Gamma-ray ground arrays

Miguel Mostafa - Penn State

RICAP 2014 - Noto, Sicily

Outline

1. Motivation
2. Detection techniques
3. Status and results
4. Outlook

Experiments Included

- ARGO
- Tibet
- HAWC
- LHAASO

Scientific Motivation

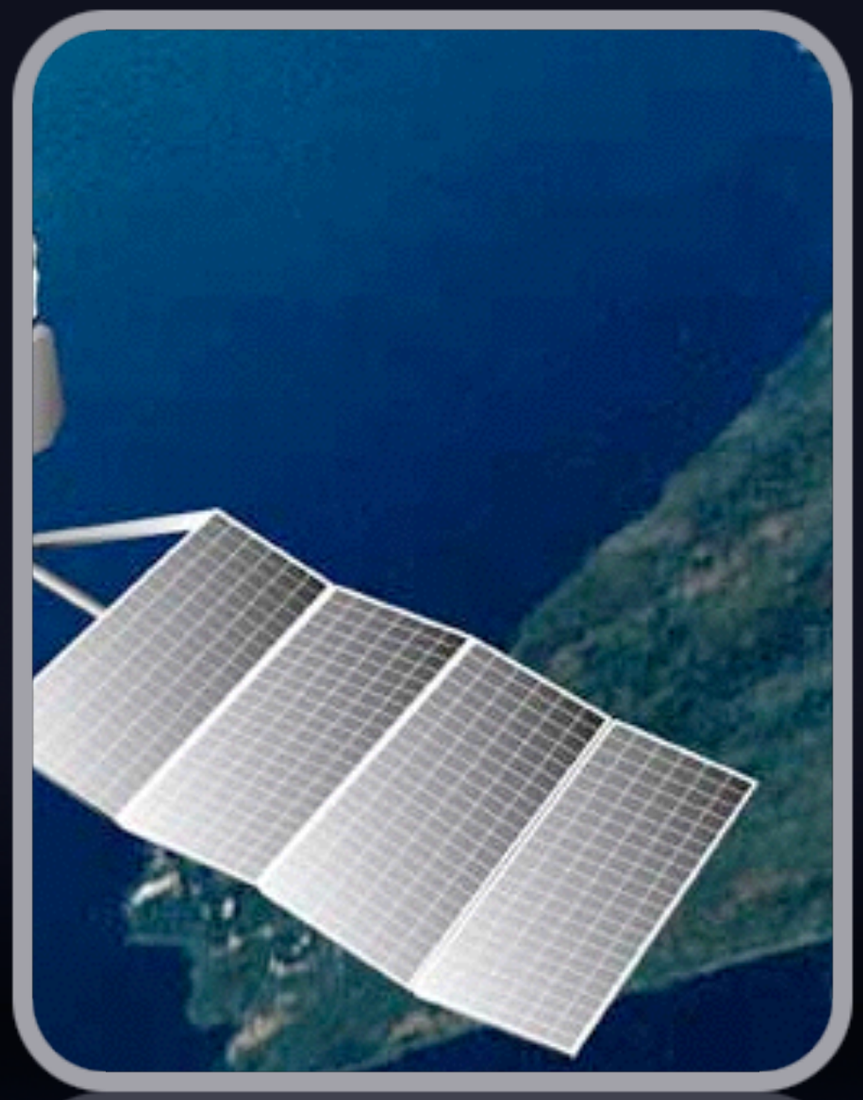
- Constrain the **origin of cosmic rays** by measuring gamma-ray spectra up to **very high energies**.
- Probe **particle acceleration** in astrophysical jets with **wide field of view, high duty factor** observations.
- Explore **new physics** with an **unbiased survey** of the **high energy sky**.

Experimental Techniques

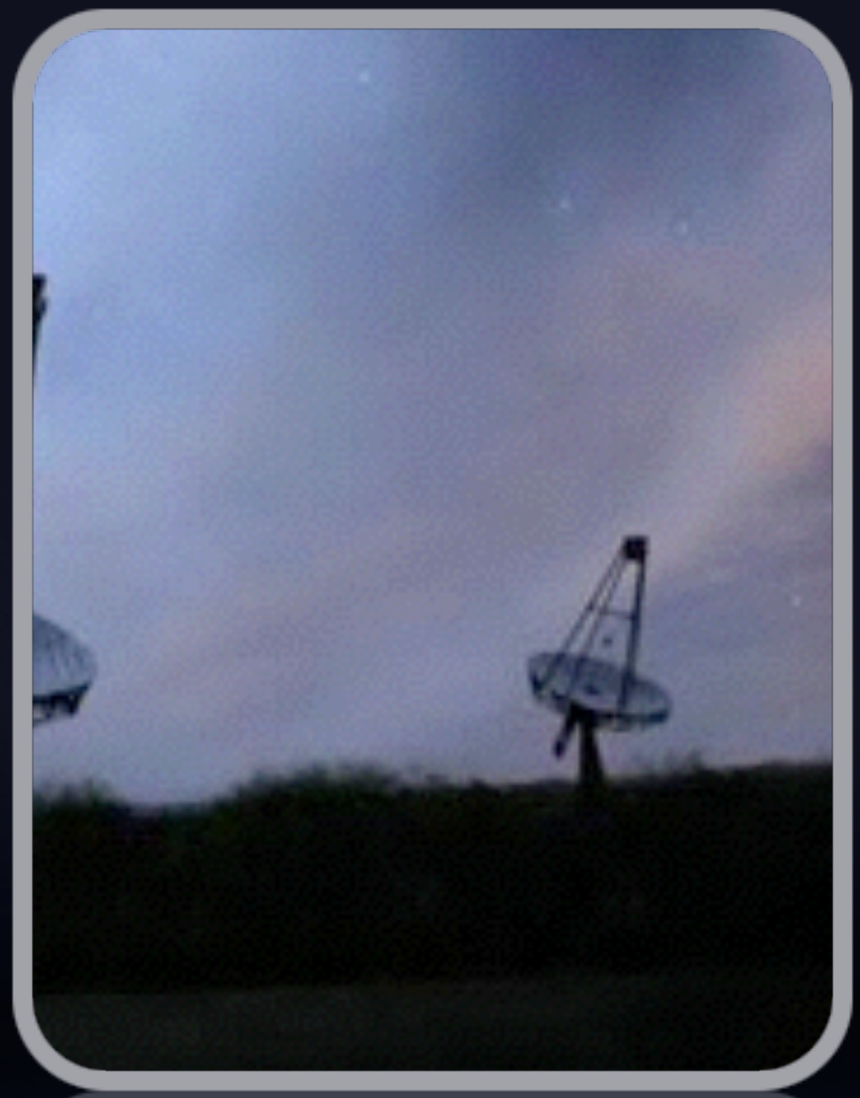
- ✓ Background free
- ✓ Large duty cycle
- ✓ Large aperture

- \- Small area

- **Space-based detectors**
  - Low energy threshold
  - EGRET, Fermi-LAT



Experimental Techniques



✓ Large effective area

✓ Excellent background rejection

- Small aperture
- Low duty cycle

- **Imaging Atmospheric Cherenkov Telescopes**
  - High sensitivity
  - HESS, MAGIC, VERITAS

Experimental Techniques

✓ Large aperture

✓ Excellent background rejection

✓ Large duty cycle

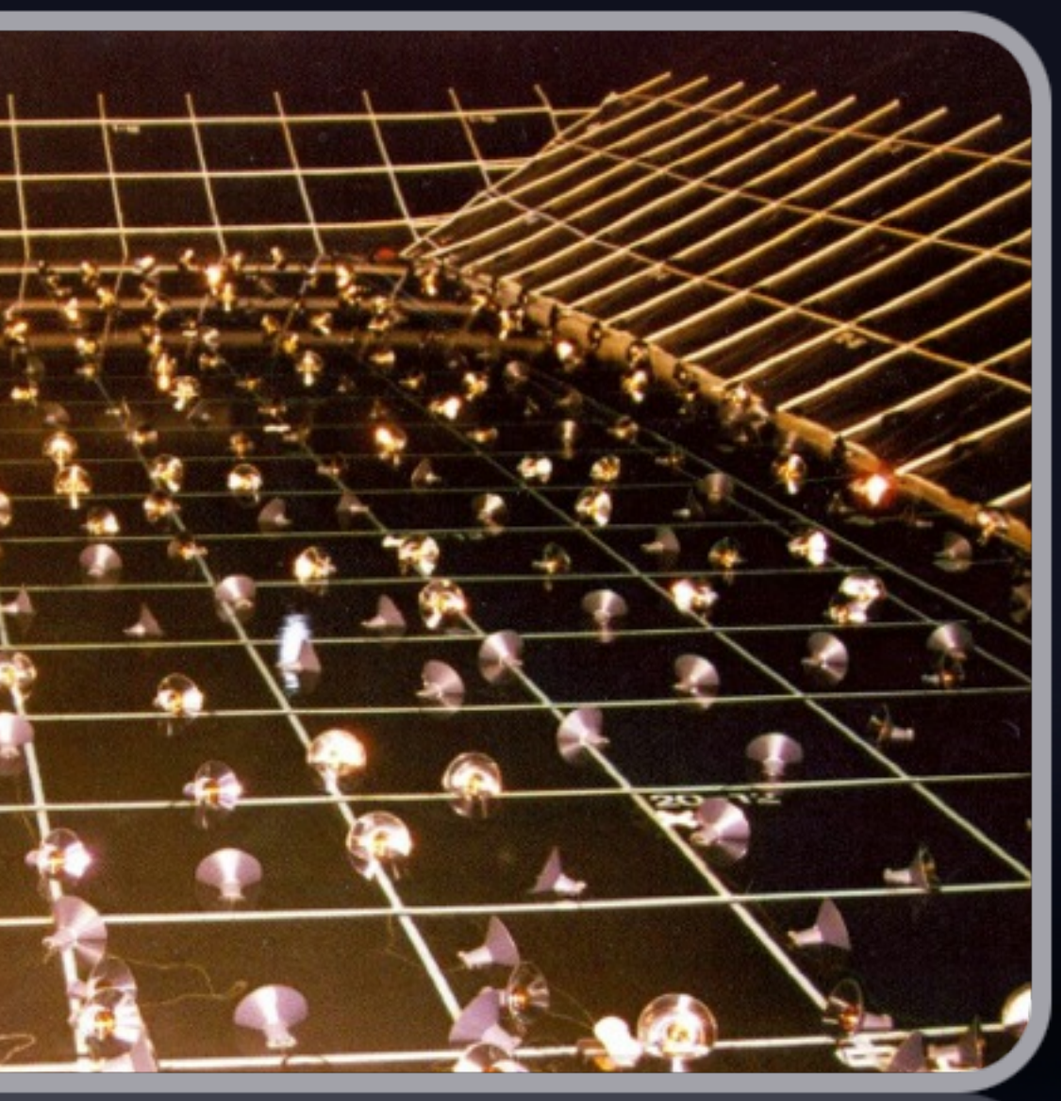
- Moderate area

- **Ground array of air-shower particle detectors**

  Large aperture + High duty cycle

  Milagro, Tibet, ARGO, HAWC, LHAASO

Detector Technologies



- Scintillators
- Resistive plate chambers
- Water Cherenkov detectors

High-altitude + large area

Ground Arrays Features

- High altitude
- Large area
- Wide field of view
- High duty cycle

Capabilities

- Survey of VHE gamma-rays for a large fraction of the sky
- High exposure to flaring activity
- CR physics at multi-TeV energies
- Particle physics
- Solar physics

ARGO-YBJ

Collaboration between:

- Istituto Nazionale di Fisica Nucleare (INFN), Italy
- Chinese Academy of Science (CAS), China

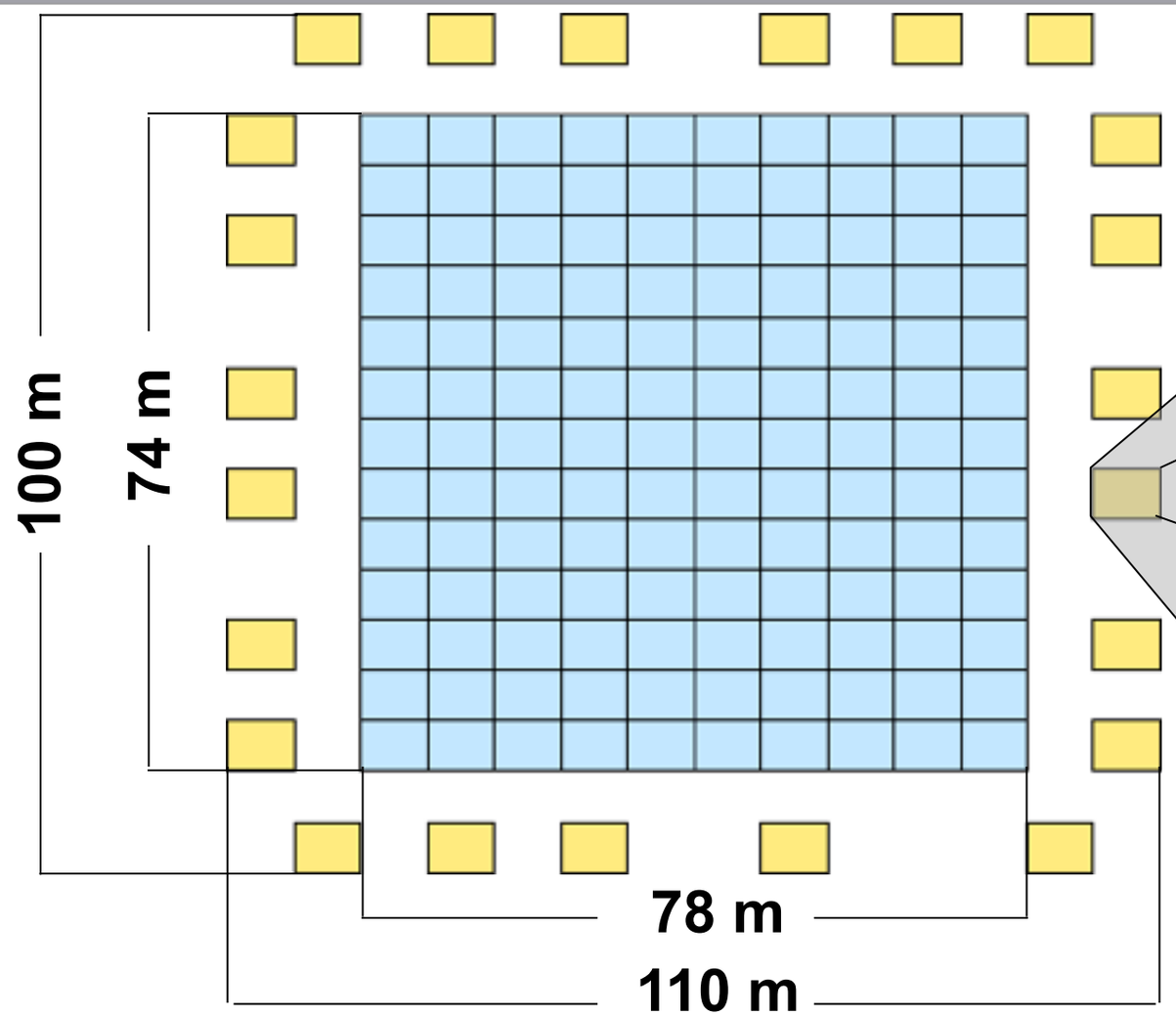
Materials courtesy of Tristano Di Girolamo & Giuseppe Di Sciascio

ARGO-YBJ location

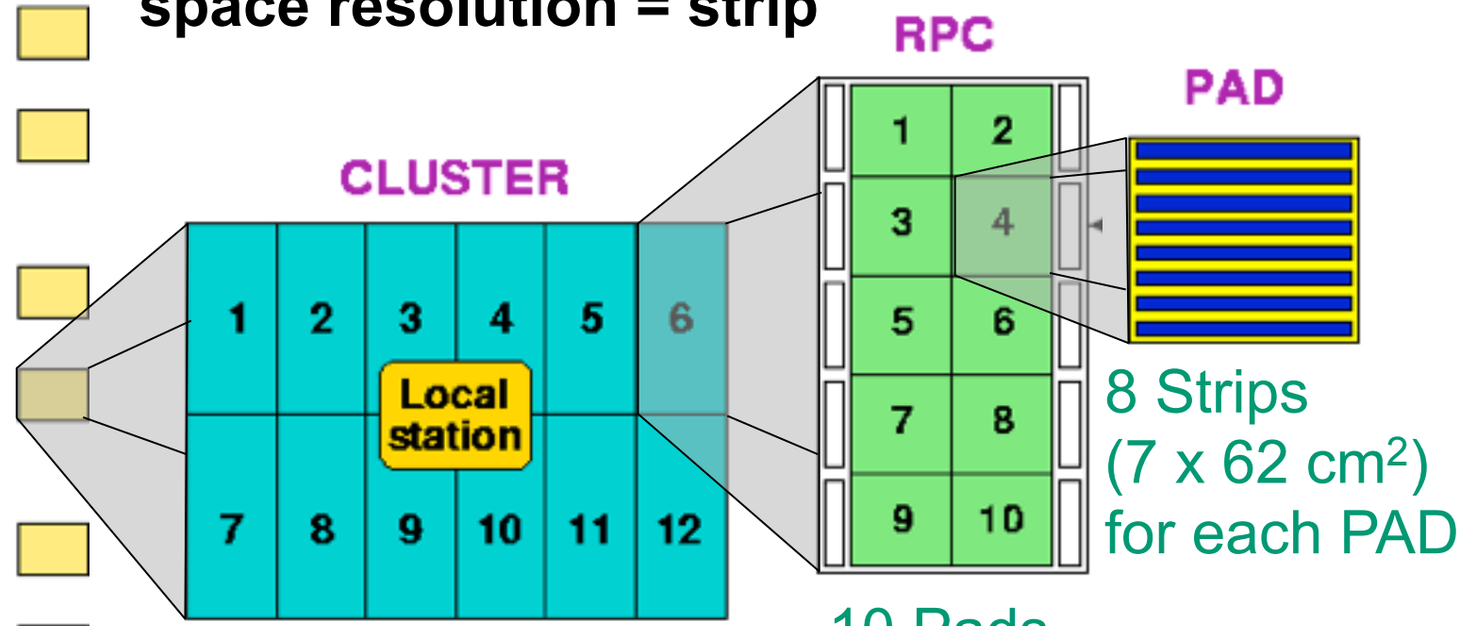
Site:

- YangBaJing Cosmic Ray Lab., Tibet, China
- 4,300 m a.s.l.

ARGO-YBJ layout



time resolution ~1.8 ns
space resolution = strip



1 CLUSTER = 12 RPCs

$(5.7 \times 7.6\ m^2)$

Single layer of Resistive Plate Chambers with full coverage (93%) of a large area (5600 m²)

$\Longrightarrow$ detection of small showers

Pad = TIME PIXEL (18360 on the full detector)

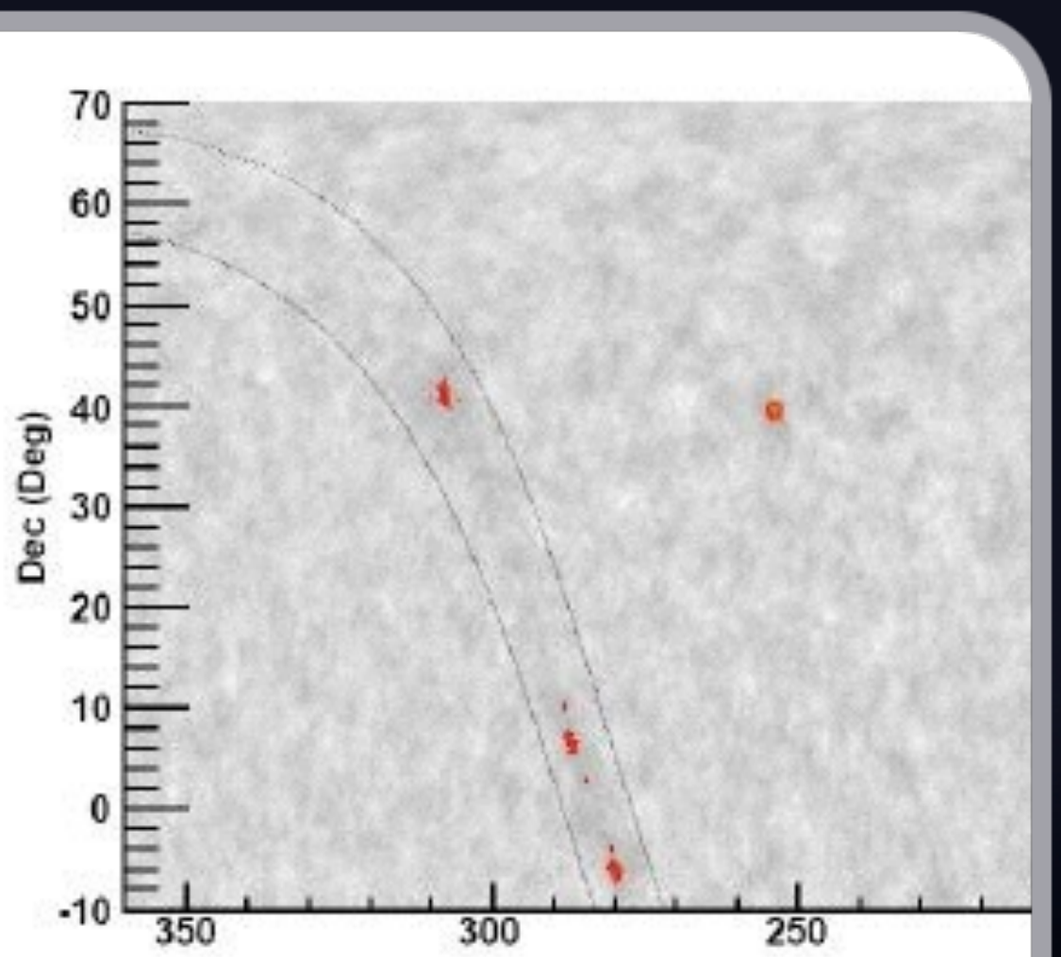
Cluster = DAQ unit

RPC

BigPad

BigPad = CHARGE READOUT PIXEL,
123 x 139 cm^2 (3120 on the central carpet)

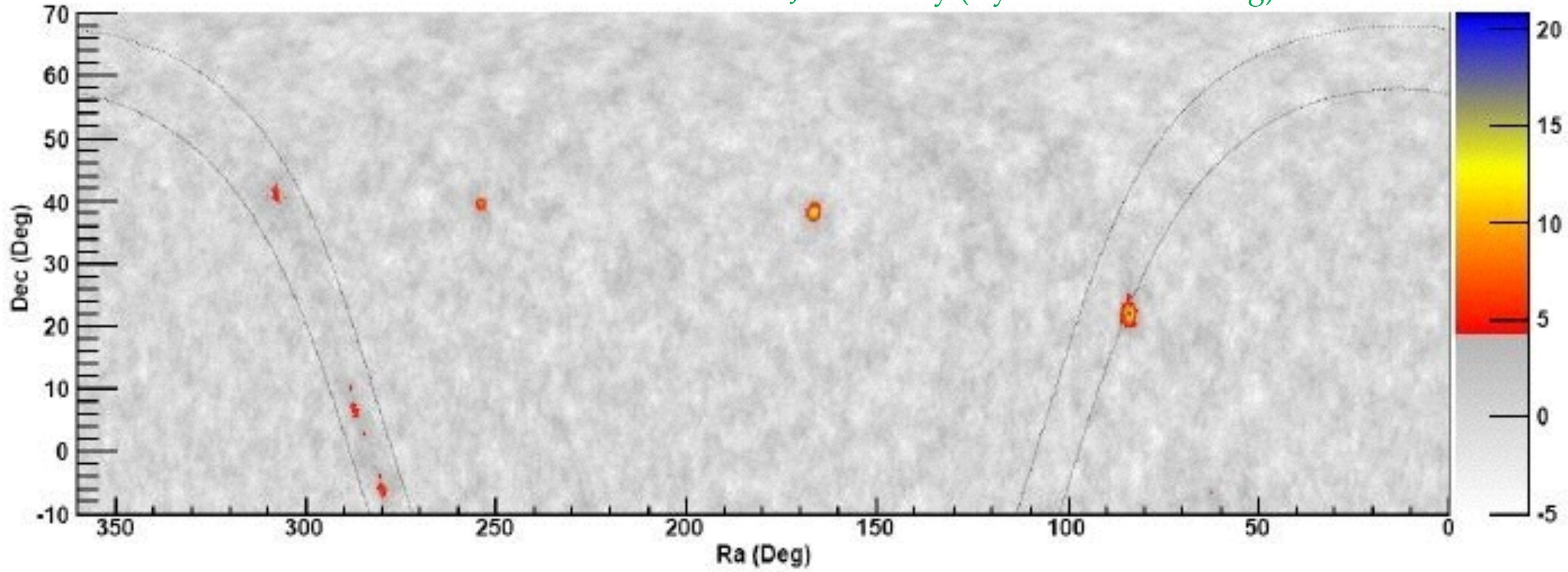
Selected results



- Sky survey
- Crab Nebula
- Mrk 501
- Cygnus Region
- Diffuse emission from the galaxy
- Gamma Ray Bursts

