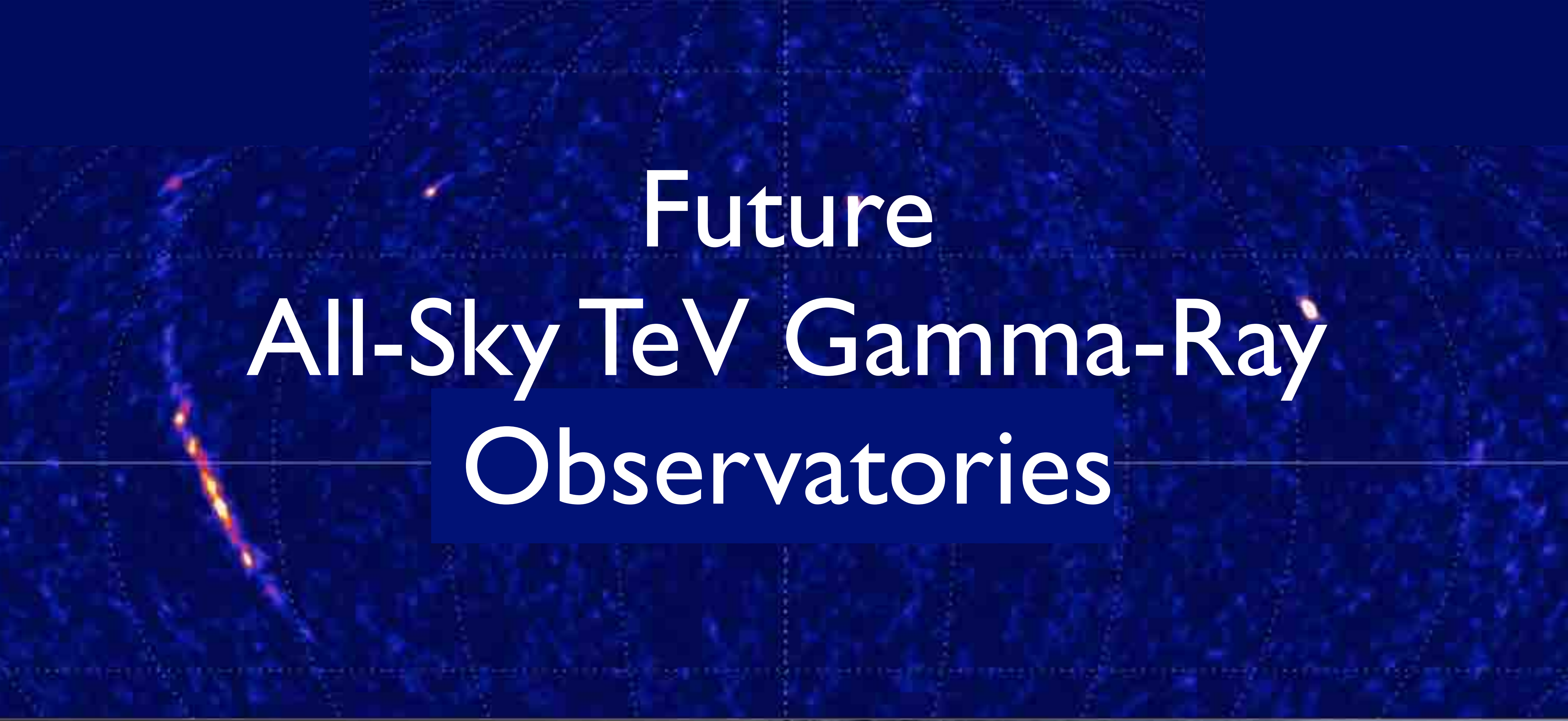


Future All-Sky TeV Gamma-Ray Observatories

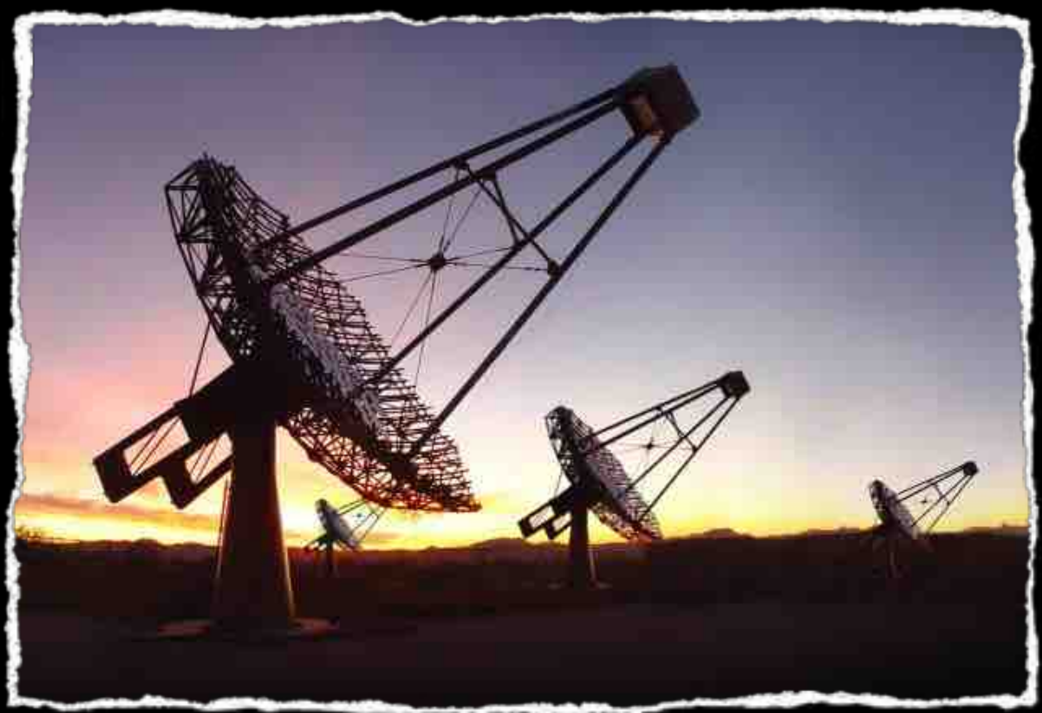
Gus Sinnis
Los Alamos National Laboratory

Goals of TeV Astrophysics

- Cosmic Rays
  - Origin of cosmic rays
  - Cosmic particle acceleration
  - Understand astrophysical jets and extreme environments
- Cosmology
  - Measure the extragalactic background light
  - Measure intergalactic magnetic fields (magnetogenesis)
- Search for new physics
  - Dark matter
  - Axion-like particles
  - Violations of Lorentz invariance

Gamma Ray Telescopes

Atmospheric Cherenkov Telescopes
H.E.S.S./VERITAS/MAGIC



50 GeV - 100 TeV
Large Area
Excellent background rejection
Small Aperture/Low Duty Cycle

Study known sources
Deep surveys of limited regions
Source morphology (SNRs)
Fast transients (AGN flares)

EAS Arrays
Milagro/Tibet/ARGO

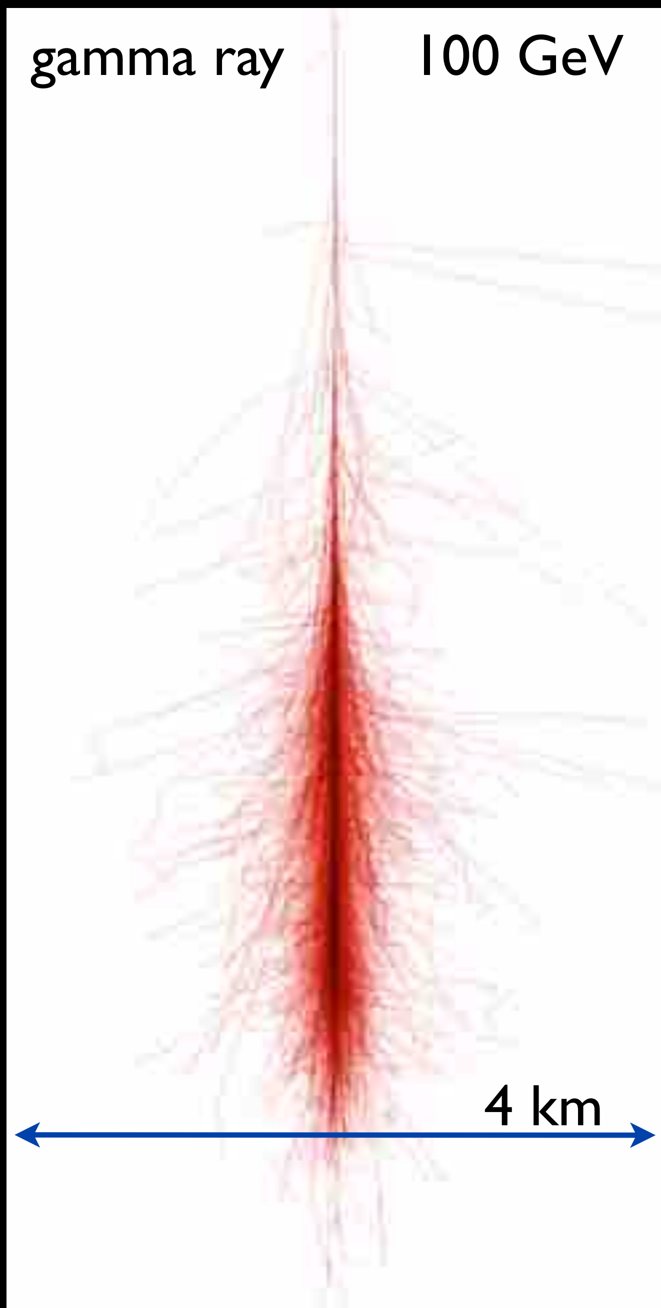
100 GeV - 100 TeV
Large Area
Good background rejection
Large Aperture & Duty Cycle

Sky survey & monitoring
Extended Sources
Transients (GRBs, AGN flares)
Highest Energies (>10 TeV)

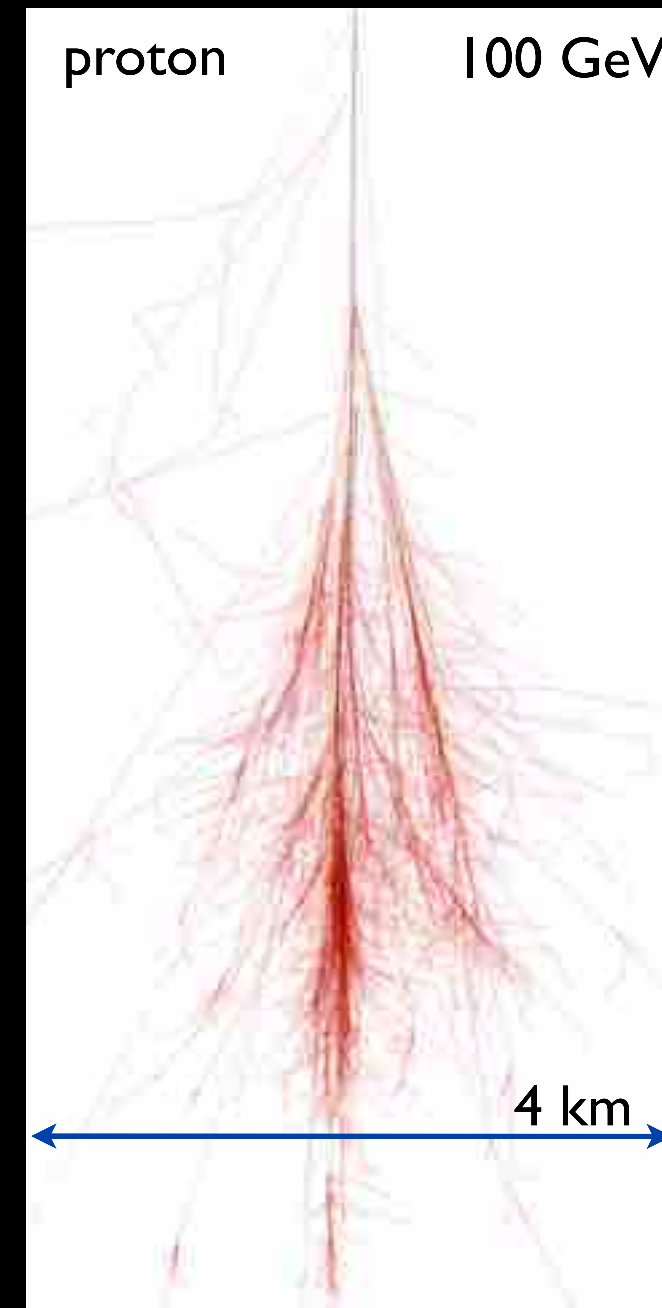
Roles of All-Sky Instrument

- Present
  - Galactic Survey at high energies
  - Extended objects (PWN, Diffuse emission)
  - High mass dark matter (>10 TeV)
  - Extragalactic surveys and transients
  - Multi-Messenger instrument
- Future (with CTA)
  - “Finder” telescope for CTA
  - Extragalactic survey (CTA will survey 1/4 of the sky)
  - Extragalactic transient (AGN, GRBs) detector
  - Multi-messenger instrument

