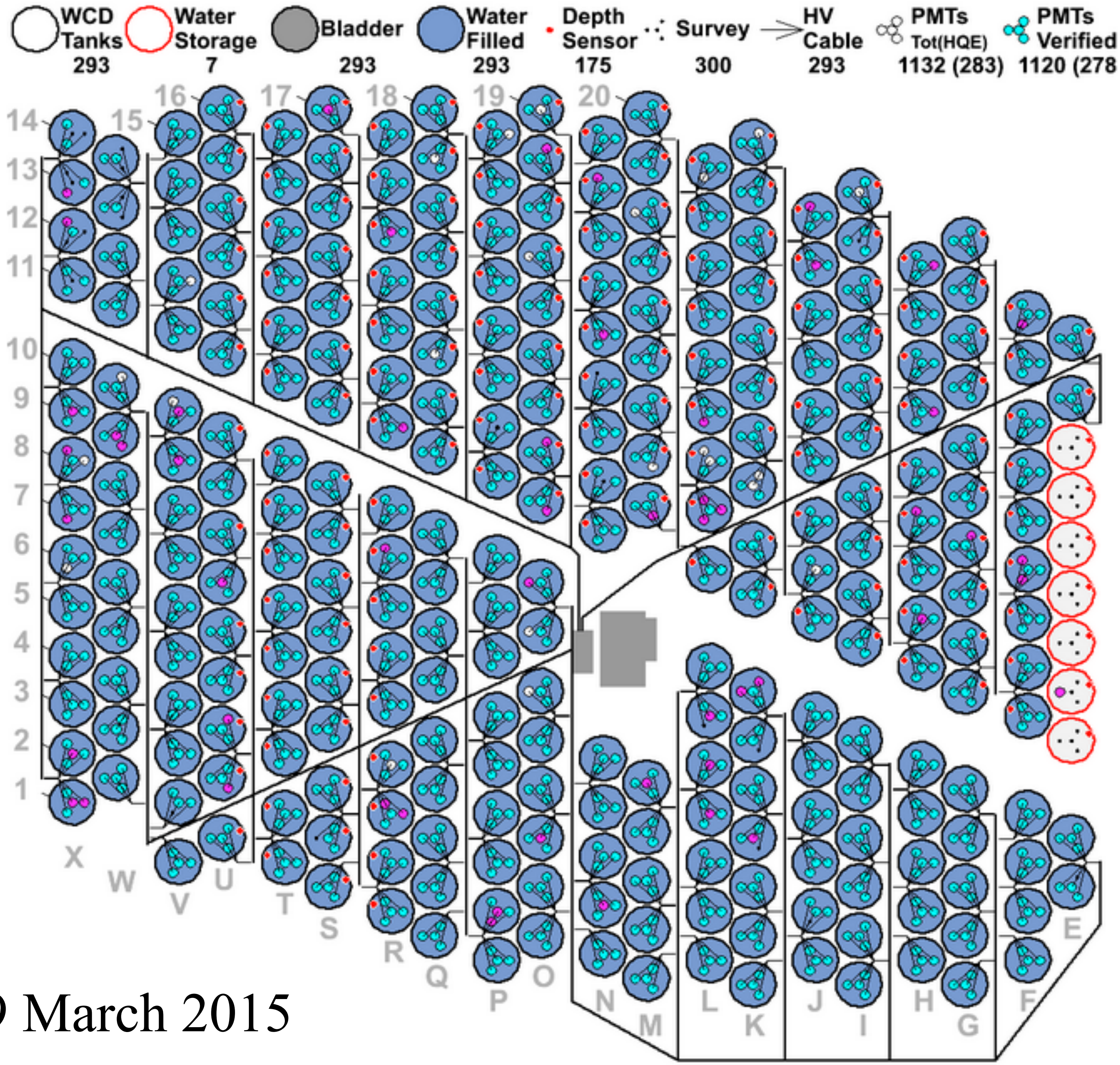
HAWC Utility Building
- Water filtration
- Bladder testing