Sky Survey

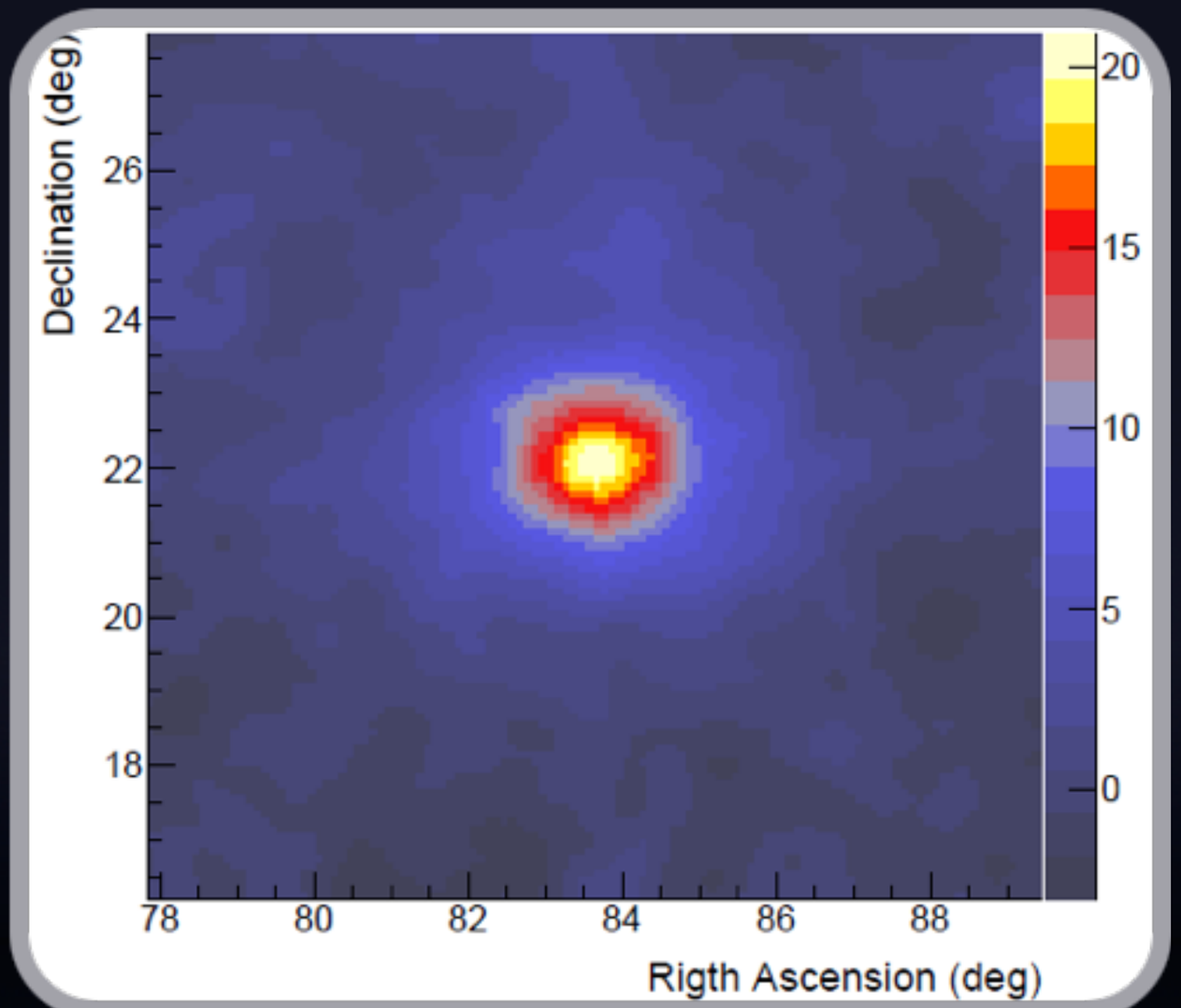
ARGO-YBJ sensitivity (5 years of data taking) : 0.24 Crab units

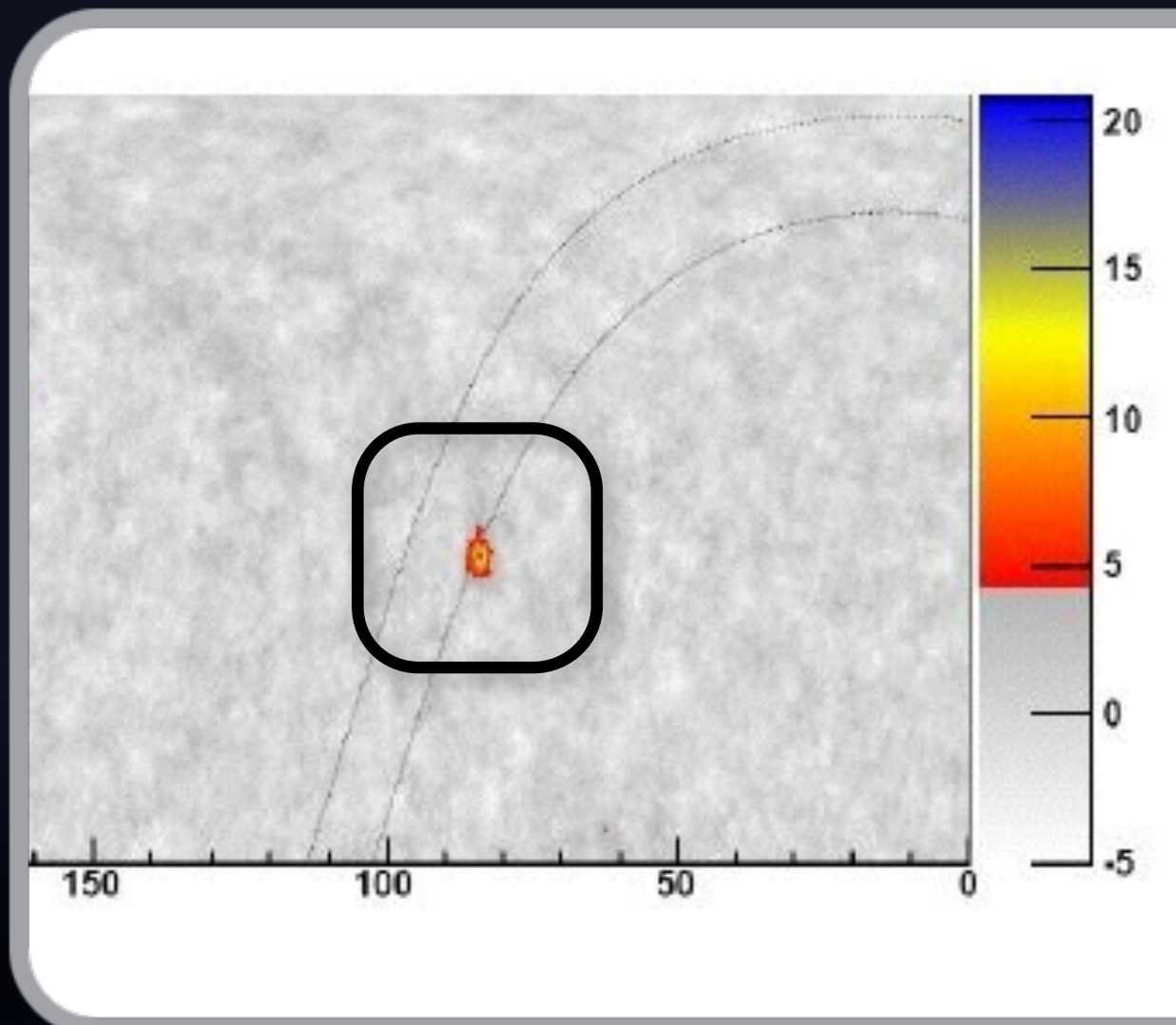


Six sources identified with significance > 5σ
+ 5 hot spots above 4σ

ARGO Collaboration, The Astrophysical Journal **779** (2013) 27

The Crab



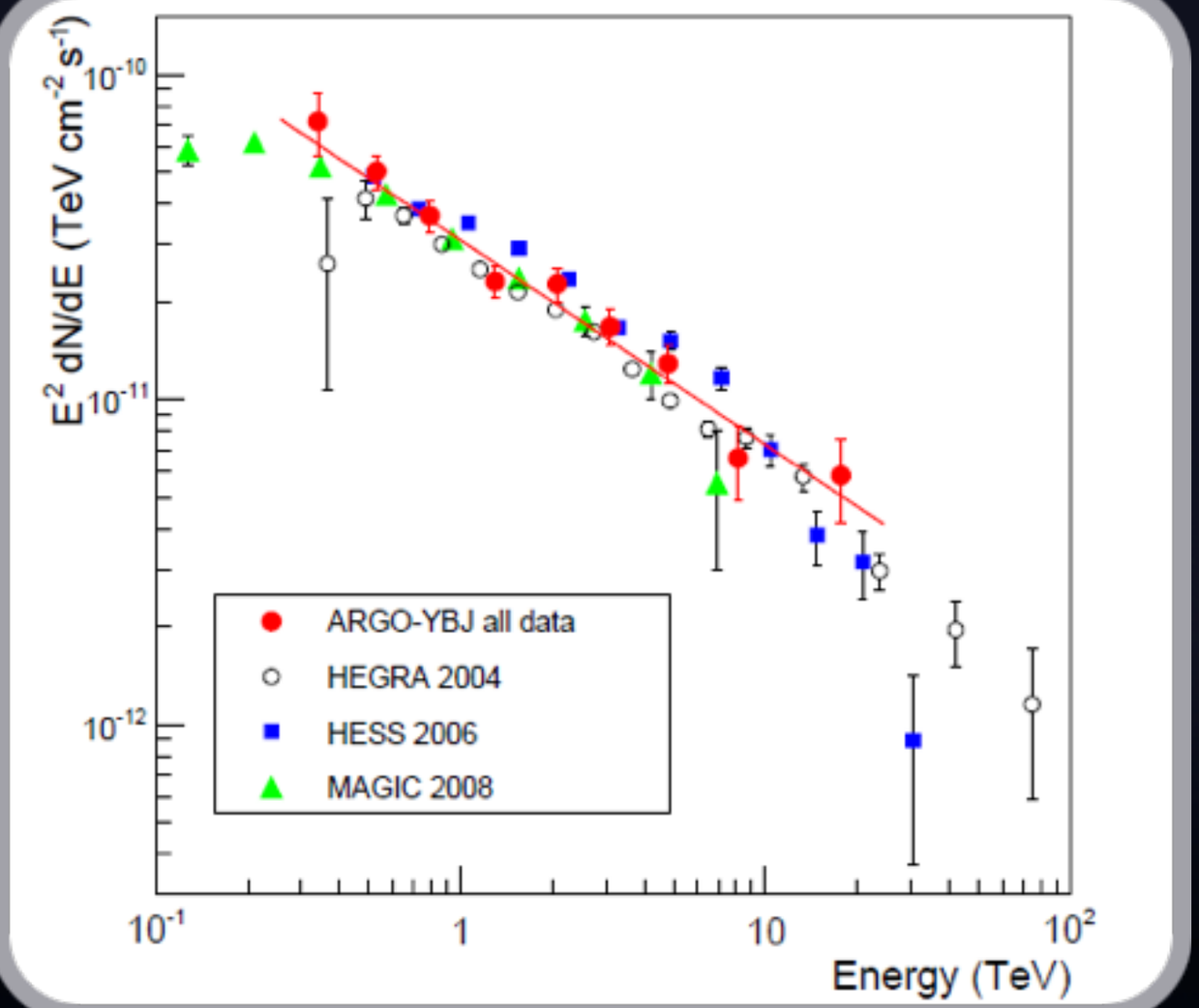


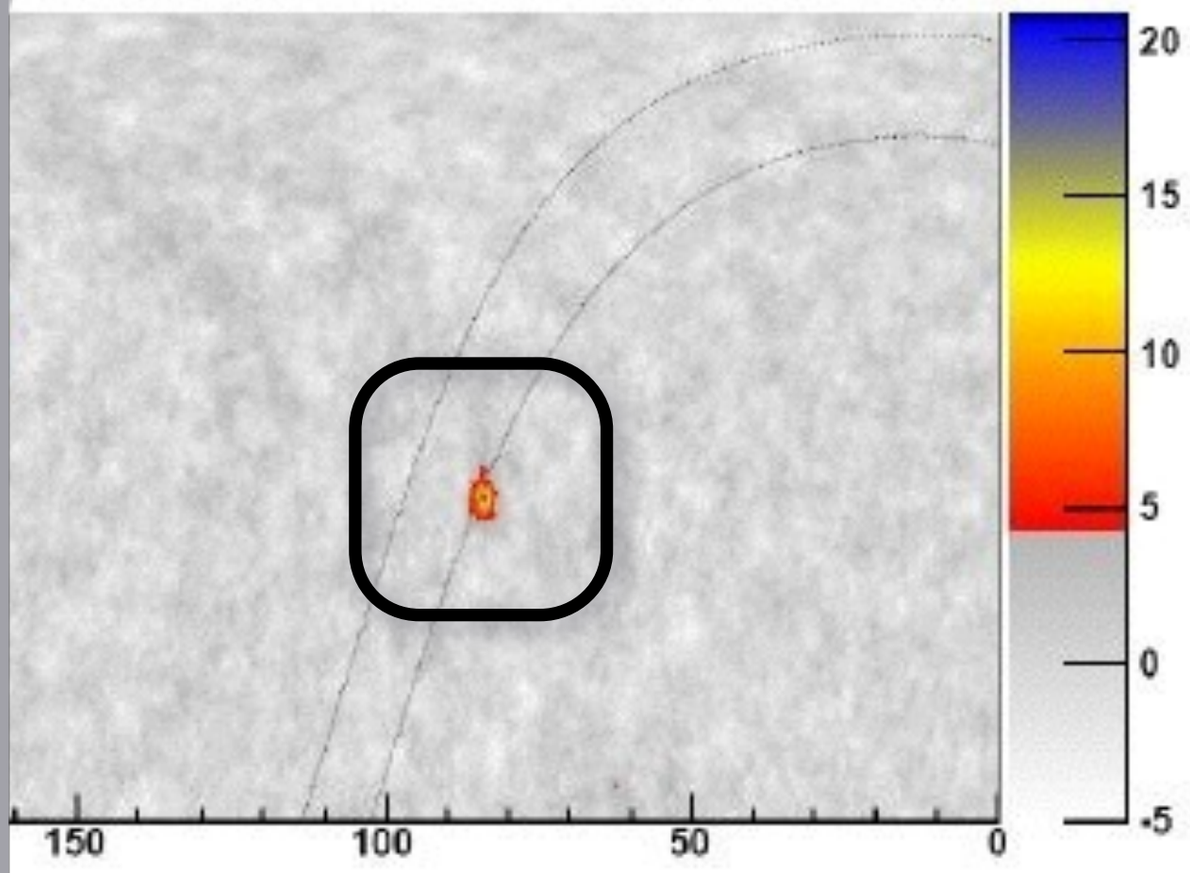
Measured PSF in agreement with expectations.

$dN/dE = (5.2 \pm 0.2) \cdot 10^{-12} \cdot (E/2\ \mathrm{TeV})^{(-2.63 \pm 0.05)}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{TeV}^{-1}$

Journal paper in preparation

The Crab





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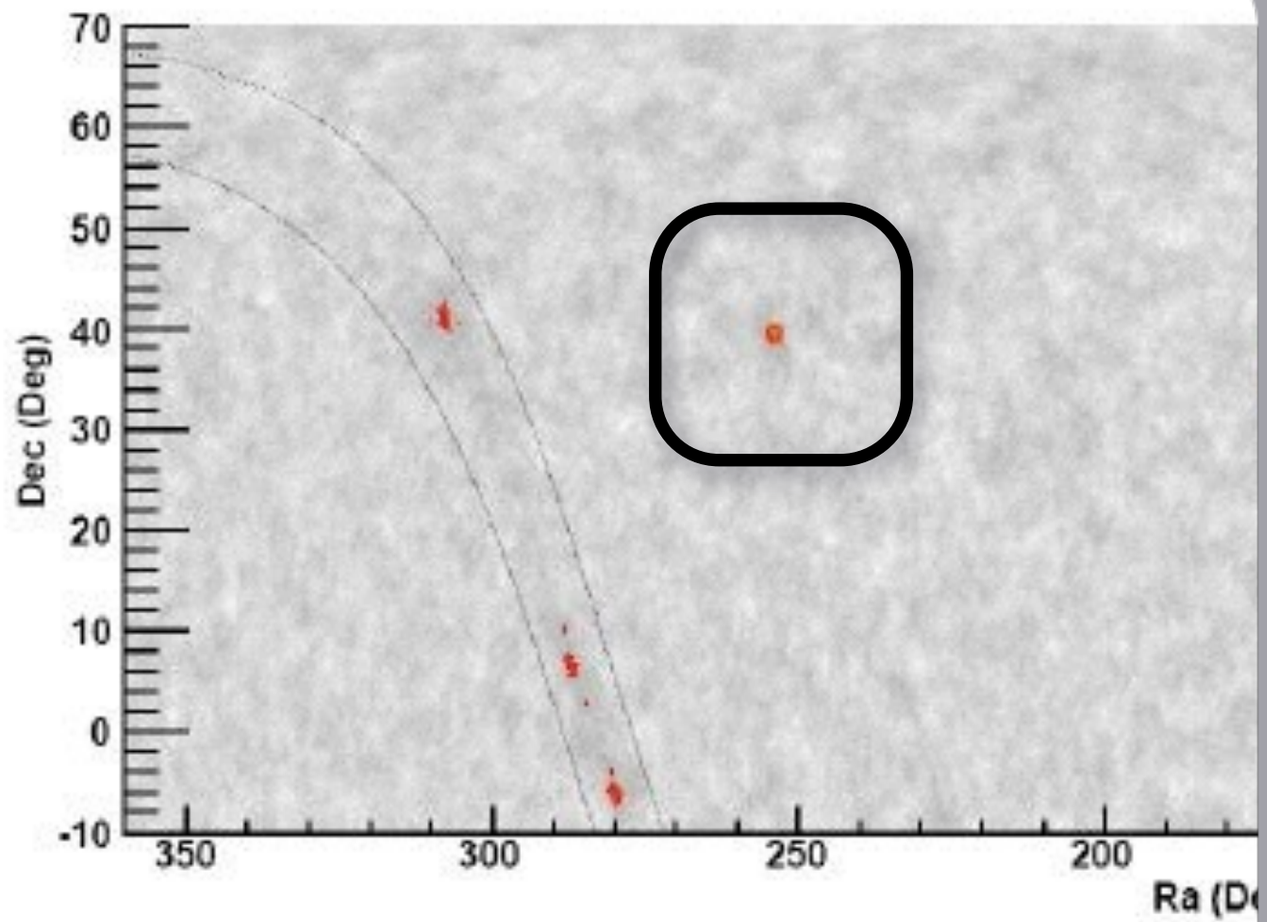
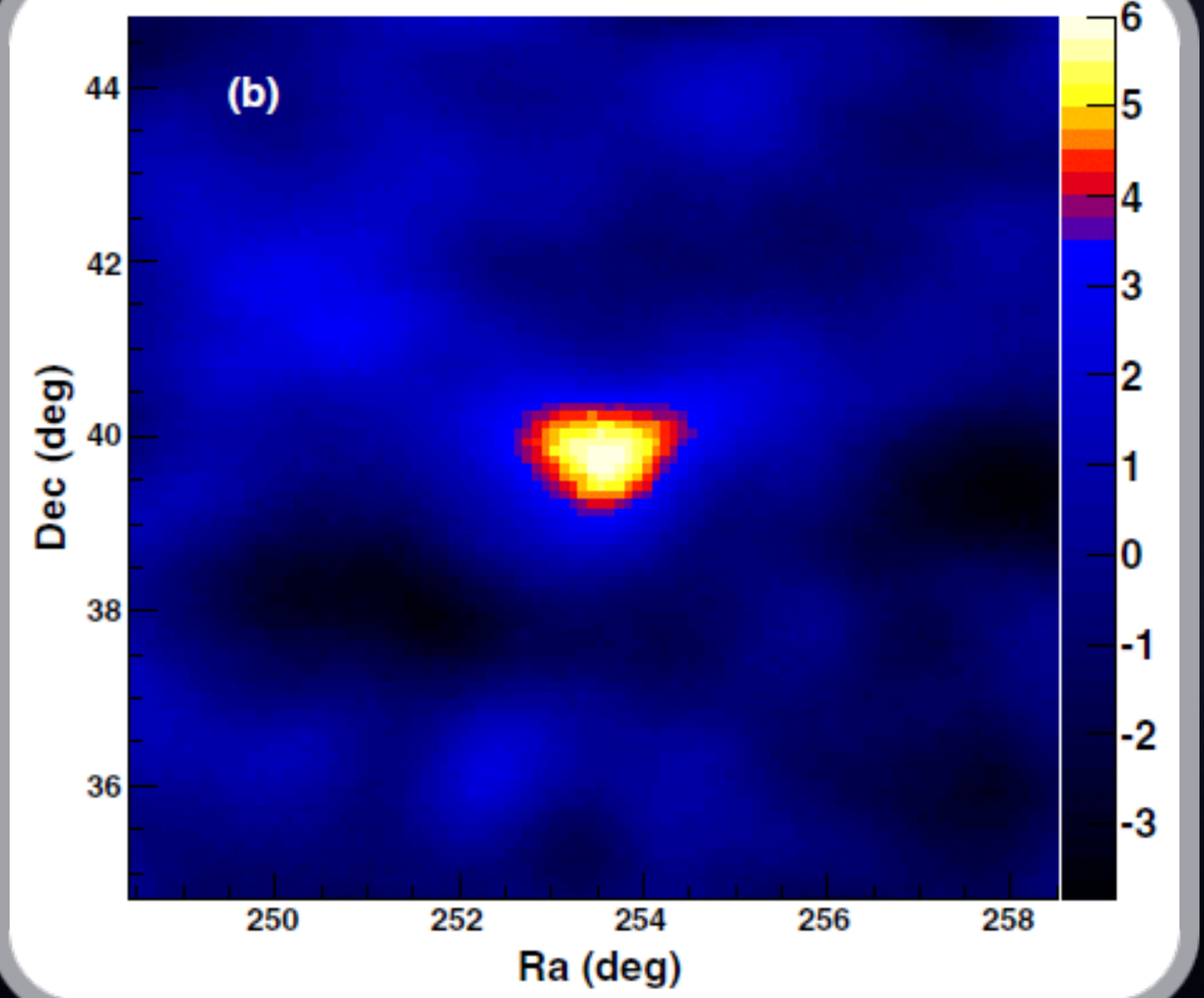
Journal paper in preparation