Extensive Air Showers

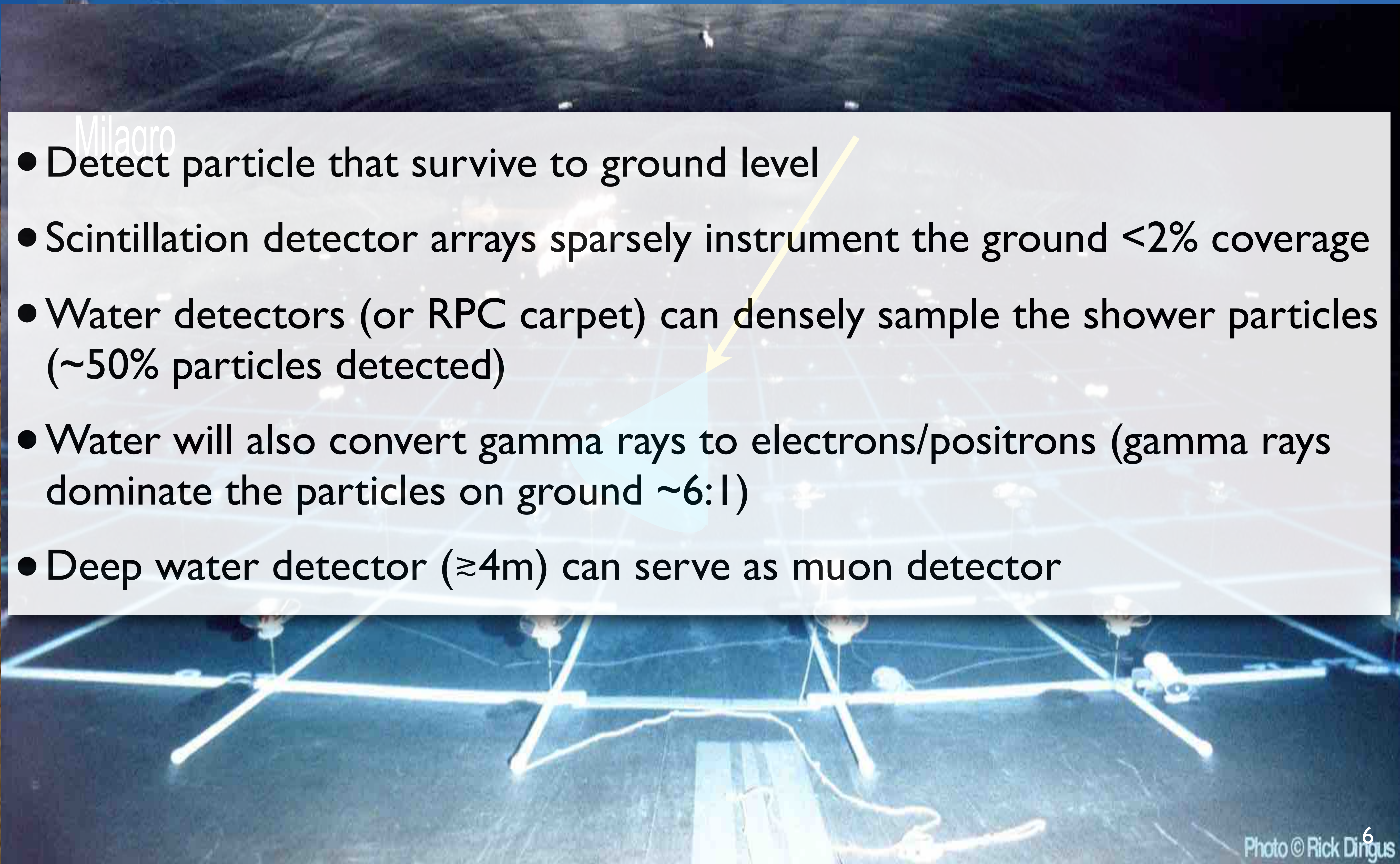


- γ showers almost purely e-m and relatively compact
- Hadronic showers contain muons (~30/TeV)
- Both have core of energetic particles
- Ground-based VHE telescopes must distinguish protons from photons



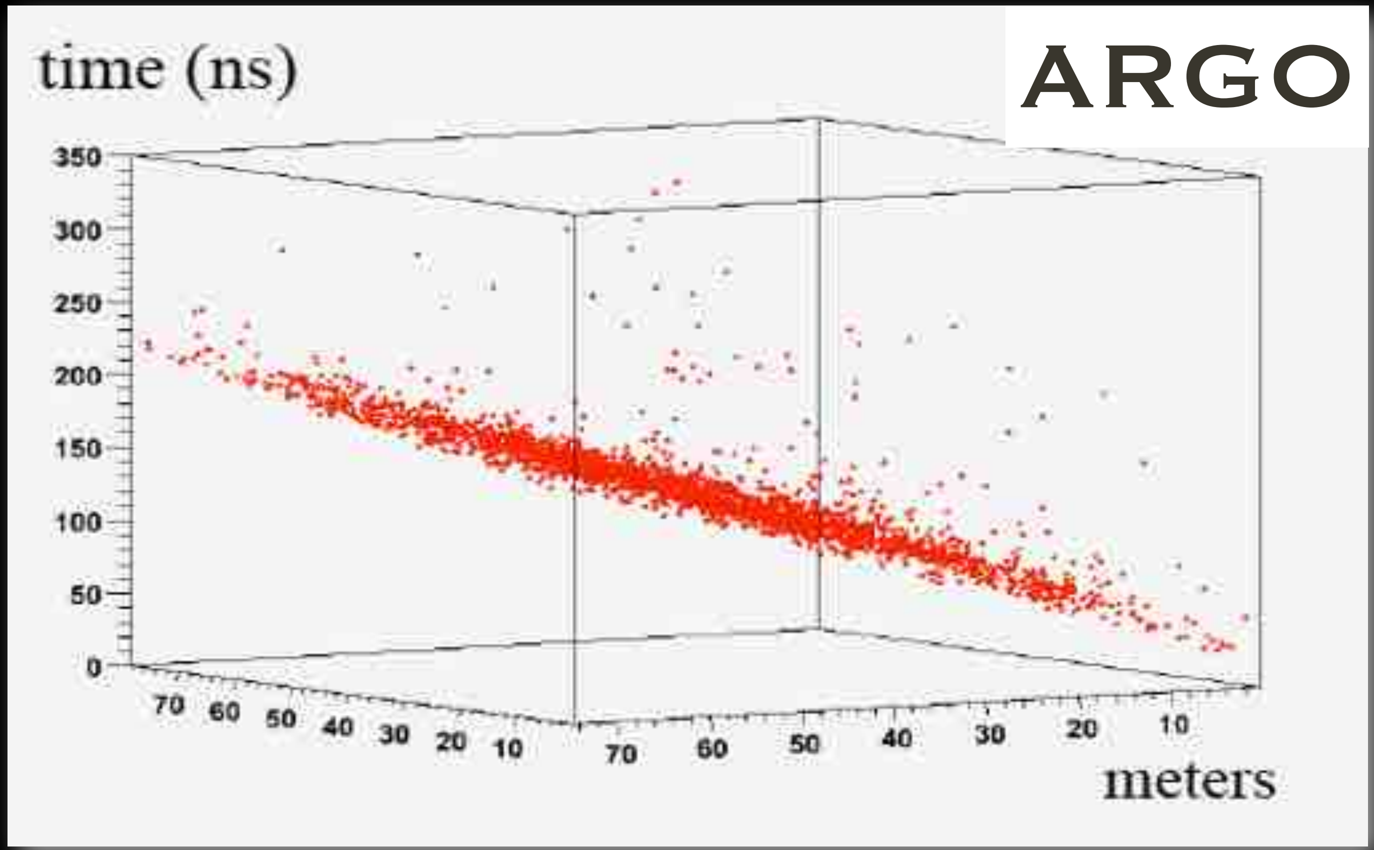
F. Schmidt, "CORSIKA Shower Images", http://www.ast.leeds.ac.uk/~fs/showerimages.html

Extensive Air Shower Arrays

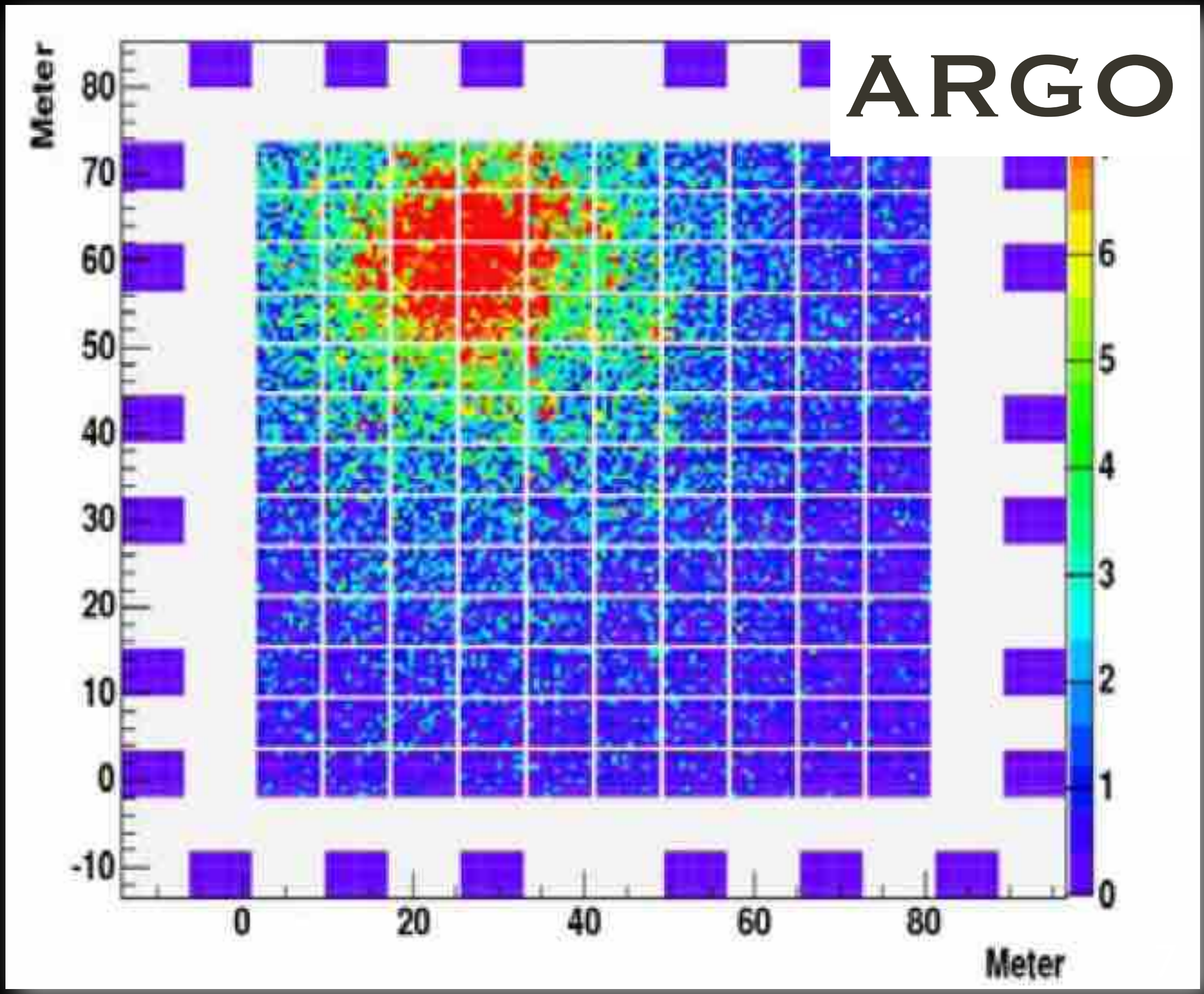


- Detect particle that survive to ground level
- Scintillation detector arrays sparsely instrument the ground <2% coverage
- Water detectors (or RPC carpet) can densely sample the shower particles (~50% particles detected)
- Water will also convert gamma rays to electrons/positrons (gamma rays dominate the particles on ground ~6:1)
- Deep water detector (≳4m) can serve as muon detector

Angular and Energy Reconstruction

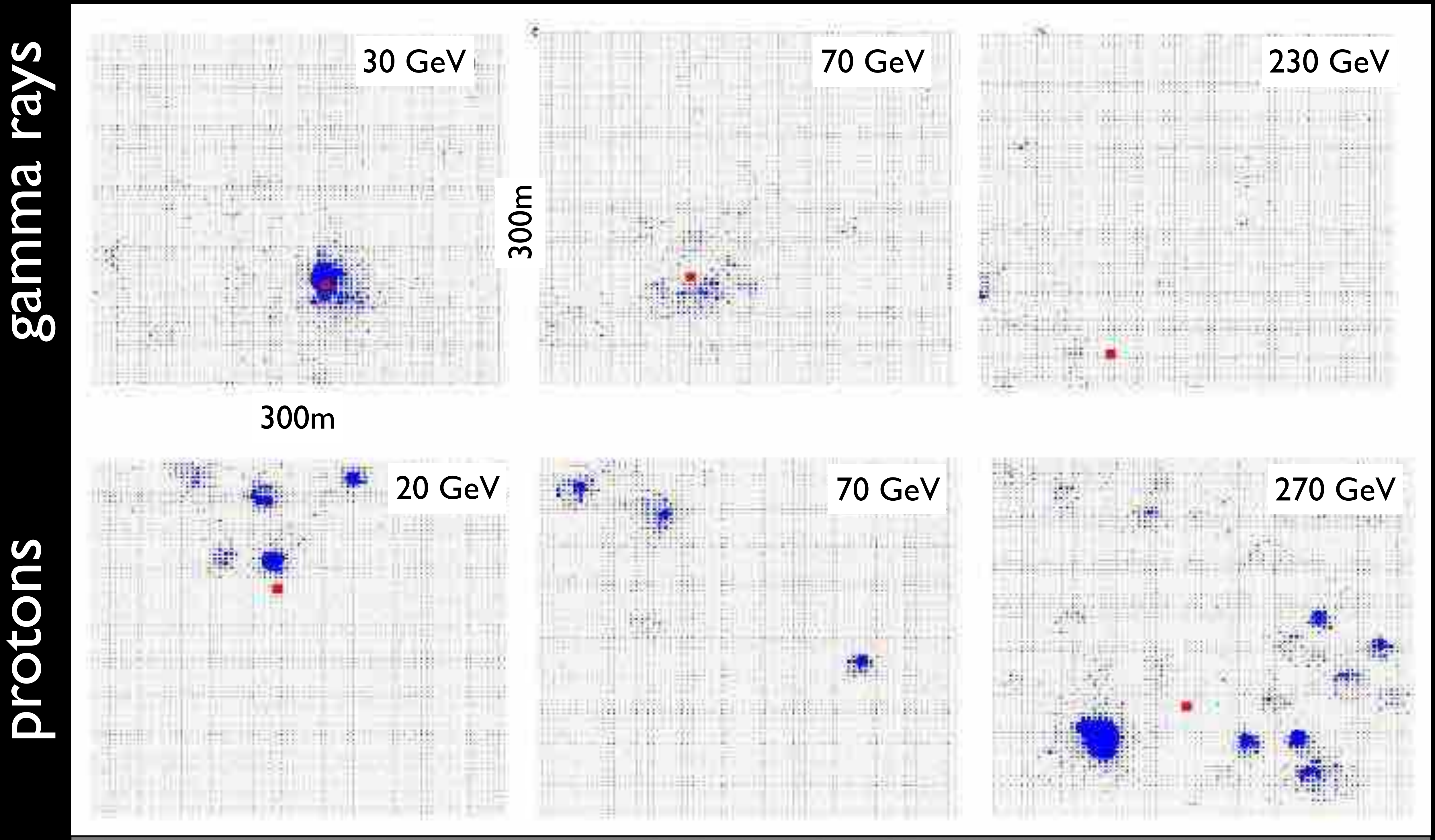


Direction via timing
(~ns timing yields 0.2°-1° resolution)

