

OVERVIEW OF ASTROPARTICLE  
PHYSICS

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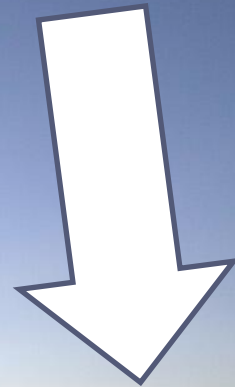
Dr. Karsten Berger

Instituto de Astrofísica de Canarias, La Laguna, Spain

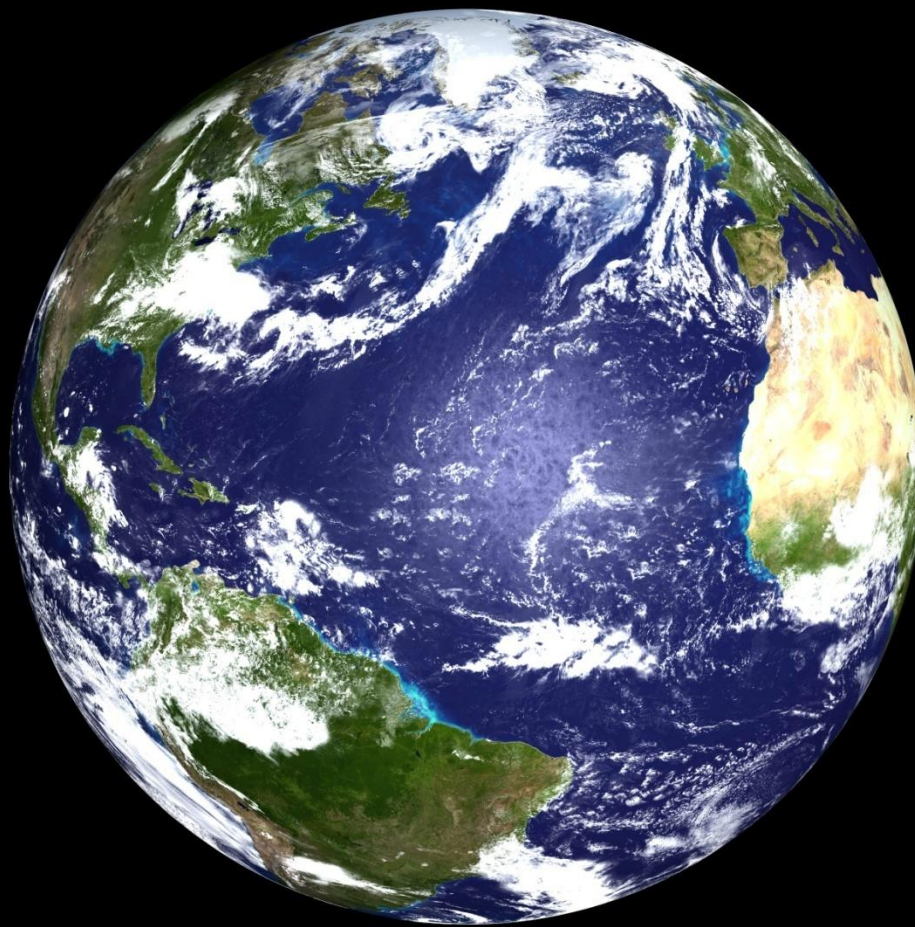
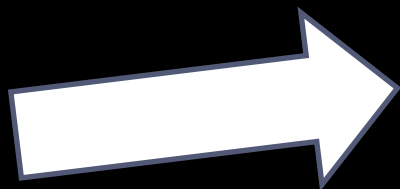


Your detector is here

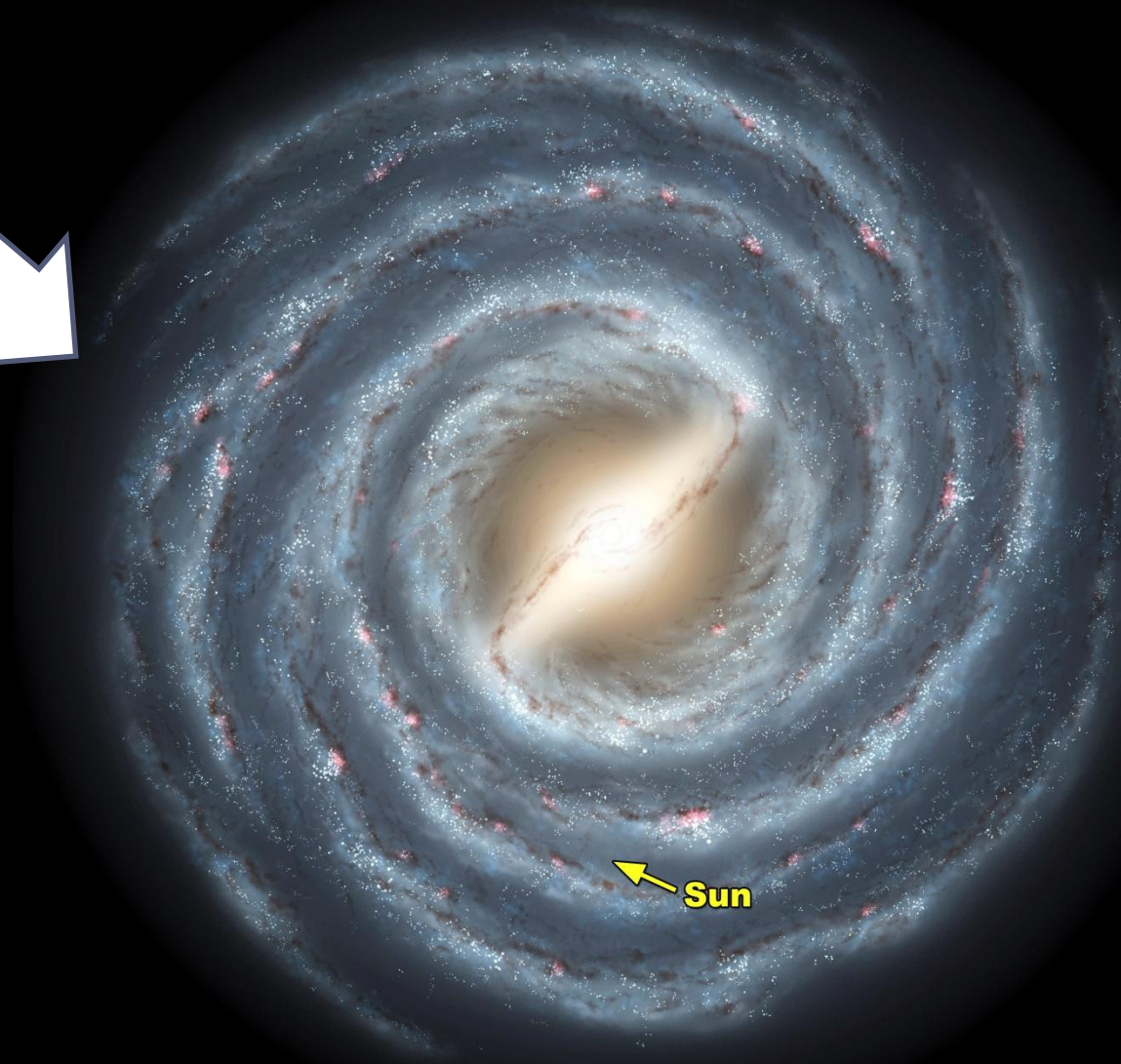
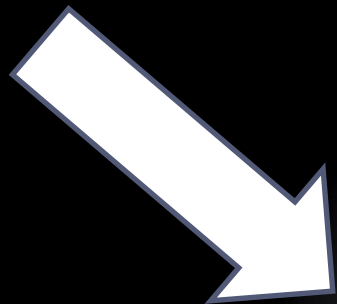
Our detectors are here...



And here...



And here...