Mrk 501





Long-term monitoring and flare

ARGO Collaboration, The Astrophysical Journal **758** (2012) 2

Mrk 501

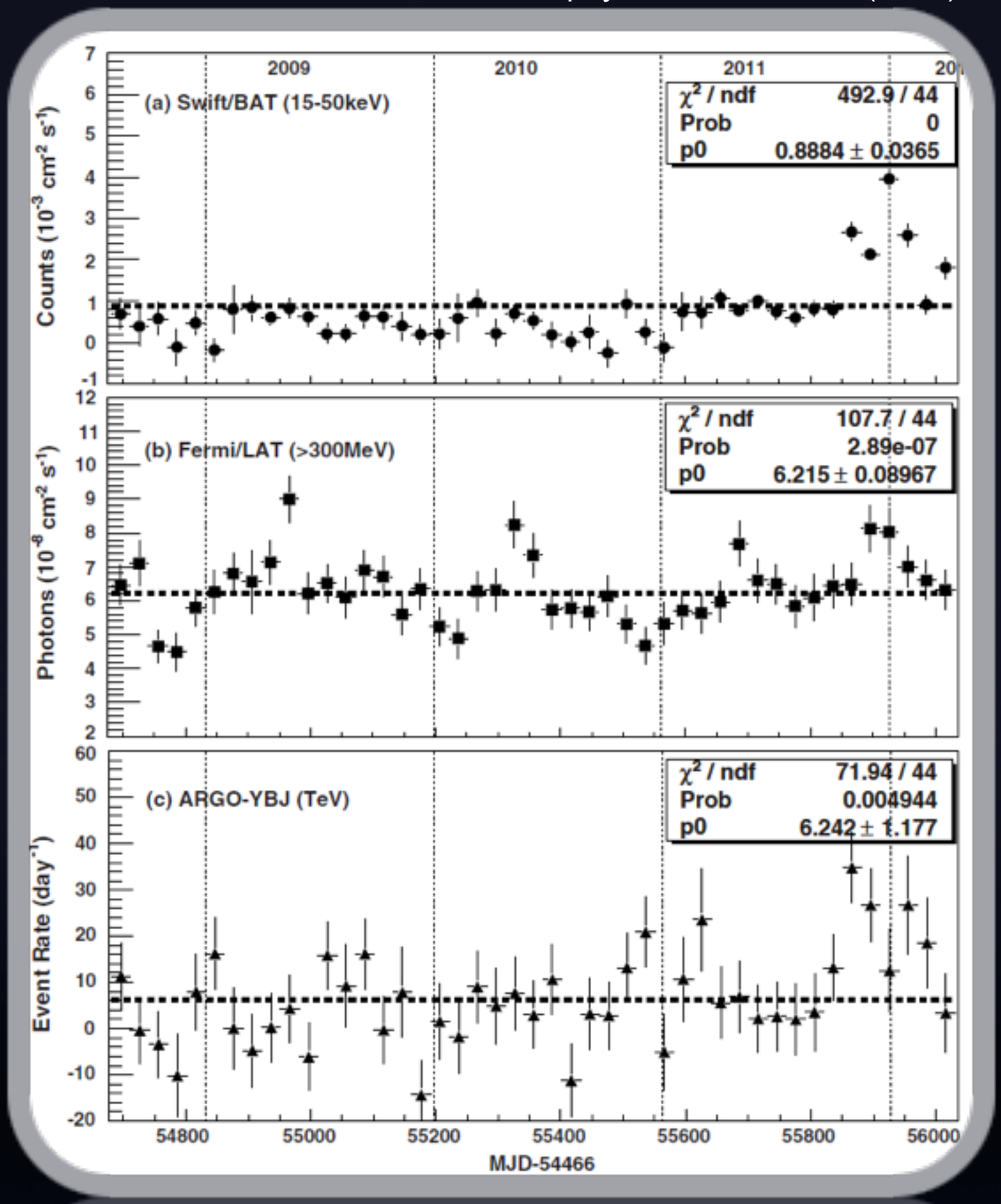
- Large flare in 2011

  Oct 17 to Nov 22

  ~ 2 Crab units

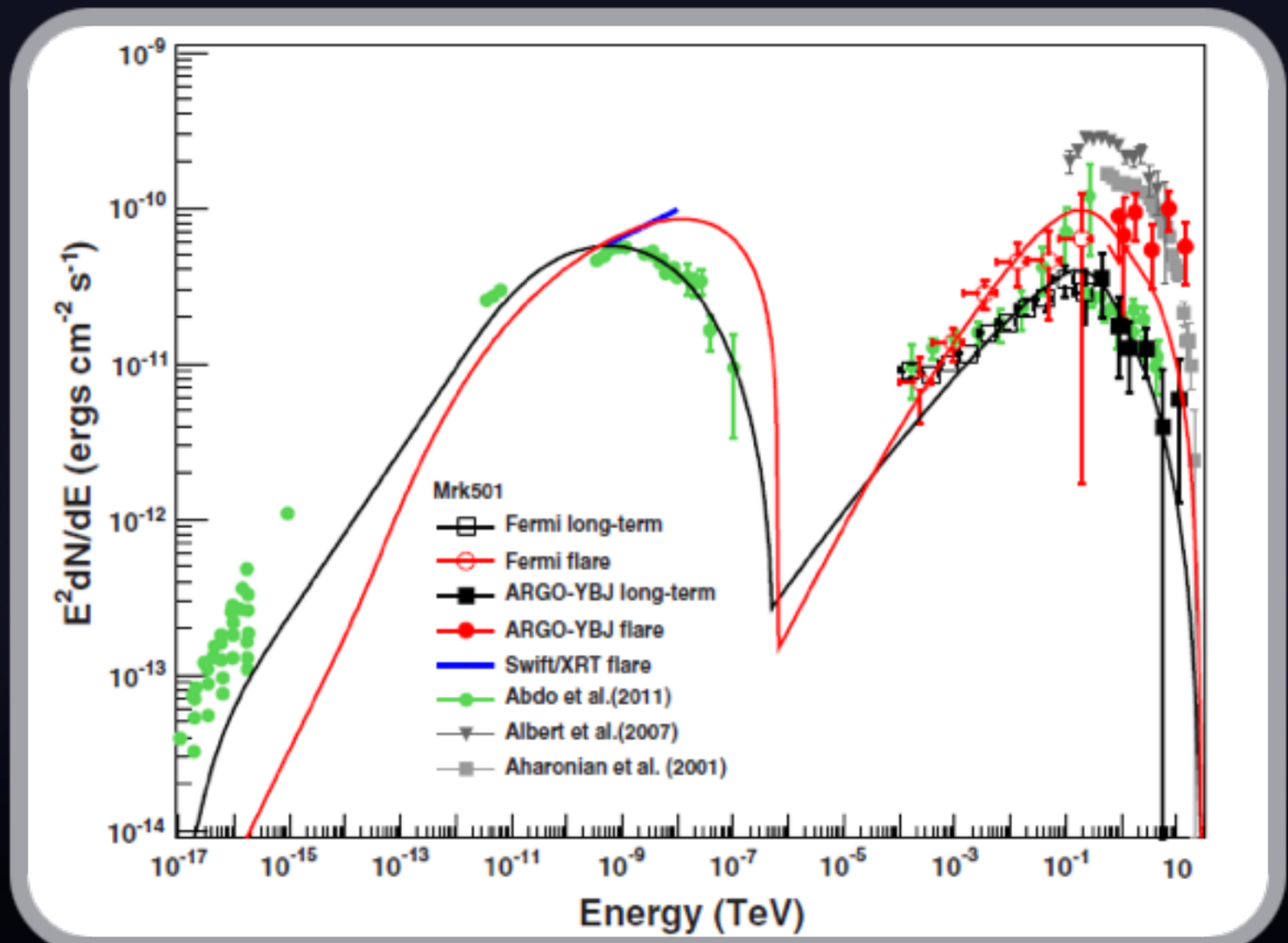
  ~ 6.6x the steady state

ARGO Collaboration, The Astrophysical Journal **758** (2012) 2



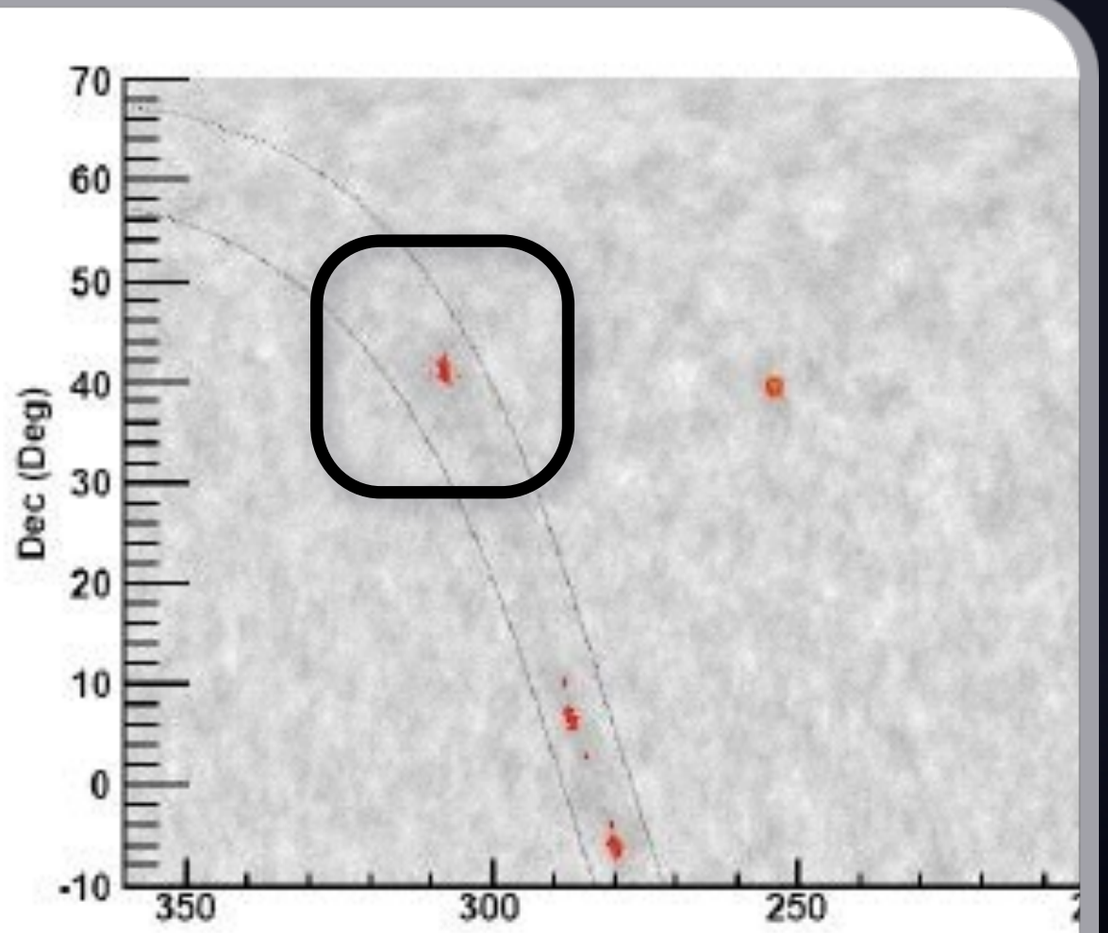
Mrk 501

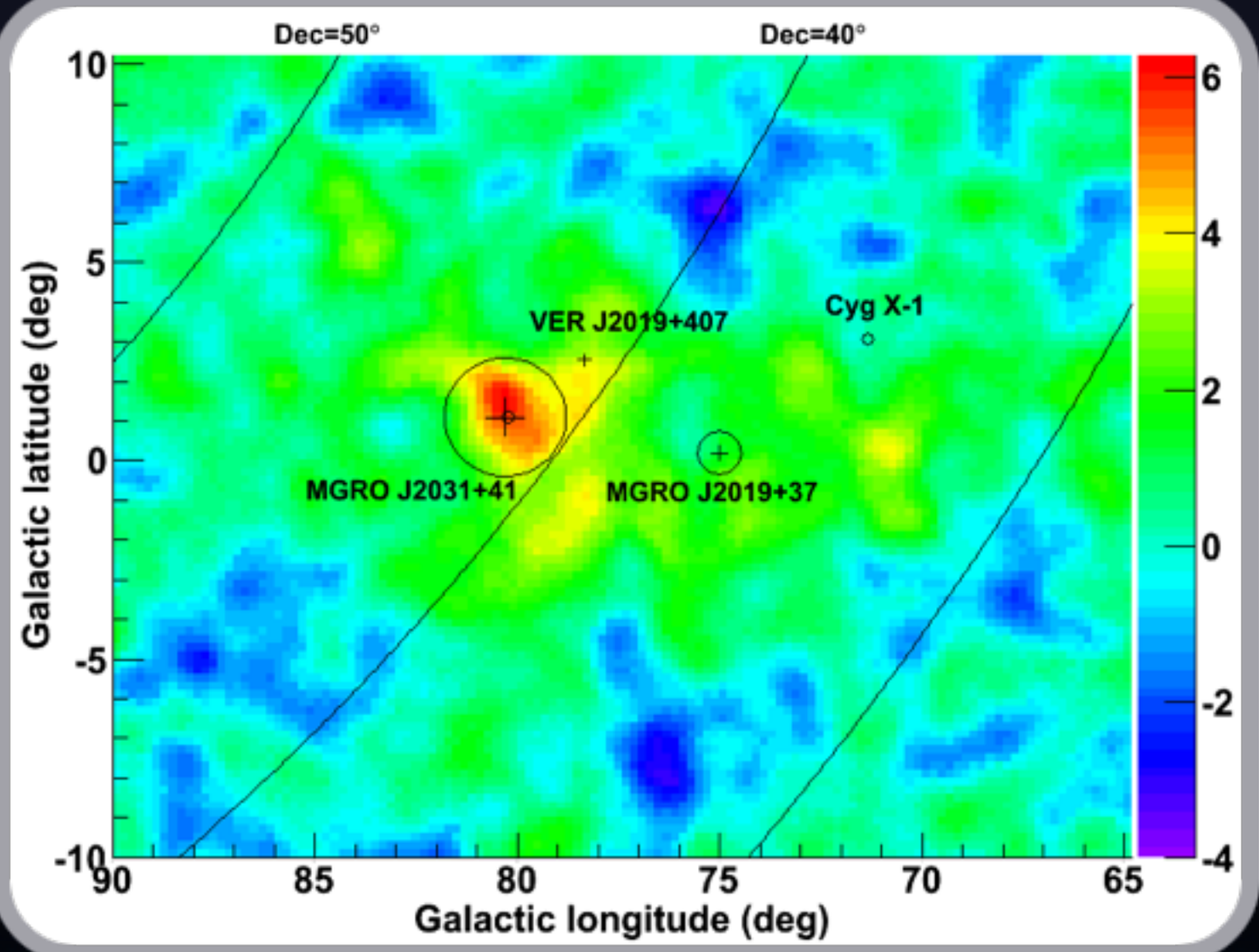
flare spectrum



A simple one-zone SSC model is unable to reproduce the flaring emission at E > 8 TeV

The Cygnus Region





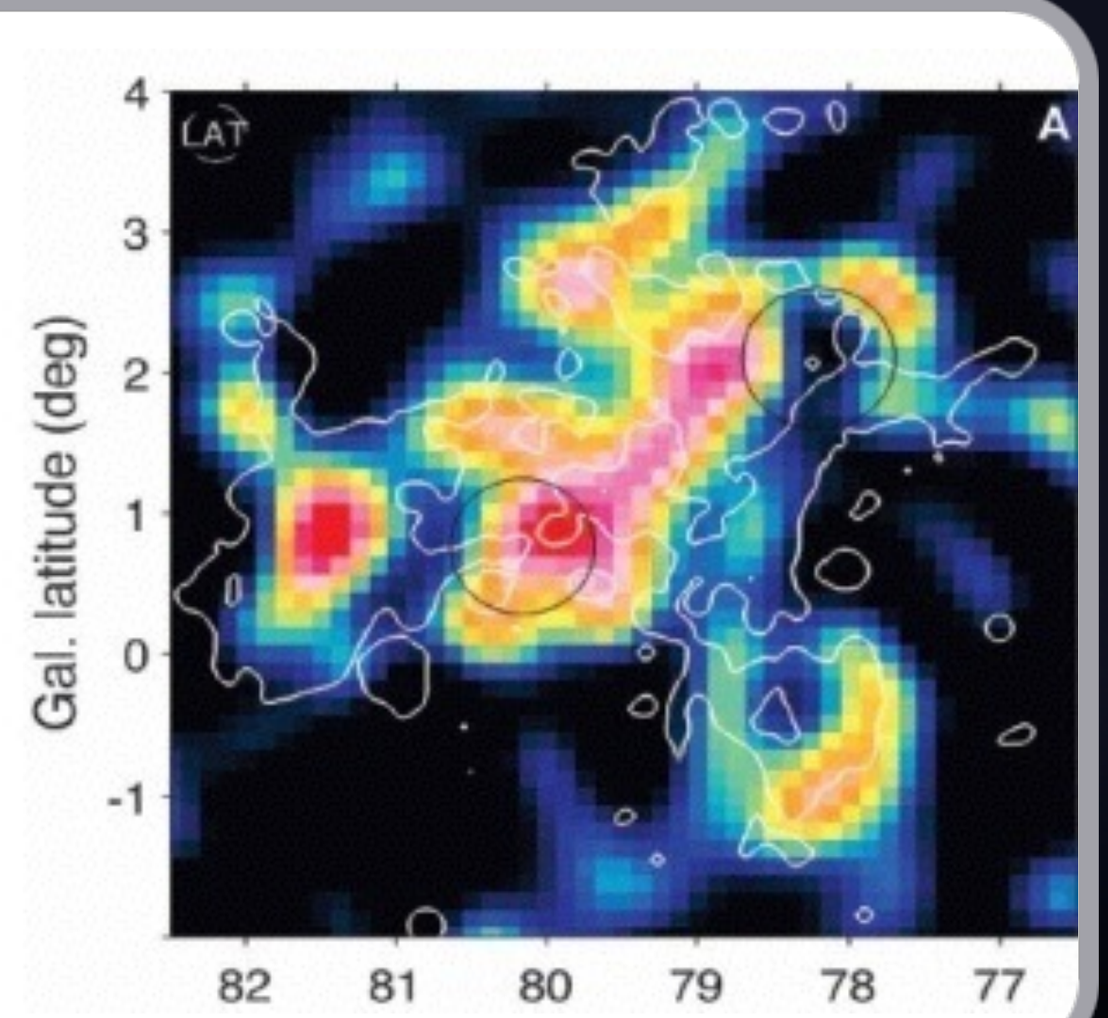
MGRO J2031+41/TeV J2032+4130 seen at 6.4σ

MGRO J2019+37 below 3σ

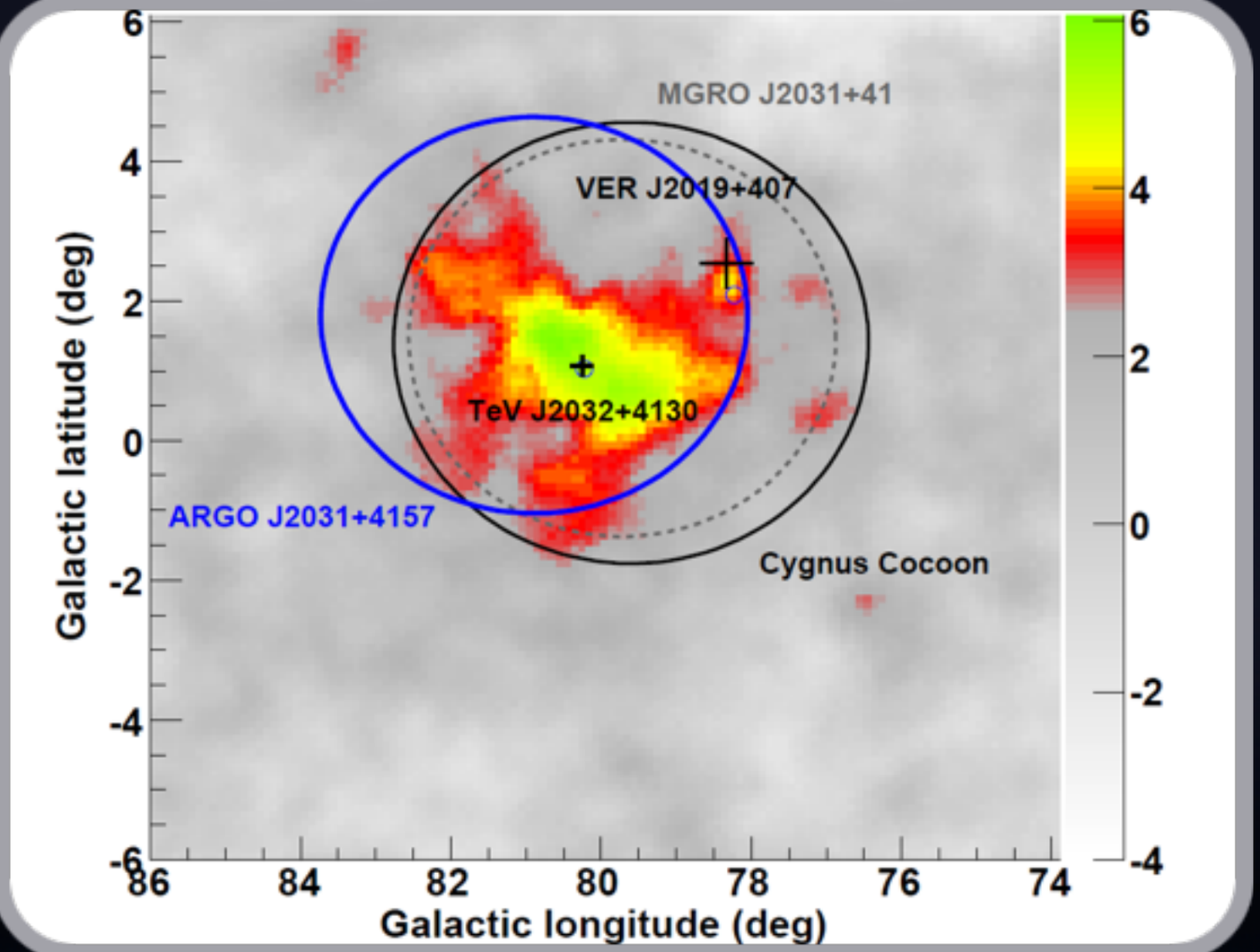
ARGO Collaboration, Astrophysical Journal Letters **745** (2012) L22

Science **334** (2011) 1103

The Cygnus Region



Fermi-LAT in the
10-100 GeV band



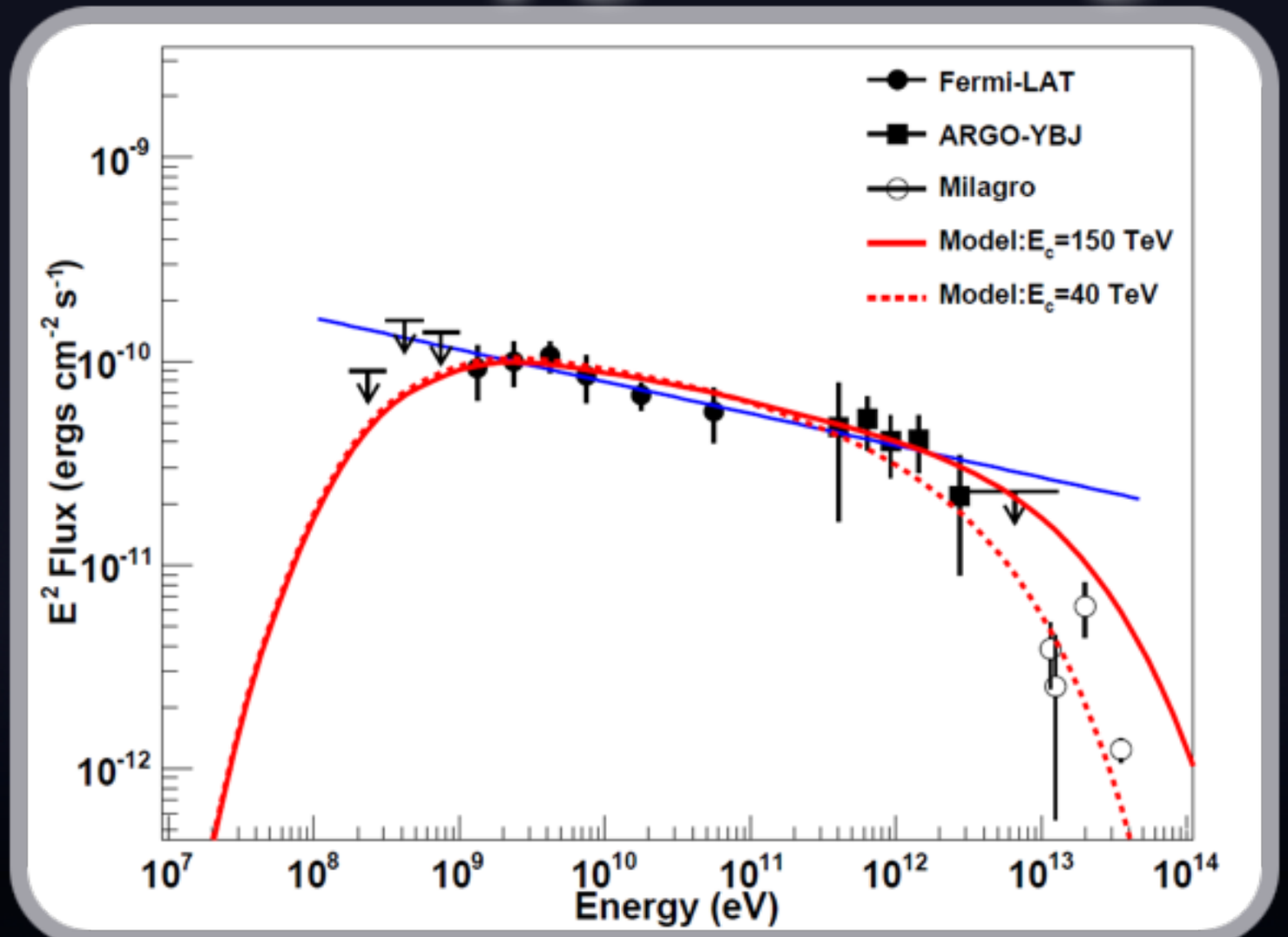
ARGO-YBJ at TeV energies

ARGO J2031+4157 consistent with the Cygnus Cocoon

ARGO Collaboration, The Astrophysical Journal **790** (2014) 152

The Cygnus Region

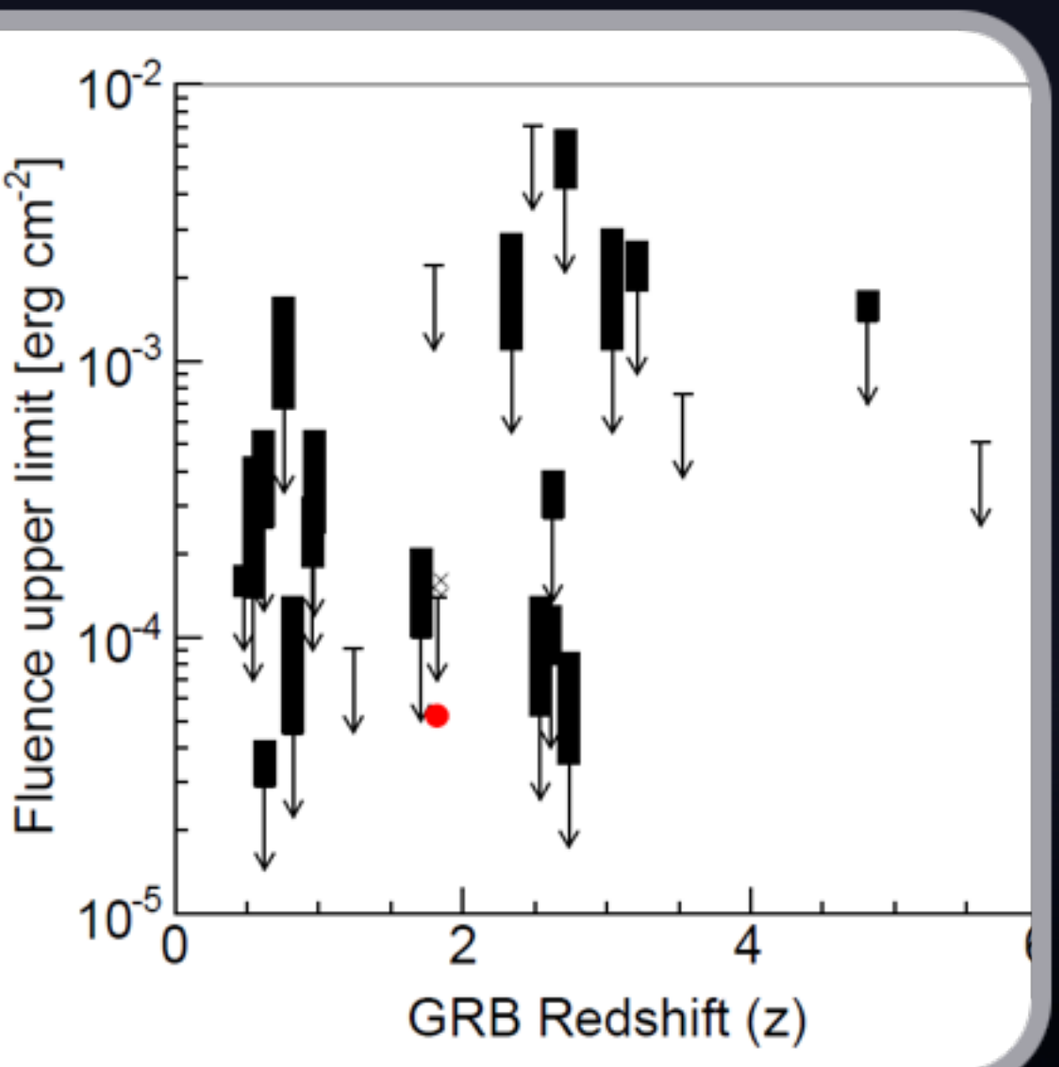
A pure hadronic model was assumed with a power law and a cutoff energy