Counting house

- DAQ & laser calibration
- system

HAWC Utility Building

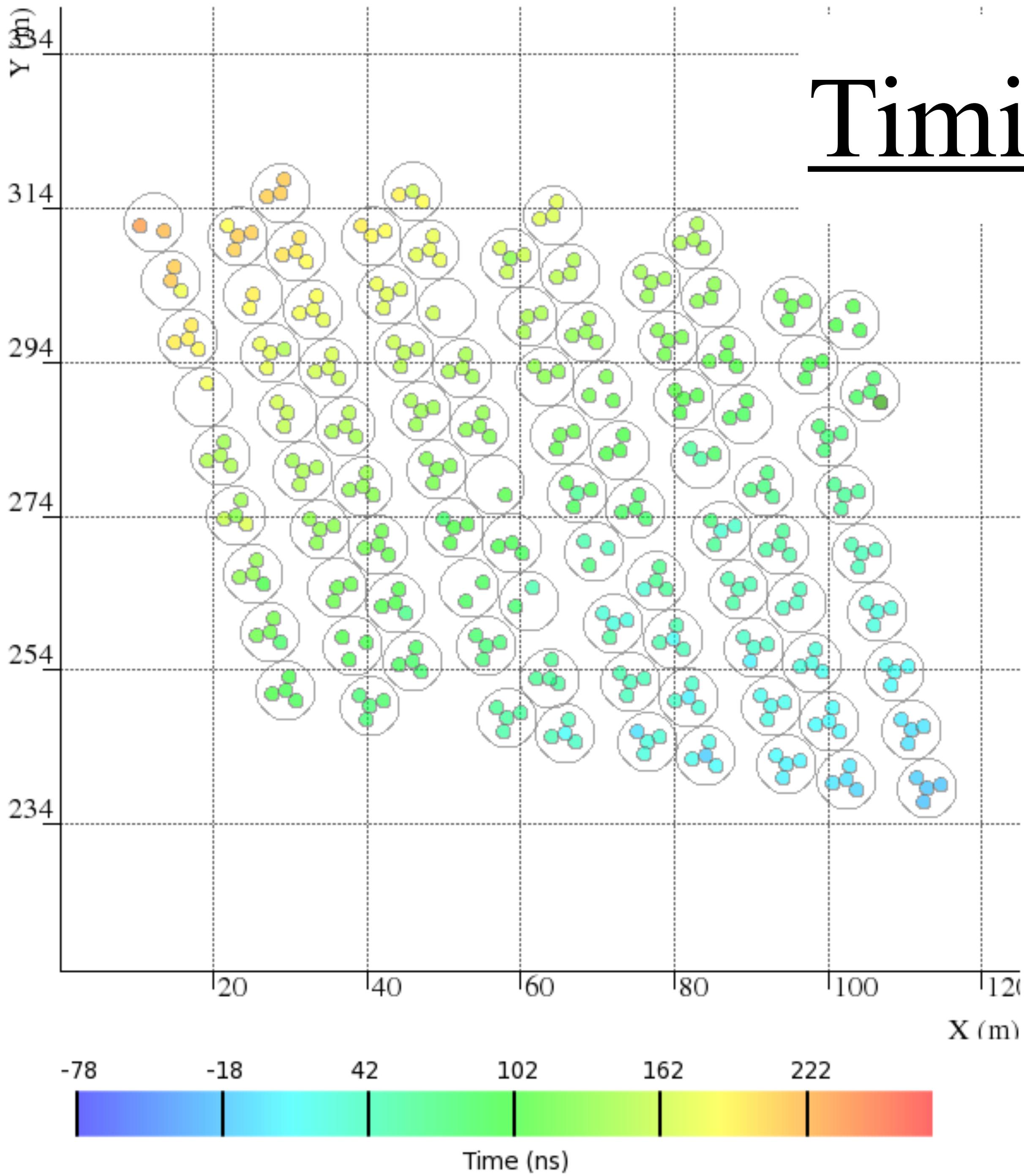
- Water filtration
- Bladder testing



HAWC - 19 March 2015

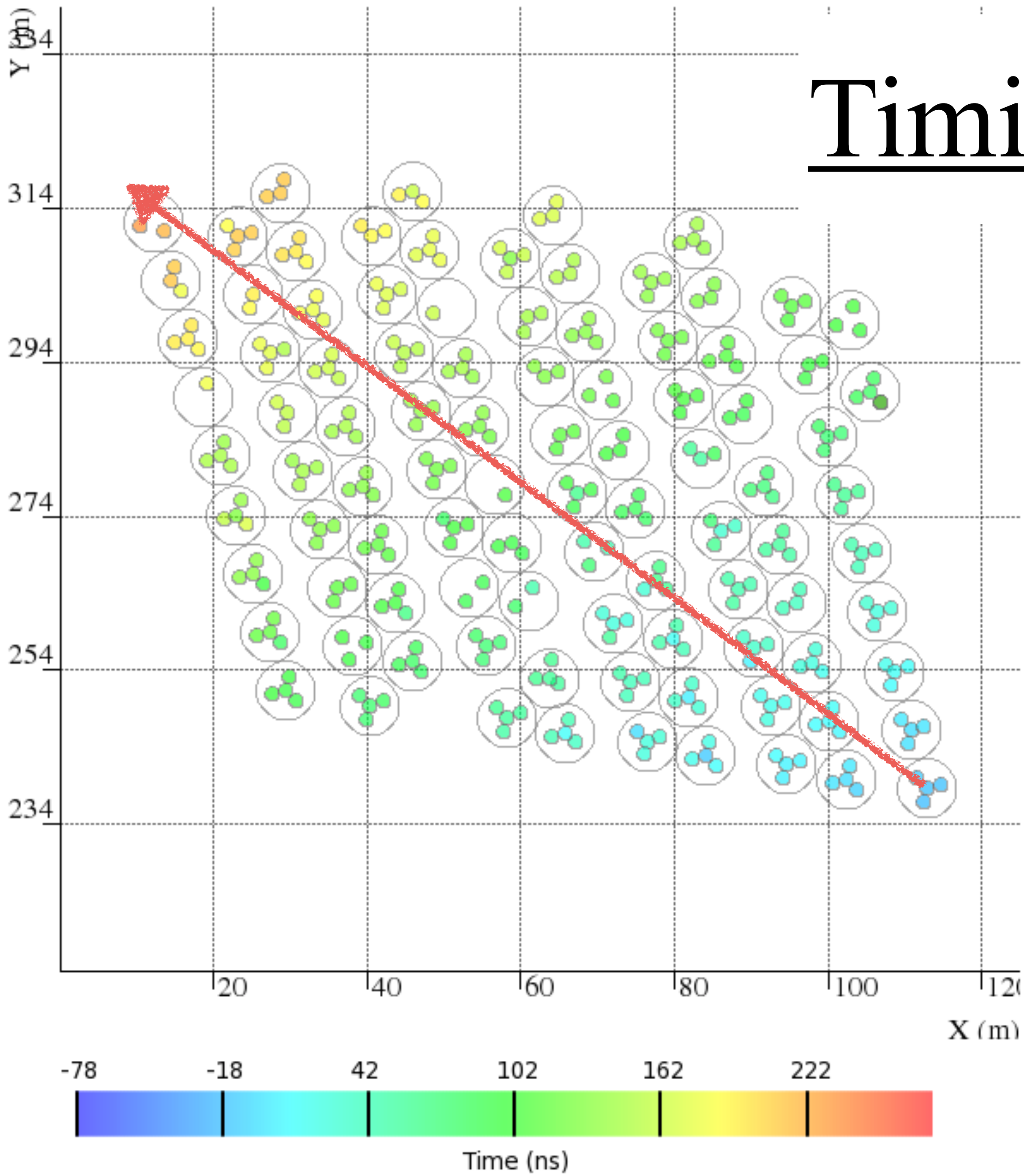

HAWC
HAWC 300
Full operations
DATE: 03/20/2015
TIME: 12:26:30
SONY

Timing information



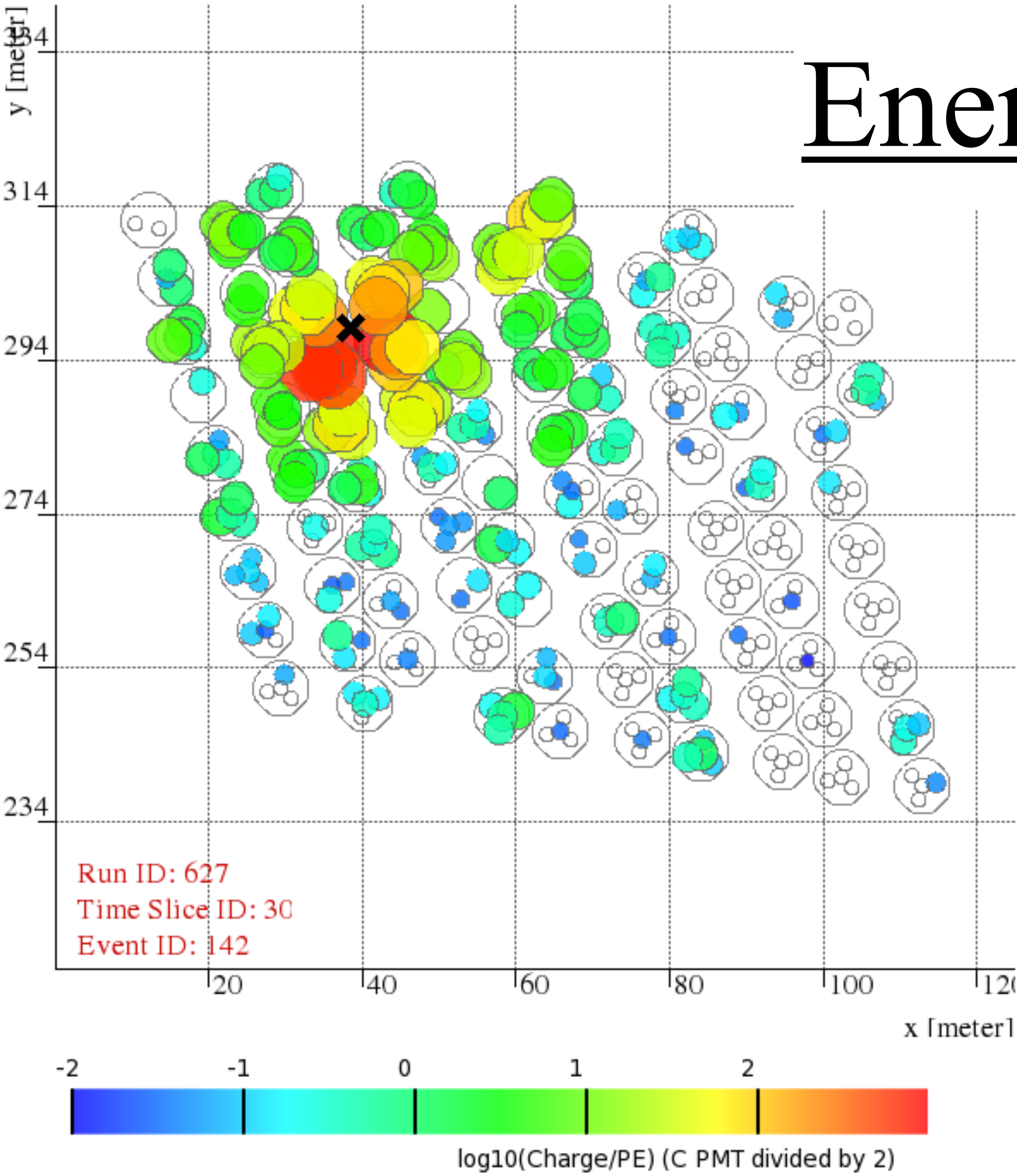
- Relative timing of signals allows to determine the arrival direction of primary particles in the sky.

Timing information



- Relative timing of signals allows to determine the arrival direction of primary particles in the sky.
- Tank spacing is 25 to 50 light-ns.
- Arrival times are fitted to a curved plane.
- HAWC timing residuals below 1ns.

Energy deposition



- PMTs measure individual pulses of light.
- Energy estimation.
- γ/hadron discrimination.
- Must define the core and model energy deposits according to standard (NKG) shower models and simulations of the response of HAWC.