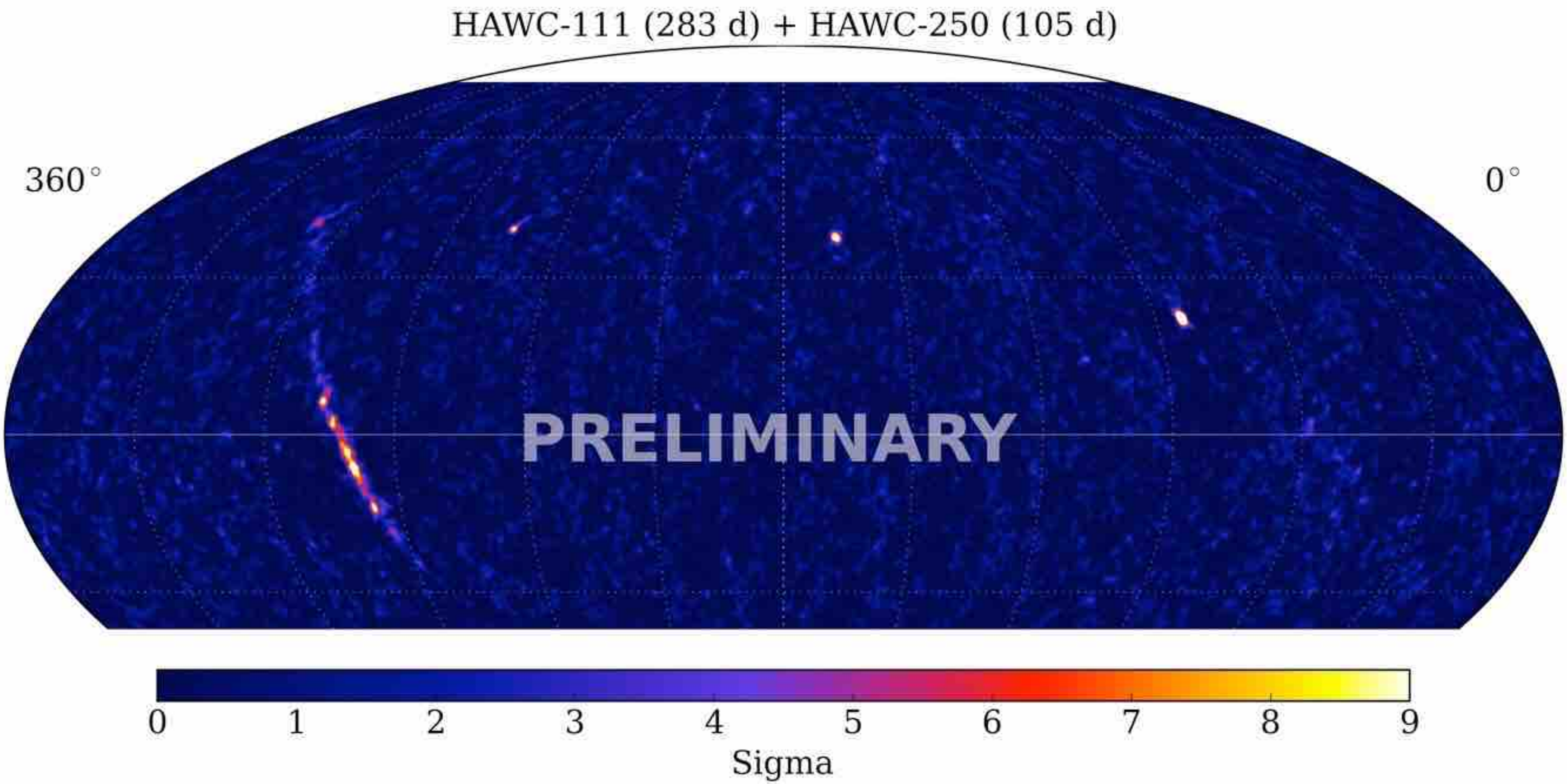


Primary energy via energy at ground (shower fluctuations dominate resolution ~40%)

Background Rejection



HAWC Sky



HAWC-111 (283 d) + HAWC-250 (105 d)
360°
0°
PRELIMINARY
0
1
2
3
4
5
6
7
8
9
Sigma

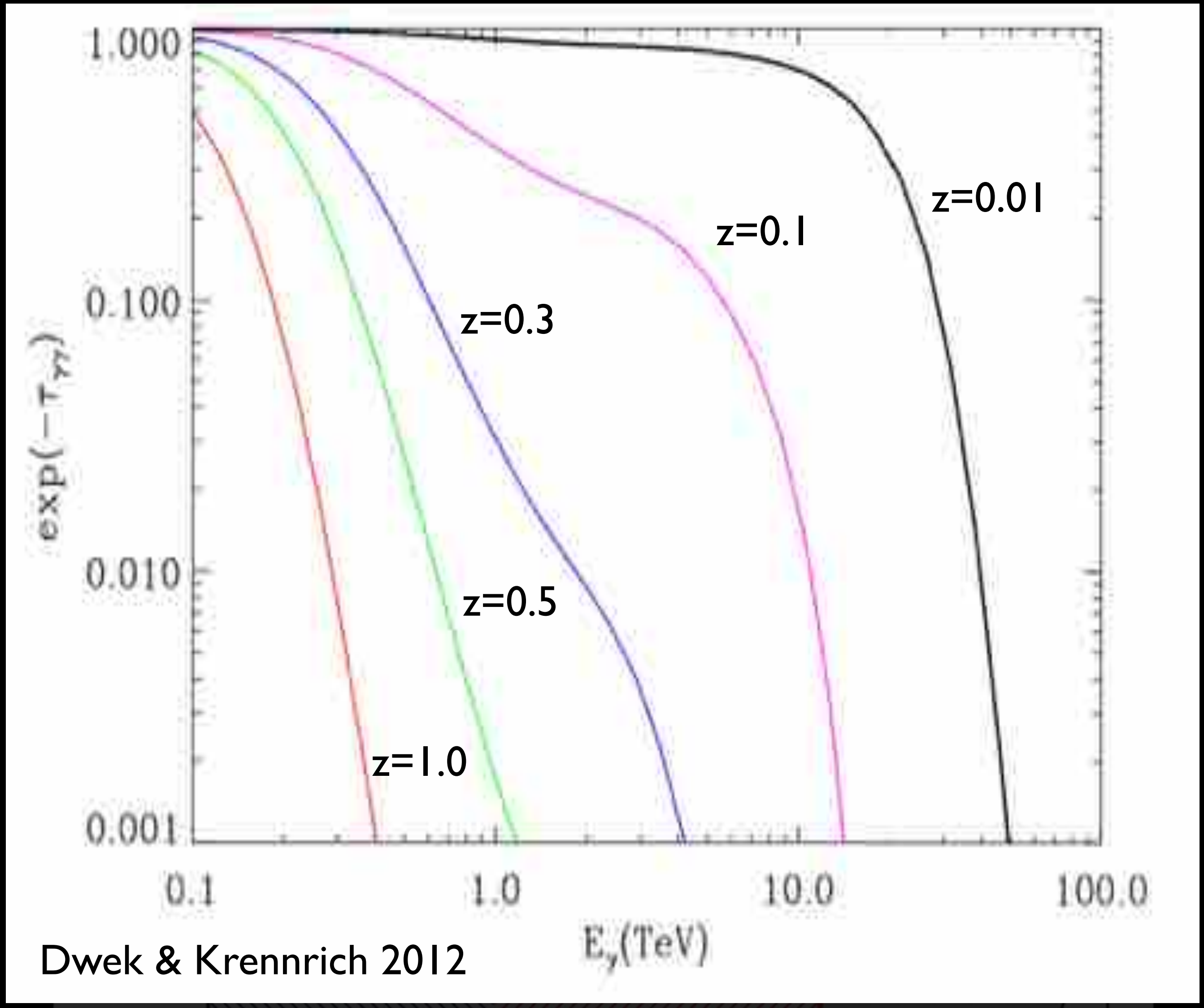
Extragalactic Gamma Rays

- Active Galaxies (57 detected in VHE band)
  - Extragalactic Background Light
  - Primordial Magnetic Fields
  - Axion-like Particle Searches
- Gamma Ray Bursts (not yet detected from ground)
  - Lorentz Invariance Violation

Extragalactic Background Light

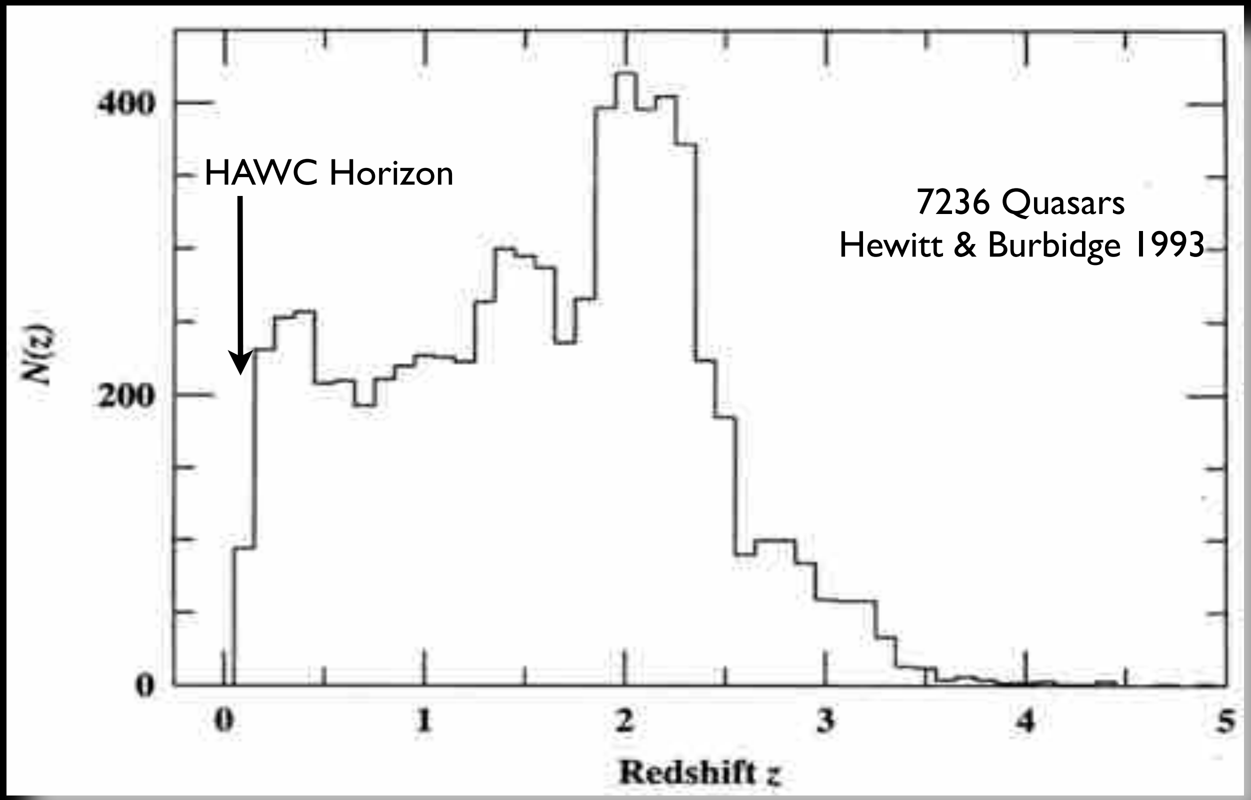
$$\gamma_{eV} + \gamma_{TeV} \rightarrow e^+ e^-$$