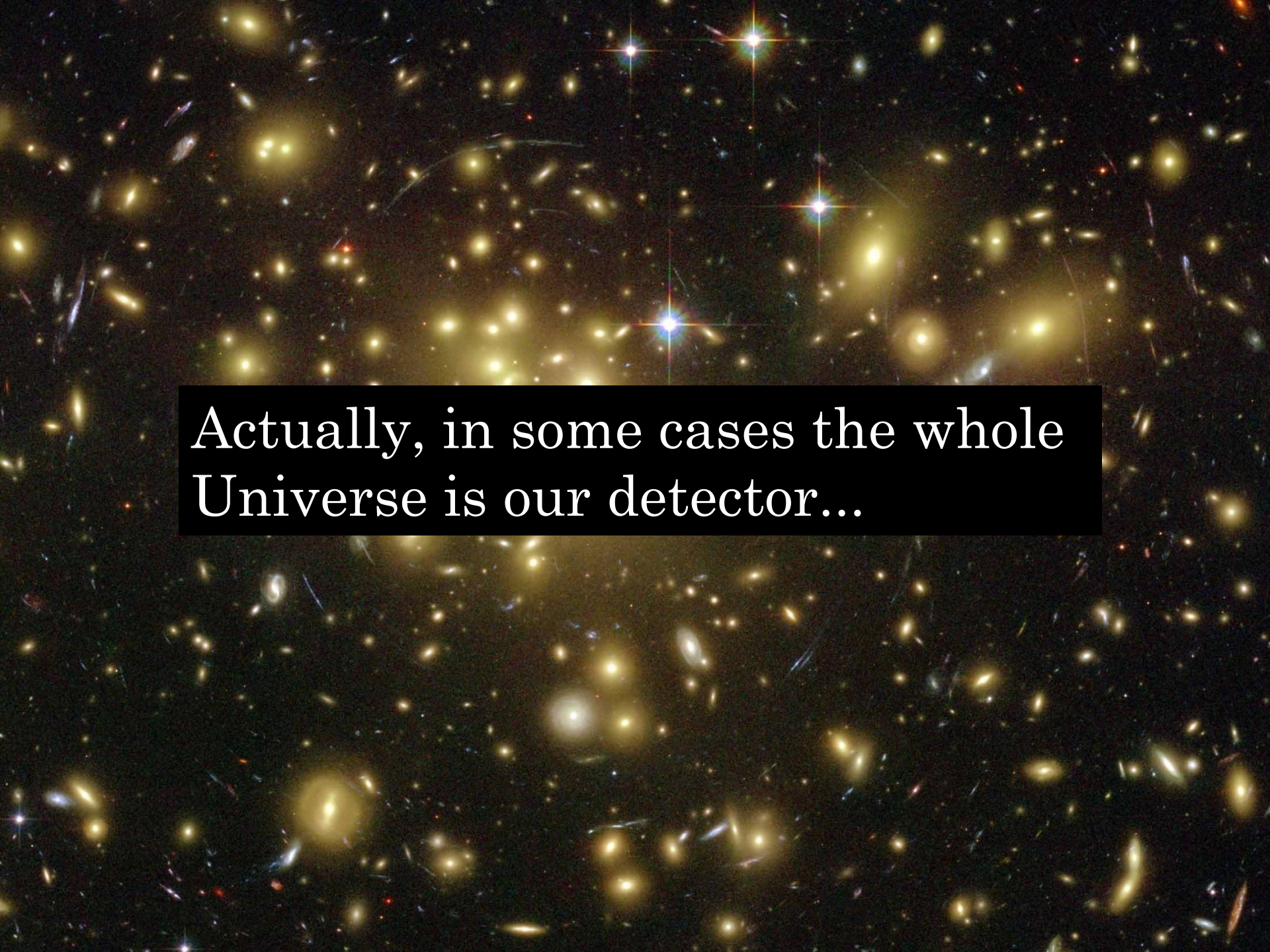


Sun

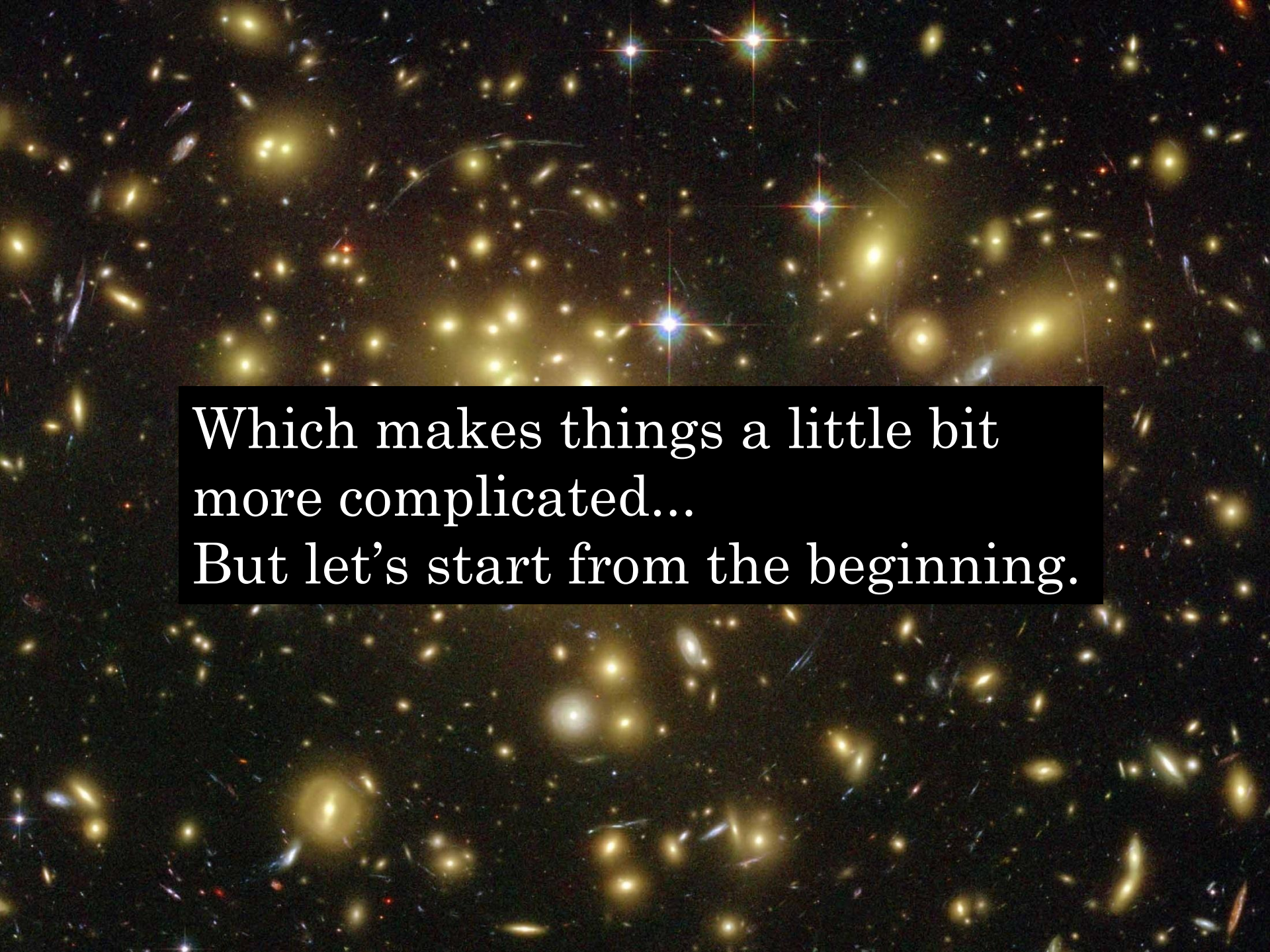


And here...



A deep field image of the universe, showing a vast field of galaxies and stars. The background is dark, with numerous bright yellow and white stars scattered throughout. Several prominent blue stars are visible, each with a cross-shaped diffraction pattern. The galaxies are mostly small, distant objects, appearing as faint, elongated shapes in various colors, including yellow, white, and blue. The overall scene is a rich, multi-colored field of celestial objects.