Sensitivity & Field of View

Transit instrument

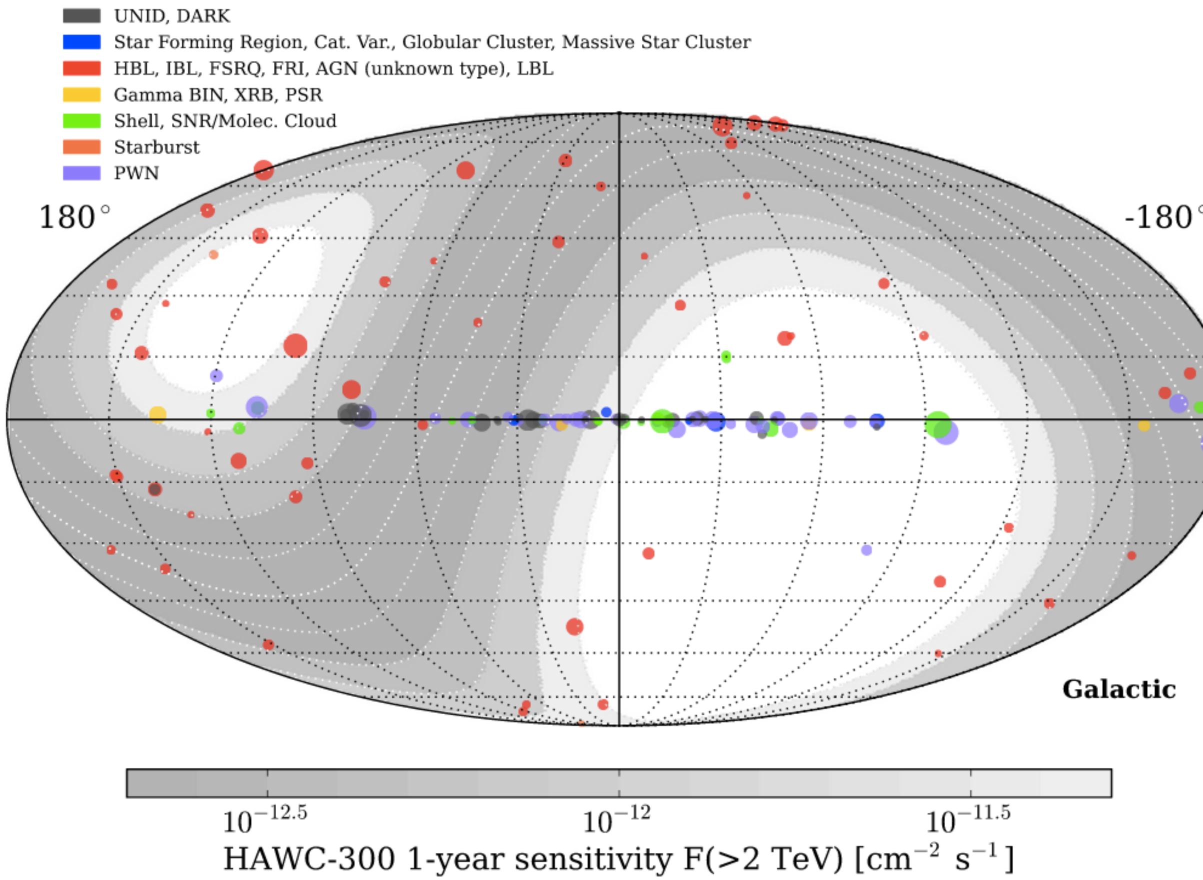
FOV = 1.8 Sr

HAWC scans 2/3 of the celestial sphere every sidereal day to a depth of 1 Crab @ 5σ:

➡ transient events

➡ extended diffuse sources

➡ 60 mCrab / sqrt(year)



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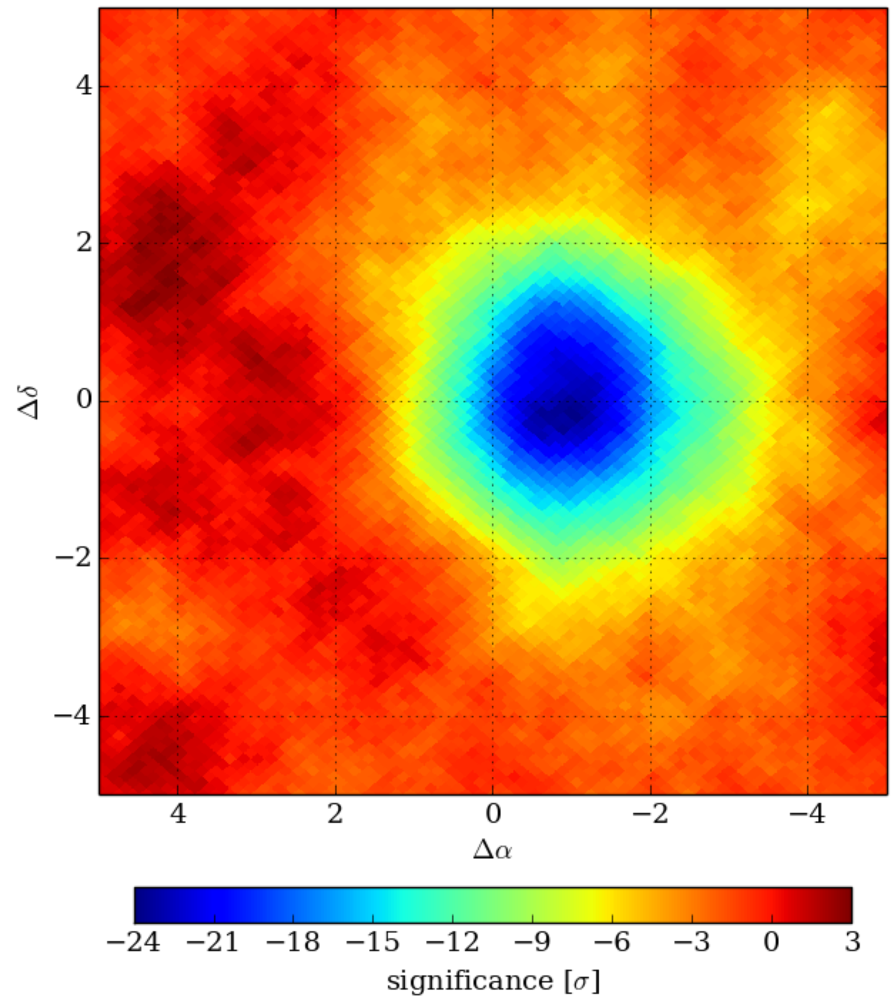
- Solar events; dark matter searches.
- Multiwavelength & multimessenger synergies.

HAWC phases

HAWC 30	September 2012	Early science data
HAWC 111	August 2013	Beginning of formal science operations
HAWC 250	November 2014	Upgrade to quasi-full detector
HAWC 300	March 2015	Inauguration and beginning of full operations

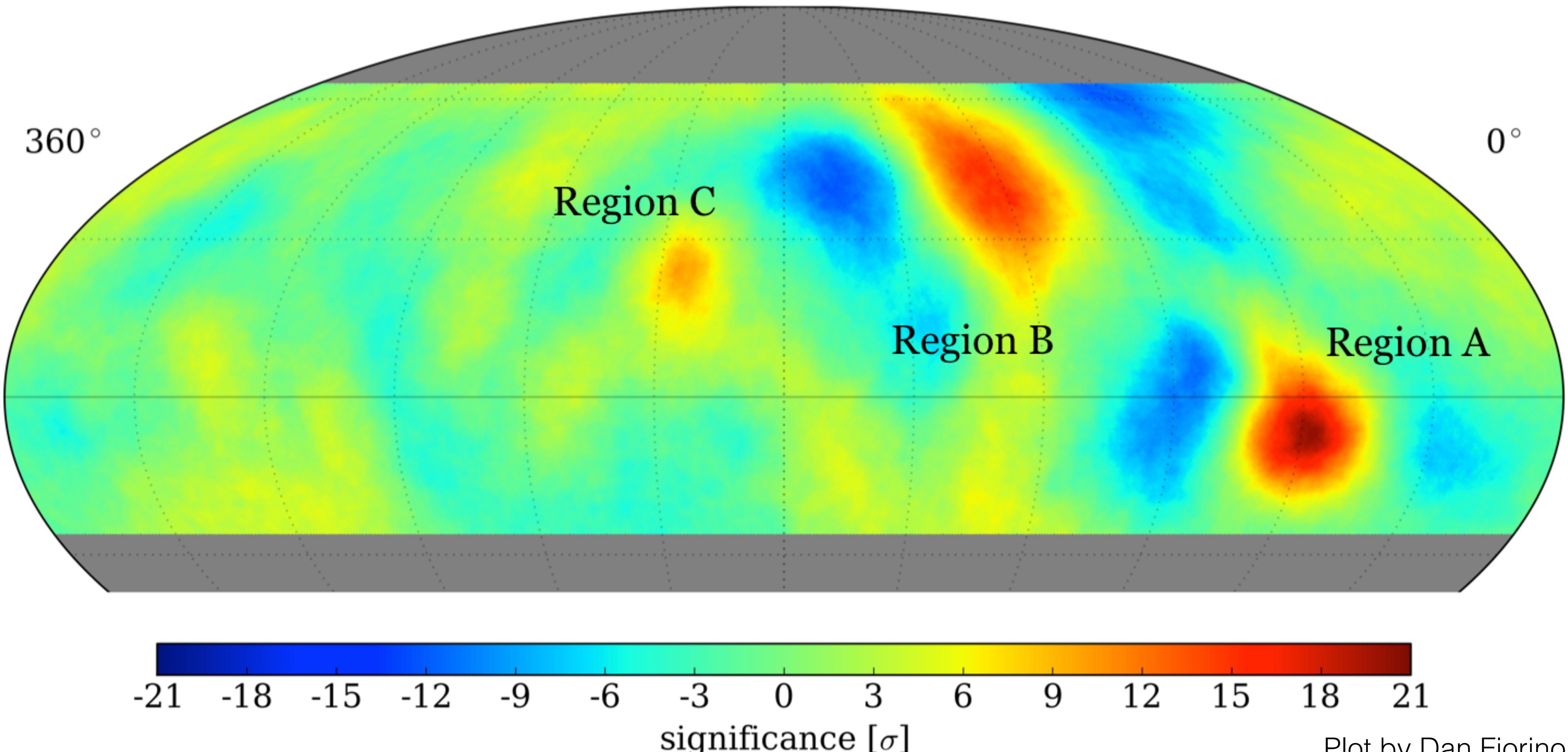
HAWC cosmic rays Moon shadow

- HAWC-95 and HAWC-111
- 12 June 2013 to 8 July 2014
- Full runs = contiguous 24hrs:
  - 181 days (4332 hours)
  - 85.6×10^9 events
- Median energy: 2 TeV
- Potential for $e^{\pm}$ flux measurements above 1 TeV.