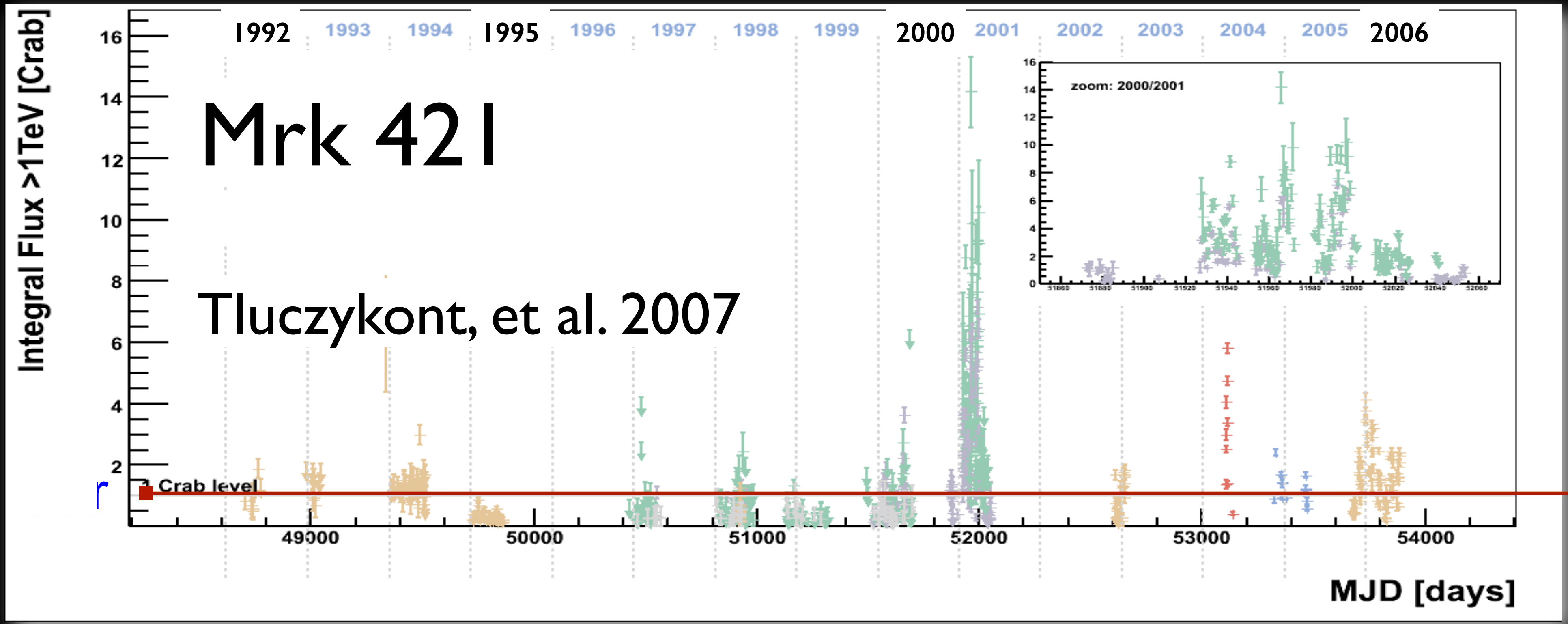
- The sum of all UV, optical, and IR radiation emitted over the history of the universe
- Main contributions from stars and light re-radiated by dust
- EBL is useful tool for probing other physics
  - Axion-like particles
  - UHECR accelerators
  - Intergalactic Magnetic Fields
- Require low threshold to see distant sources



Active Galaxies

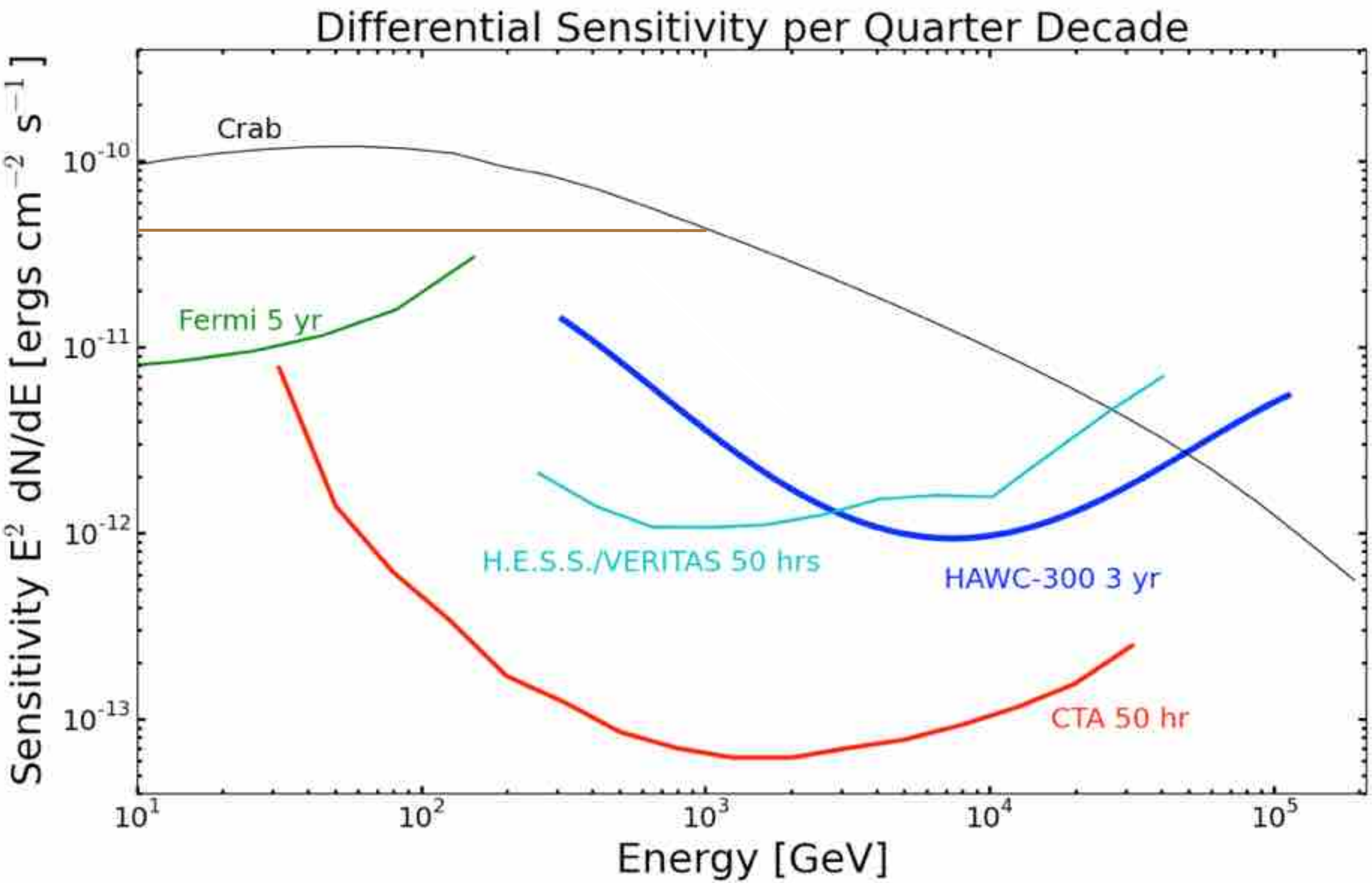
- Variability detected in ~20% of VHE AGN
- Alert CTA of flaring activity





HAWC 1-day sensitivity

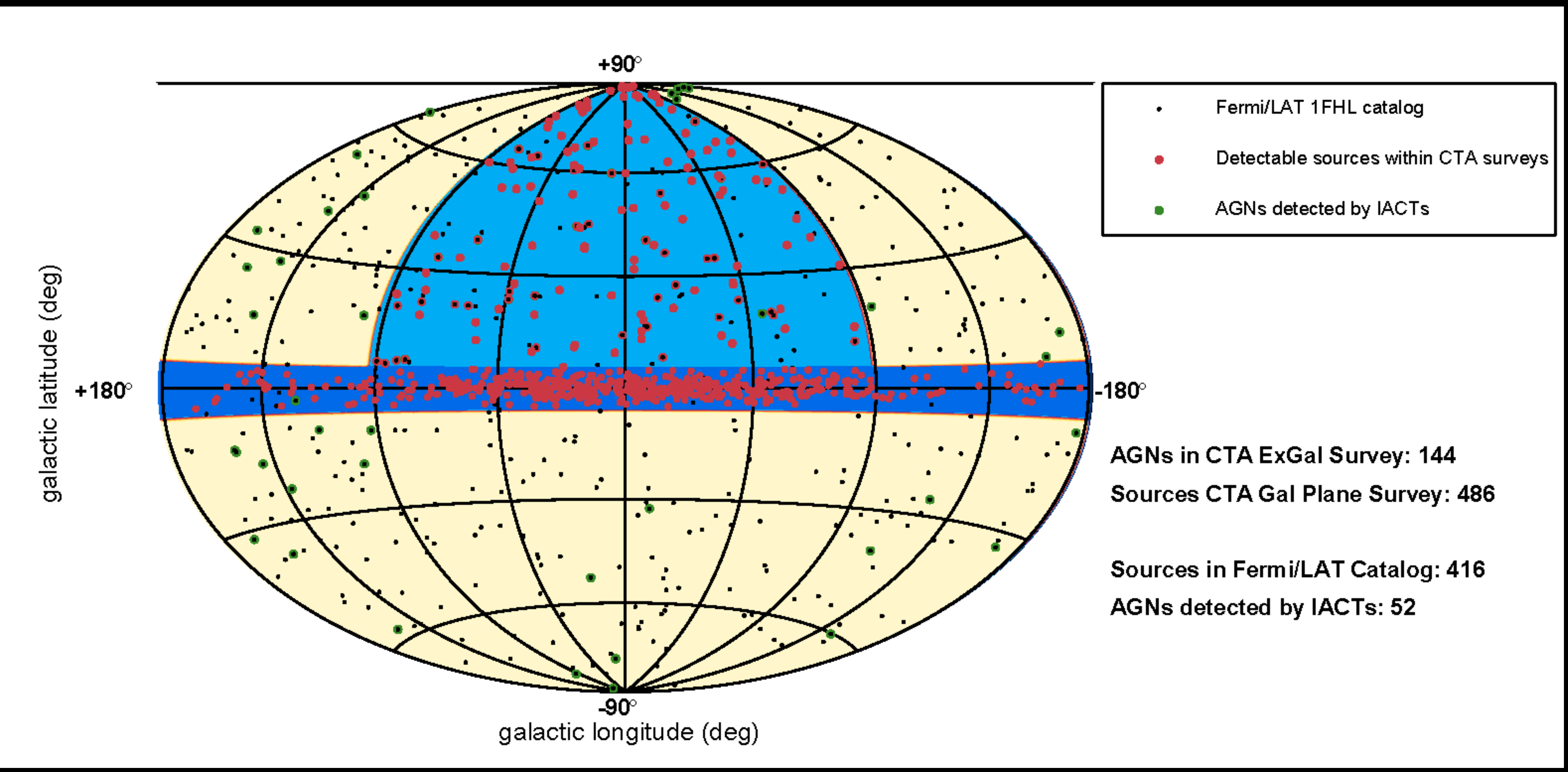
CTA and HAWC



Differential Sensitivity per Quarter Decade
Sensitivity E^2 dN/dE [ergs cm^{-2} s^{-1}]
Energy [GeV]
Crab
Fermi 5 yr
H.E.S.S./VERITAS 50 hrs
HAWC-300 3 yr
CTA 50 hr
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^1
10^2
10^3
10^4
10^5

CTA Survey Plans

Survey the Galaxy to 3.8 mCrab (~5x sensitivity of HAWC 5yr)



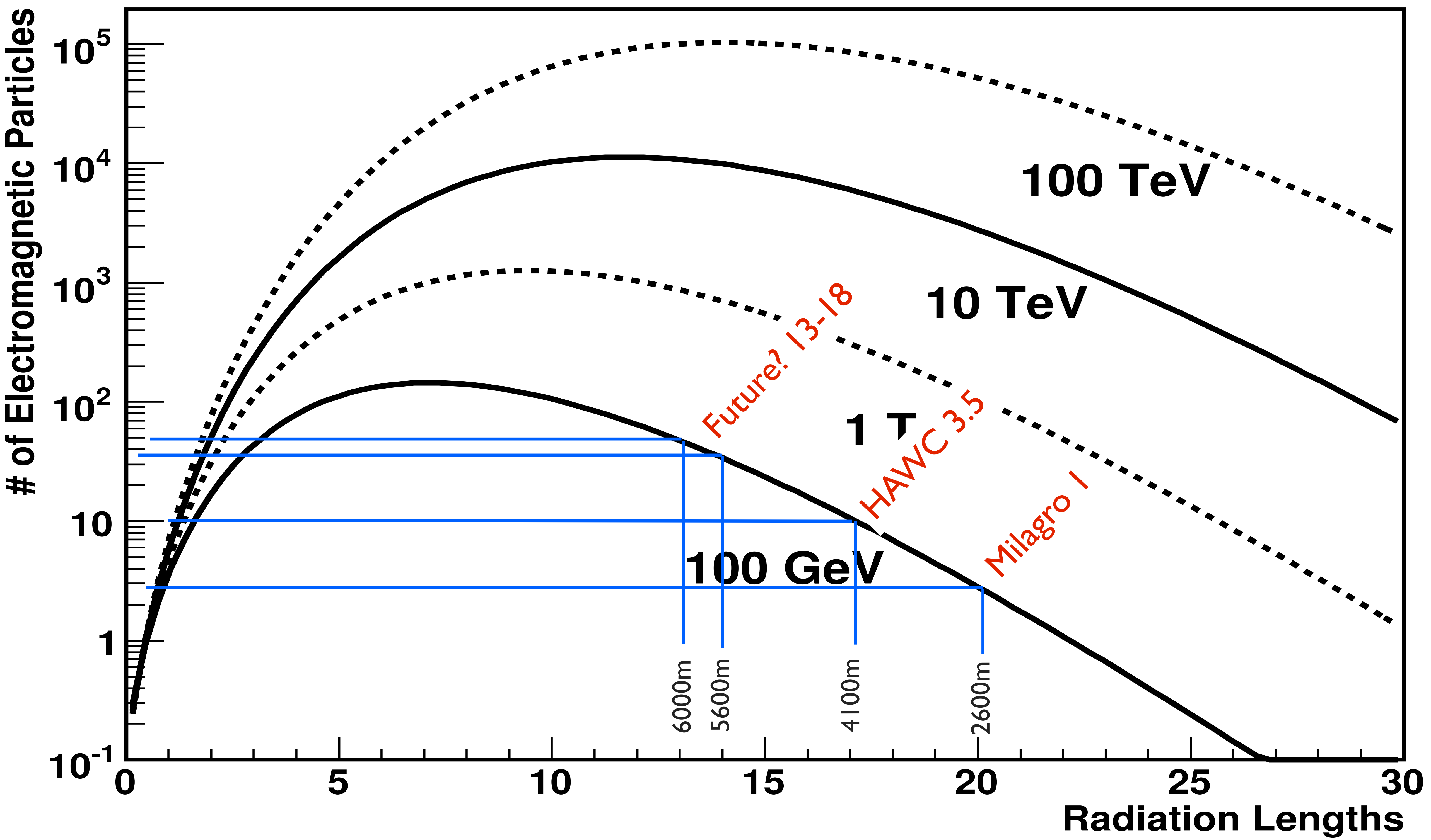
Survey 1/4 of the sky to 6.5 mCrab ~3x HAWC 5yr

from R. Ong

CTA and HAWC

- HAWC sensitivity well matched to current generation of IACTs (VERITAS, H.E.S.S., and MAGIC)
- To be useful to CTA we need:
  - ~10x greater sensitivity
  - Ability to detect extragalactic transients (AGN, GRBs)
  - Significantly lower median energy (~300 GeV)
  - Southern hemisphere site
- Is this possible?