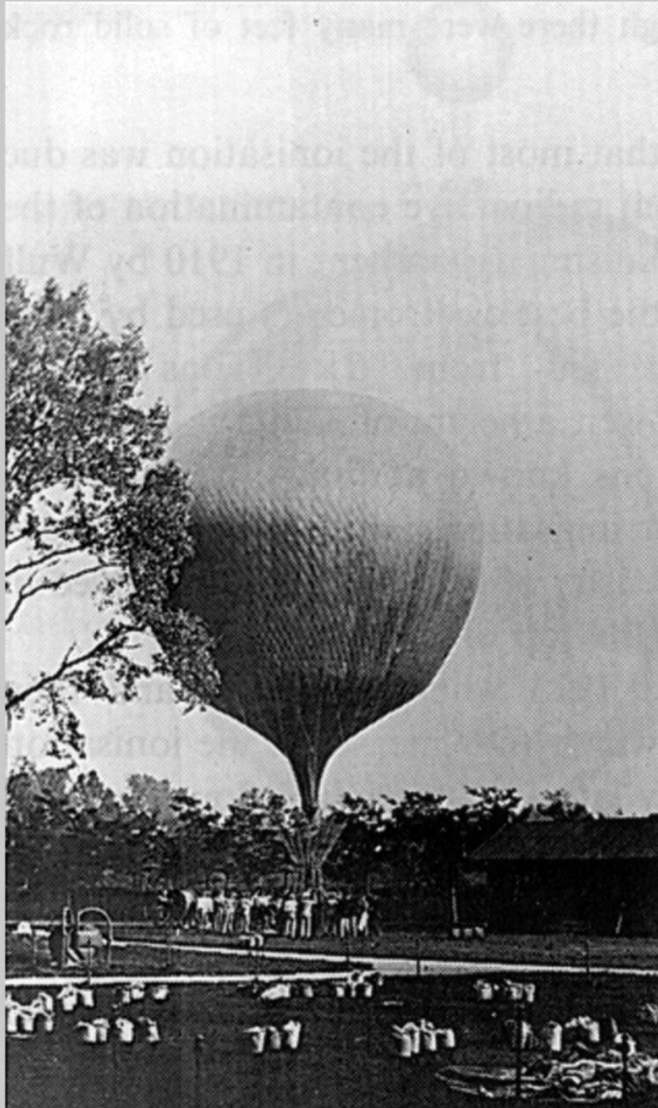
Actually, in some cases the whole  
Universe is our detector...

A vast field of galaxies, including spiral, elliptical, and irregular shapes, scattered across a dark cosmic background. The galaxies are primarily yellow and white, with some blue and red ones interspersed. A grid of faint red lines is overlaid on the image, and several bright stars with diffraction spikes are visible.

Which makes things a little bit  
more complicated...  
But let's start from the beginning.