Abeysekara et al.
ApJ 796, 108 (2014)
astro-ph/1408.4085

Cosmic-ray anisotropies

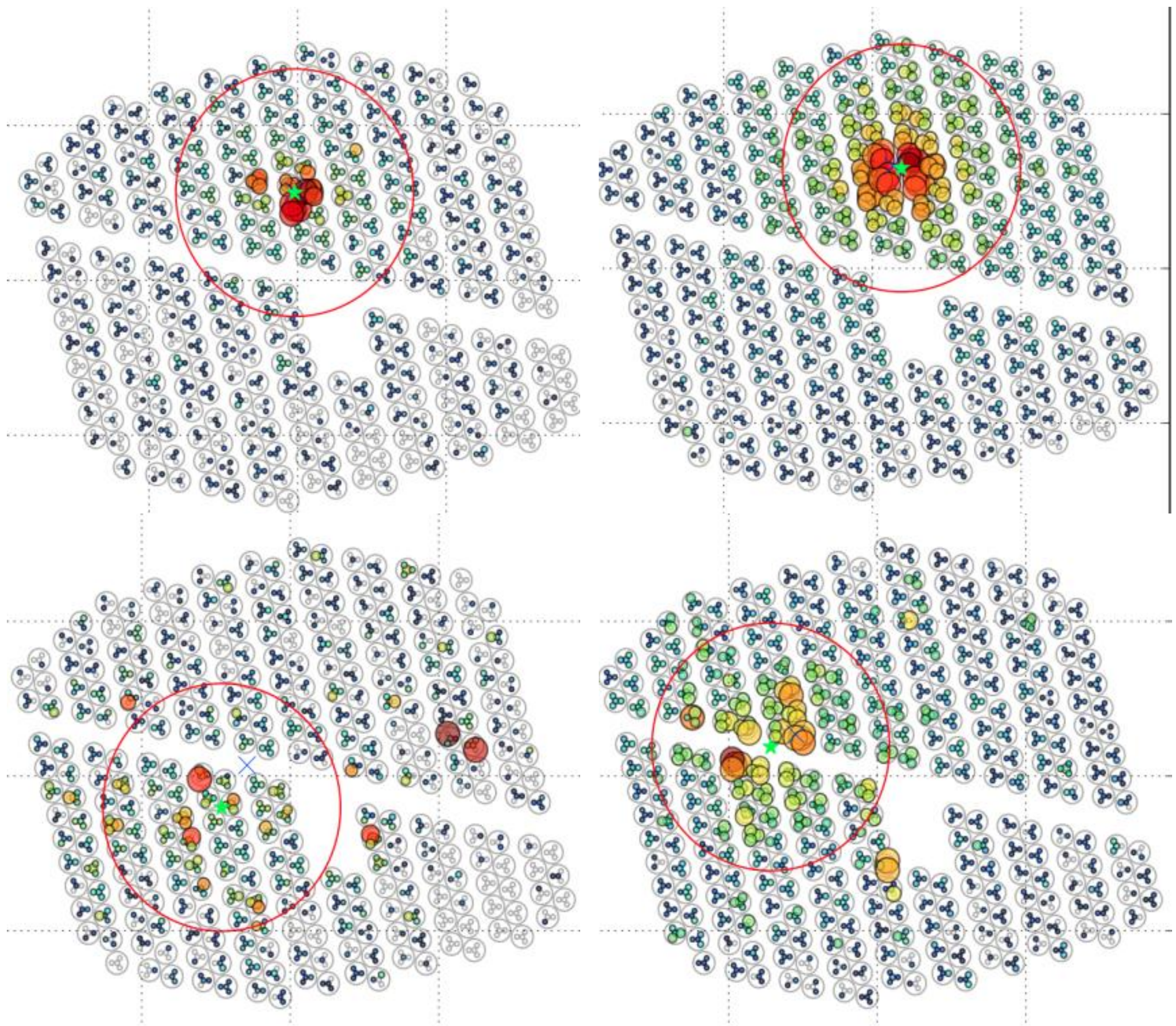


Plot by Dan Fiorino

γ / hadron discrimination

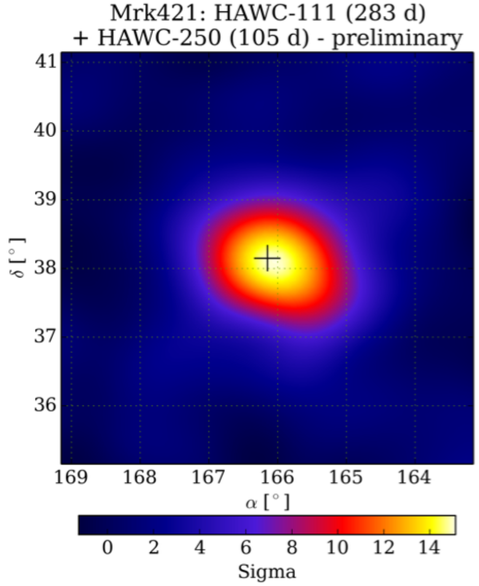
γ-ray

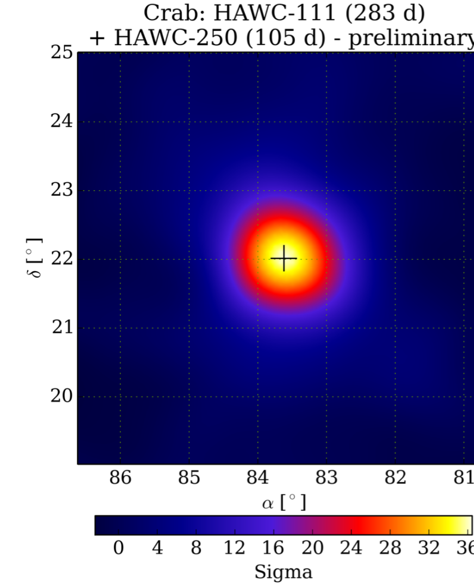
Hadron

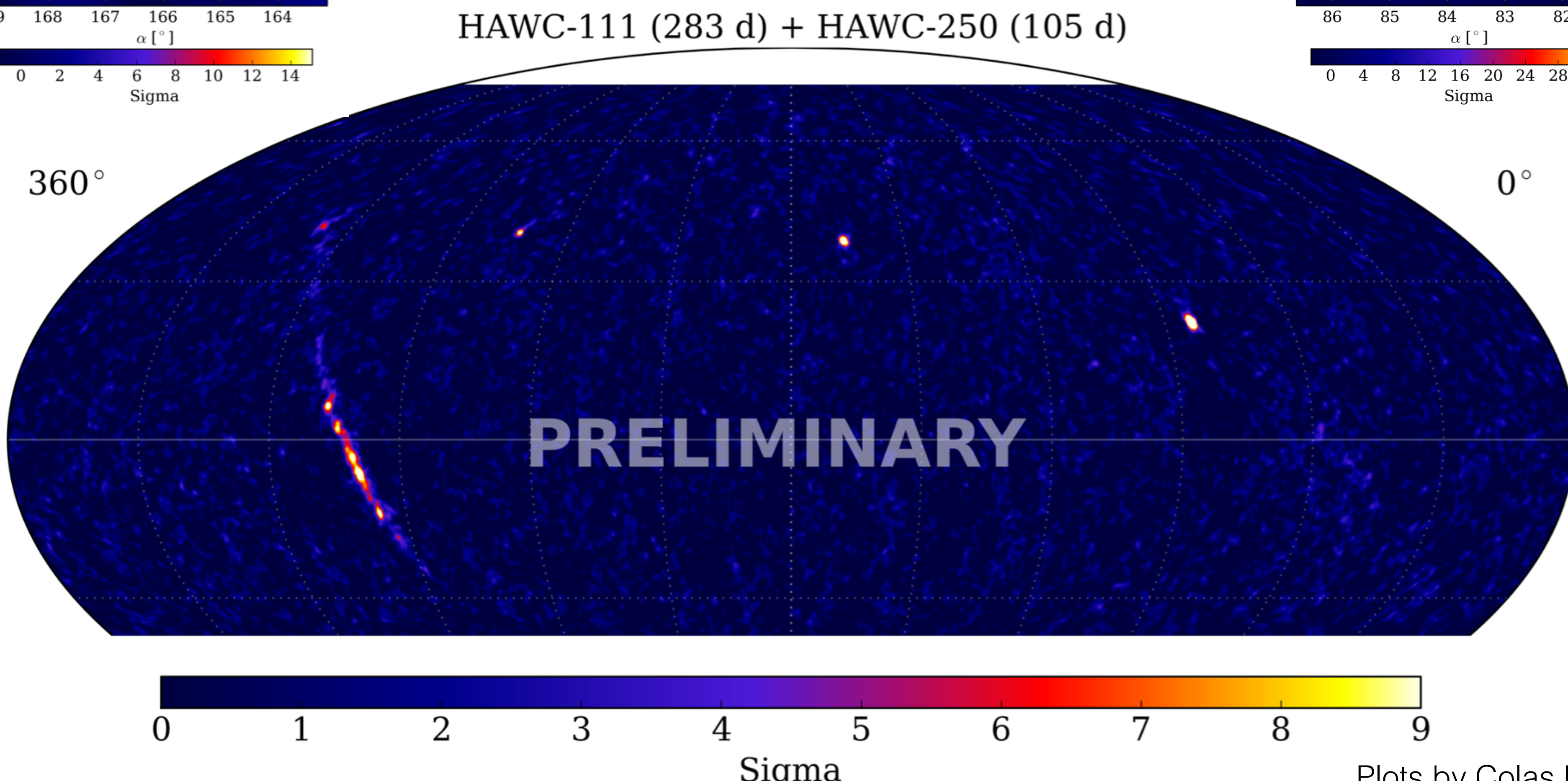


E

HAWC
γ-ray skymap

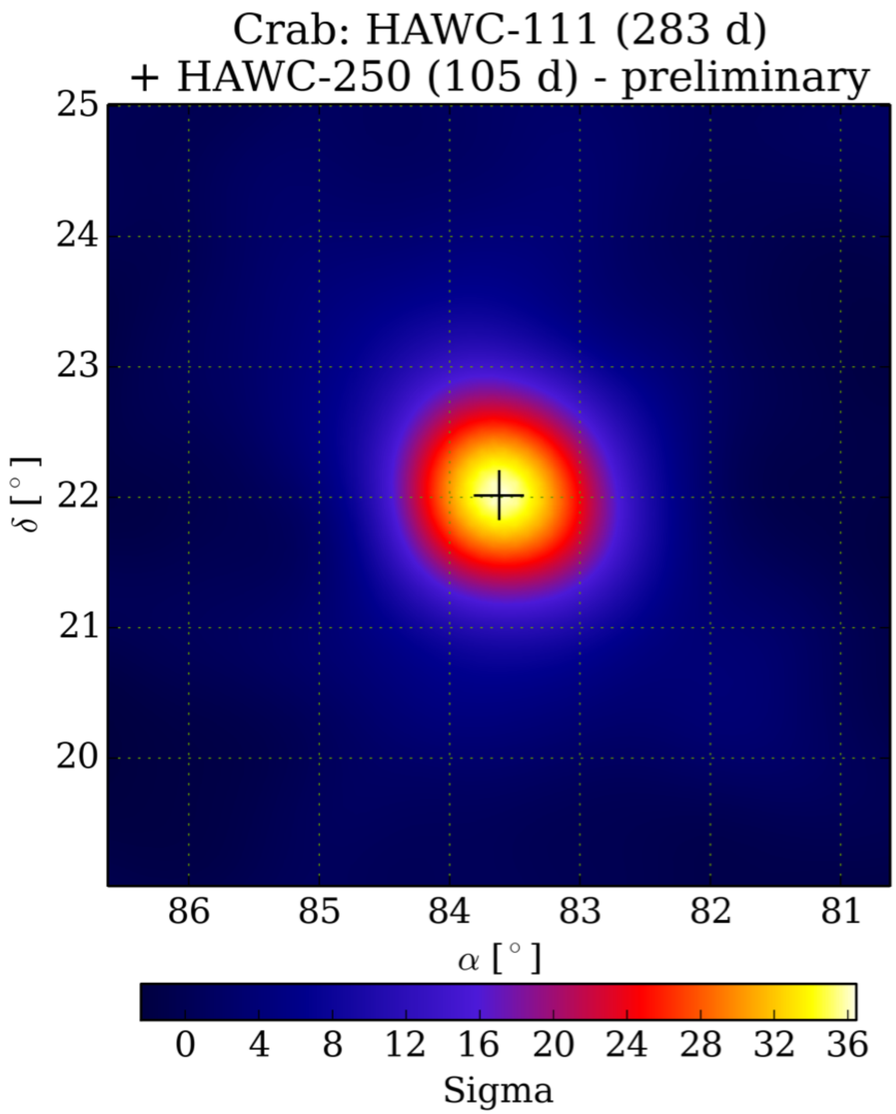


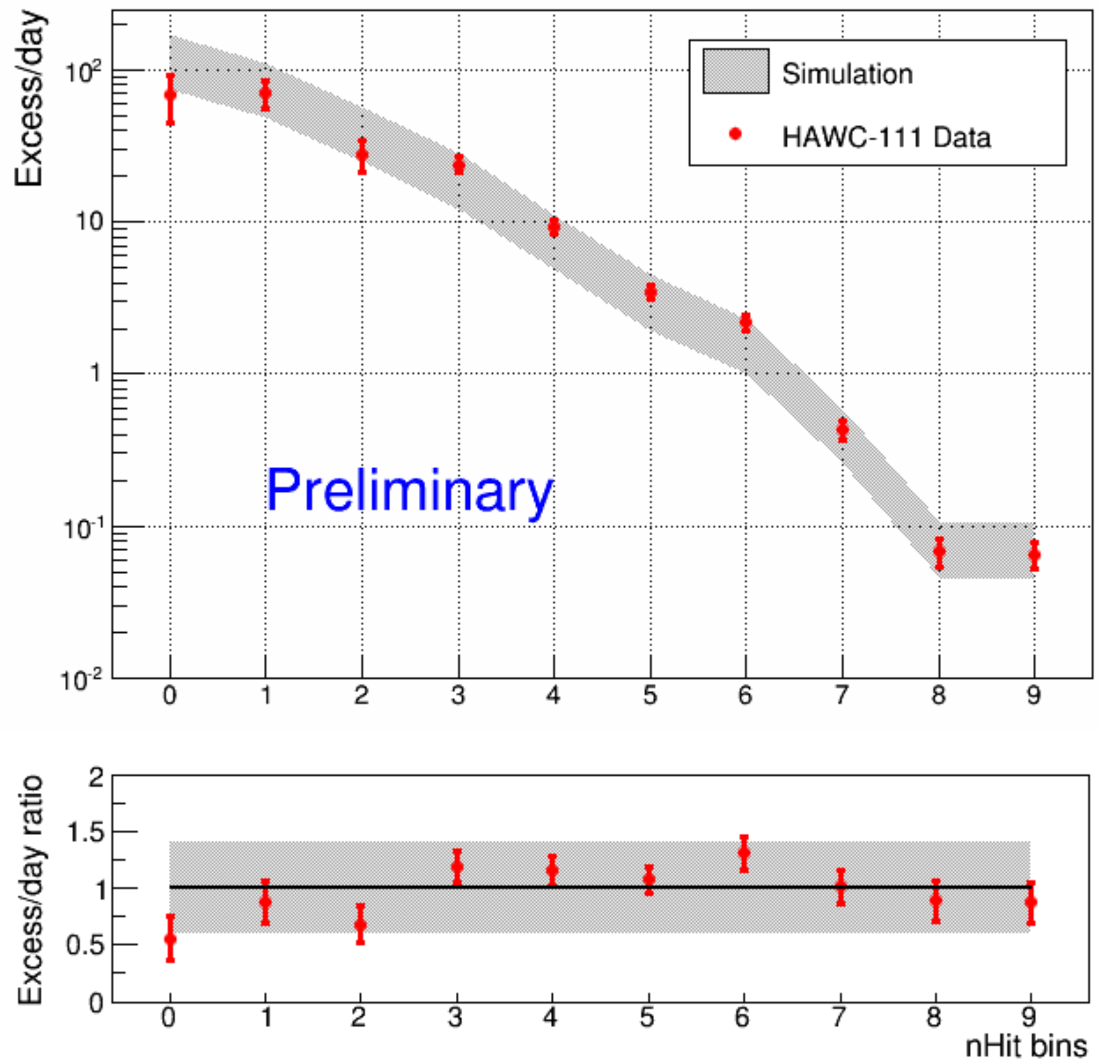




Plots by Colas Rivière

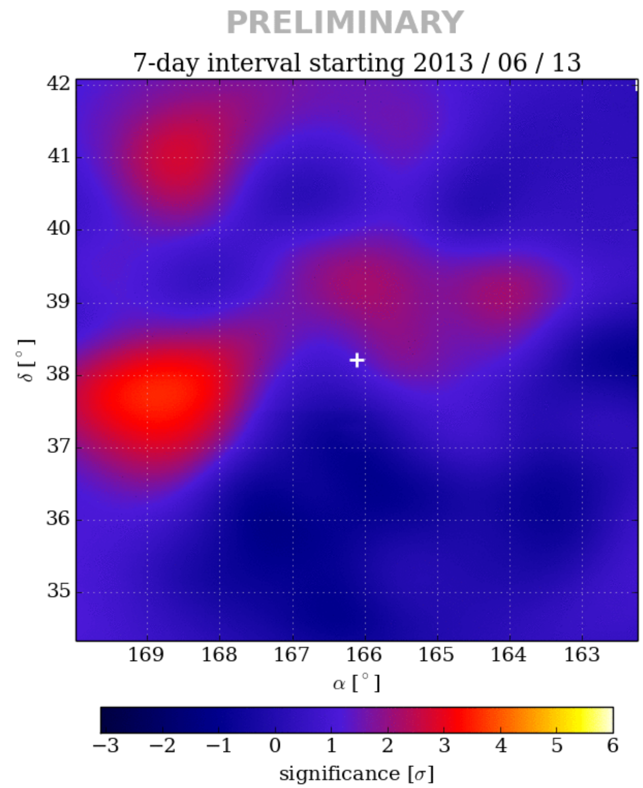