Flux upper limits indicate a change of slope (~1 GeV) and a cutoff (~10 TeV)

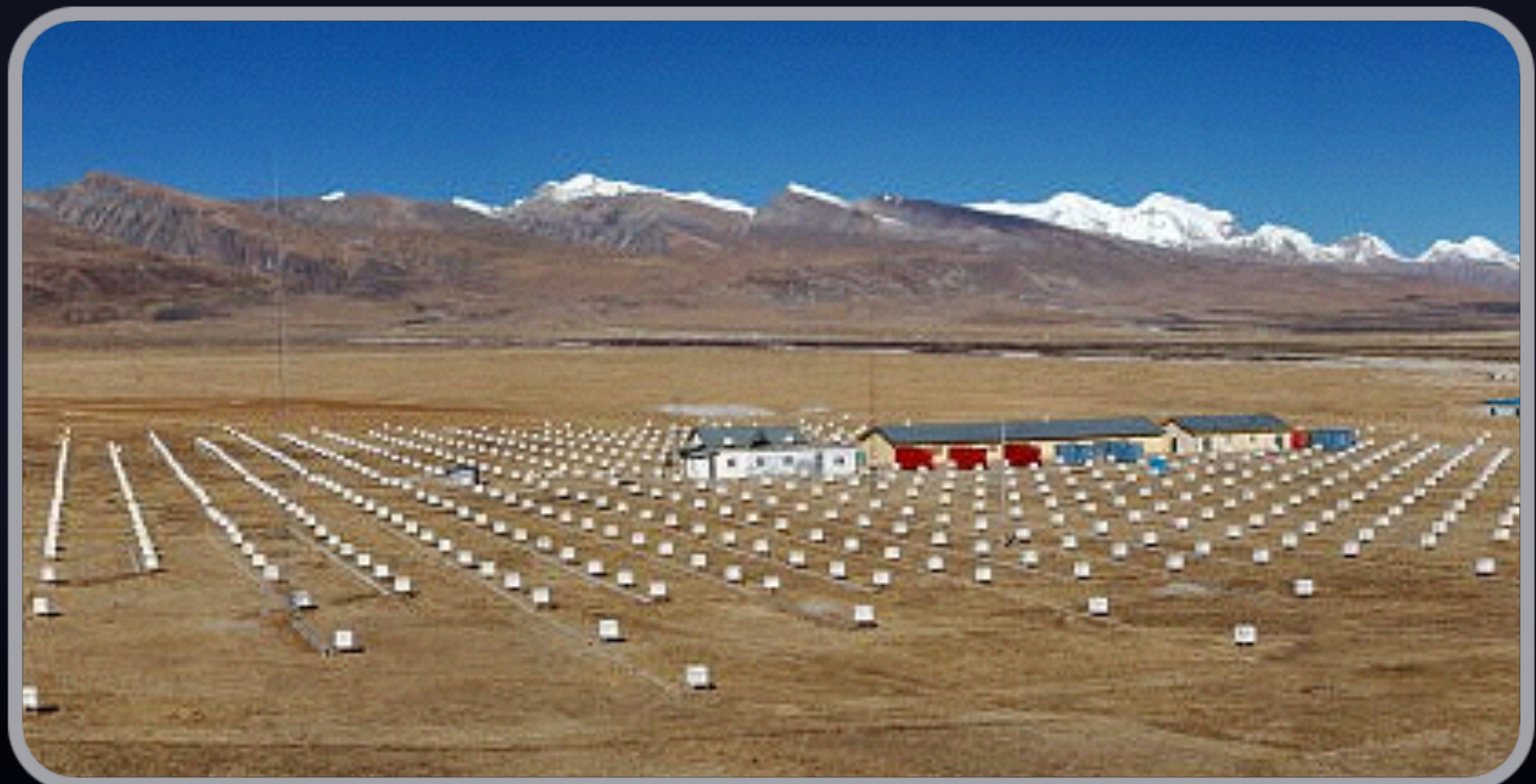
ARGO Collaboration, The Astrophysical Journal **790** (2014) 152

ARGO Summary



- TeV survey of the Northern sky
- Crab Nebula spectrum
- Monitoring of flaring sources
- The Cygnus Region
- Galactic diffuse gamma-rays
- Upper limits to GRBs

Tibet AS-γ

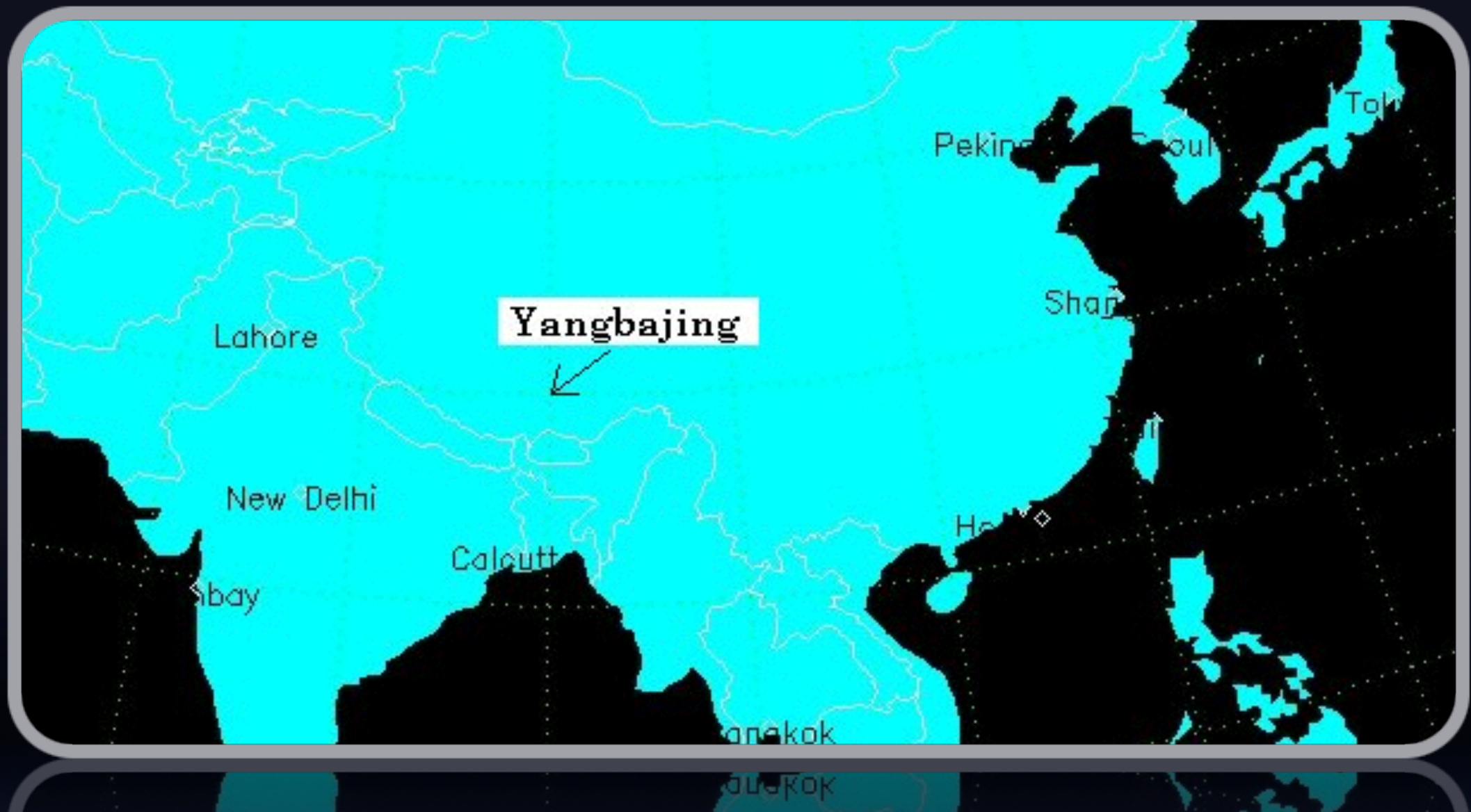


Collaboration between:

- Minister of Education, Science, Sports, and Culture, Japan
- Chinese Academy of Science (CAS), China

Materials from http://www.icrr.u-tokyo.ac.jp/em/index.html

Tibet AS-γ



Site:

- YangBaJing Cosmic Ray Lab., Tibet, China
- 4,300 m a.s.l.

Tibet AS-γ

- plate of plastic scintillator
  0.5 m^2 area and 3 cm thickness
- 697 scintillation counters with
  7.5 m spacing
- 36 scintillation counters with
  15 m spacing

Tibet AS-γ

- burst detectors and emulsion chambers (80 m^2)
- plastic scintillator with 4 photodiodes
- 6 layers of emulsion chambers

measure the proton component around the *"knee"*

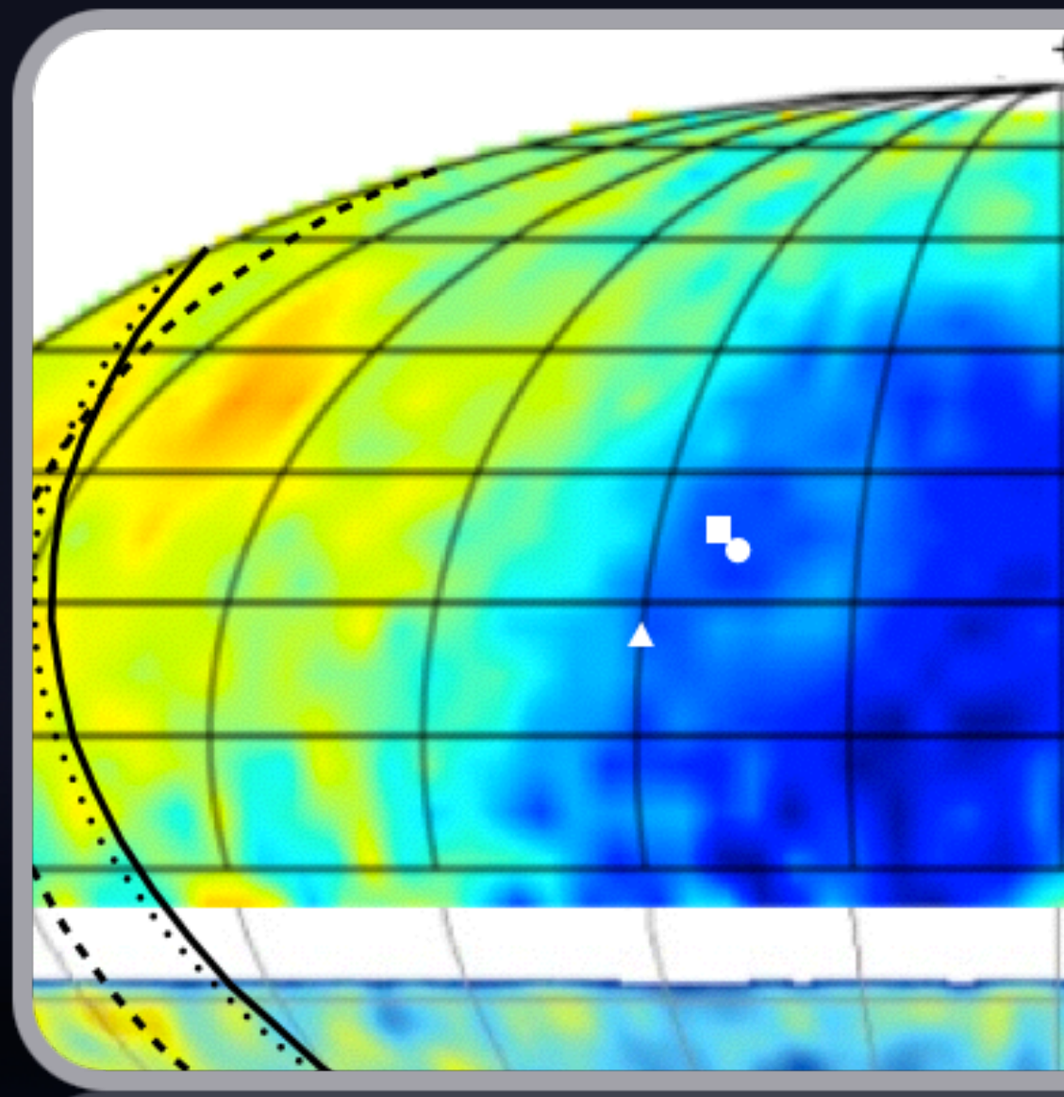
Tibet AS-γ

- solar neutron telescope (9 m^2)
- plastic scintillator plates with PMTs, surrounded by proportional tubes

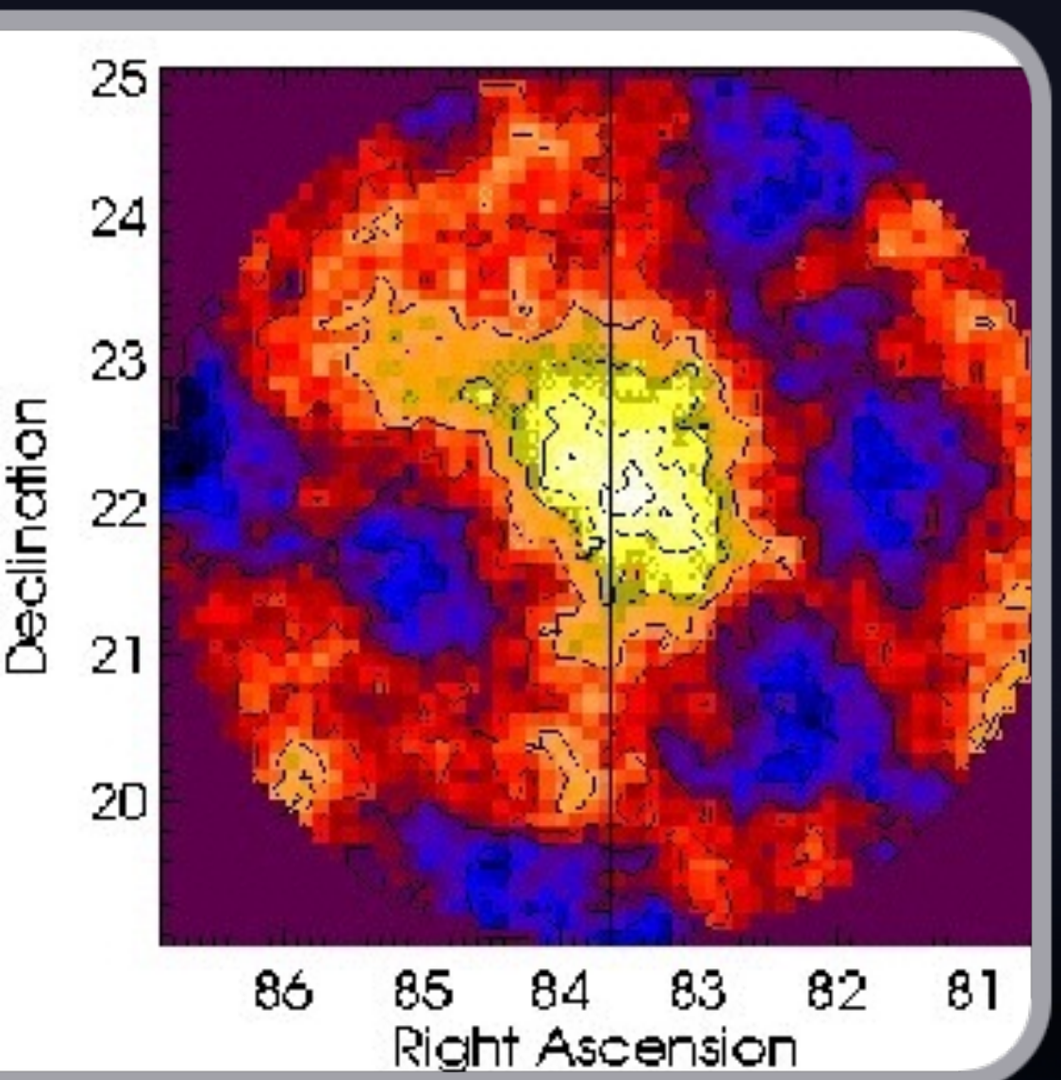
detecting high-energy neutrons from solar flares