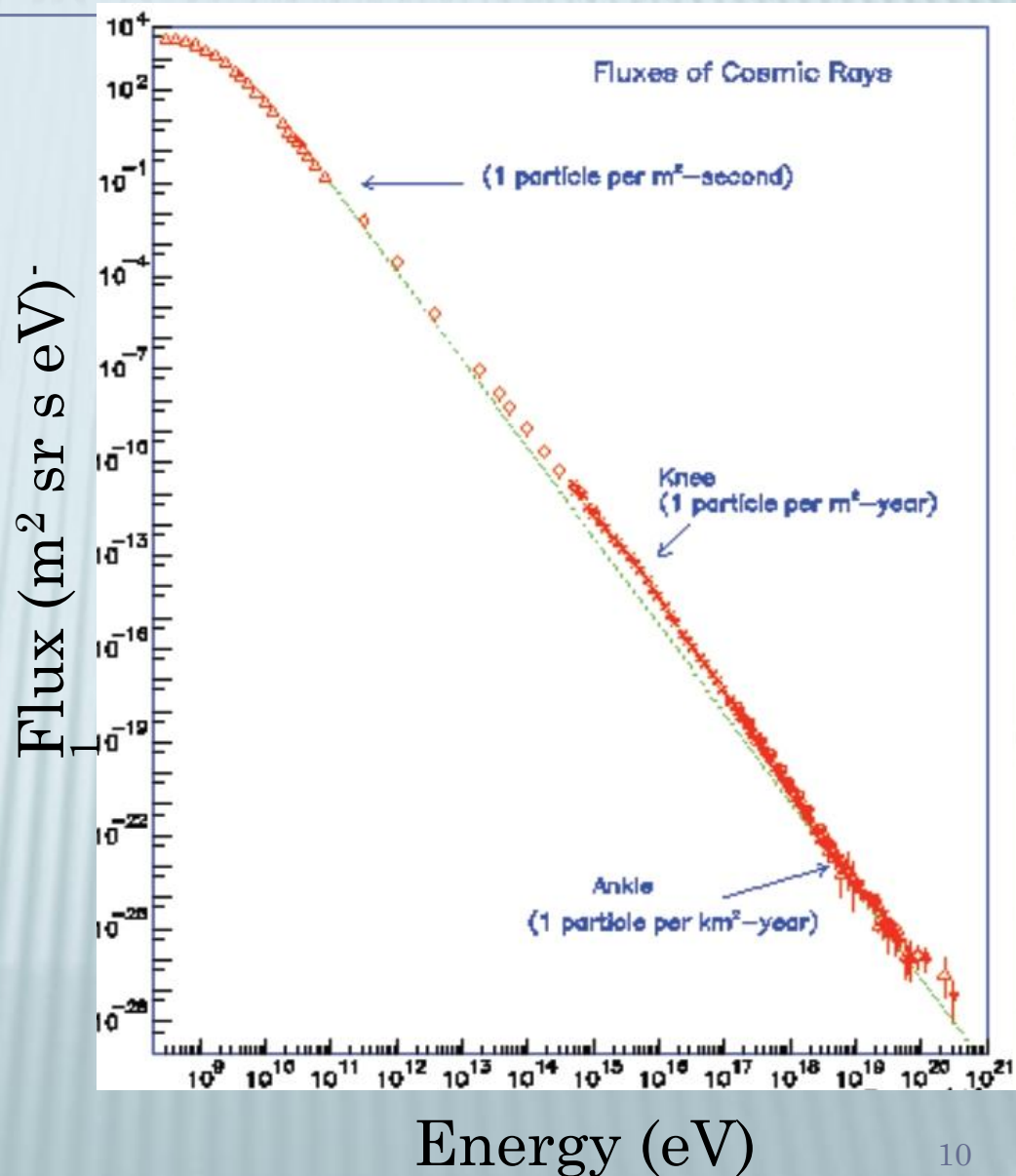


# DISCOVERY OF "COSMIC RAYS" IN 1912



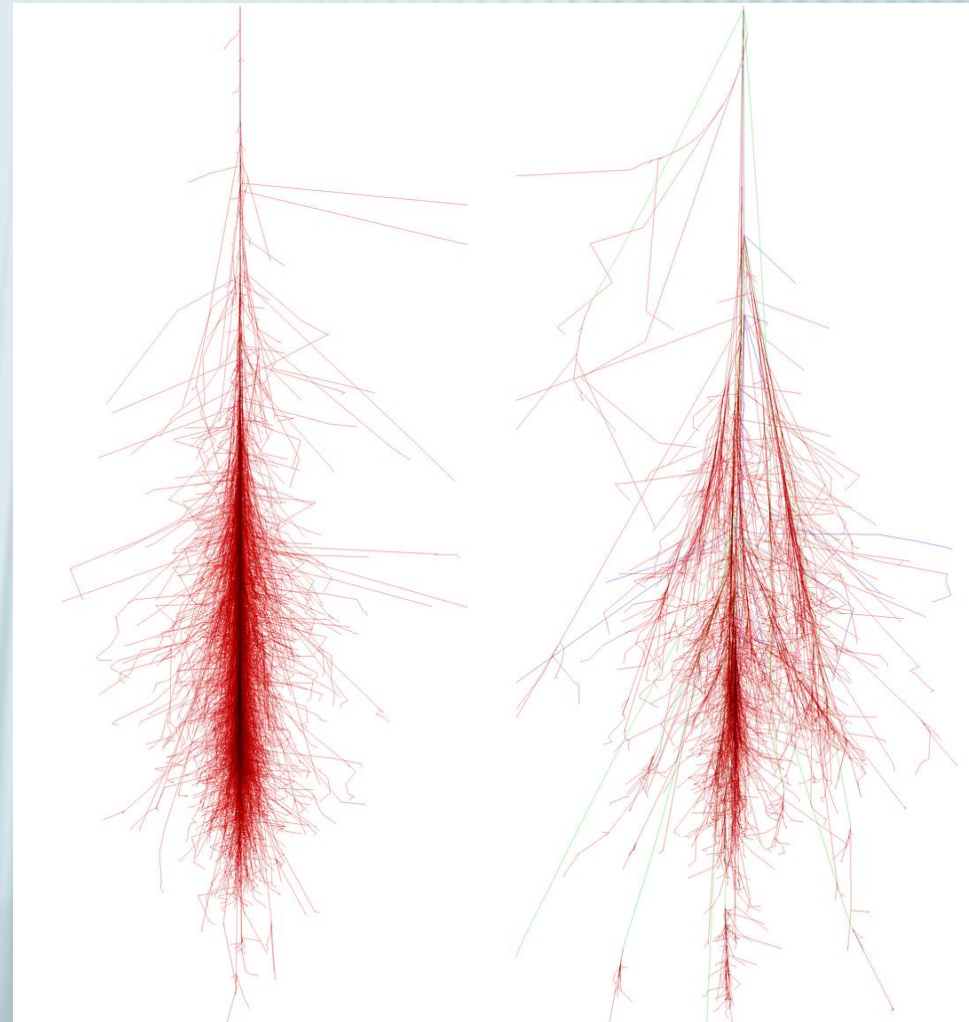
# DISCOVERY OF “COSMIC RAYS”

- × Composition: ca. 90% protons, 10% helium, heavier ions and “electrons”, only 0.01% photons, neutrinos?
- × Energy spectrum: power law with some features
- × What are the sources of these cosmic rays?
- × How do they produce them?
- × How do they accelerate the cosmic rays?
- × What is the maximum energy?



# HOW THE EARTH PROTECTS US FROM COSMIC RAYS

- ✘ Interaction with air molecules (pair production in coulomb field, interactions with nucleus) produce  $e^+/e^-$  pairs, pions, k-mesons, neutrinos, etc.
- ✘ Cascading effect, development of particle showers
- ✘ Shape and composition of showers unique tracer for primary particle

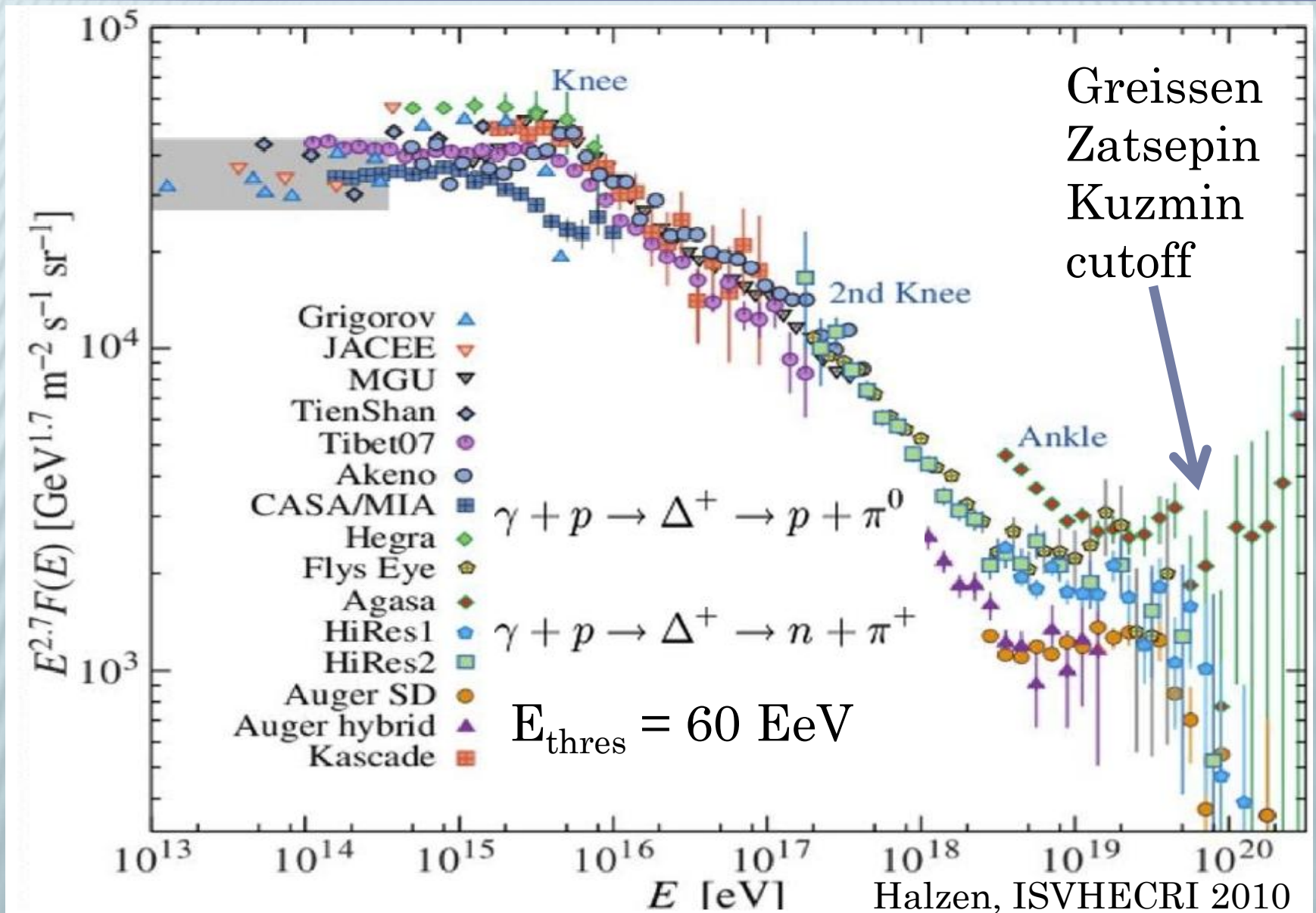


Primary particle:

Gamma

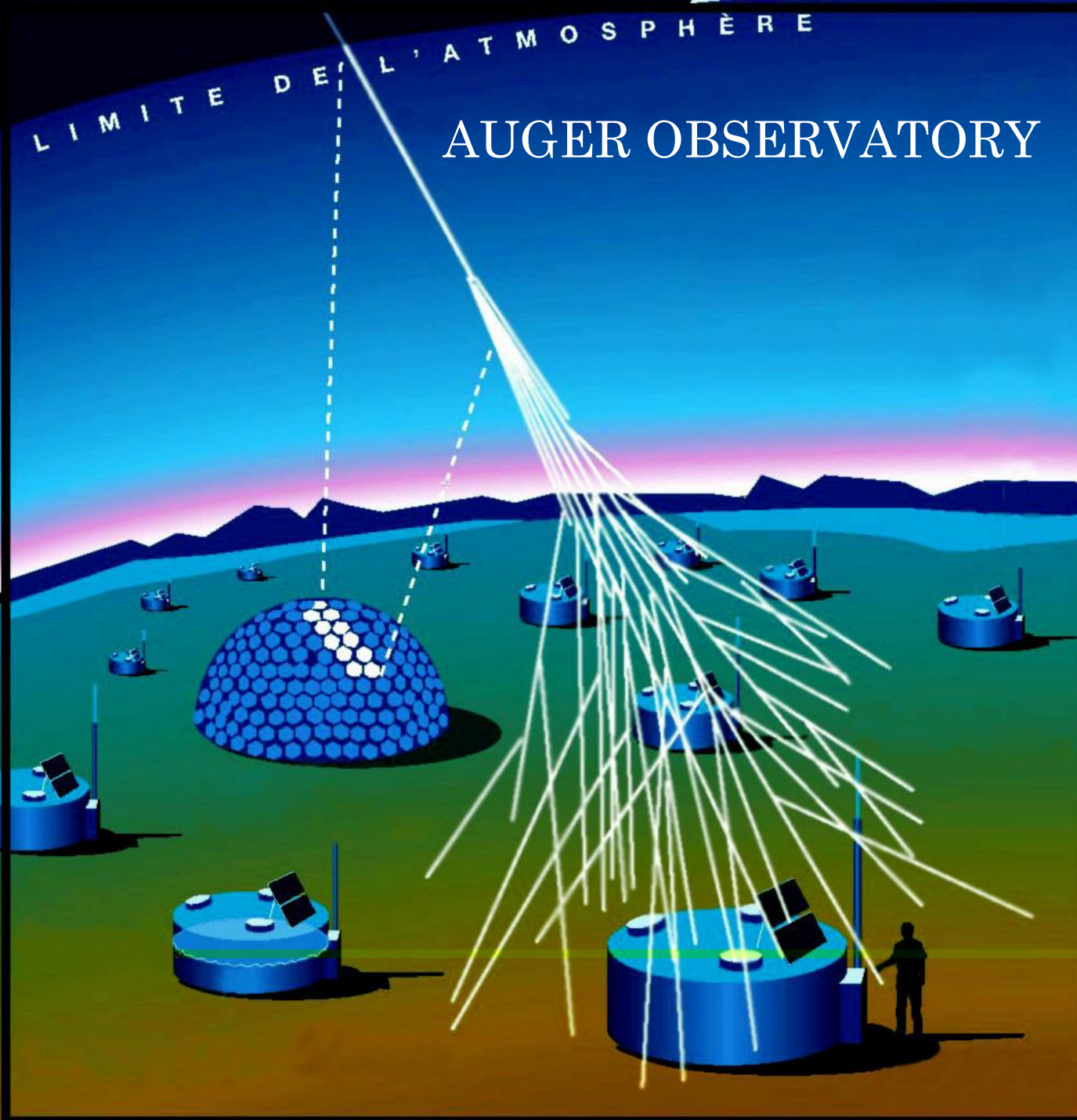
Proton

# AGREEMENT BETWEEN INSTRUMENTS



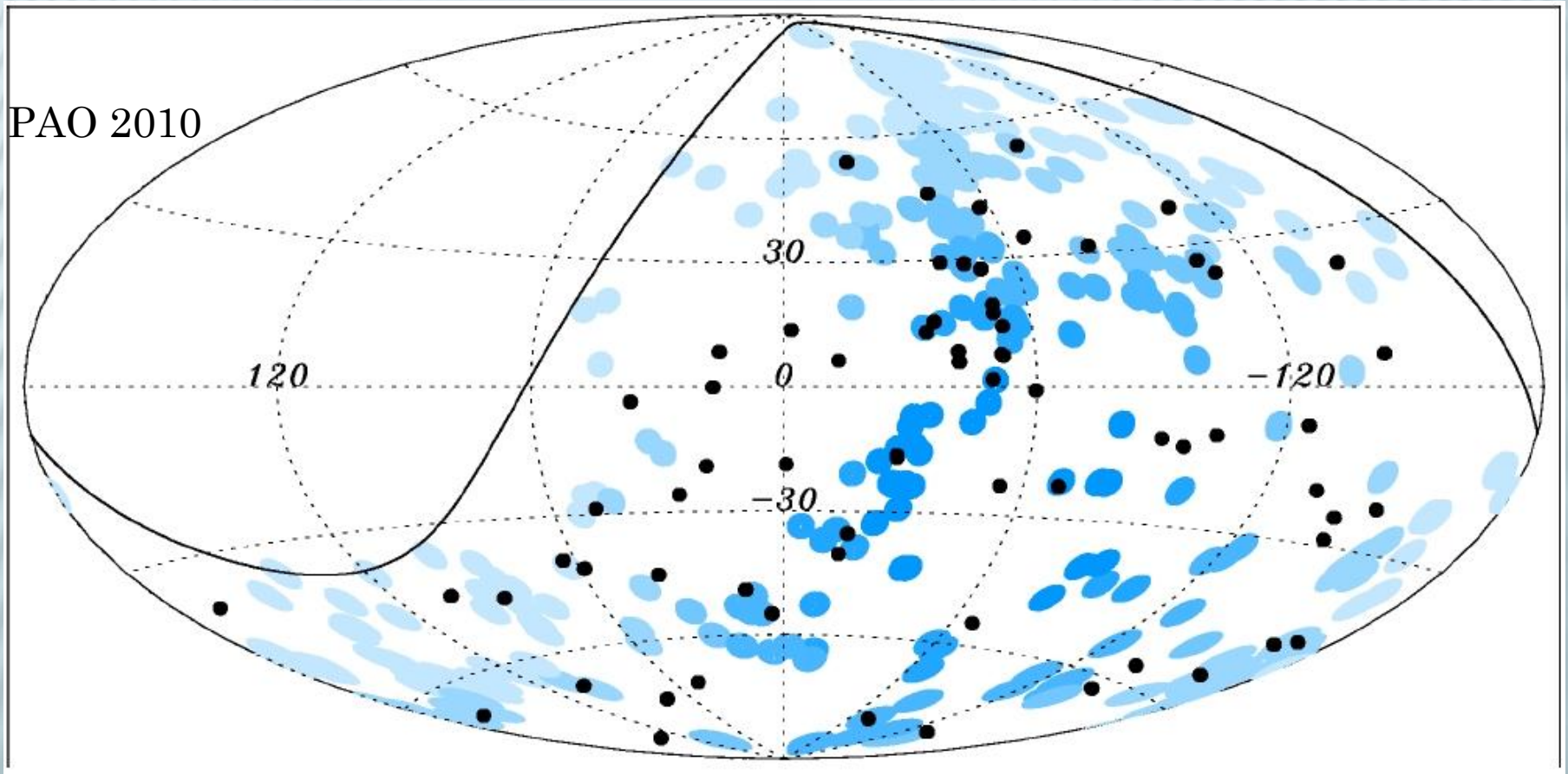
LIMITE DE L'ATMOSPHÈRE

# AUGER OBSERVATORY



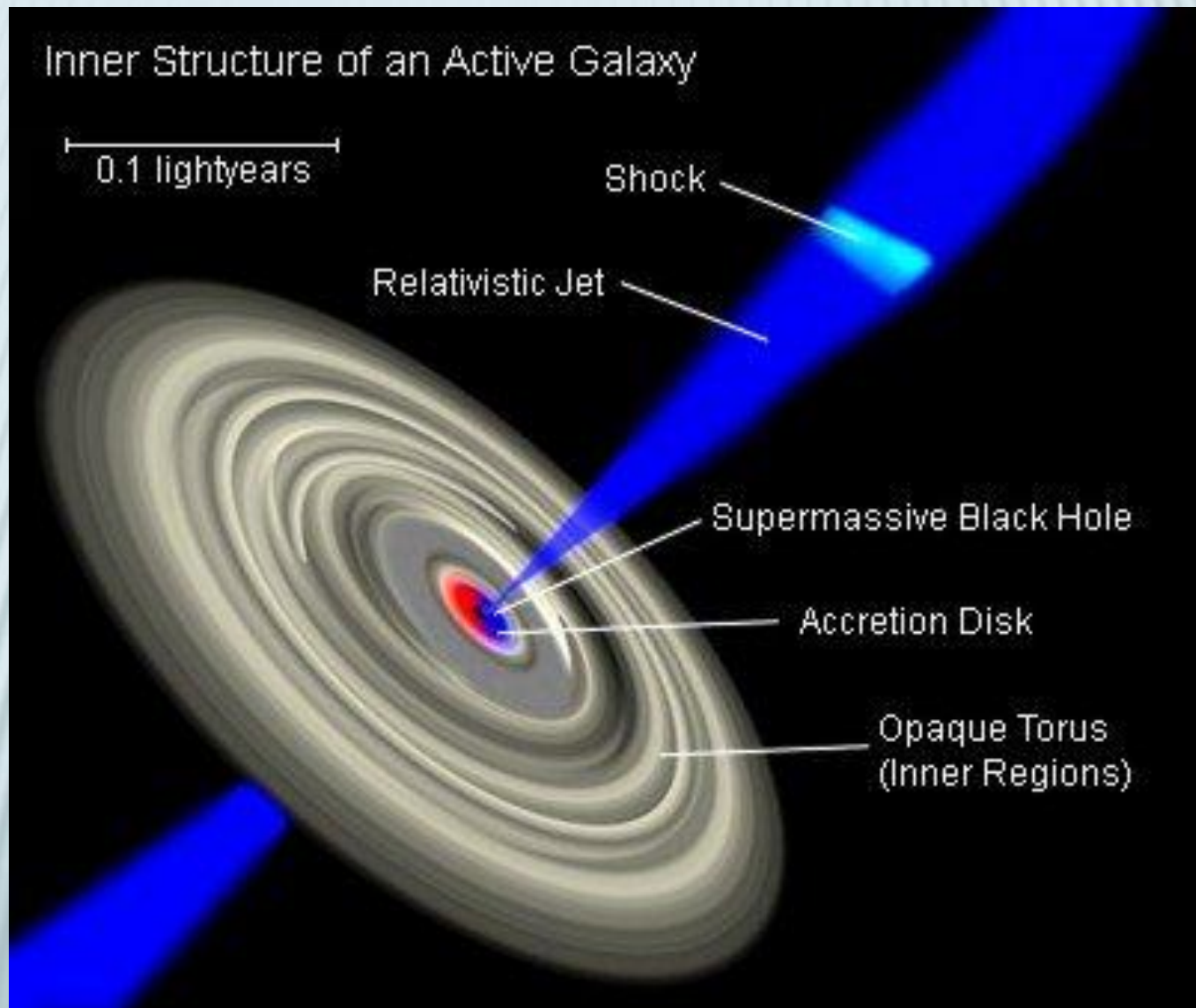
# GZK SUPPRESSION

- ✘ The highest energy cosmic rays must be from nearby extra galactic sources  $< 50$  Mpc