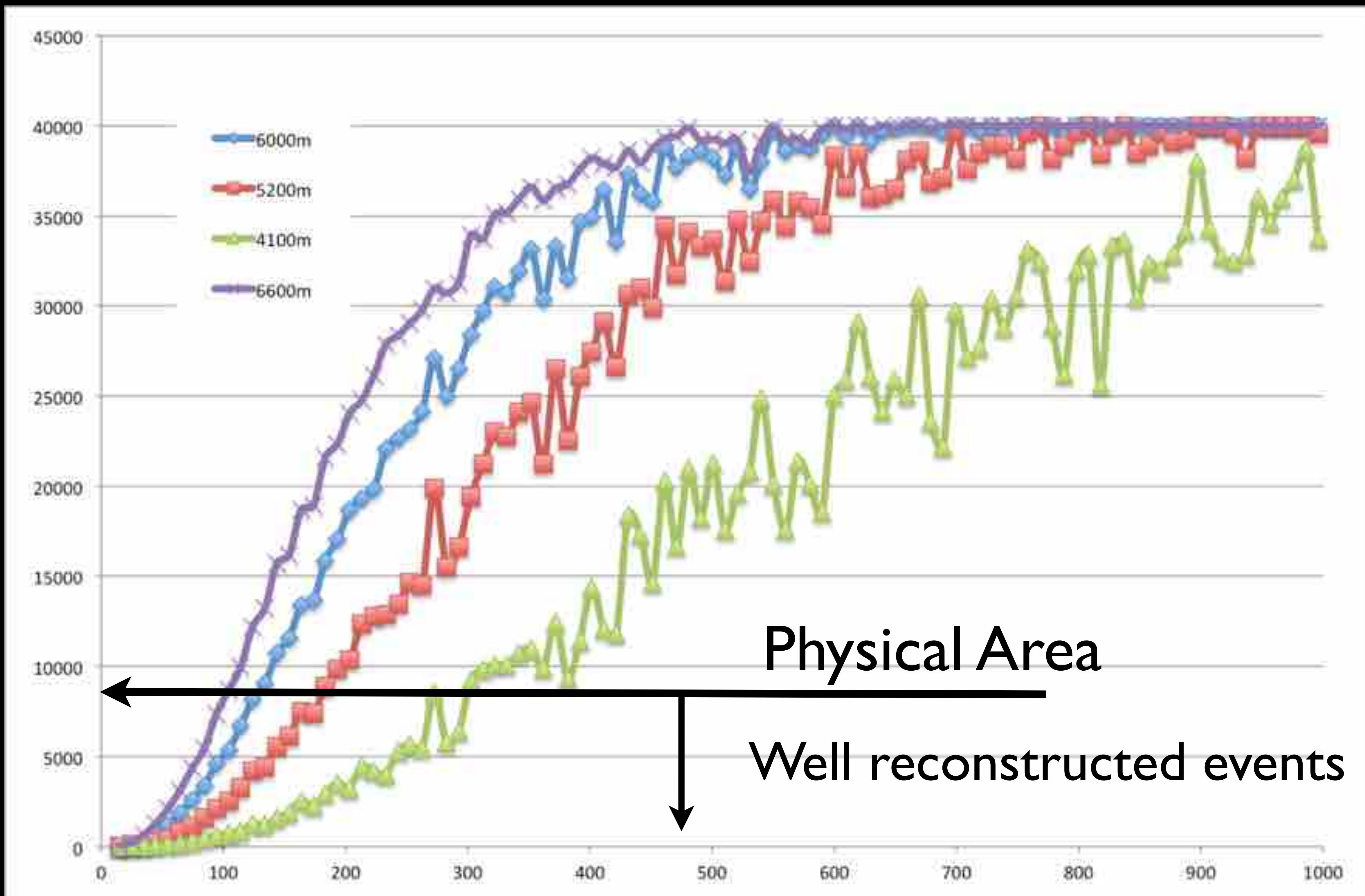
Extreme Altitude Array



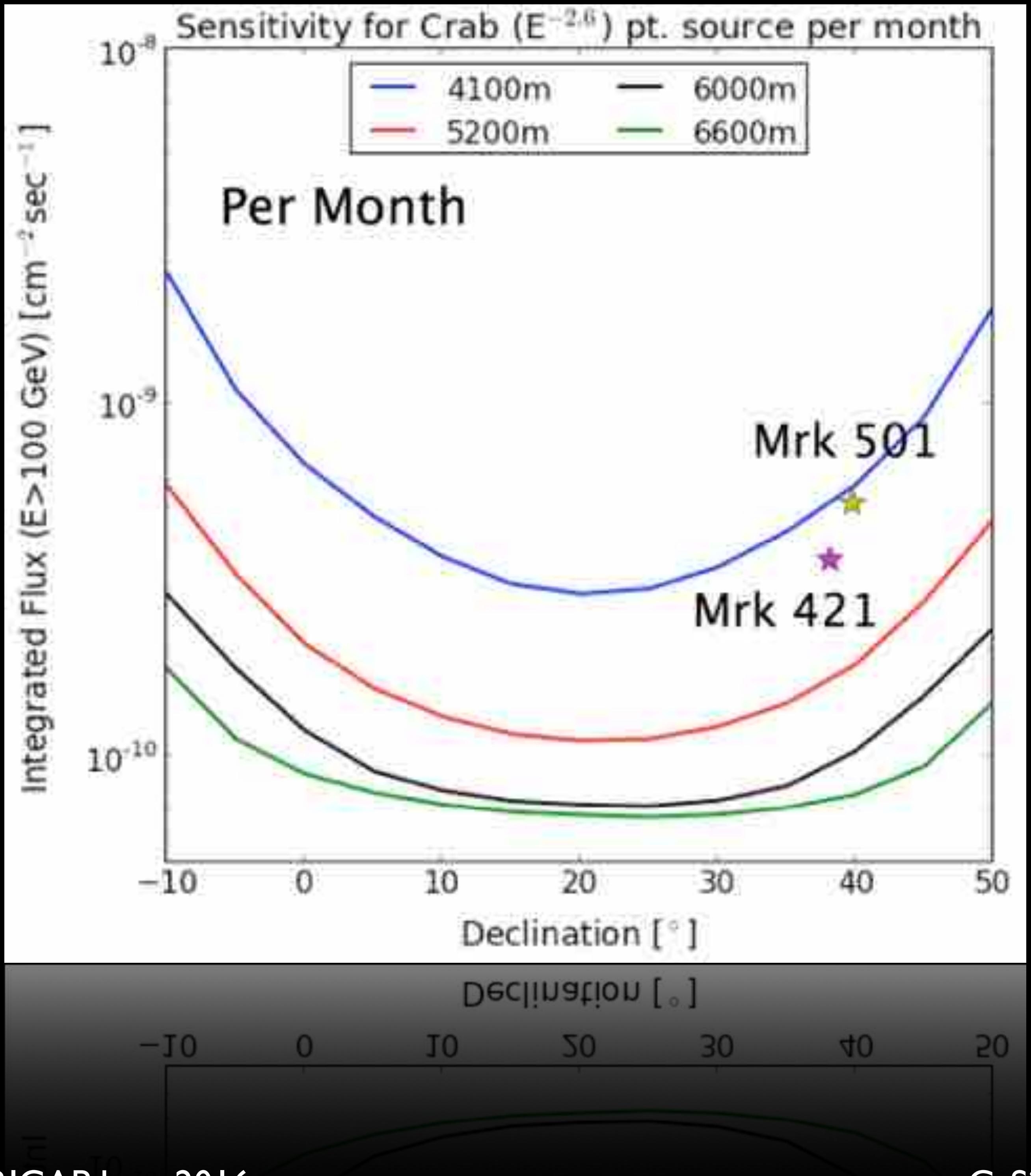
Extreme Altitude Study

- Assume a 30 x 30 tank array with 3m separation (8100 m^2 total area)
- Each tank 1.5m deep x 3m diameter (dense pack)
- Single 10” high QE PMT at bottom looking up
  - 0.25 PE/MeV
  - 0.10 PE/MeV in HAWC
- Trigger on 30 (of 900) tanks
- No noise in simulation
- Test altitudes of 4100m (HAWC), 5200m, 6000m, 6600m
- Gamma rays from 10 GeV to 1 TeV ($E^{-2.3}$ spectrum)
- Protons from 10 GeV to 1 TeV ($E^{-2.7}$ spectrum)

Results: Effective Area

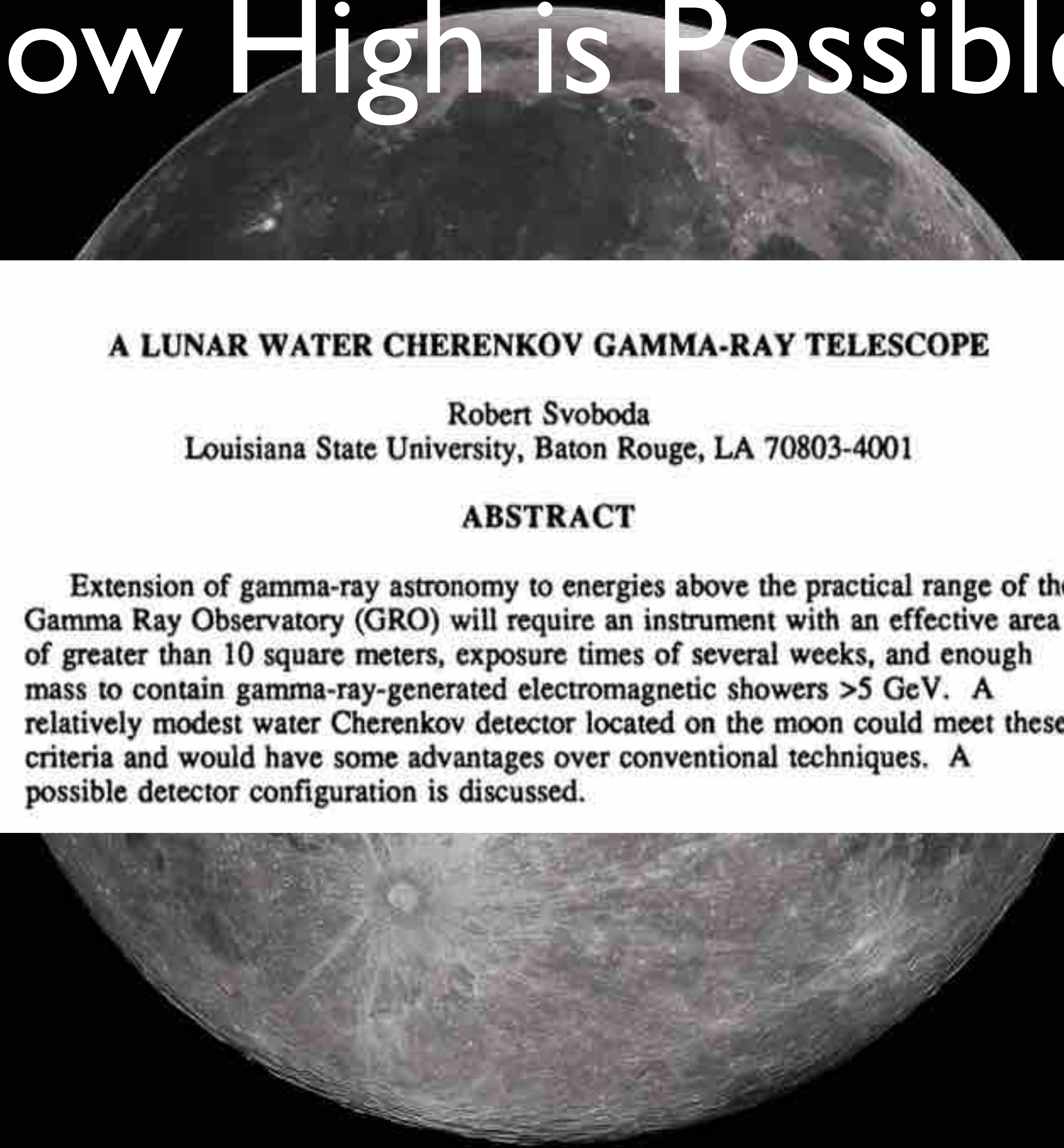


Results: Sensitivity



- An array at 6000m is ~5x more sensitive than the same array at 4100m
- >10x area at 100 GeV
- Larger improvement for extragalactic sources
- AGN and GRBs are strength of extreme altitude array
- 5-10x GRB detection capability of HAWC

How High is Possible?