Tibet AS-γ Results

- Crab Nebula
- Mrk 501 & 421 + flares
- Cosmic rays from the knee

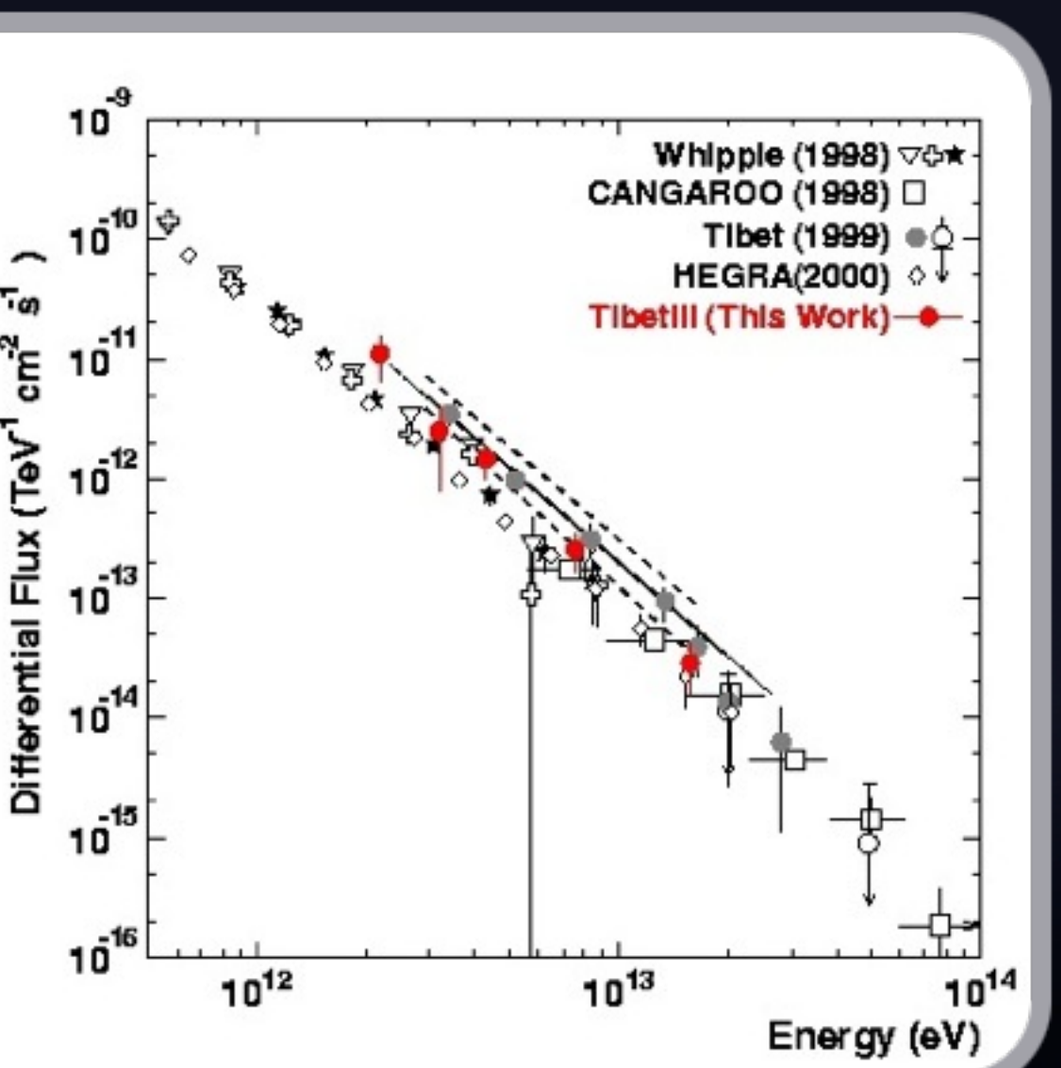


The Crab



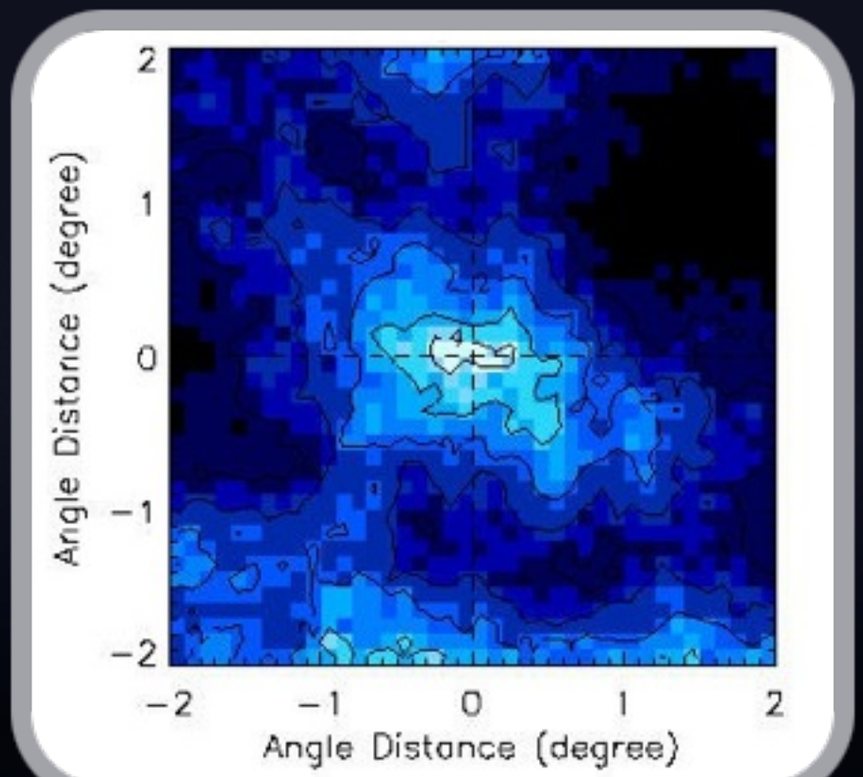
- excess events in 1 sigma steps

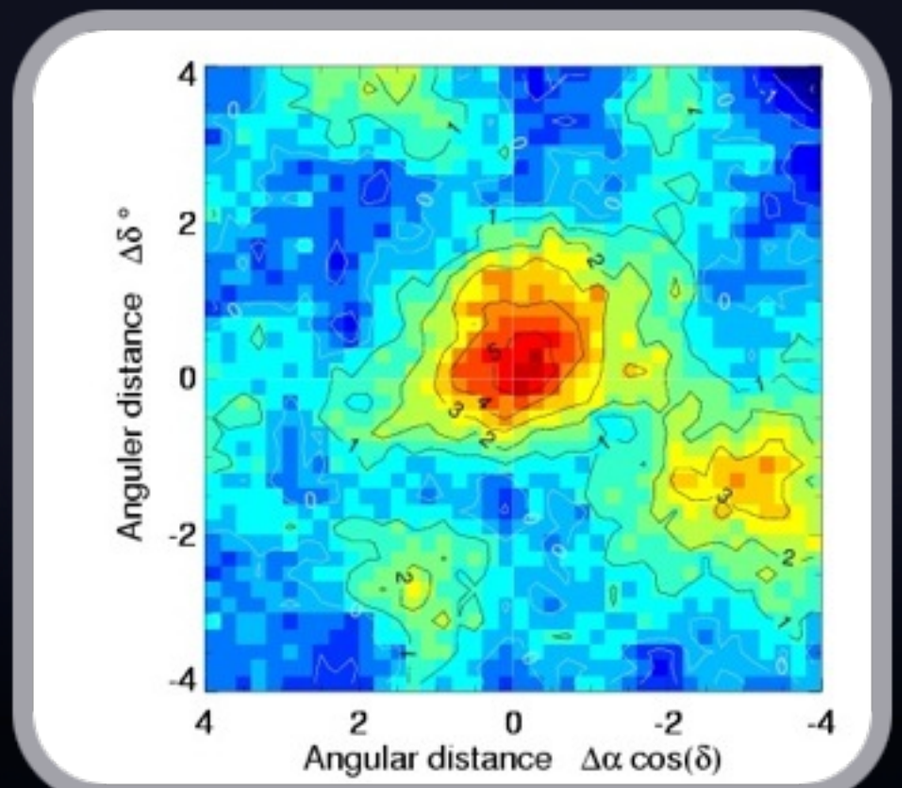
The Crab

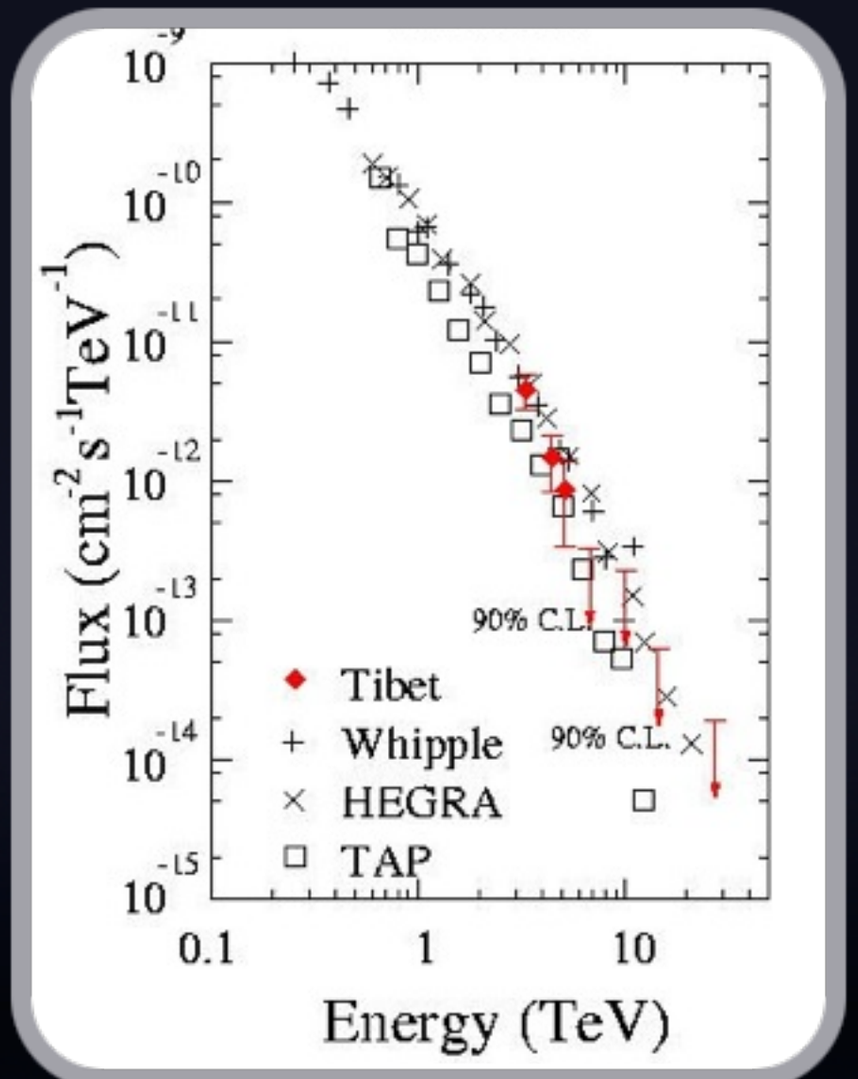


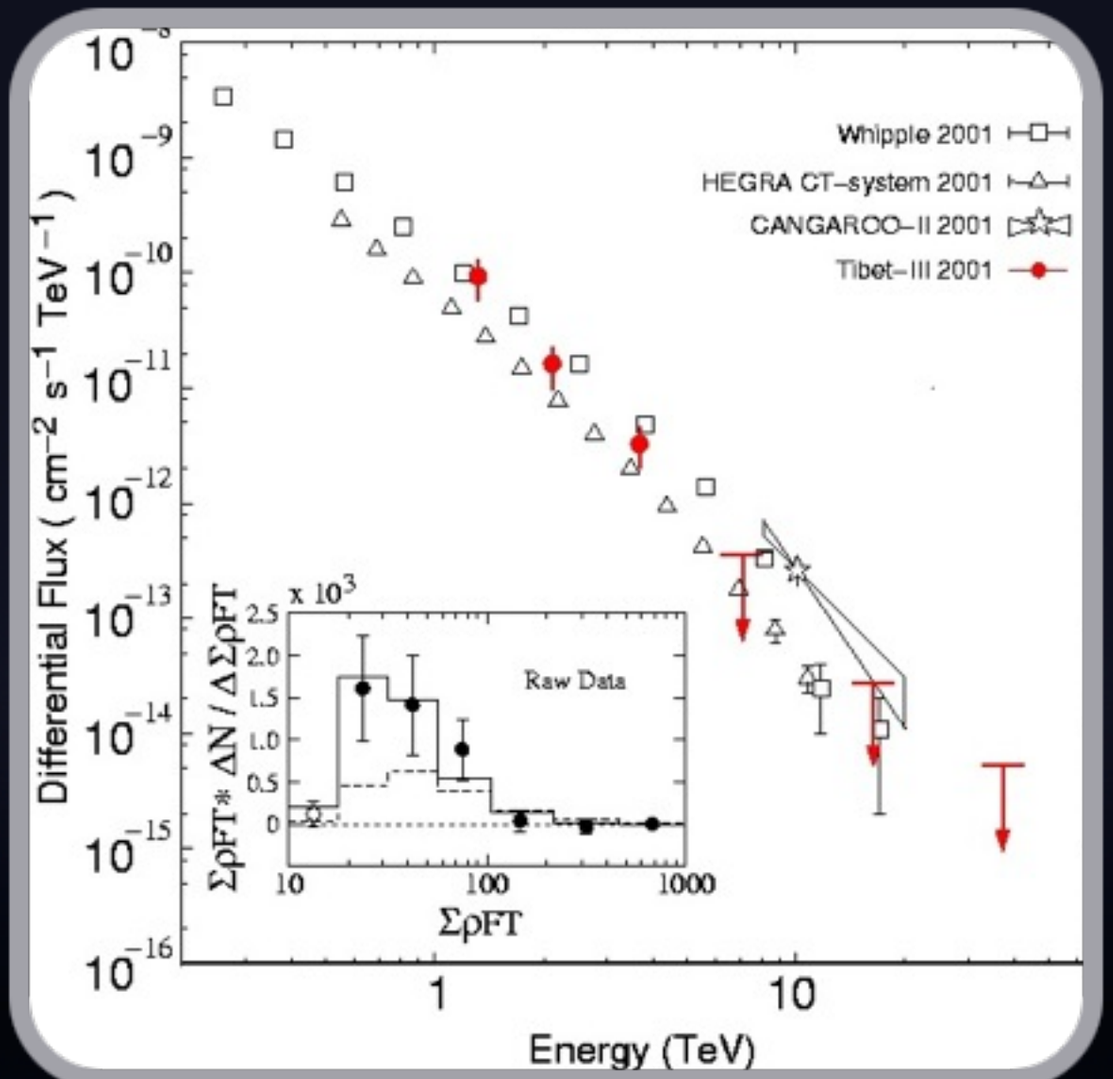
- excess events in 1 sigma steps
- spectrum in agreement with other experiments

Mrk 501 & 421


Angle Distance (degree)
Angle Distance (degree)
2
1
0
−1
−2
−2
−1
0
1
2


Anguler distance Δδ°
Angular distance Δα cos(δ)
4
2
0
-2
-4
4
2
0
-2
-4

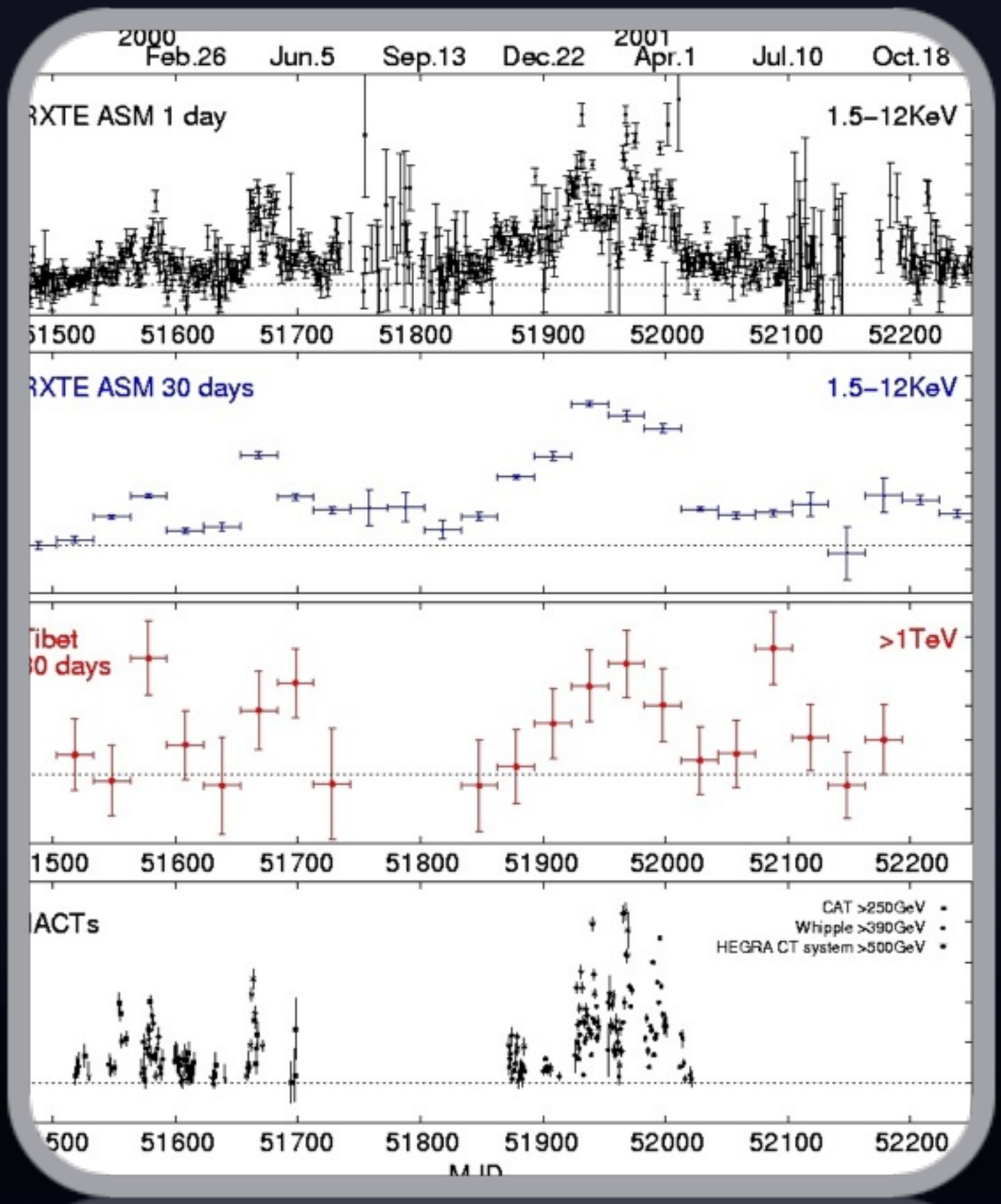

Flux (cm^{-2}s^{-1}TeV^{-1})
Energy (TeV)
Tibet
Whipple
HEGRA
TAP
90% C.L.
90% C.L.


Differential Flux (cm^{-2} s^{-1} TeV^{-1})
Energy (TeV)
Whipple 2001
HEGRA CT–system 2001
CANGAROO–II 2001
Tibet–III 2001
Raw Data
ΣρFT
ΣρFT* ΔN / ΔΣρFT
x 10^3

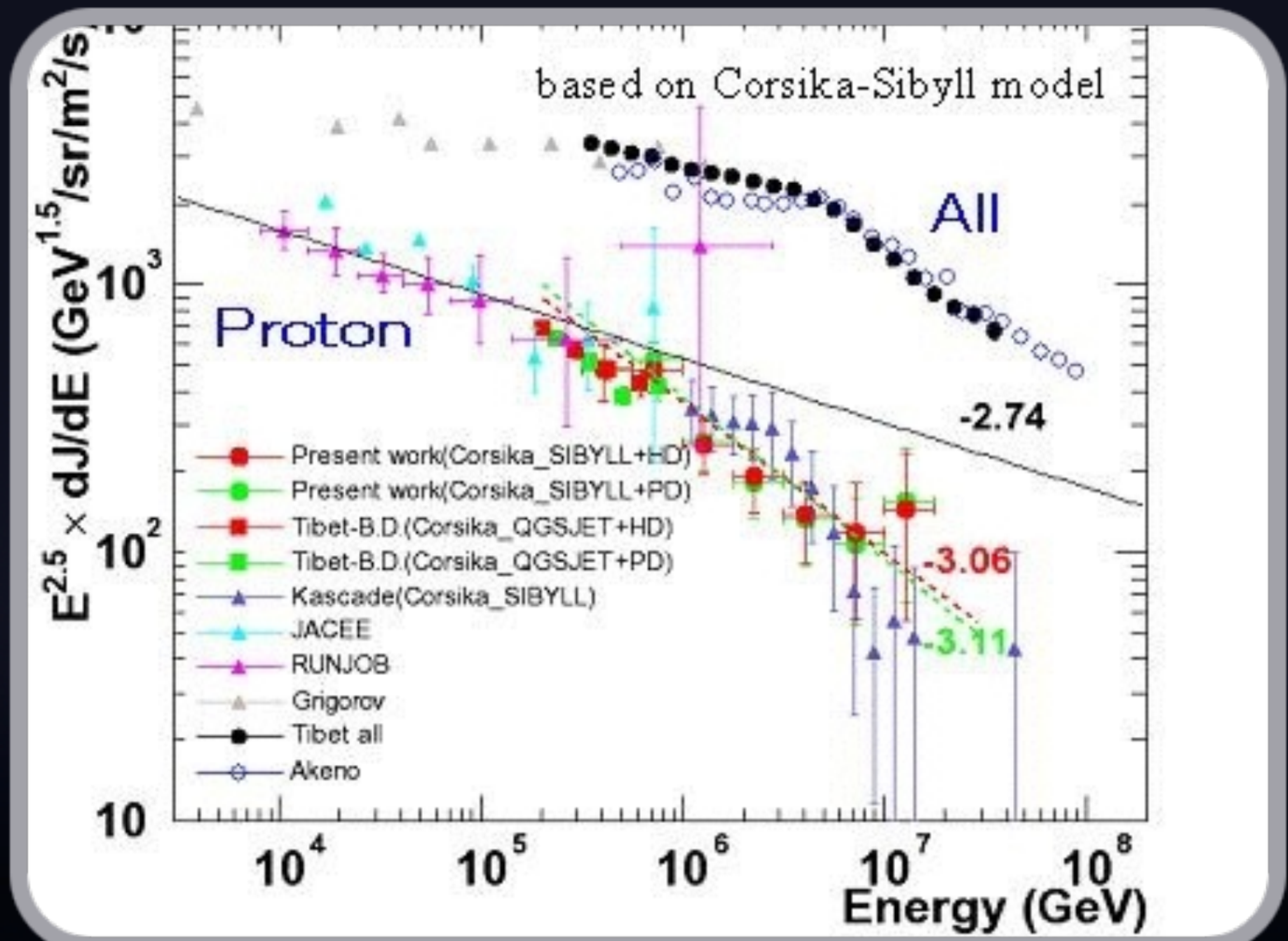
Mrk 501 & 421

Mrk 421

- Time profile 31-day moving average for Tibet
- Correlation with RXTE and IACTs

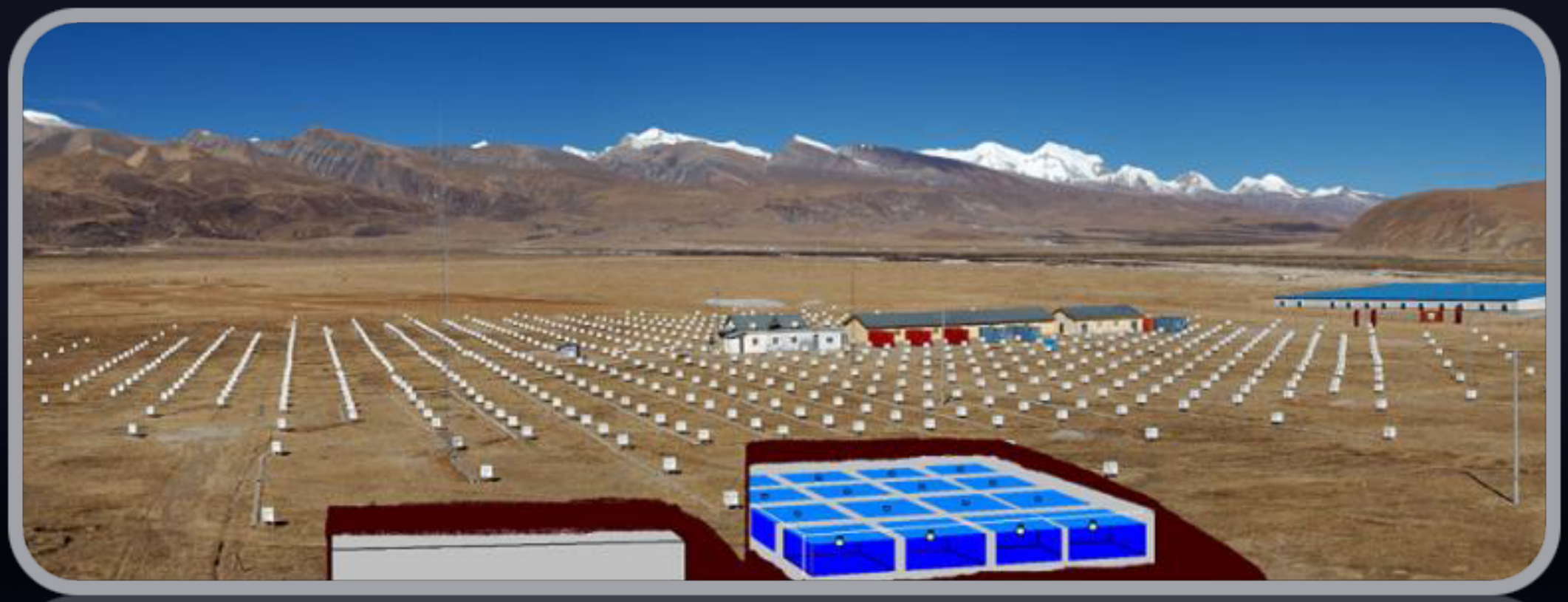


energy spectrum of primary cosmic rays in the *"knee"* region



Composition

Outlook



2013: a low threshold burst-detector-grid (~500 m^2), the Tibet air-shower array (~50,000 m^2), and a large underground water Cherenkov muon detector array (~4,500 m^2). Data taking started in February, 2014.

HAWC

Collaboration between:

- Consejo Nacional de Ciencia y Tecnología, Mexico
- Dept. of Energy and the National Science Foundation, U.S.

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

HAWC tanks

Auger tank

HAWC bladders

HAWC components

We will reuse from Milagro:

- 900 encapsulated PMTs
- Front-end electronics
- Water filtration system
- Technical expertise & experience

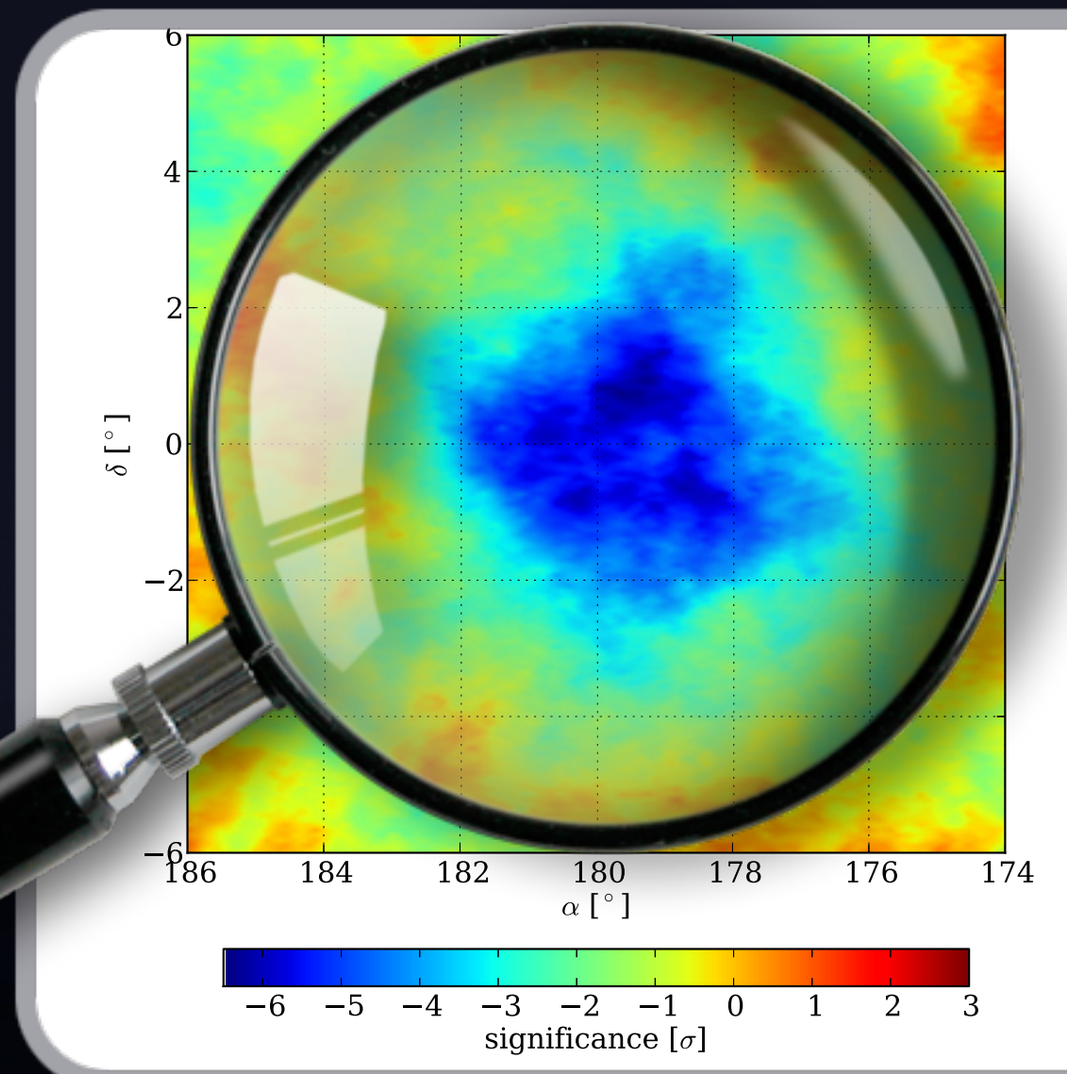
Off-the-shelf components:

- VME TDCs, trigger, scalers, HV
- 300 10” HE PMTs

HAWC Calibration

New dedicated **laser** system

- Timing calibration
- Charge calibration



HAWC site


UNEP
Jalapa
Veracruz
Tlaxcala
Tlaxcala
de Mexico (Mexico City)
Distrito Federal
Veracruz
HAWC Site
Puebla, PU, Mexico
Puebla
Cuernavaca

HAWC site

Status at the site

February 2011

Status at the site

February 2012

Status at the site

September 2012

Status at the site

January 2013

Status at the site

May 2013

Status at the site

December 2013

Status at the site

March 2014

Status at the site

May 2014

Status at the site

August 2014

HAWC-30, -77, -95, -111 Results

BBC

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15 April 2013 Last updated at 01:22 ET

Hawc gamma-ray telescope captures its first image

By Jason Palmer
BBC News, Denver

México, Martes, 16 de abril de 2013 a las 09:36

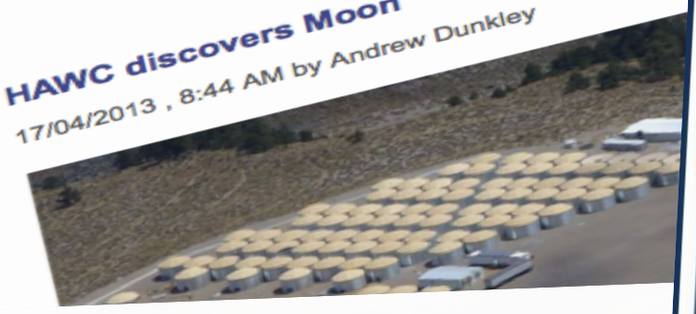
HAWC, el mejor detector de rayos gamma en el mundo, realiza sus primeras observaciones

Ubicado en las faldas del Volcán Sierra Negra en el Parque Nacional Pico de Orizaba, HAWC monitoreará las 24 horas del día fuentes celestes emisoras de rayos gamma

6:00am - 6:40am
6:55am - 7:45am

HAWC discovers Moon

17/04/2013 , 8:44 AM by Andrew Dunkley



Tendencias

30 ◦ Miércoles 17 de abril de 2013 ◦ jalisco.milenio.com

Integró la primera imagen de la sombra de la Luna

MILENIO

México estrena el mejor detector de rayos gamma

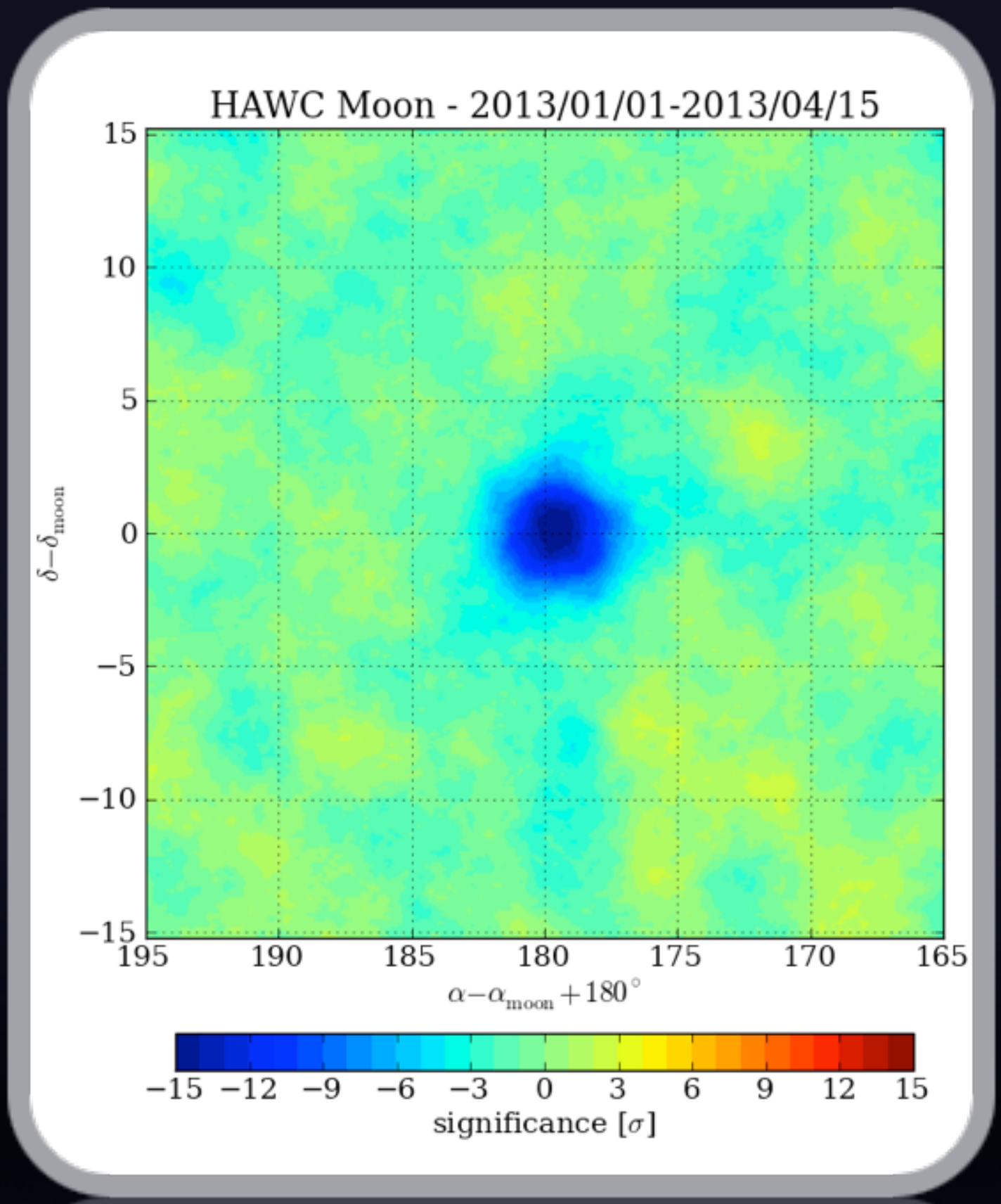
CIENCIA

Registran sombra de la luna en observatorio de rayos gamma

e-consulta Lunes 15 Abril 2013 - 19 : 16

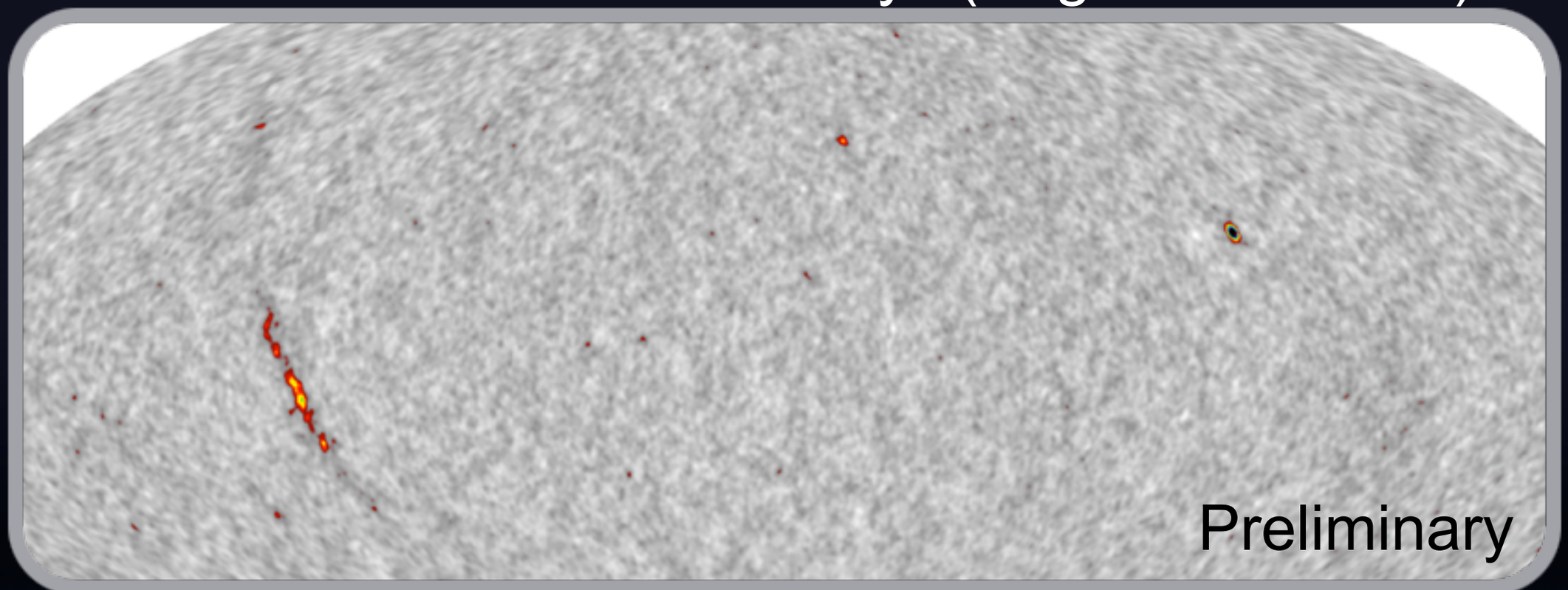
First Results

Moon Shadow



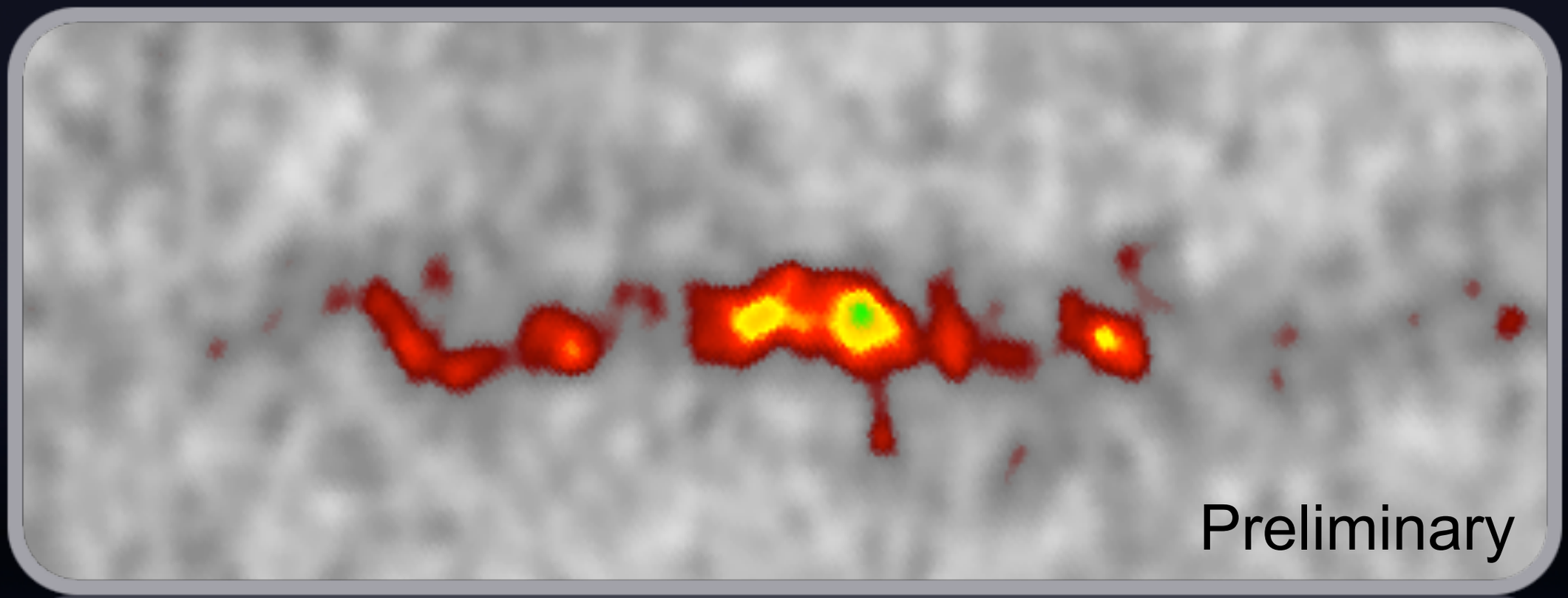
Bright Sources List

HAWC-95/111 data - 260 days (Aug ’13 - Jun ’14)



“On the discovery of **new sources** of Very High Energies Gamma-Rays with the HAWC Observatory”

CYGNUS REGION & The Inner Galaxy

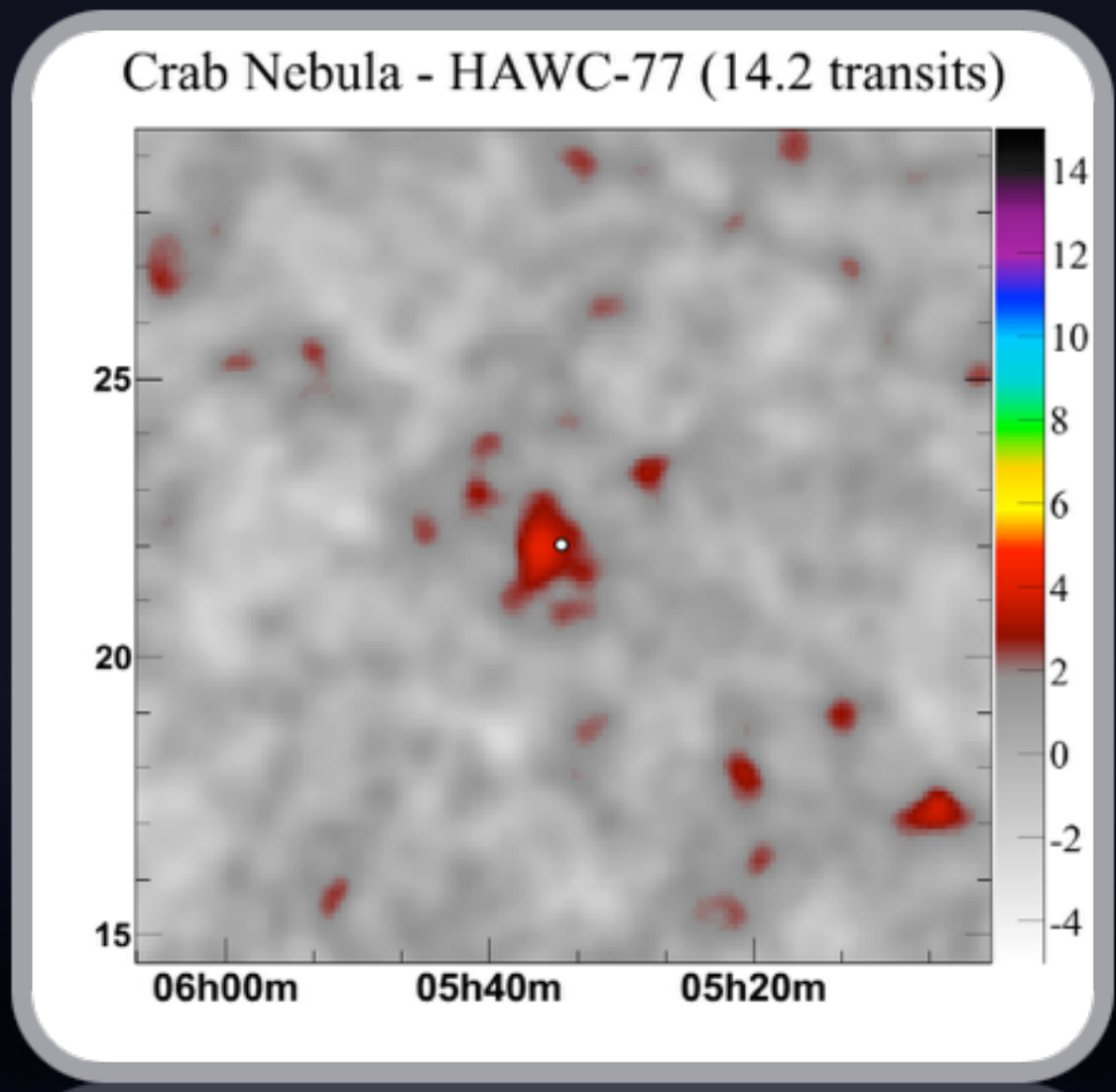


Clear emission from multiple source regions along the Galactic Plane.

Paper in preparation

GALACTIC PHYSICS

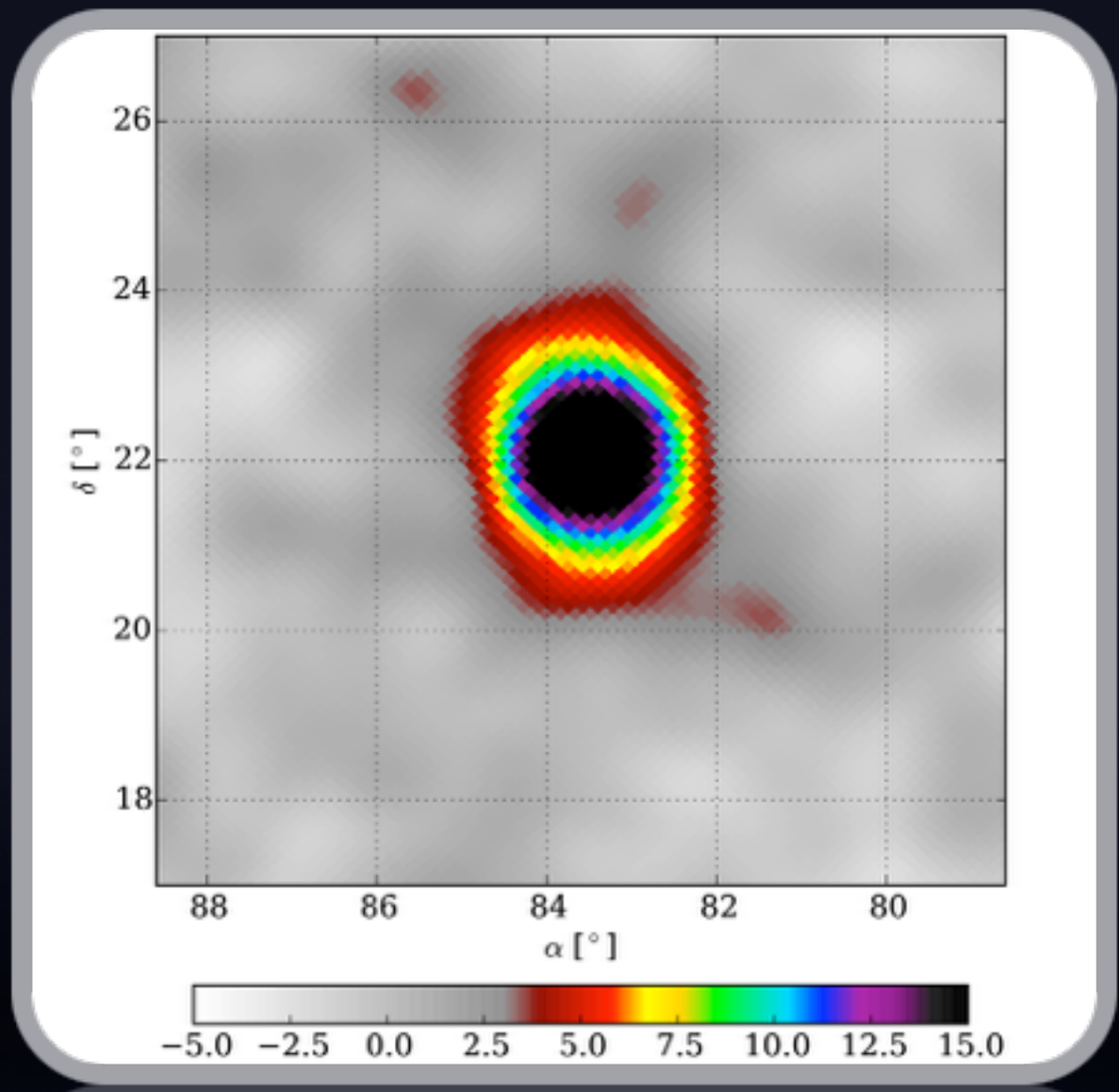
The CRAB



"HAWC Observations of the **Crab Nebula** During the March 2013 Flare"

GALACTIC PHYSICS

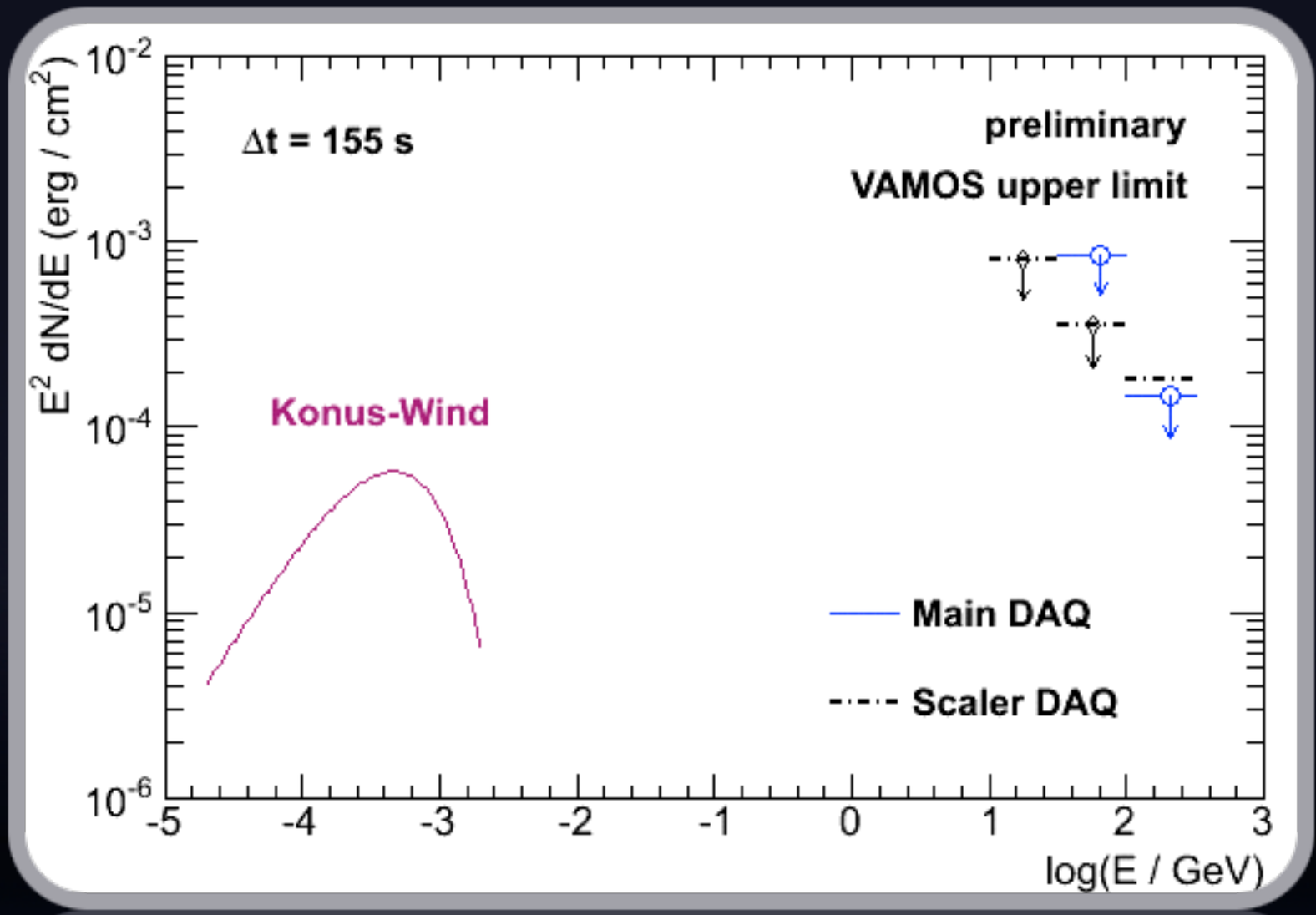
The CRAB



*Current **Crab** paper in preparation!*

EXTRAGALACTIC PHYSICS

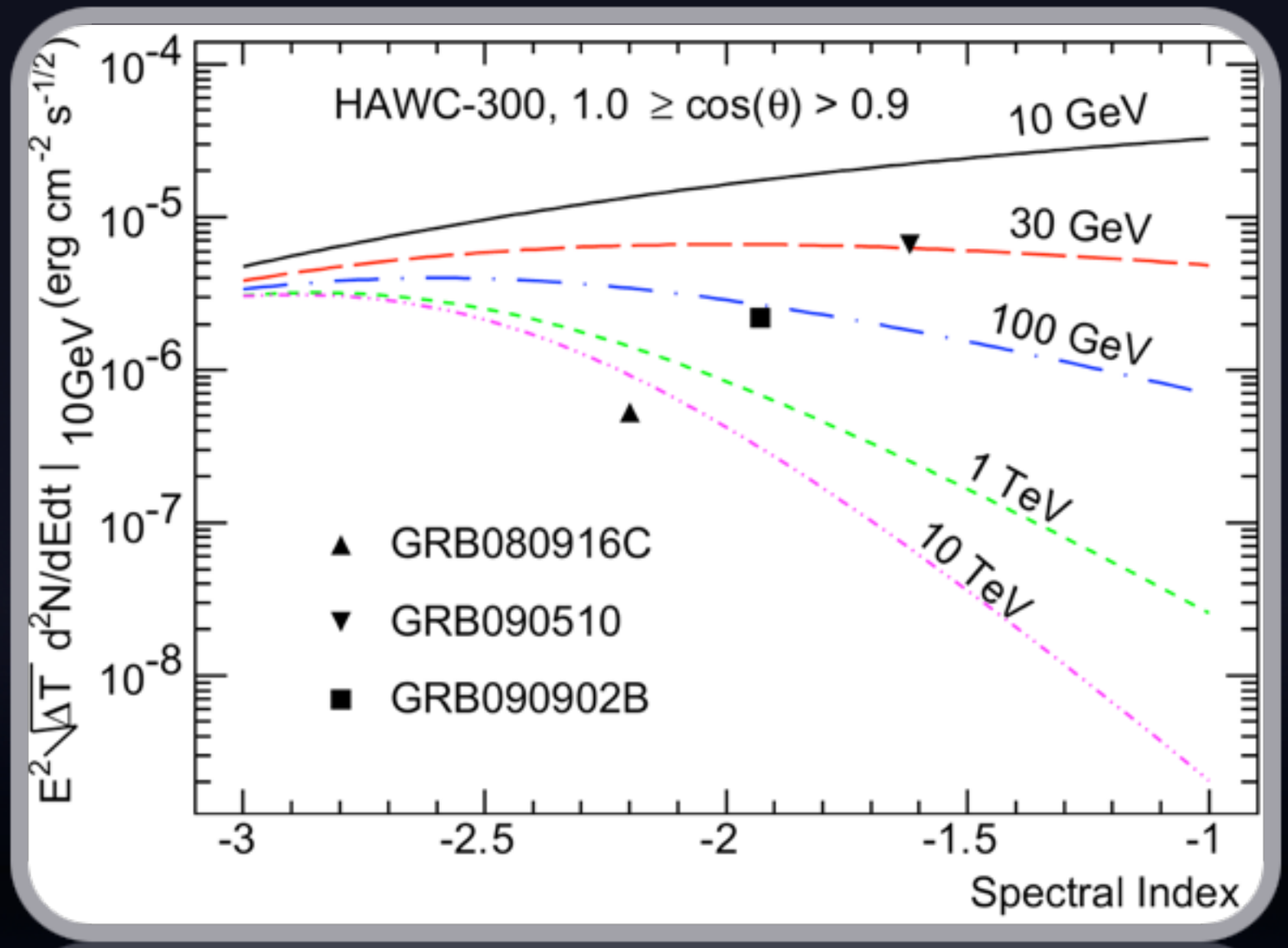
First GRB results



"Search for high energy **emission from GRBs** with the HAWC Observatory"