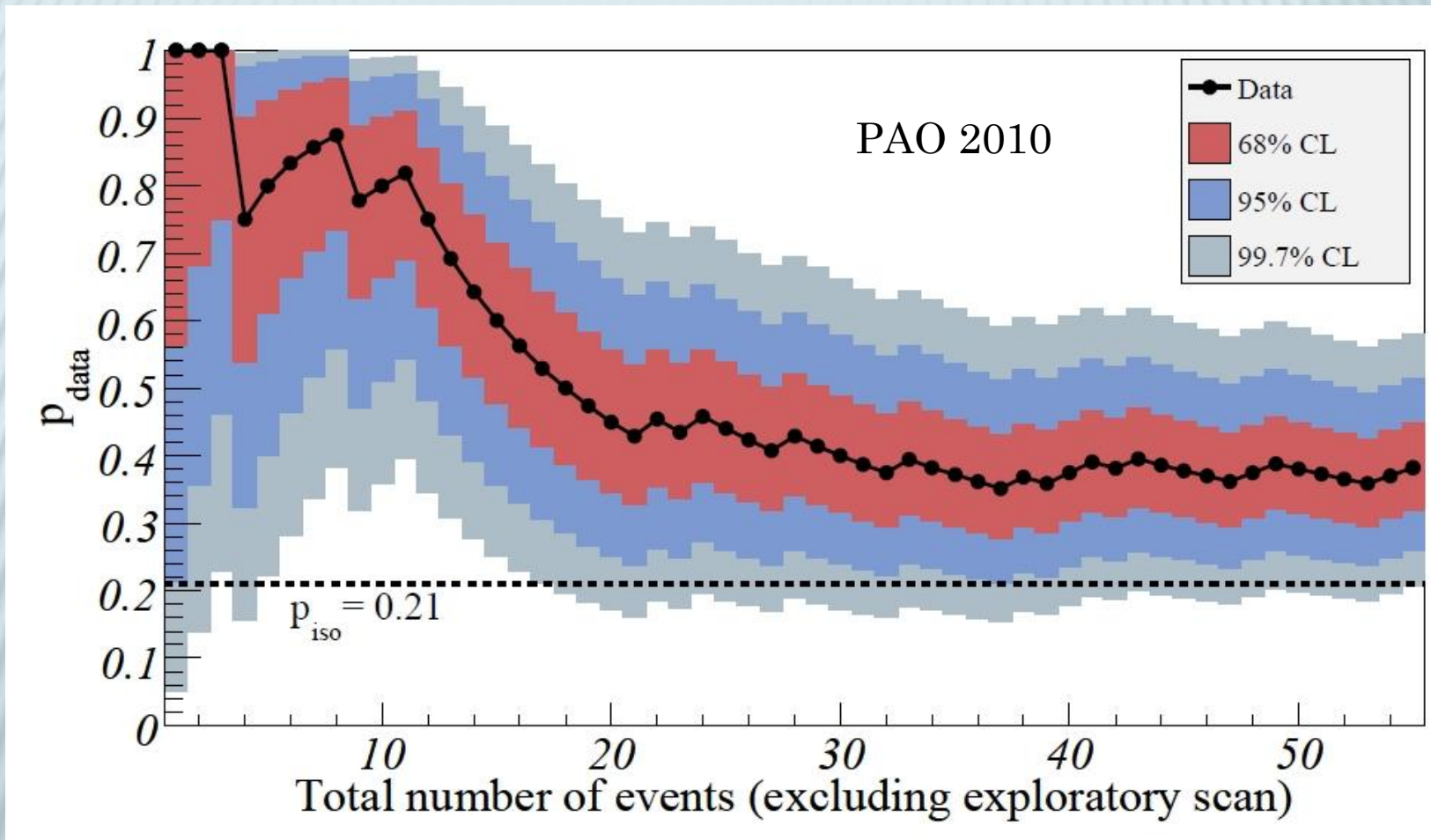


Black dots: Arrival directions of cosmic rays  $E > 55$  EeV  
Blue dots: AGNs of the Véron-Cetty and Véron Catalogue

# WHAT IS AN AGN?



# AGNS AS THE SOURCE OF COSMIC RAYS?



-> HighRes did not observe such a correlation in the northern hemisphere...