The Crab

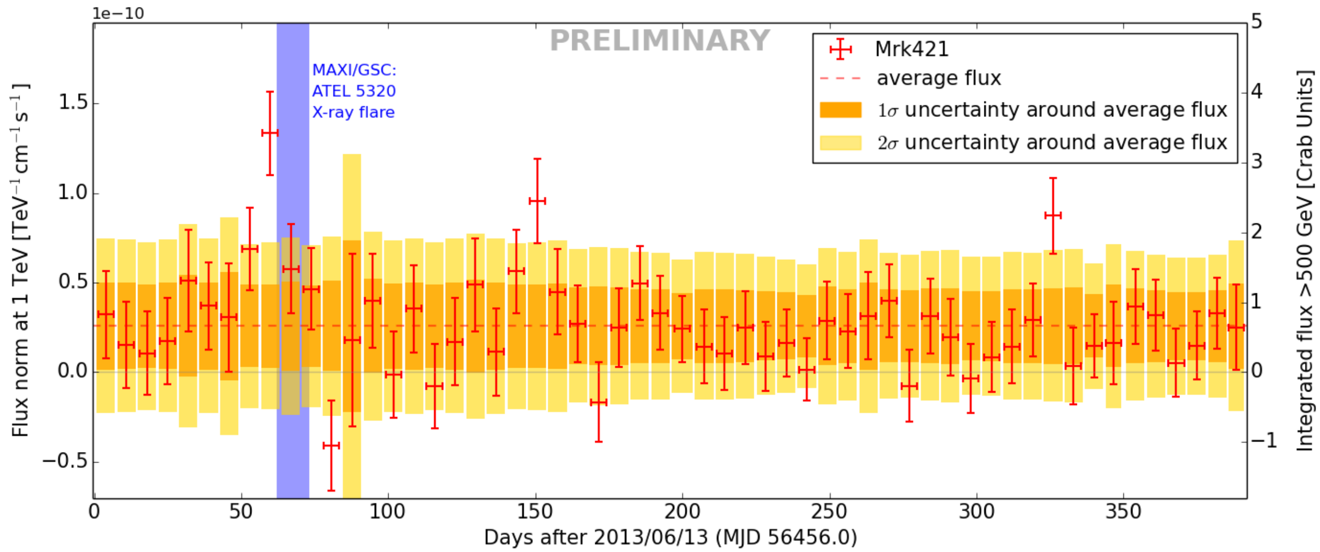

Crab: HAWC-111 (283 d)
+ HAWC-250 (105 d) - preliminary
25
24
23
22
21
20
δ [°]
86
85
84
83
82
81
α [°]
0 4 8 12 16 20 24 28 32 36
Sigma


Excess/day
Simulation
HAWC-111 Data
Preliminary
Excess/day ratio
nHit bins

Mrk 421

- Brightest quasar in the night sky
- Nearby Bl Lac at z = 0.03.
- First extragalactic TeV source (Punch et al. 1992).
- Detected by Milagro.

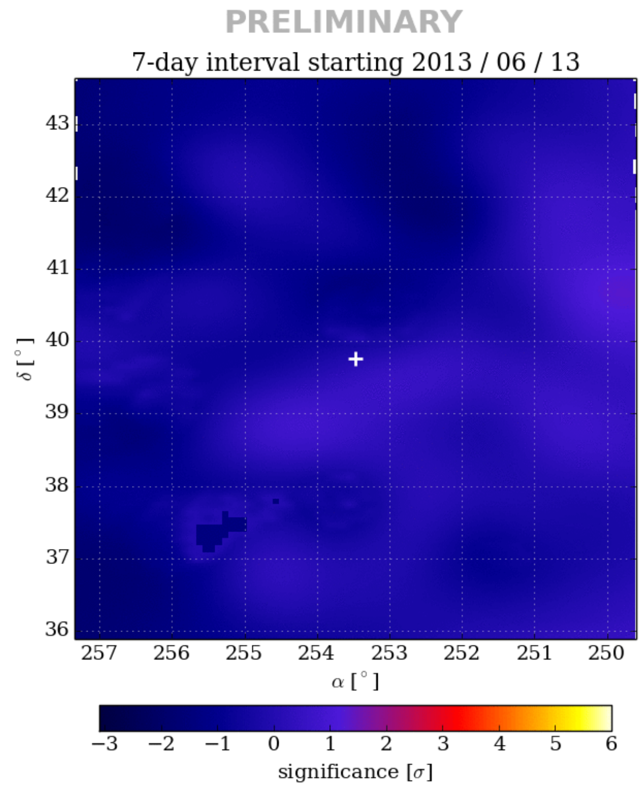