EXTRAGALACTIC PHYSICS

GRBs w/scalers

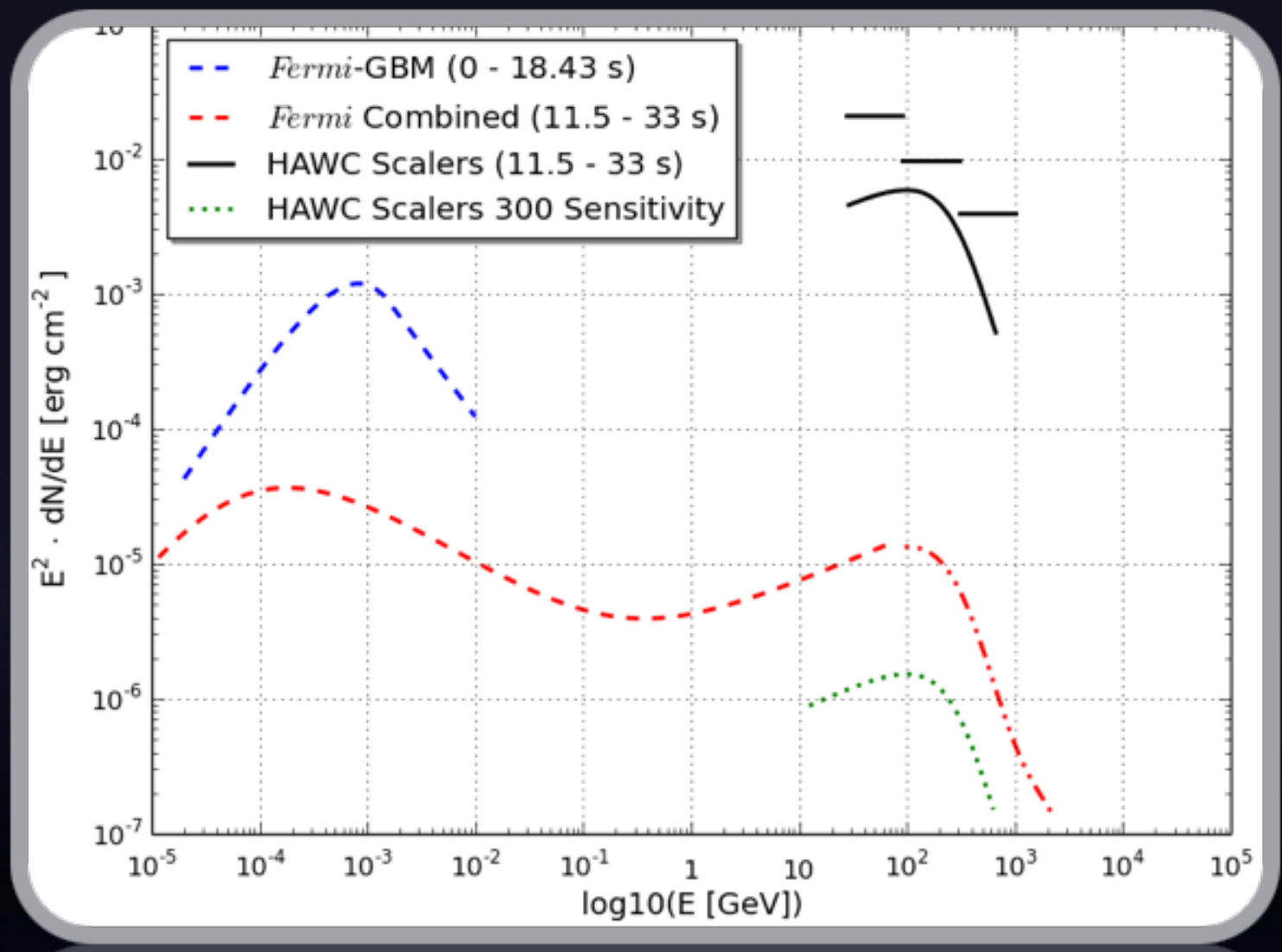


"Sensitivity of the HAWC Observatory to **GRBs** Using the **Scaler System**"

HAWC Collaboration, The Astrophysical Journal **35** (2012) 641

EXTRAGALACTIC PHYSICS

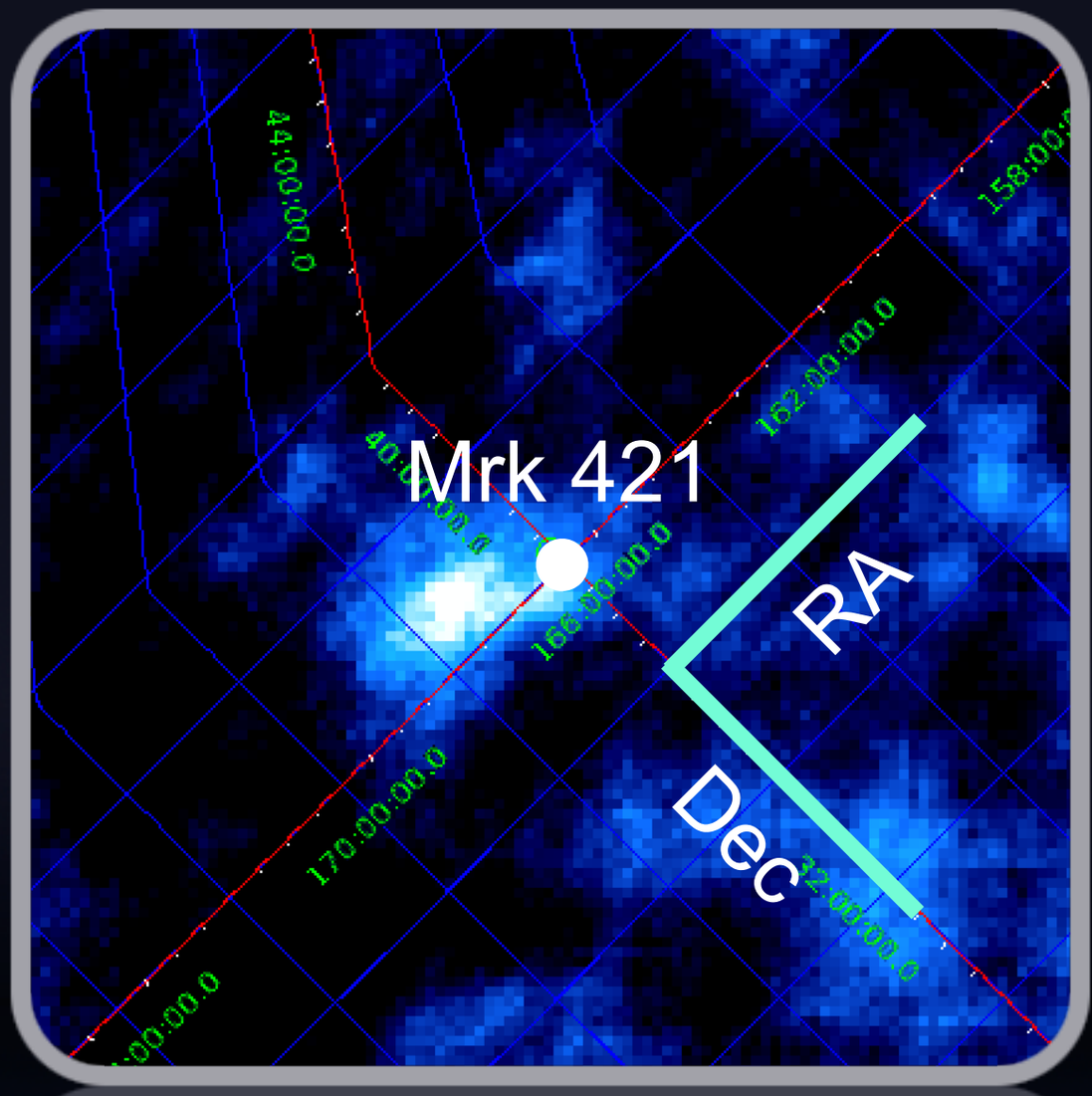
GRBs w/scalers



"Search for gamma-rays from the unusually bright **GRB 130427A** with the HAWC Observatory"

HAWC Collaboration, Submitted to The Astrophysical Journal

Mrk 421 flare

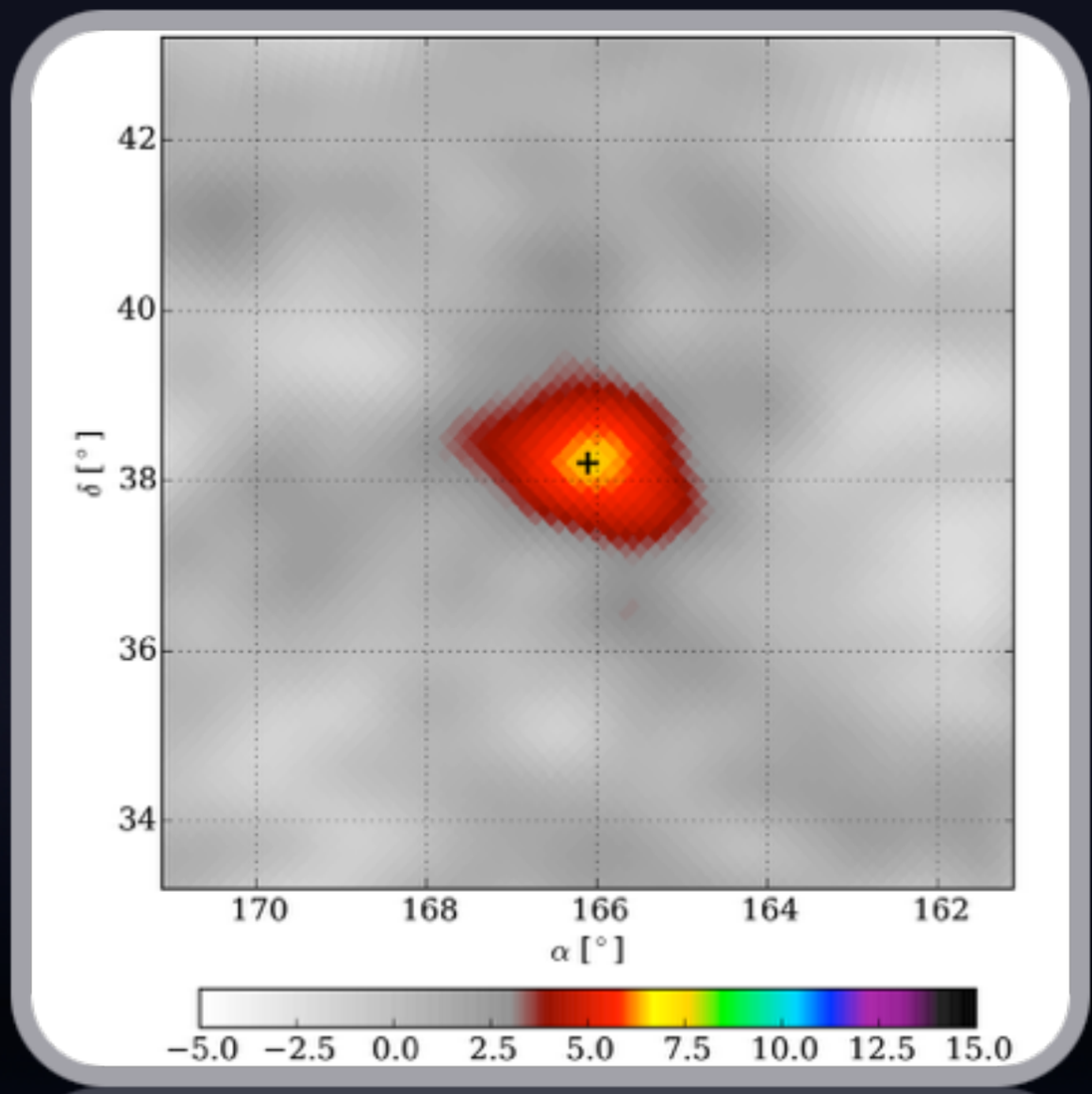


April 14 - 15, 2013

> 3.3 σ

EXTRAGALACTIC PHYSICS

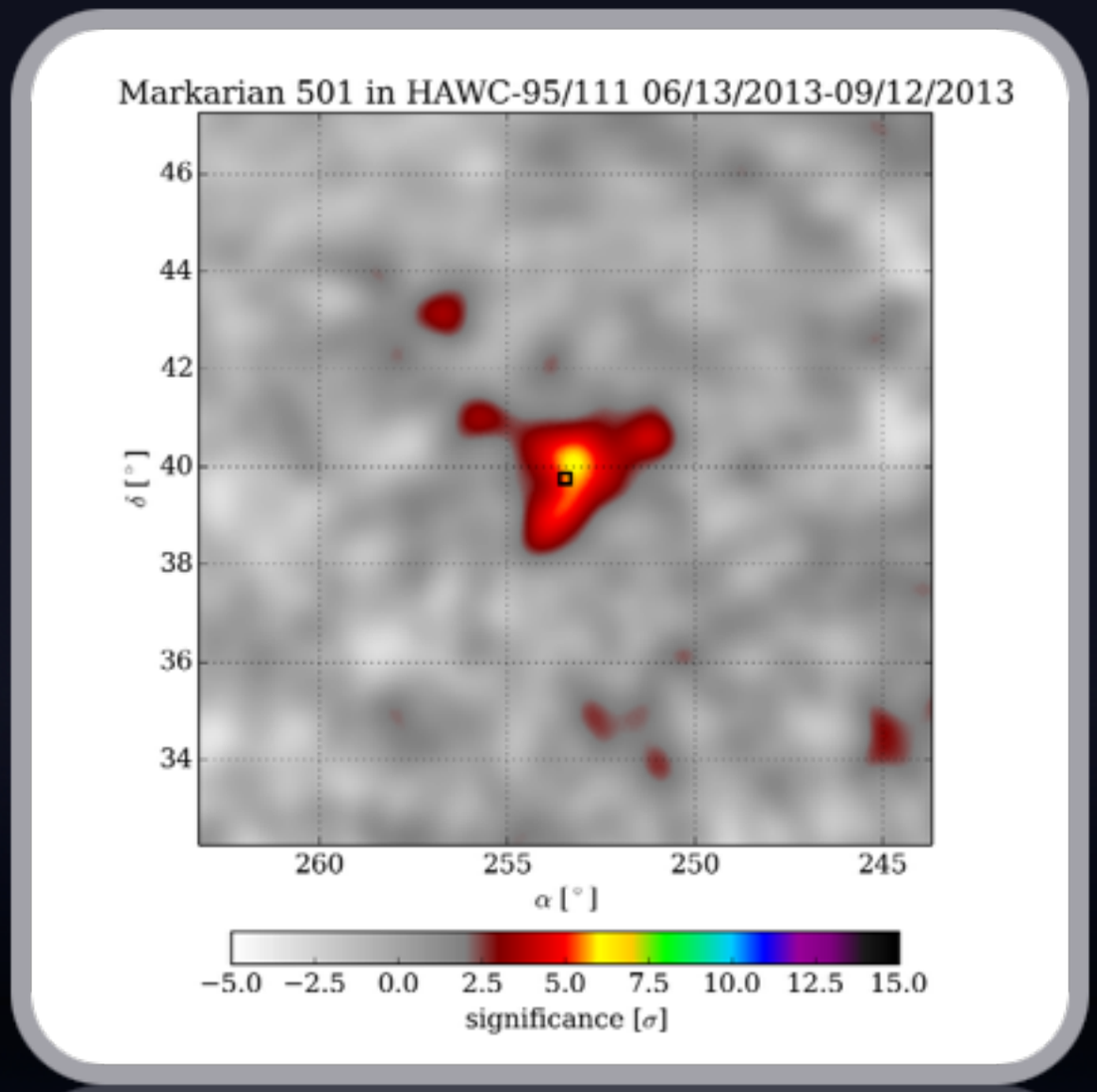
Mrk 421



detected with HAWC-111 at 6.5σ in 260 days

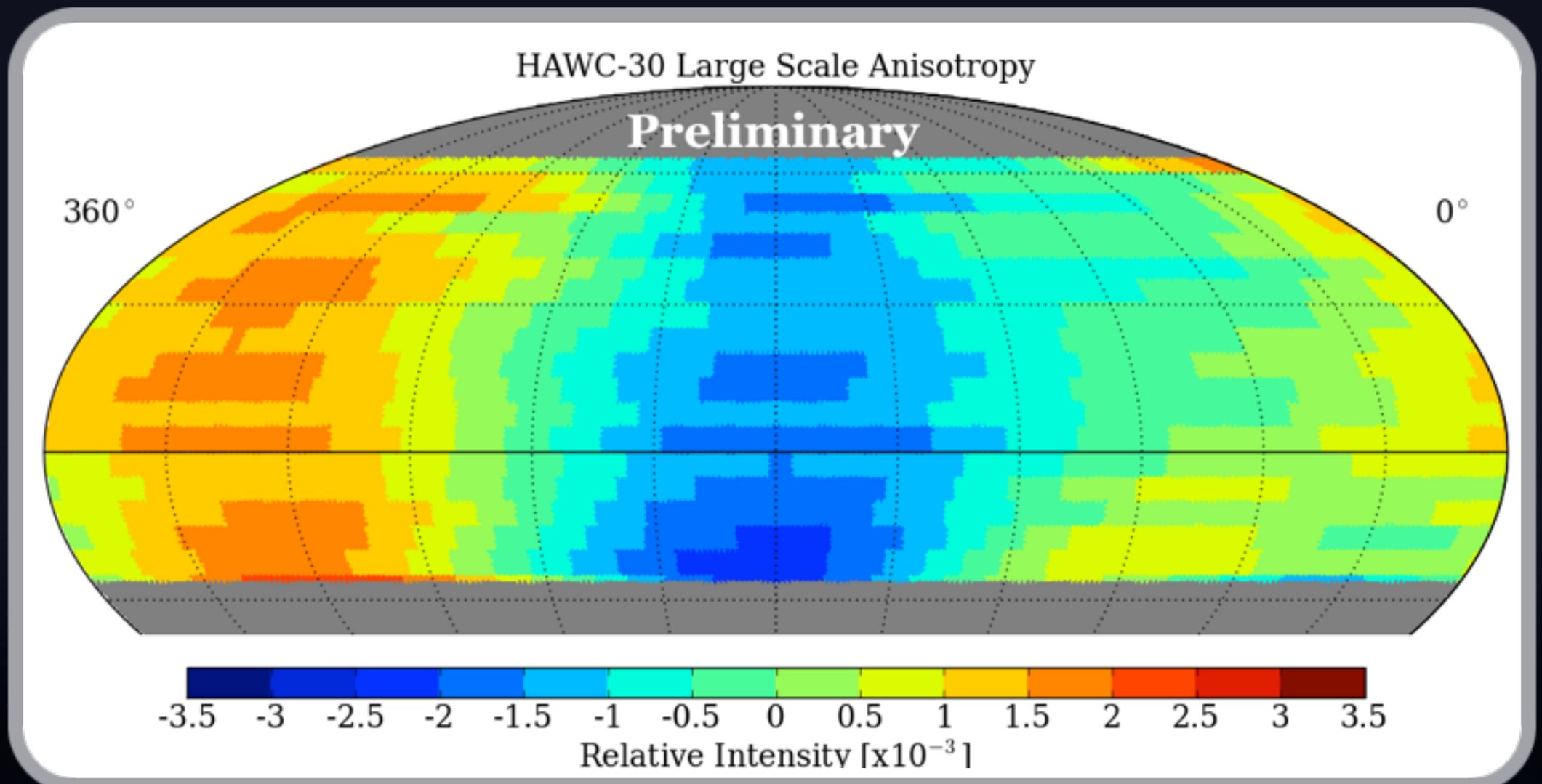
EXTRAGALACTIC PHYSICS

Mrk 501



COSMIC RAY PHYSICS

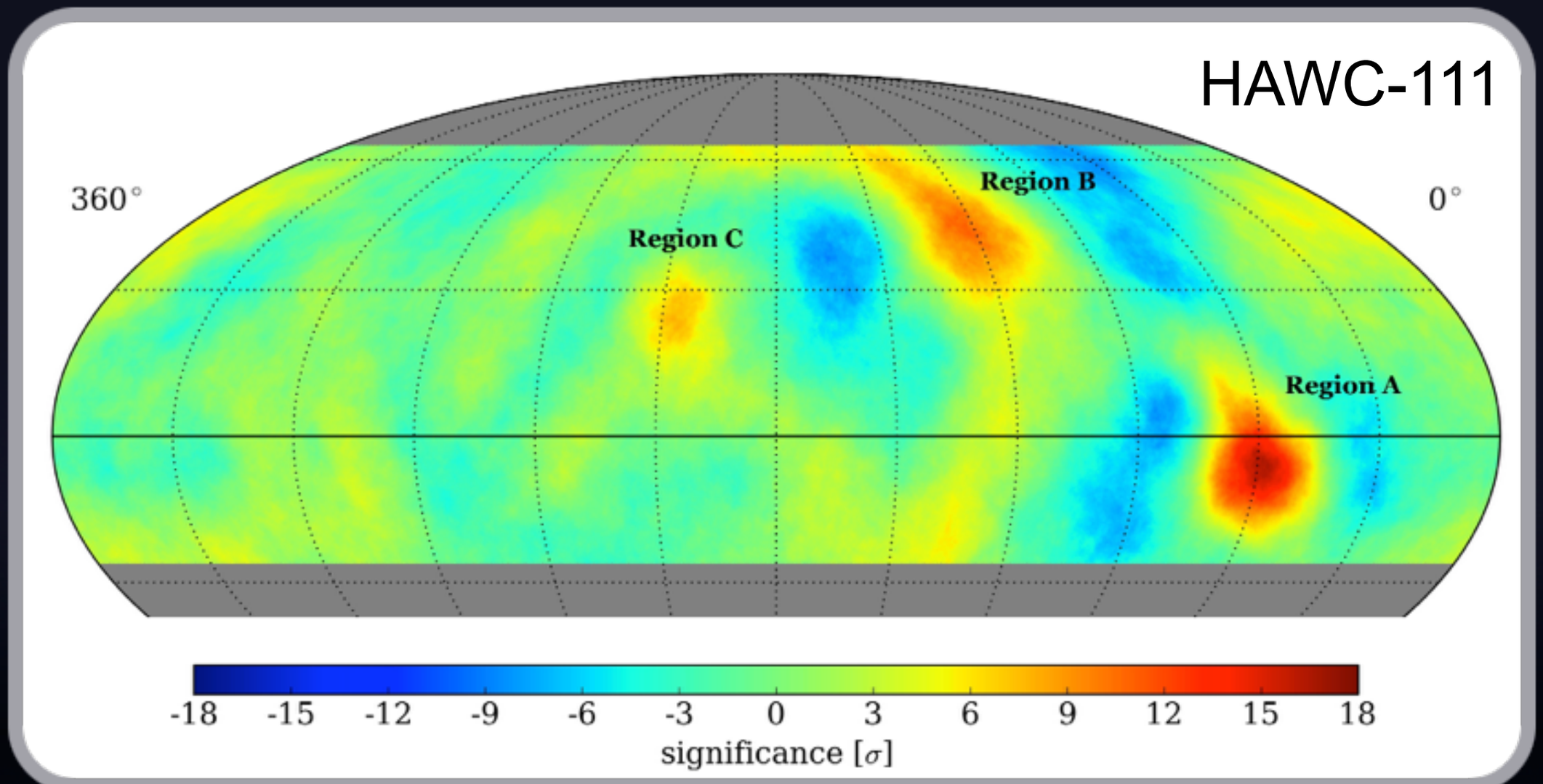
COSMIC RAY ANISOTROPY



"Observation of the **Anisotropy of Cosmic Rays** at the HAWC Observatory"