A LUNAR WATER CHERENKOV GAMMA-RAY TELESCOPE

Robert Svoboda
Louisiana State University, Baton Rouge, LA 70803-4001

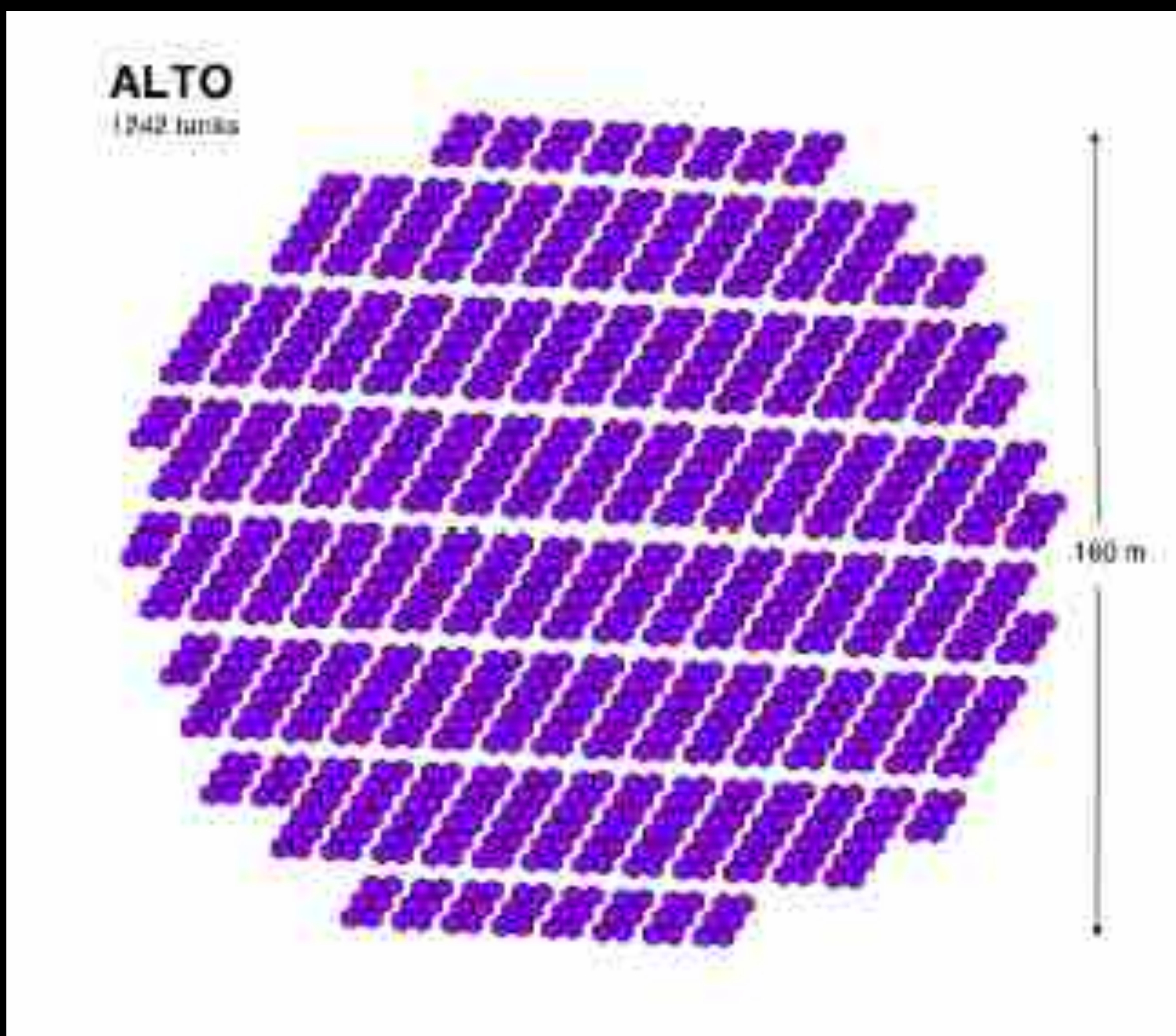
ABSTRACT

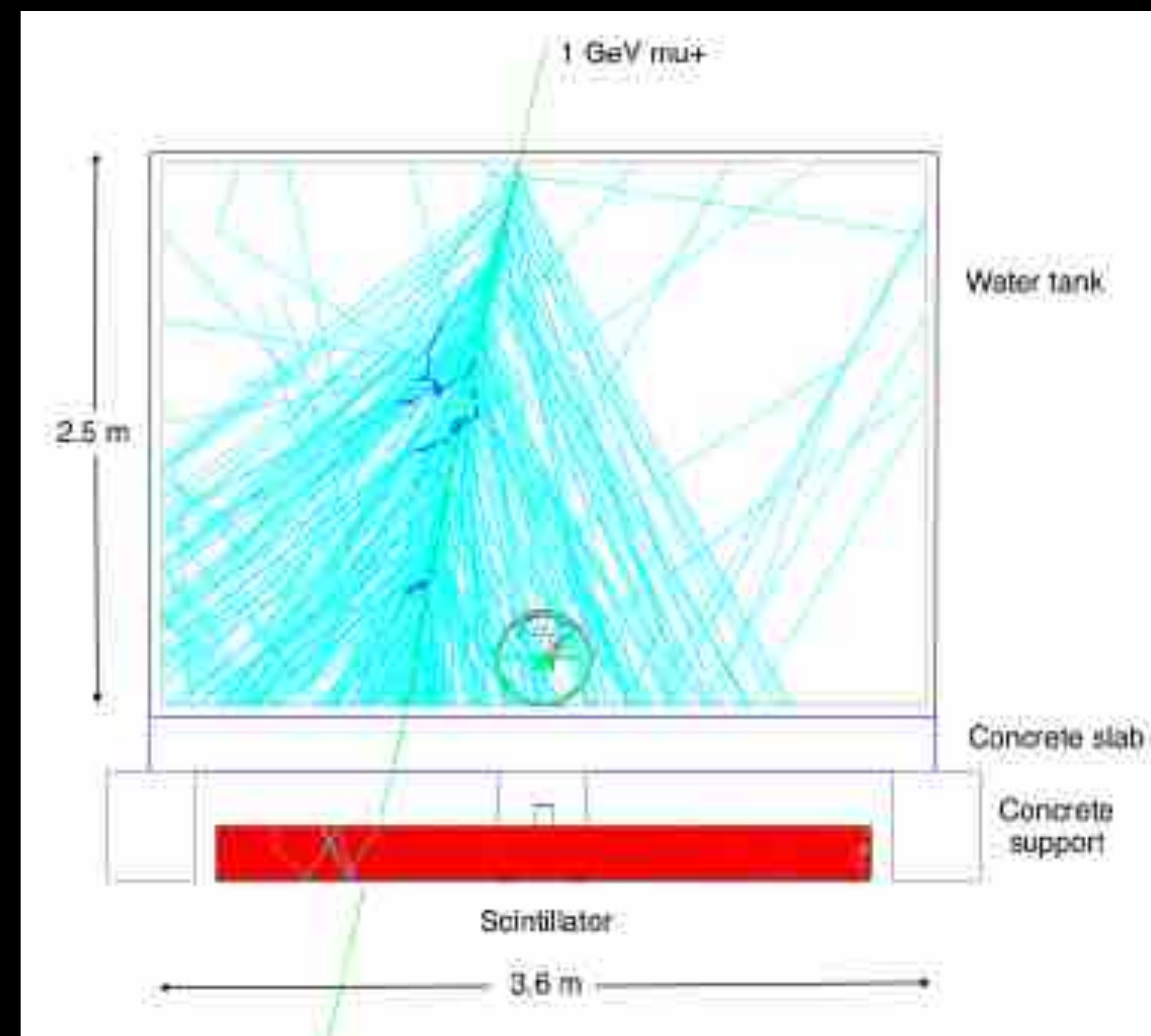
Extension of gamma-ray astronomy to energies above the practical range of the Gamma Ray Observatory (GRO) will require an instrument with an effective area of greater than 10 square meters, exposure times of several weeks, and enough mass to contain gamma-ray-generated electromagnetic showers >5 GeV. A relatively modest water Cherenkov detector located on the moon could meet these criteria and would have some advantages over conventional techniques. A possible detector configuration is discussed.


Cerro Toco (5604m)
Cerro Chanjnator (5610m)
Cerro ?? (5650m)
-23.00789, -67.68269
27
Image © 2014 DigitalGlobe
US Dept of State Geographer
Image © 2014 CNES / Astrium
© 2014 Mapcity
Google earth

Concept Studies Underway
Dense pack 1242 tanks

Water tank
w/muon detector

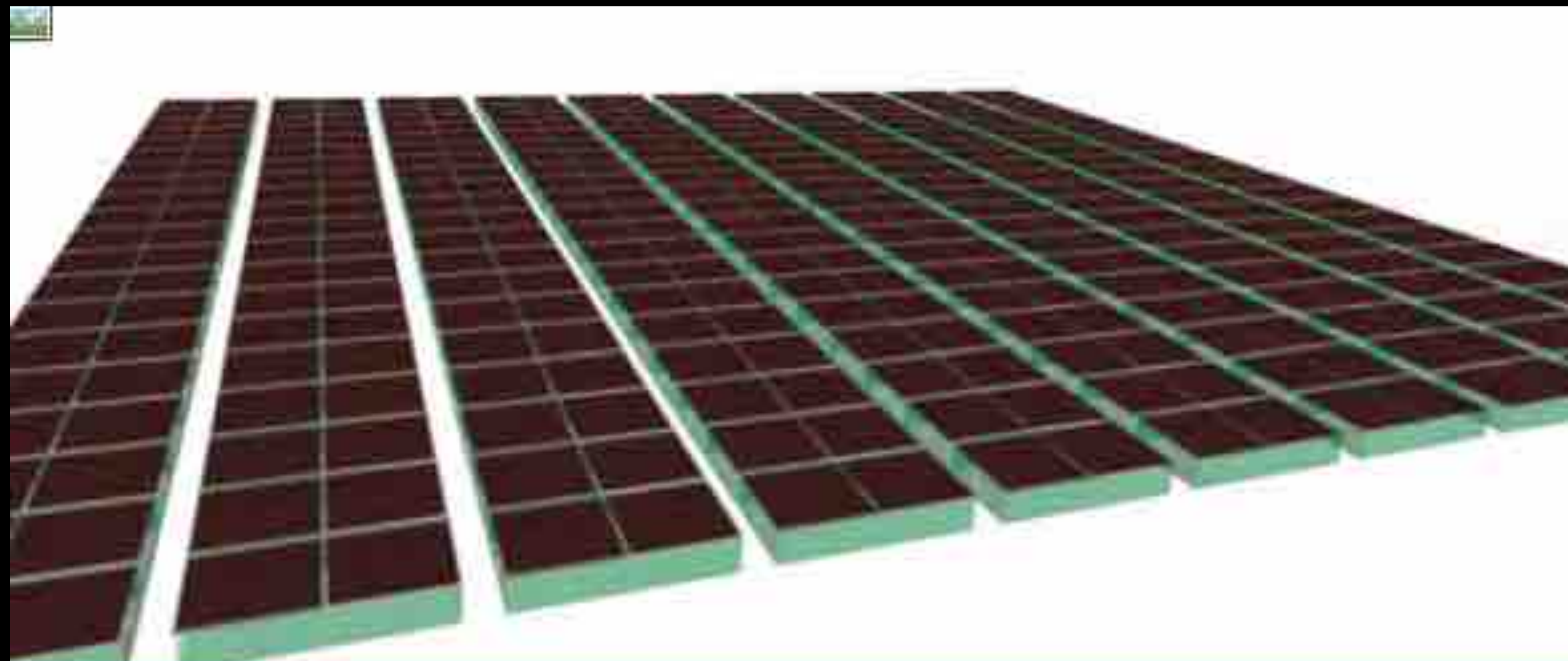




~20,000 m^2

Y. Becherini and M. Punch - Linneaus University

LATTES



10,000-20,000 m^2
of layered
detectors
60x30 array

Pb sheet, RPC,
water Cherenkov

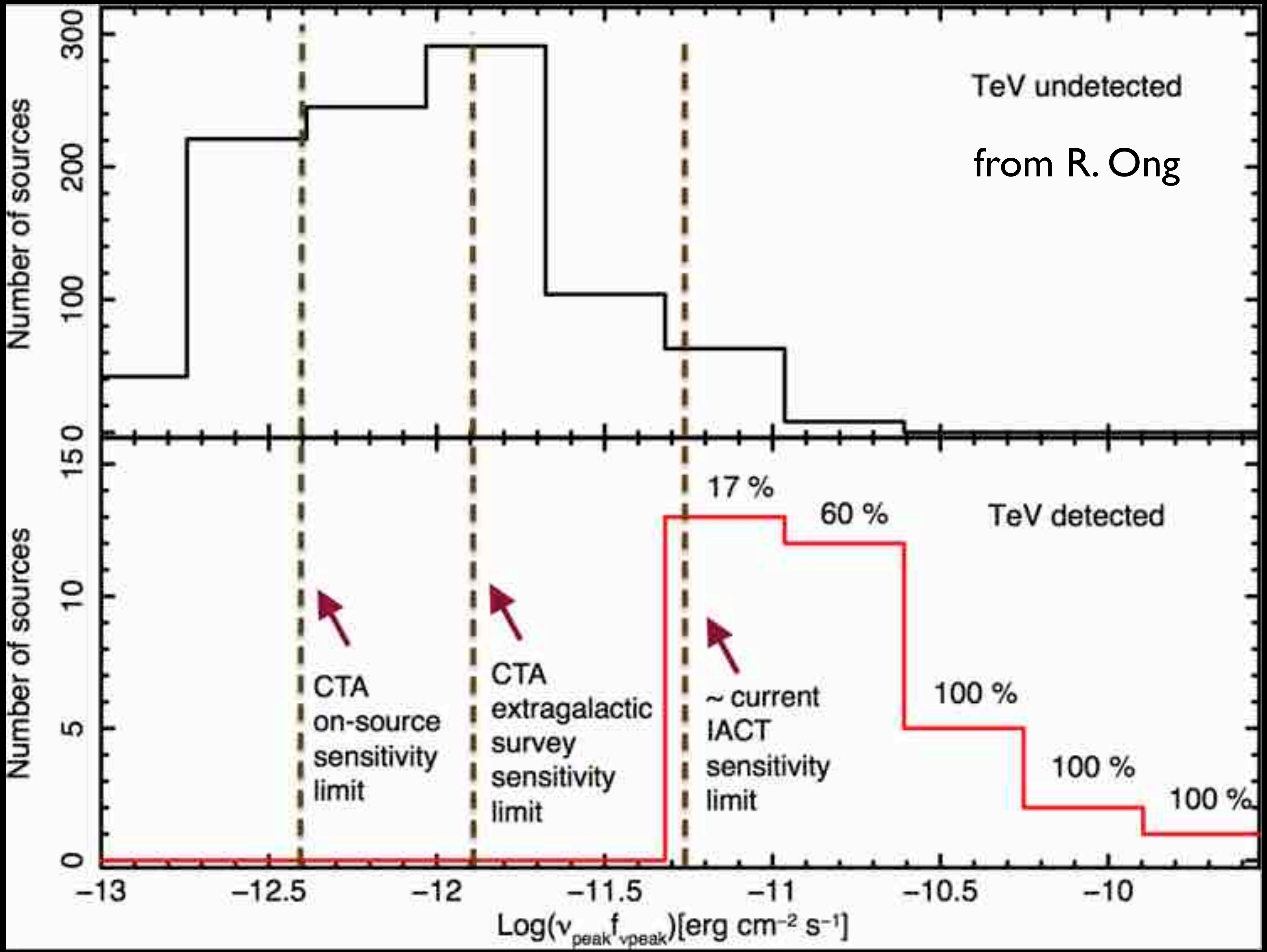
P. Assis, U. Barres de Almeida, A. Blanco, R. Conceição, A. De Angelis,
P. Fonte, L. Lopes, G. Matthiae, M. Pimenta, R. Shellard, B. Tomé