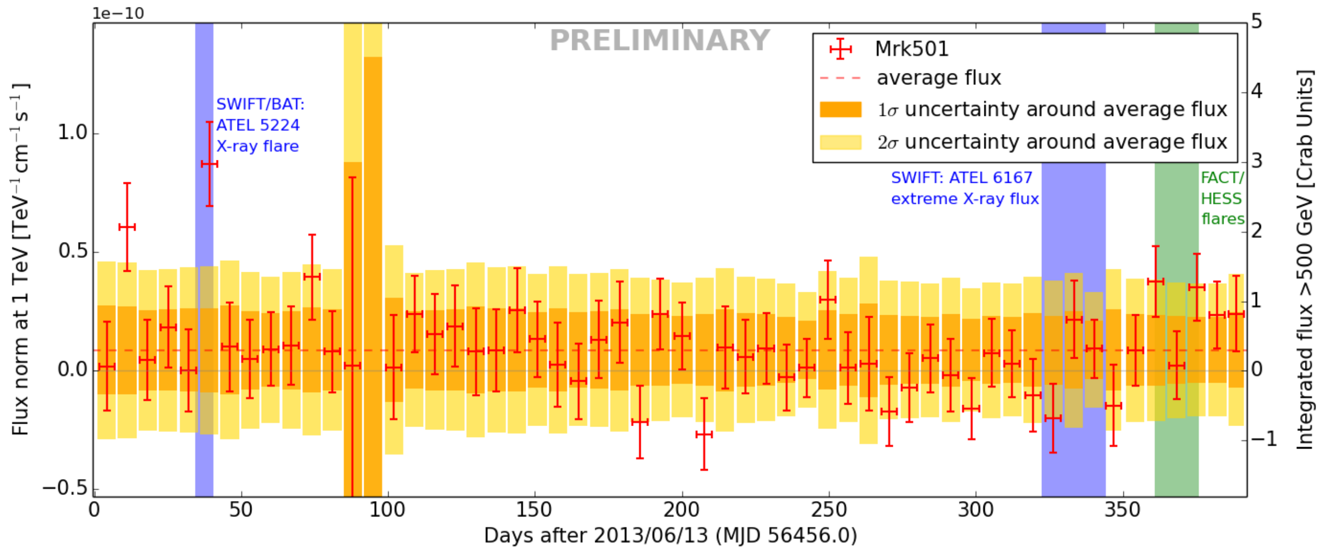


Animations and light curves by Robert Lauer

Mrk 501

- Nearby Bl Lac at z = 0.033.
- Highly variable TeV emission, with short timescales (Quinn et al. 1996).
- Marginal detection with Milagro.





Animations and light curves by Robert Lauer

AGN / EBL

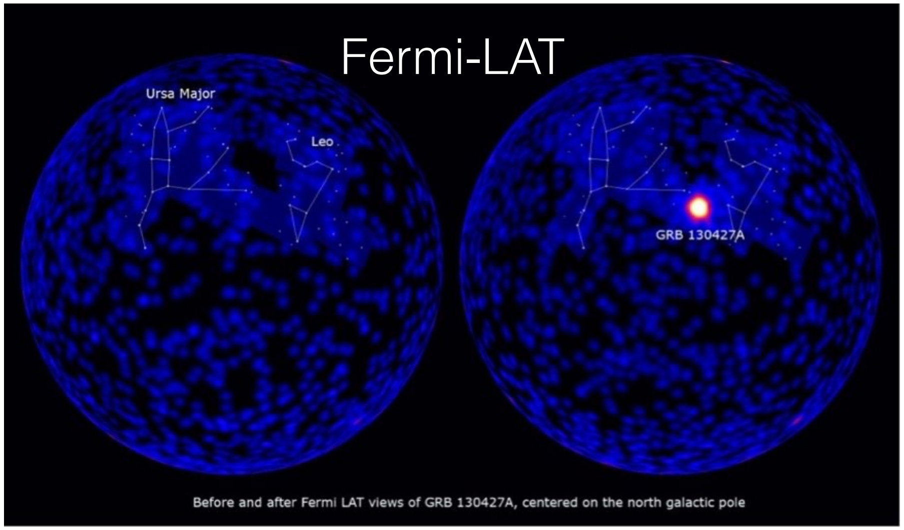
- HAWC horizon limited to z≲0.3 due to γγ→ee interaction with the extragalactic background light.
- Axions may explain TeV detections beyond EBL.