COSMIC RAY PHYSICS

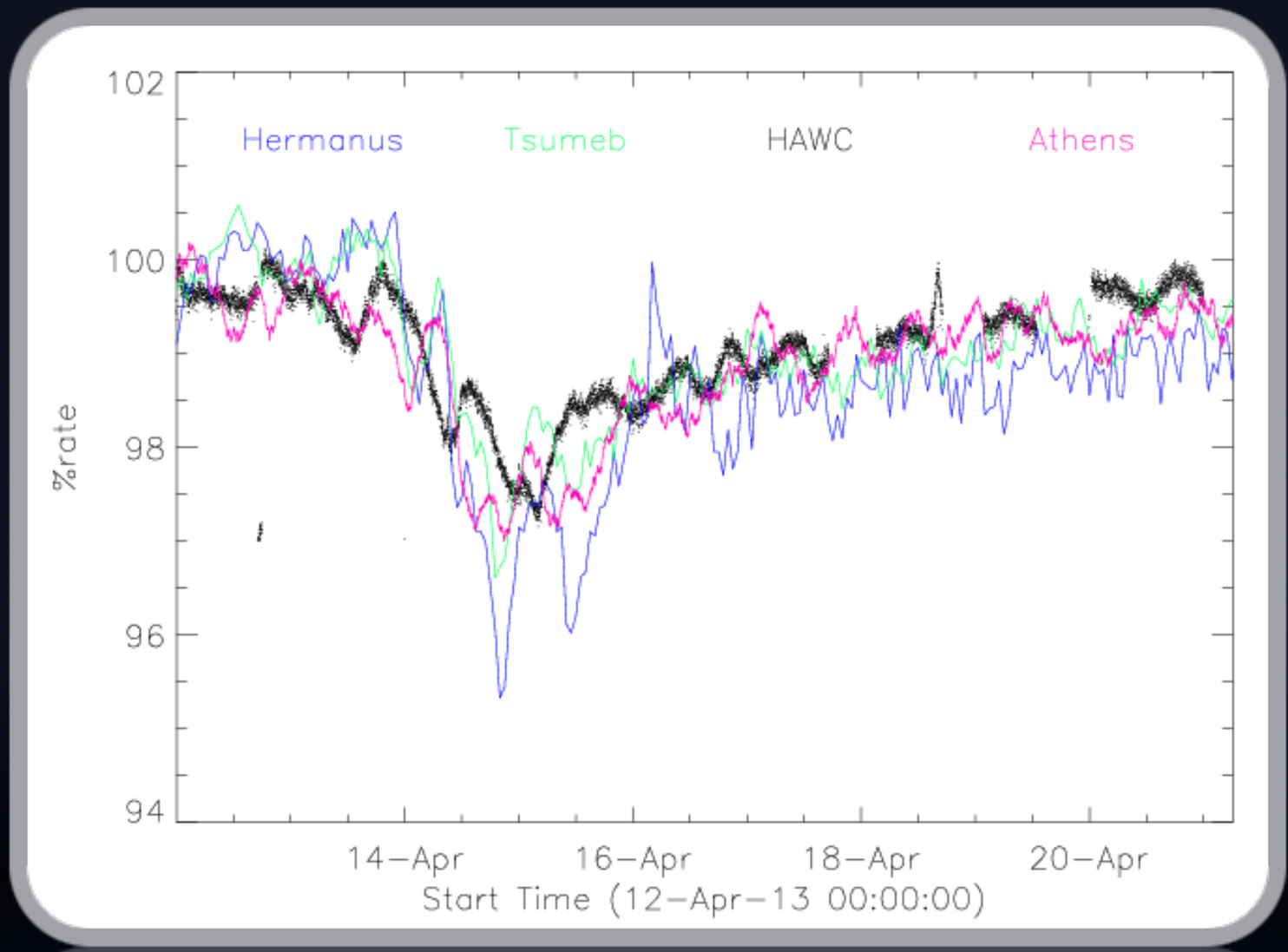
COSMIC RAY ANISOTROPY



HAWC Collaboration, Accepted for publication in The Astrophysical Journal

COSMIC RAY & SOLAR PHYSICS

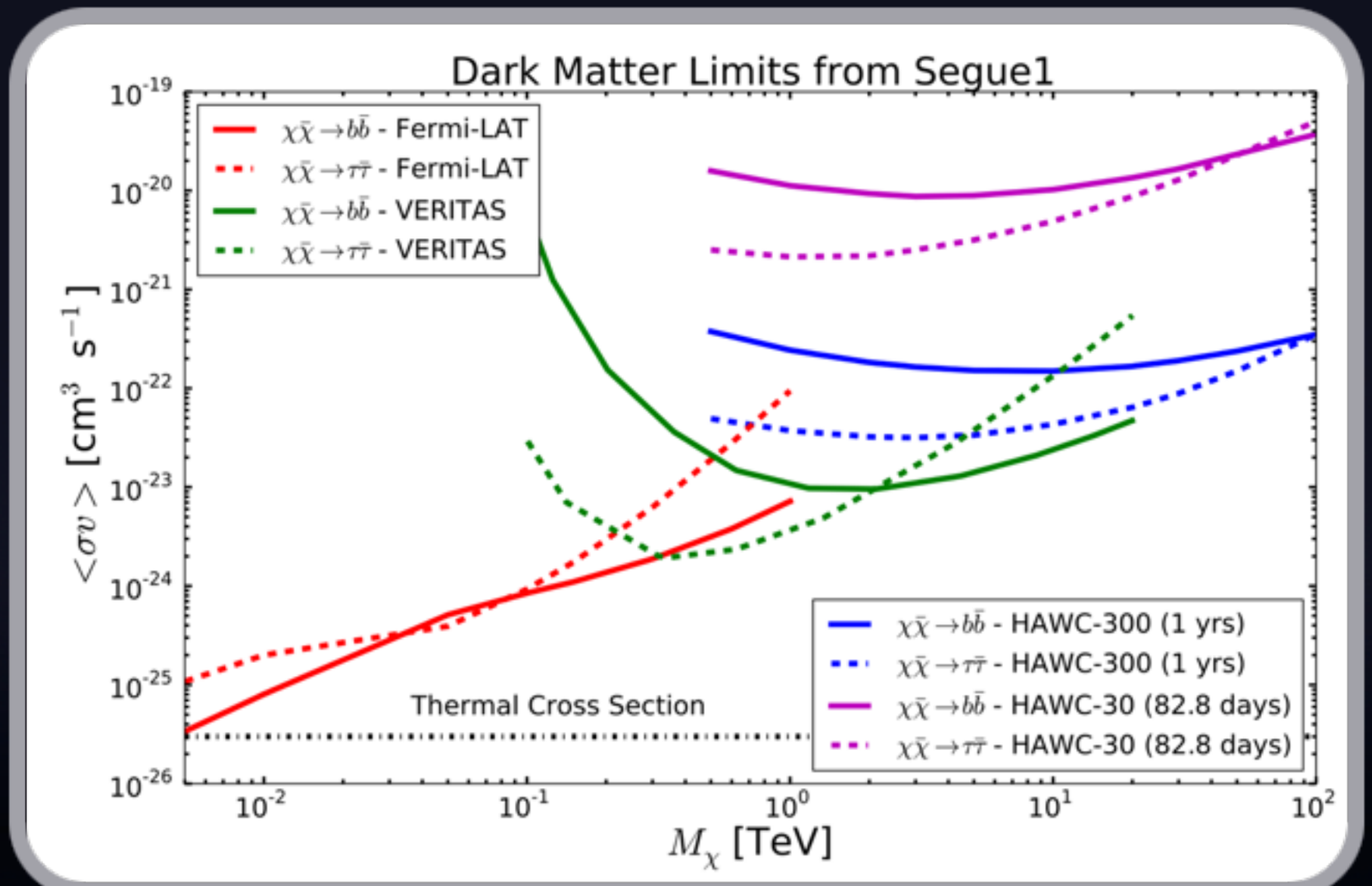
SOLAR EVENTS



"HAWC sensitivity to **Solar events**"

PARTICLE PHYSICS

WIMP Limits

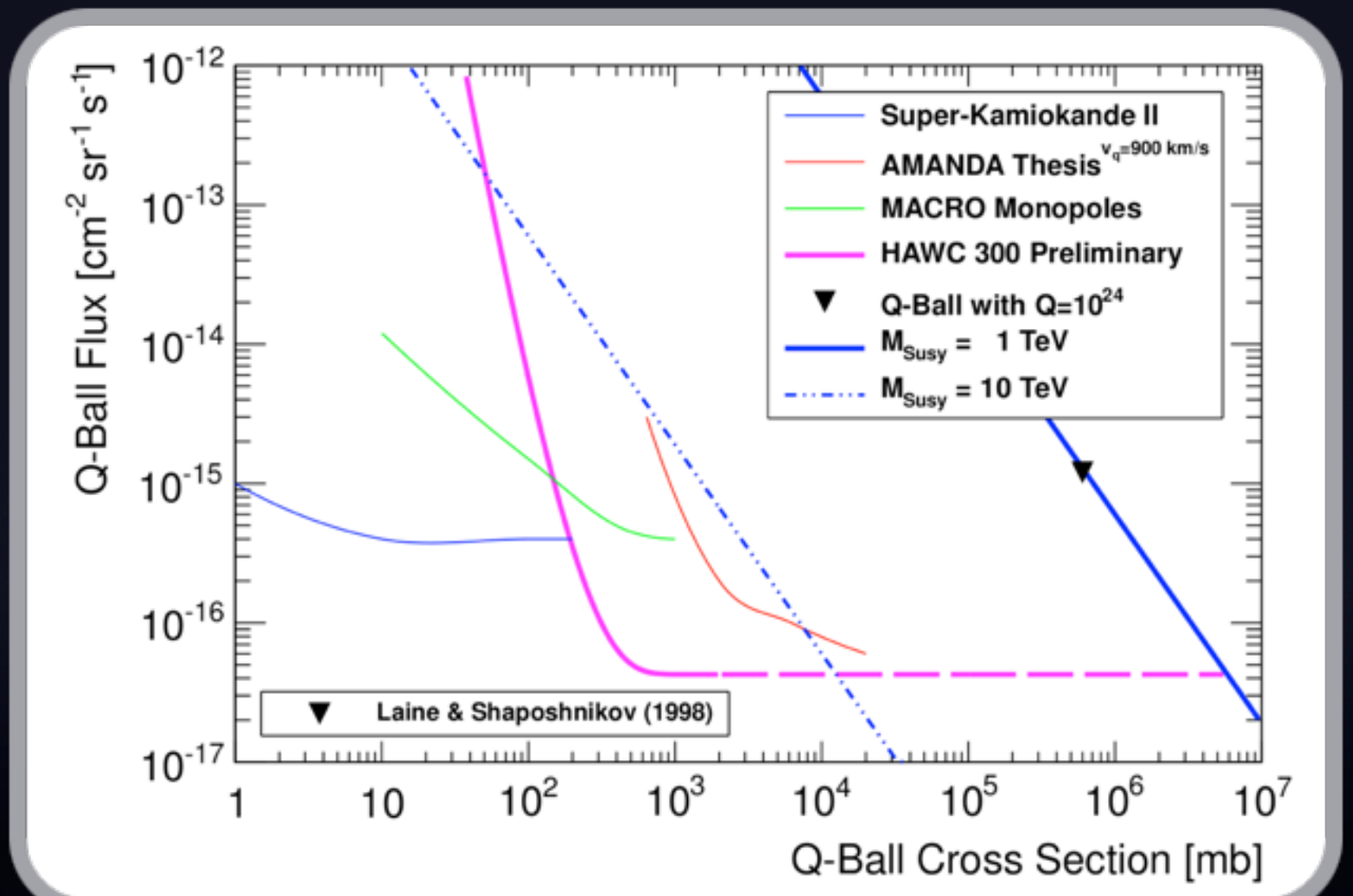


"Limits on **Indirect Detection of WIMPs** with the HAWC Observatory"

HAWC Collaboration, Submitted to **PRD**

PARTICLE PHYSICS

Q-balls



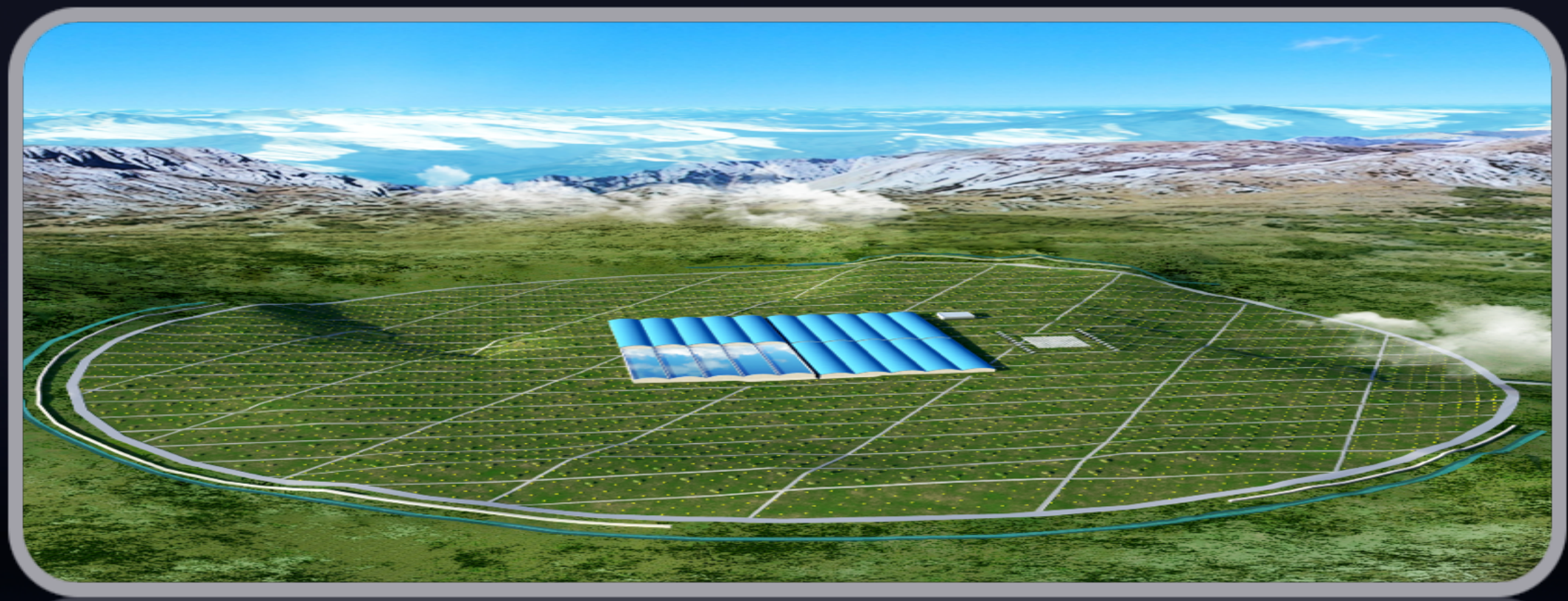
"Searching for **Q-balls** with the High Altitude Water Cherenkov Observatory"

PARTICLE PHYSICS

- Limits to Lorentz Invariance Violation
- IGMF studies
- Sensitivity to PBH (*)

(*) HAWC Collaboration, Submitted to The Astrophysical Journal

LHAASO



Materials courtesy of 曹臻 (Zhen Cao)

LHAASO Project

Water Cherenkov Detector
90,000 m^2

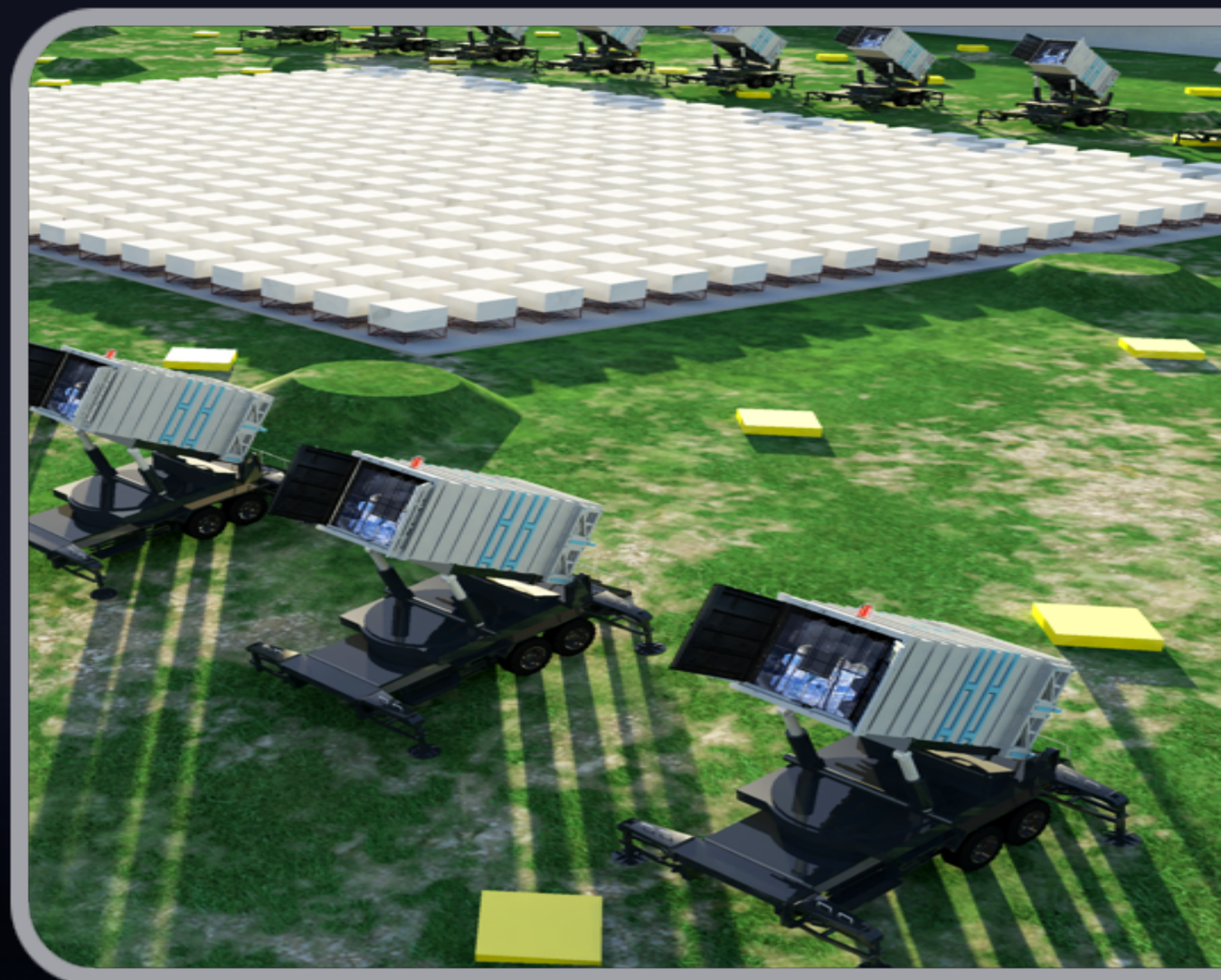
Main Array
6,300 scintillator detectors every 15 m
1,220 μ–detectors every 30 m

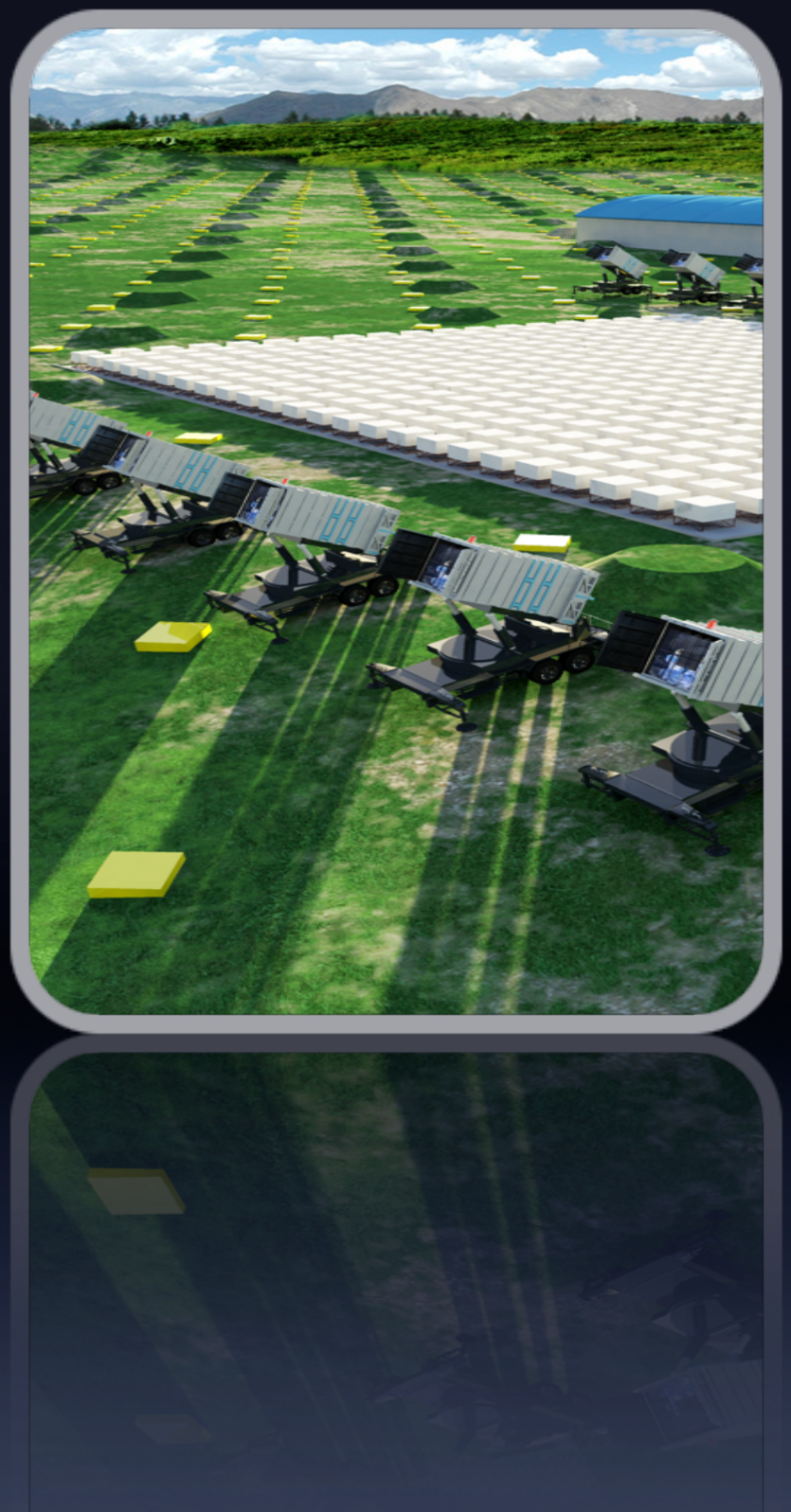
Central Array
24 wide field of view Cherenkov telescopes
542 burst detectors

LHAASO Project

LHAASO Status

- selected for funding in China
- site approved by the Sichuan province government
- start construction in 2015





Summary

- Current air shower arrays
- Exciting new results
- ***The future is bright!***

Thank You!