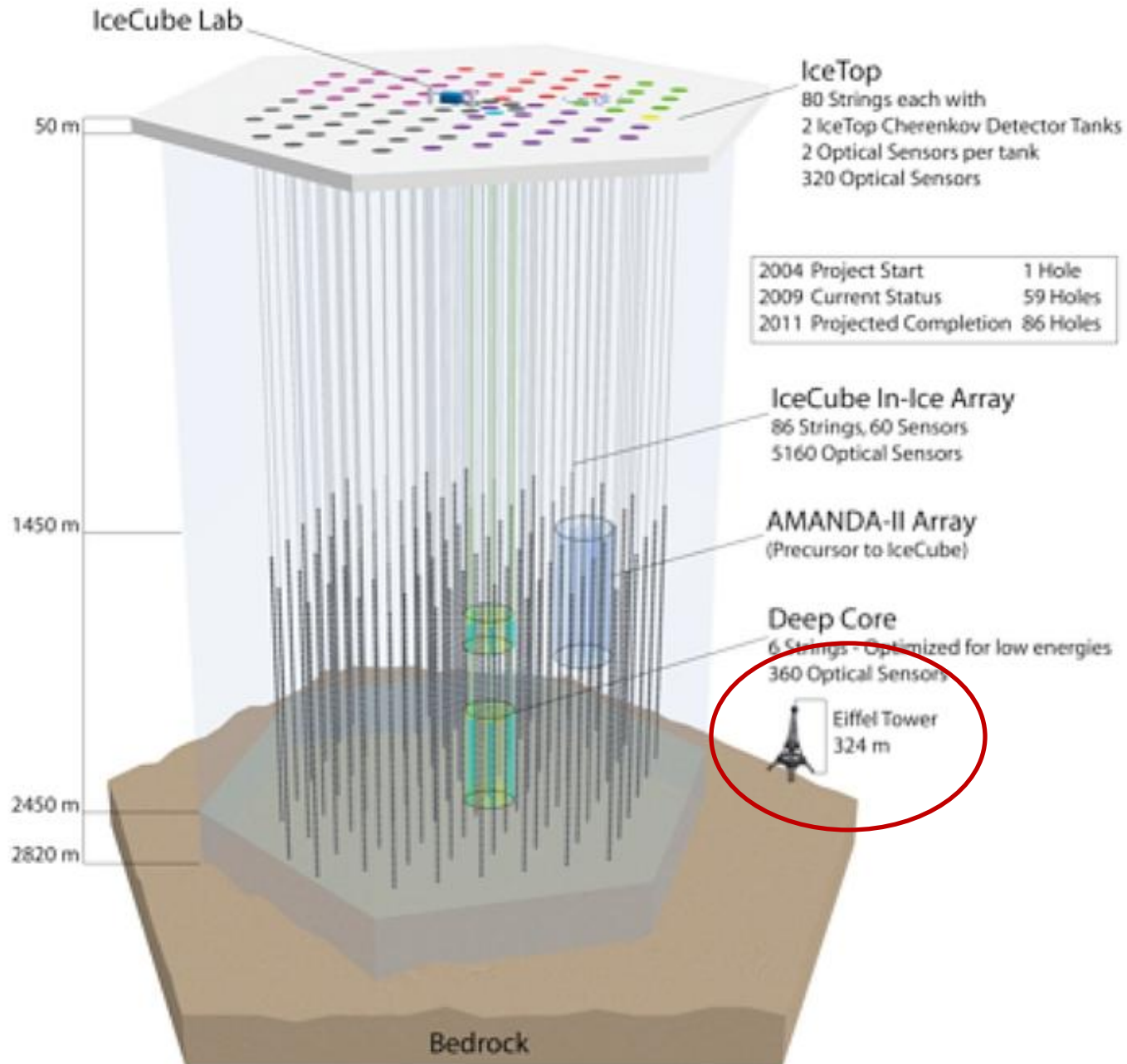


# COSMIC RAY PROPAGATION

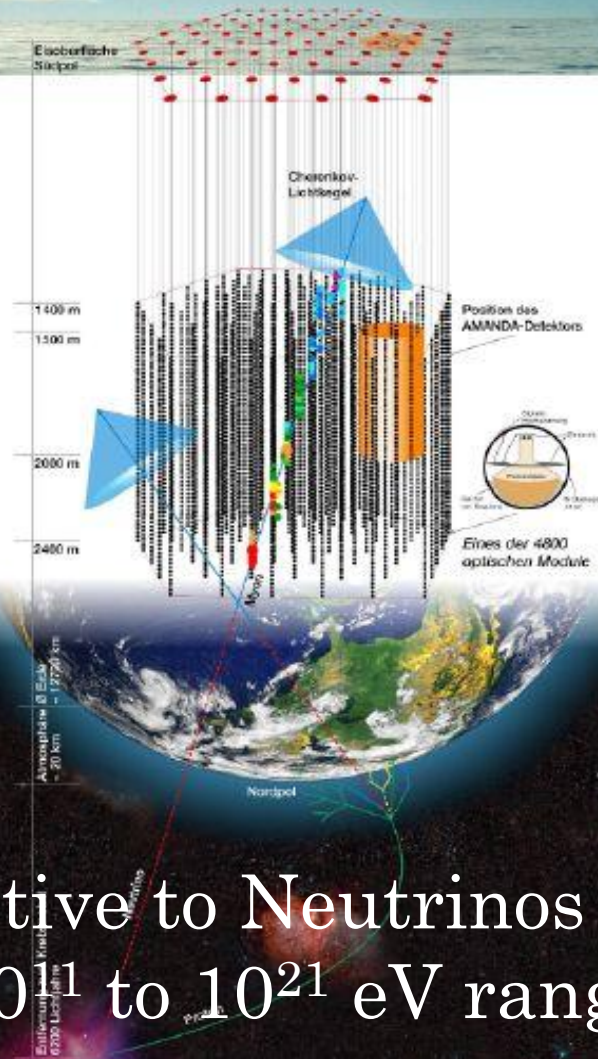
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- × Protons deflected by magnetic fields (extra galactic magnetic fields poorly constraint)
- × Photons and neutrinos point directly towards the source
- × VHE photons interact with IR radiation of early stars and galaxies and produce  $e^+/e^-$  pairs -> “EBL” absorption limits the  $\gamma$ -ray horizon
- × Cosmic neutrinos could be detected over vast distances -> interesting to probe the early universe and young cosmic ray emitters

# IceCube



# Detection principle

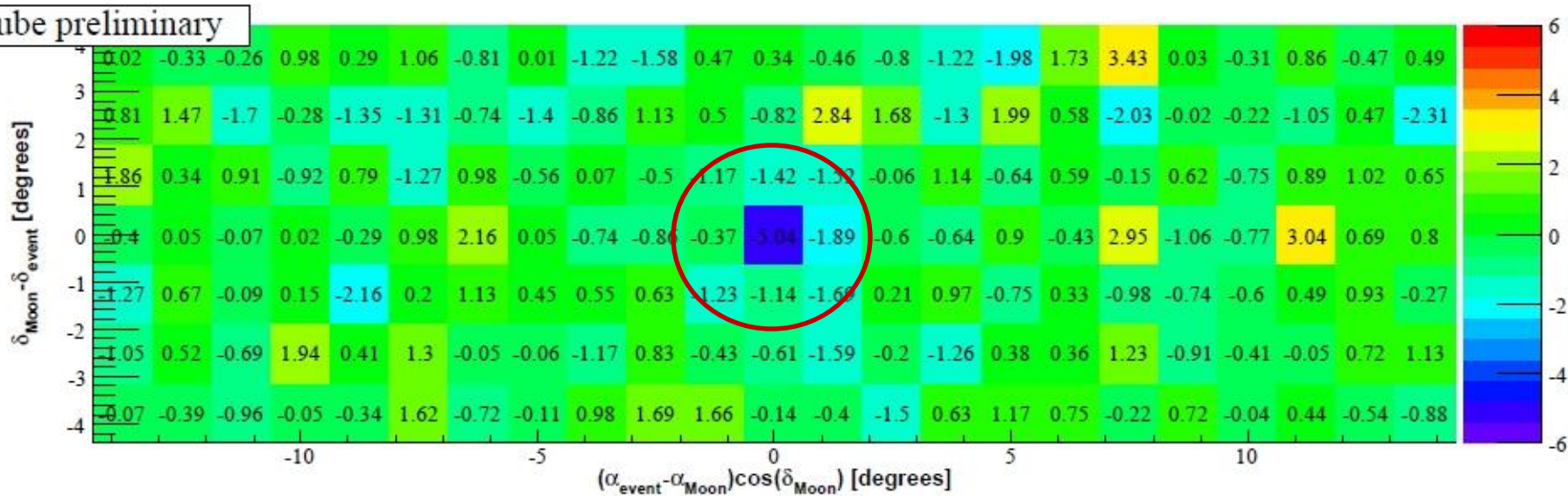


Sensitive to Neutrinos in  
the  $10^{11}$  to  $10^{21}$  eV range

# ICECUBE

- × Interaction with nuclei produces Muons, Tauons
- × They produce Chrenkov light
- × Detected by PMTs in strings in the arctic ice
- × Reconstruction of shower composition and direction/energy
- × Completion in 2011
- × Very low event rate -> only few events from external (not atmospheric) Neutrinos expected, detection of GZK Neutrinos more likely