Summary

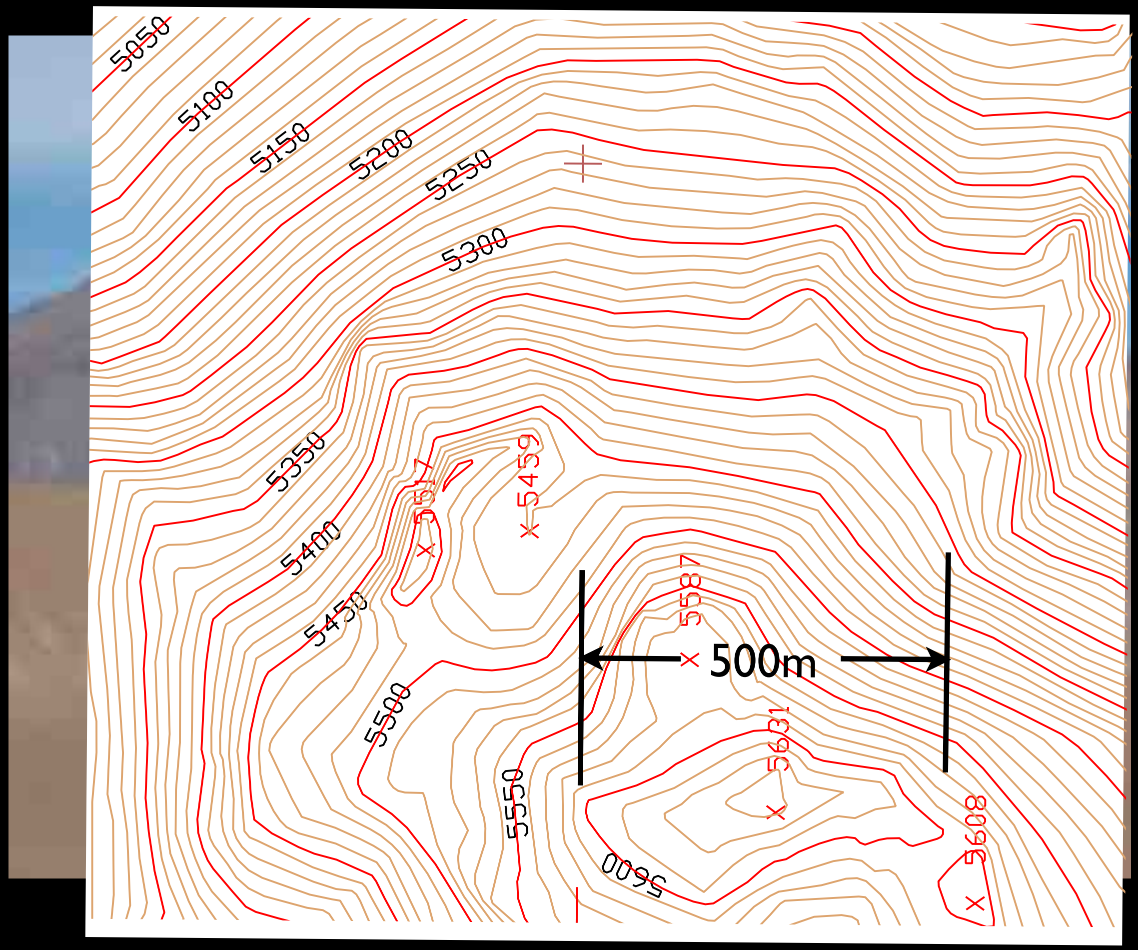
- Gamma-Ray experimental techniques have made enormous progress in the past 25 years
- Complementarity of all-sky and pointed instruments
- With CTA coming a future all-sky array should have ~10x increase in sensitivity over HAWC
- Extragalactic transient detection requires low threshold, ~few 100 GeV
- Extreme altitude is key
- 5600 meters asl seems feasible
- New detector ideas are under study

Back Up

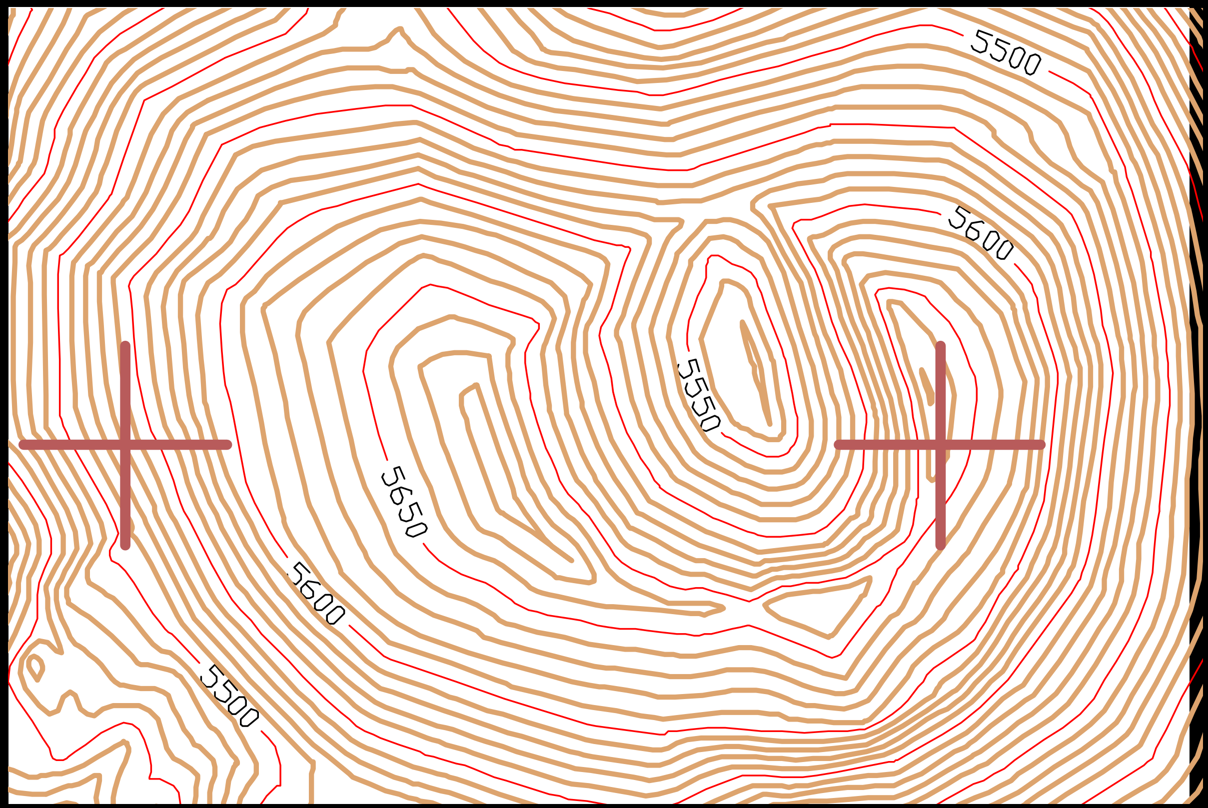
Extragalactic Survey



Possible Sites
Chajnantor Science Preserve



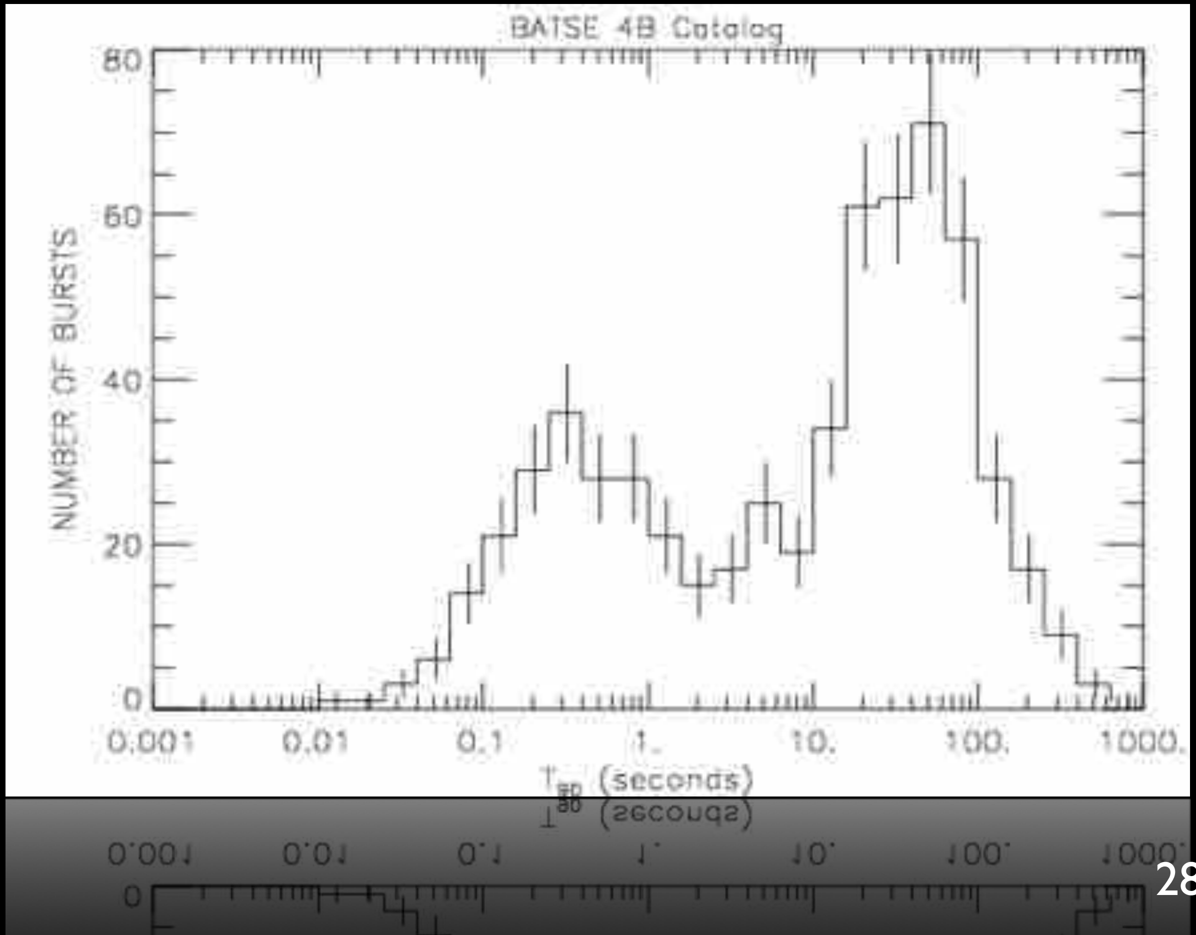
Cerro Chajnantor
Location of CCAT
S 22º 59' 8.3"
W 67º 44' 25.0"
5611 m asl