Fuentes extragalácticas 1FHL potencialmente detectables con HAWC

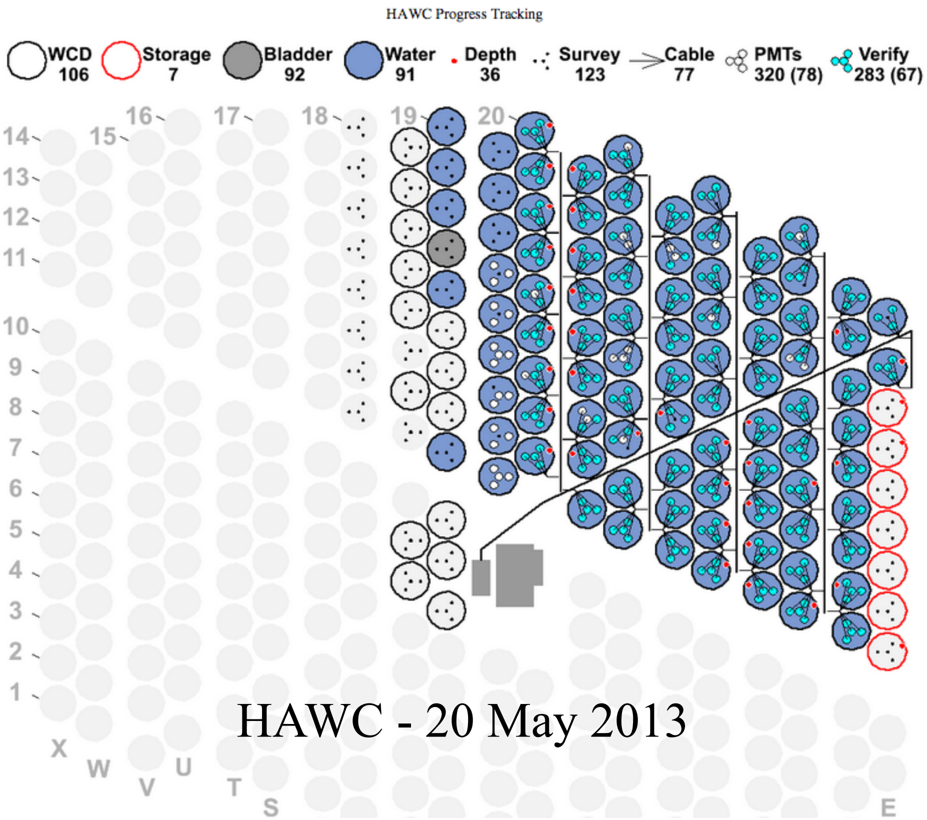
1FHL	Asociación	Tipo	z	Γ	σ / √yr
J0035.9+5950	1ES 0033+595	bzb	0.086	1.74 ± 0.18	6.02
J0152.6+0148	PMN J0152+0146	bzb	0.080	1.77 ± 0.34	4.85
J0316.6+4119	IC 310	rdg	0.019	1.31 ± 0.45	13.16
J0521.7+2113	VER J0521+211	bzb	0.108	1.97 ± 0.14	3.02
J0650.8+2504	1ES 0647+250	bzb	0.203	1.56 ± 0.18	10.25
J0816.3-1310	PMN J0816-1311	bzb	0.046	2.06 ± 0.27	3.19
J1104.4+3812	Mkn 421	bzb	0.031	1.91 ± 0.06	6.23
J1230.8+1224	M 87	rdg	0.004	1.25 ± 0.50	20
J1653.9+3945	Mkn 501	bzb	0.034	1.86 ± 0.10	5.30
J1728.3+5014	I Zw 187	bzb	0.055	1.67 ± 0.34	3.85
J2322.5+3436	TXS 2320+343	bzb	0.098	1.51 ± 0.32	9.68
J2347.0+5142	1ES 2344.514	bzb	0.044	1.48 ± 0.18	5.14

HAWC AGN/EBL sample by Sara Coutiño

Gamma-Ray Bursts

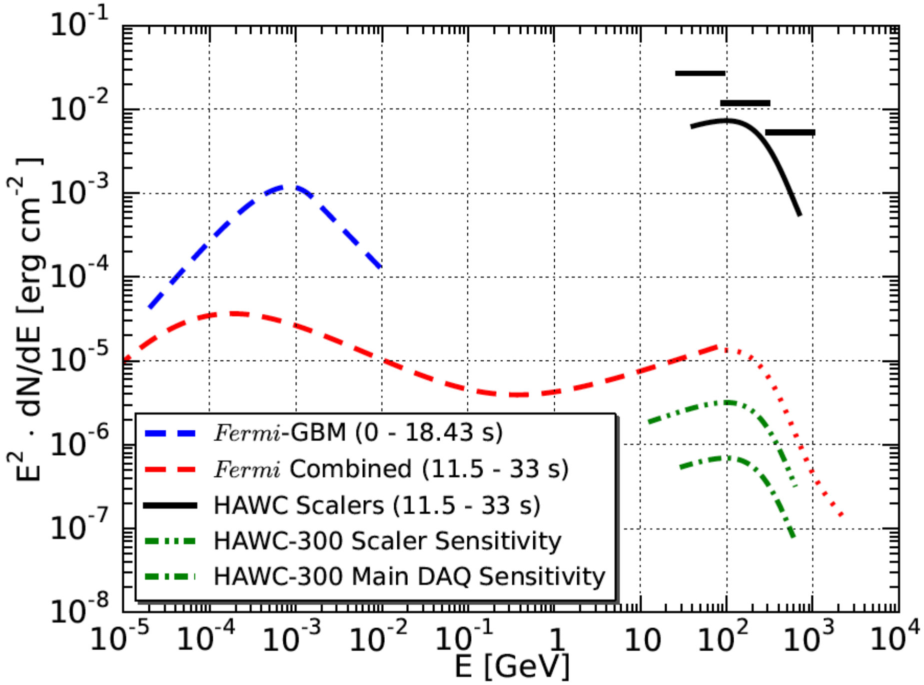


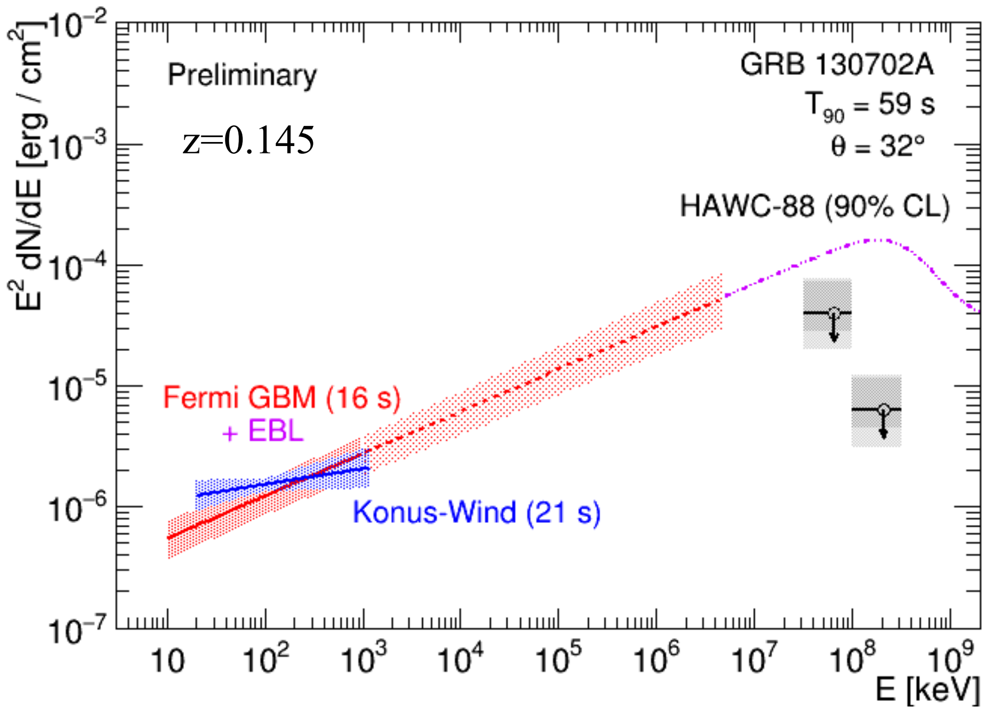
- GRB 130427A: one of the brightest and most energetic GRBs detected:
  - Bright optical counterpart: magnitude 7.4 and z=0.34.
  - Highest energy photon detected (95 GeV) in any GRB.
- Main HAWC DAQ not running at the time of burst.
- Zenith angle (57°) was too large for a HAWC detection.



HAWC - 20 May 2013

Gamma-Ray Bursts





GRB 130427A
Abeysekara et al., ApJ 800, 78 (2015)

Kathryne Sparks Woodle
APS 2015 presentation

Primordial Black Holes

- Originated in density fluctuations in the very early Universe:
  - Collapse of cosmic loops.
  - Bubble collisions.
  - Collapse of domain walls.
- Alternative to Pop III remnants or Direct Collapse scenarios.
- Potential probes of:
  - early Universe: PBHs affect early Universe processes.
  - viable dark matter candidates
  - high energy physics: contributions to γ-ray background among other.
  - quantum gravity: evaporation process.

Carr (2005), Carr et al. (2010)

Primordial Black Holes

BH radiate thermally with a temperature (Hawking 1974):

$$T_{\rm BH} = \frac{\hbar\, c^3}{8\pi\, G\, M\, k_{\rm B}} \sim 10^{-7} \left(\frac{M}{M_\odot}\right)^{-1} {\rm K},$$

and evaporate in a time scale:

$$\tau(M) \sim \frac{G^2\, M^3}{\hbar\, c^4} \sim 10^{64} \left(\frac{M}{M_\odot}\right)^{3} {\rm yr}\,.$$

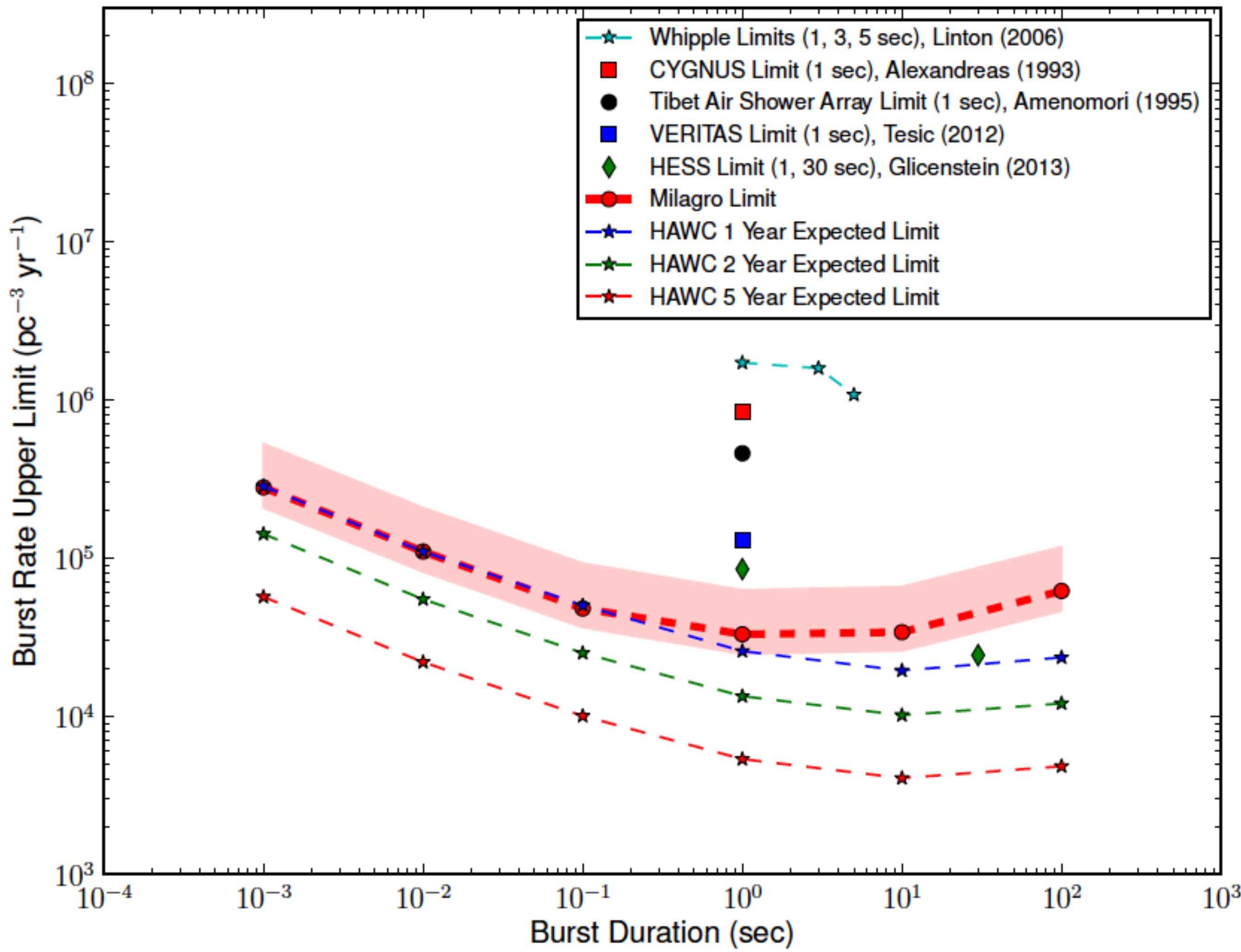
Only PBHs smaller than 10^{15}g would have evaporated by now.

Primordial Black Holes

PBH evaporation limits on multiple time scales set with Milagro (Abdo et al. 2015).

HAWC will set the most stringent upper limits for burst lasting 1ms - 100s and emitting in the TeV range.

ICRC-0708 (Ukwatta et al).



HAWC PBH expectations by Tilan Ukwatta

HAWC @ ICRC

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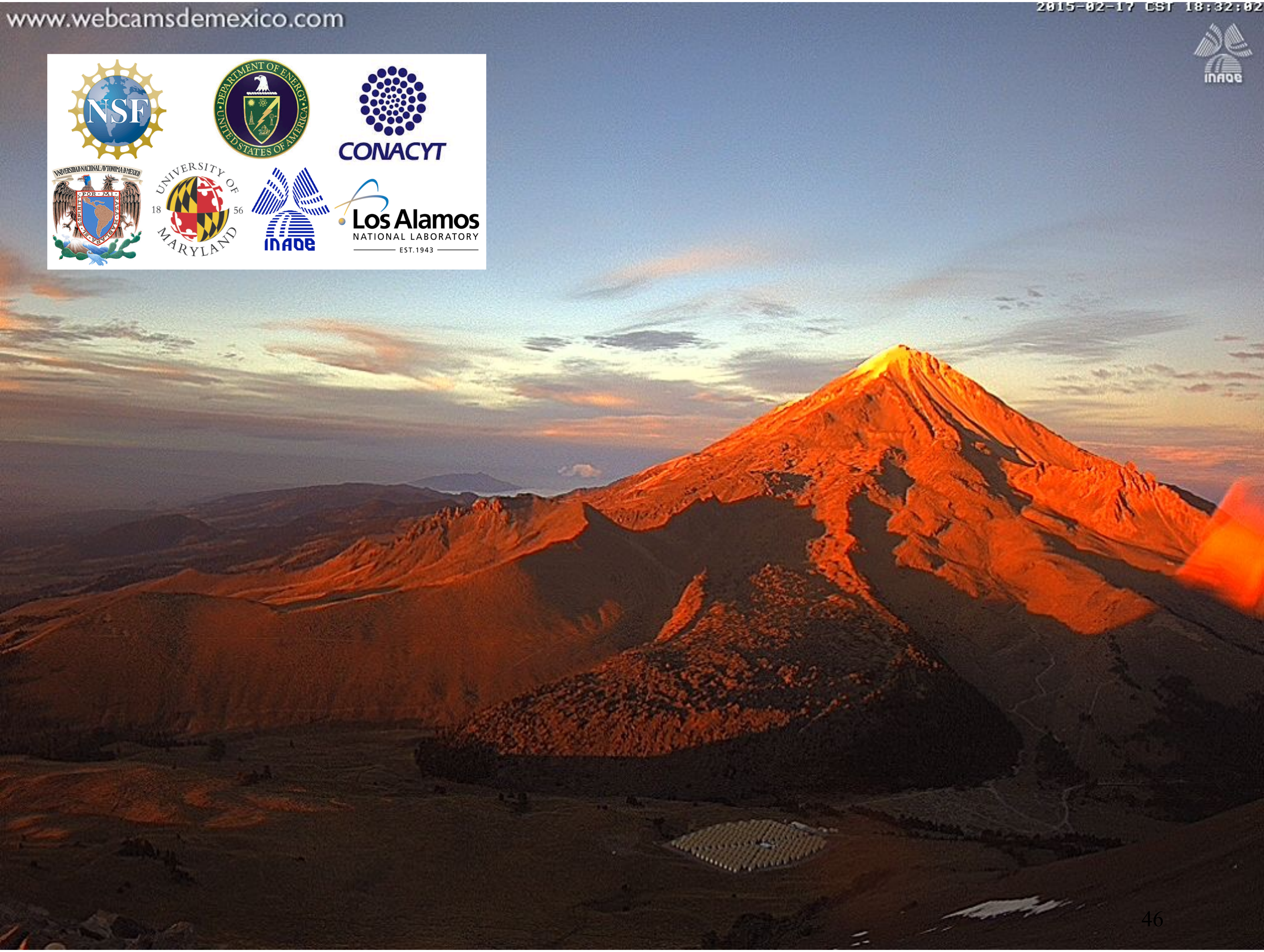
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