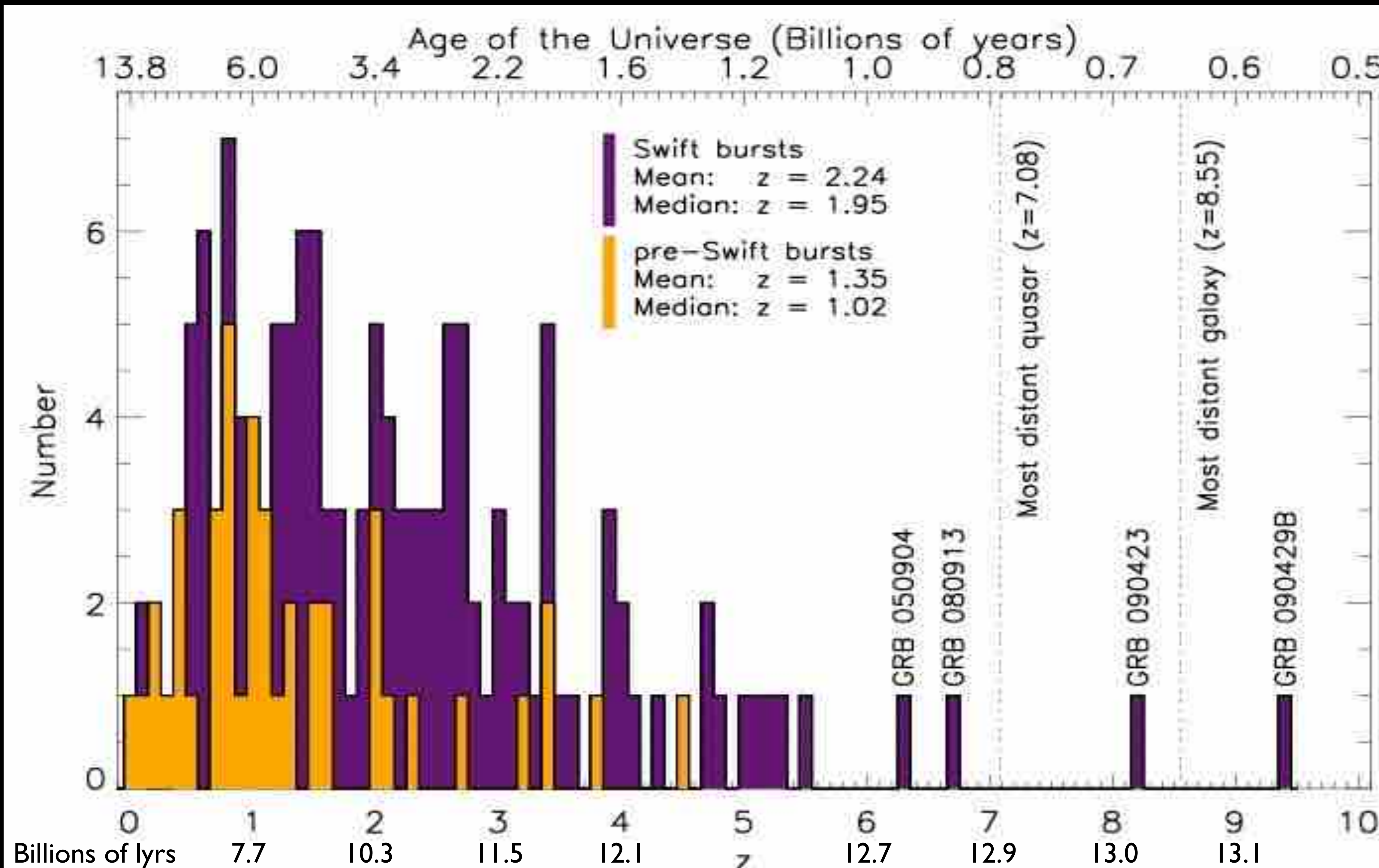
Cerro ??
S 23º 0' 28.5"
W 67º 41' 8.0"
5650 m asl

Gamma-Ray Bursts

- Discovered in 1960's - Vela satellite
- Most energetic events in the universe
- Detected to z~9.4
- $\sim 10^{51}$ ergs released in gamma rays
- Emission highly collimated (1°-10°)
- Bi-modal duration distribution
  - short duration bursts <2 seconds (binary neutron star mergers)
  - long duration bursts >2 seconds (hypernovae - collapse of massive stars)



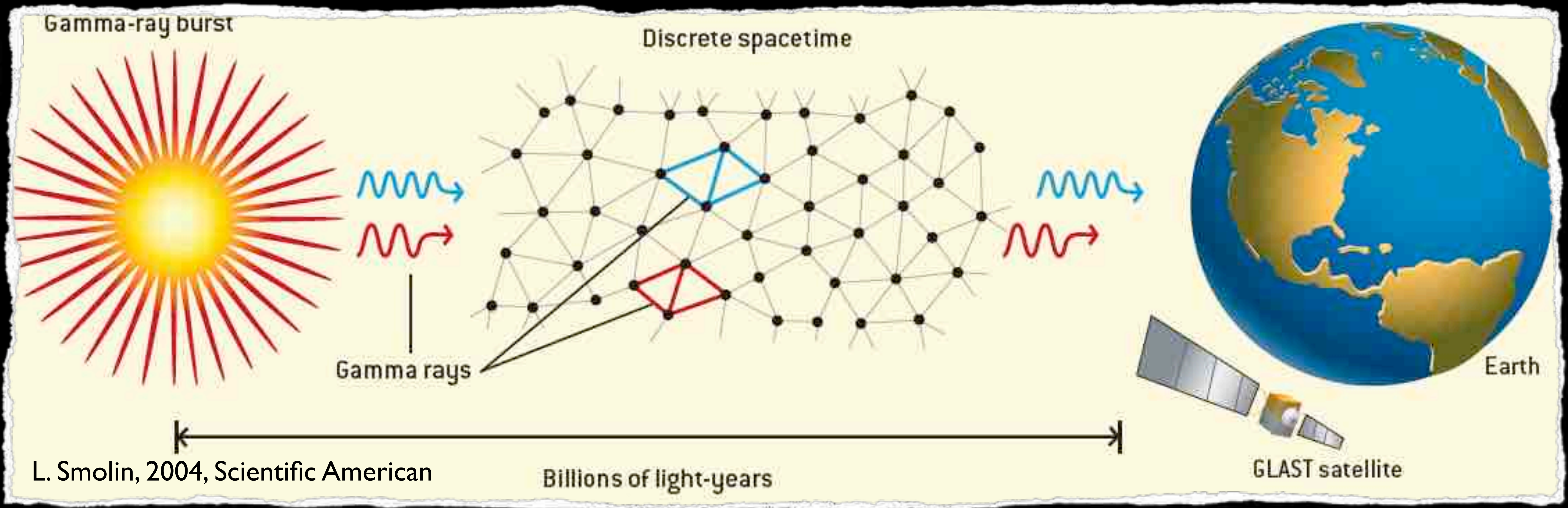
GRB Distances



P. Jakobsson http://www.raunvis.hi.is/~pja/GRBsample.html

Testing Lorentz Invariance

- Many theories of quantum gravity violate Lorentz invariance
- Can be manifest as an energy dependent speed of light
- Gamma ray bursts and AGN flares provide an excellent probe of LIV

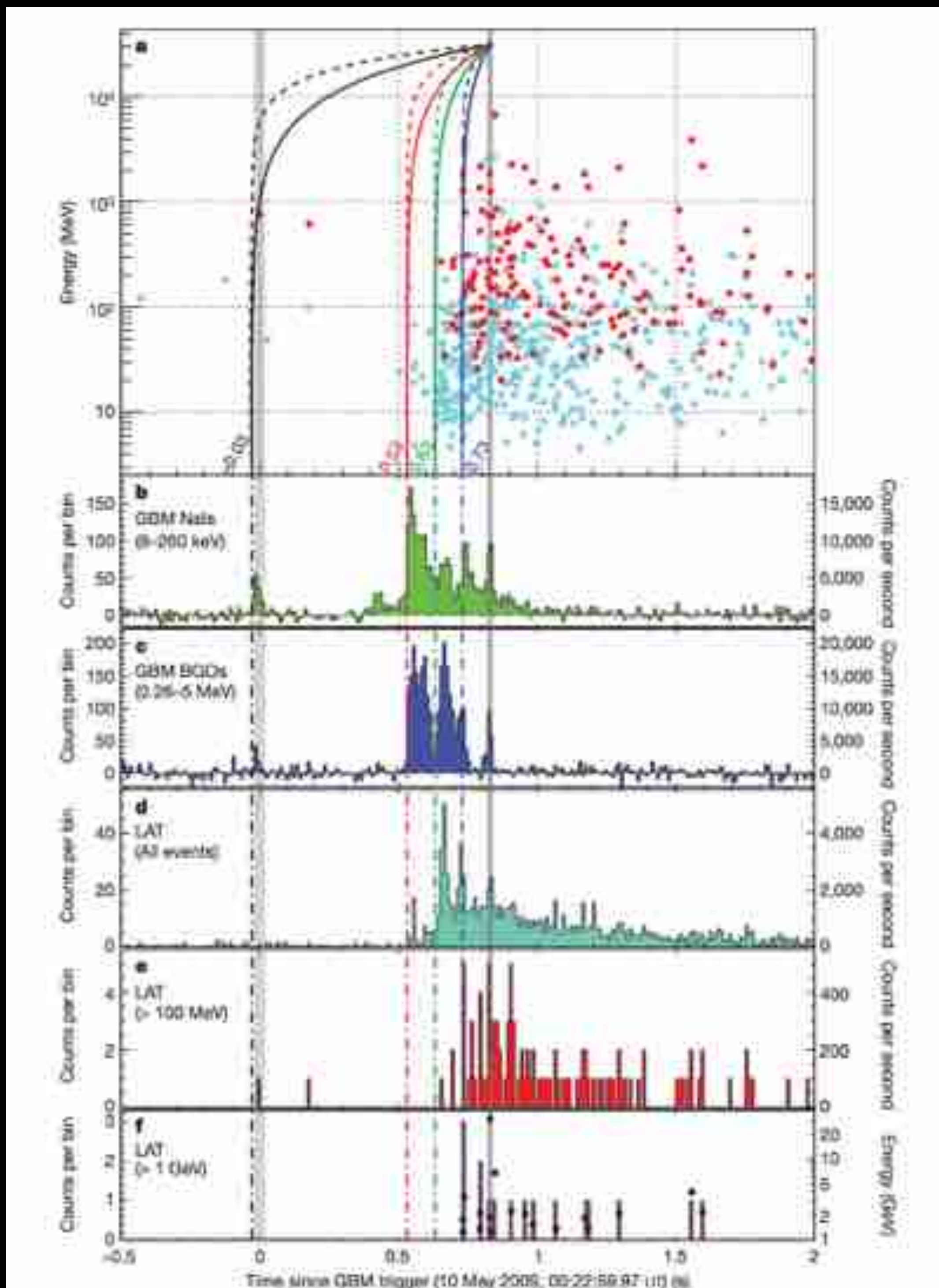


L. Smolin, 2004, Scientific American

$$v_l \approx c\left(1 - \xi_1 \frac{E}{M_{QG}}\right)$$

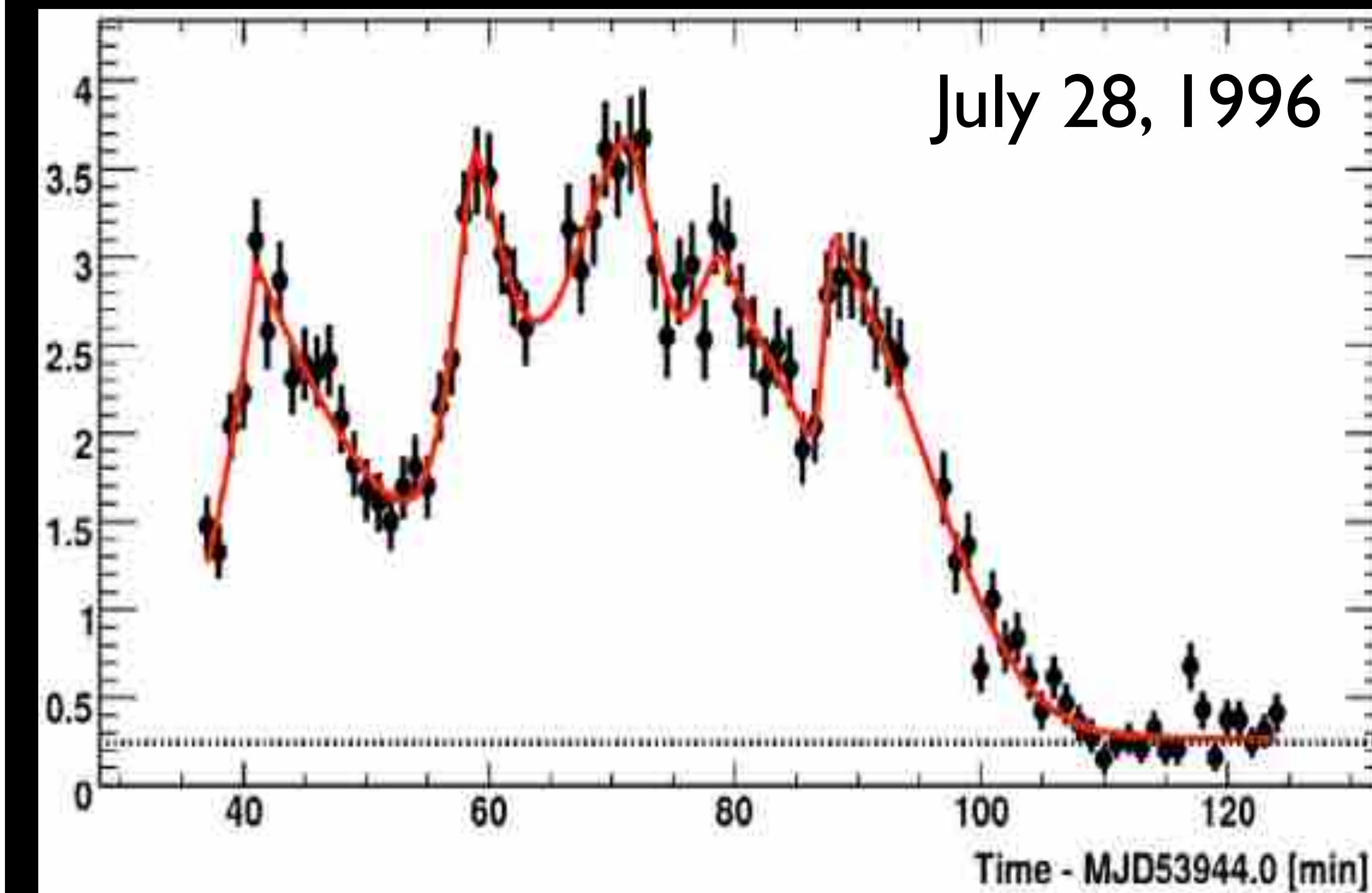
$$v_q \approx c\left(1 - \xi_2 \frac{E^2}{M_{QG}^2}\right)$$

GRB 090510
z=0.903 E_{max} = 31 GeV



Fermi collaboration, Nature, 2009 v. 462 p331

PKS 2155-304
z=0.116   Emax=2 TeV



H.E.S.S. Collaboration, Astroparticle Physics, 2011 v34 p738