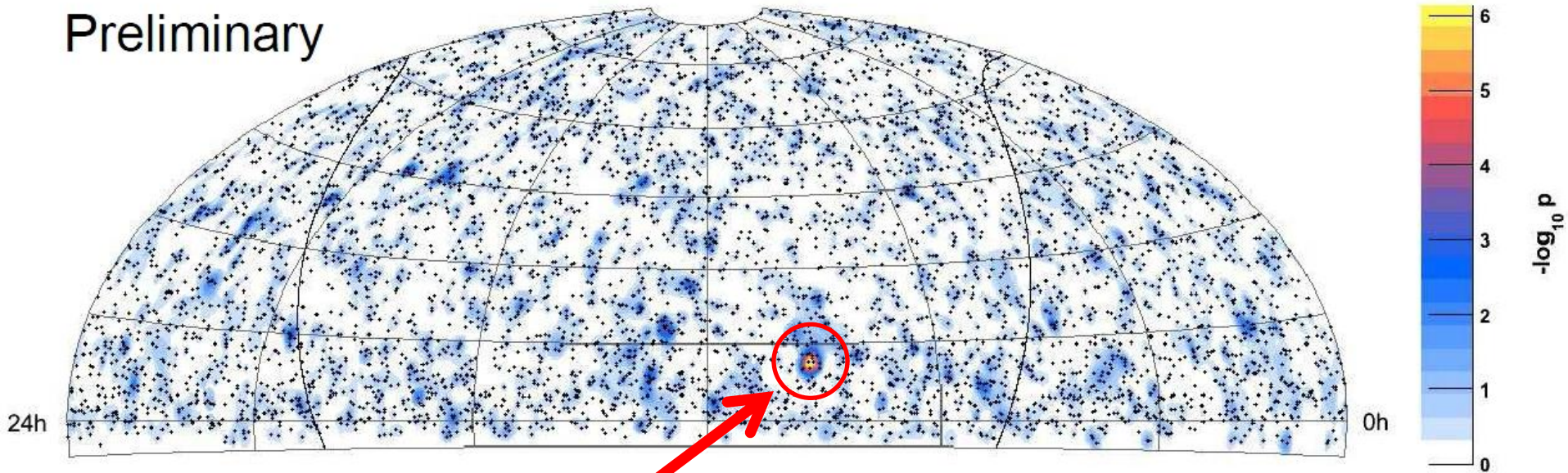
Yes, we can... also use the Moon as a detector!



Ice Cube Coll.  
ICRC 2009

# ICE CUBE POINT SOURCE SEARCH

Preliminary

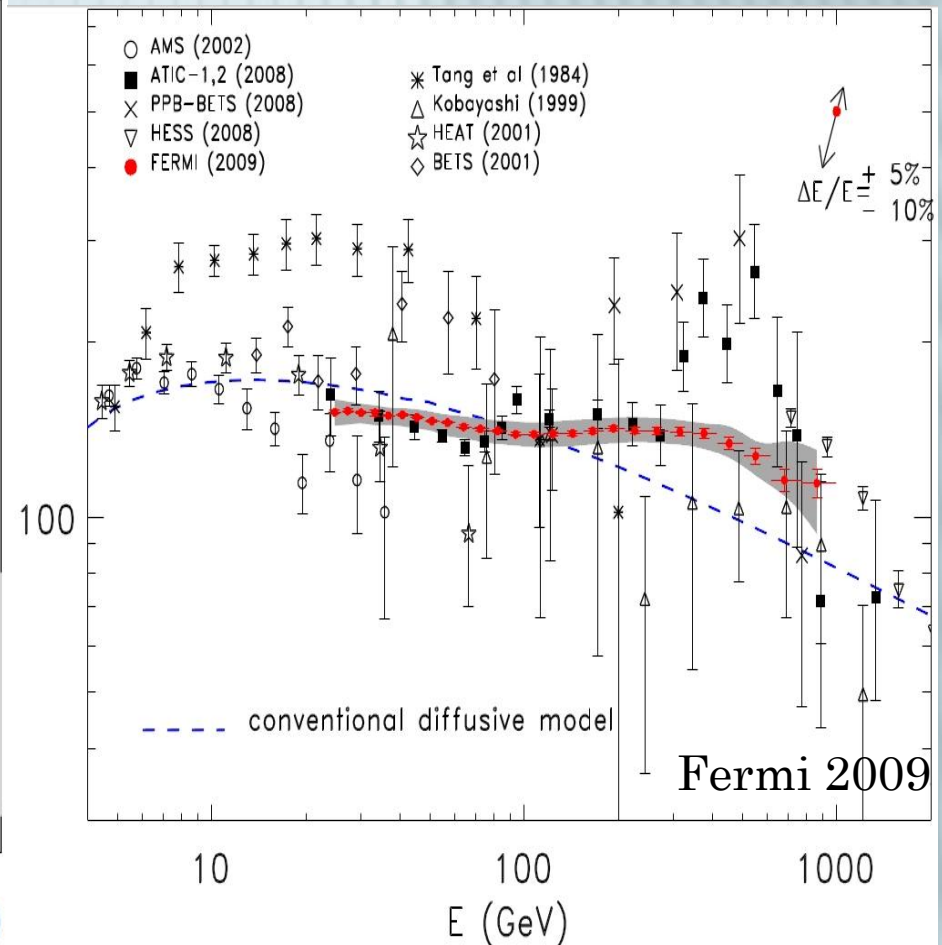
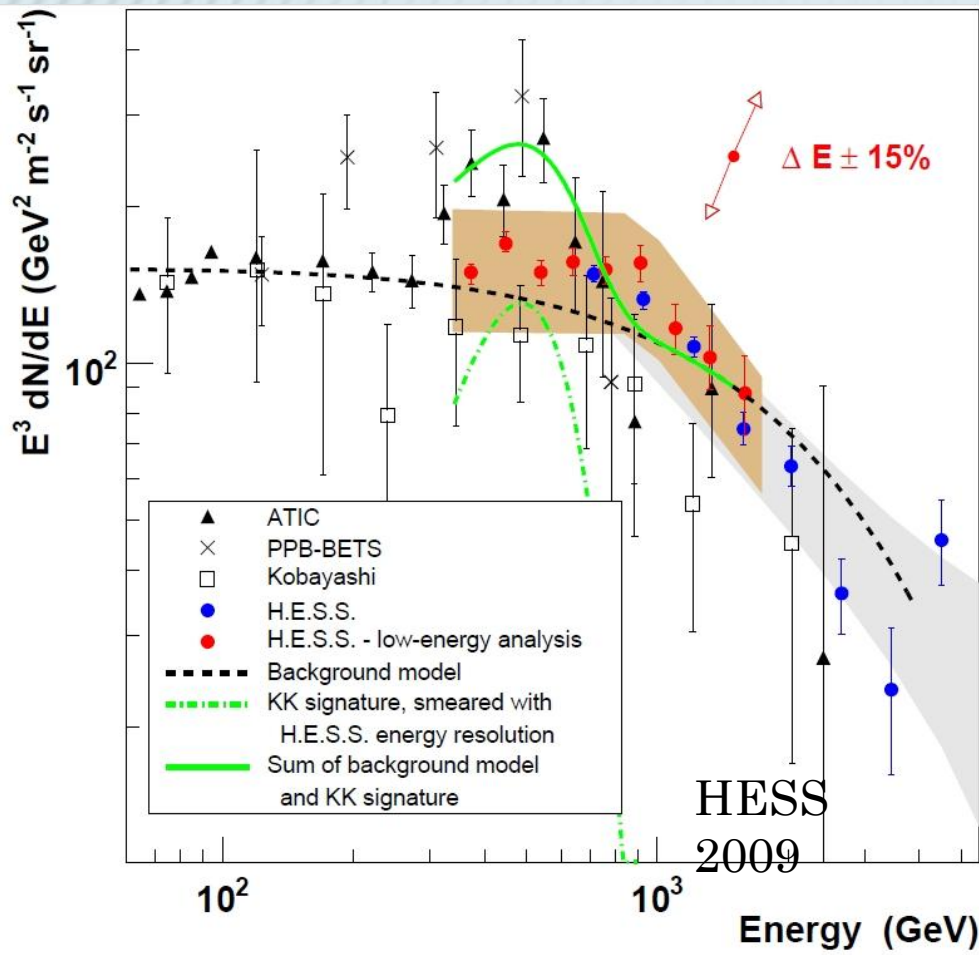


Is **NO!!!** significant or not?  
consider trials... Only  
 $2.2\sigma$  effect!

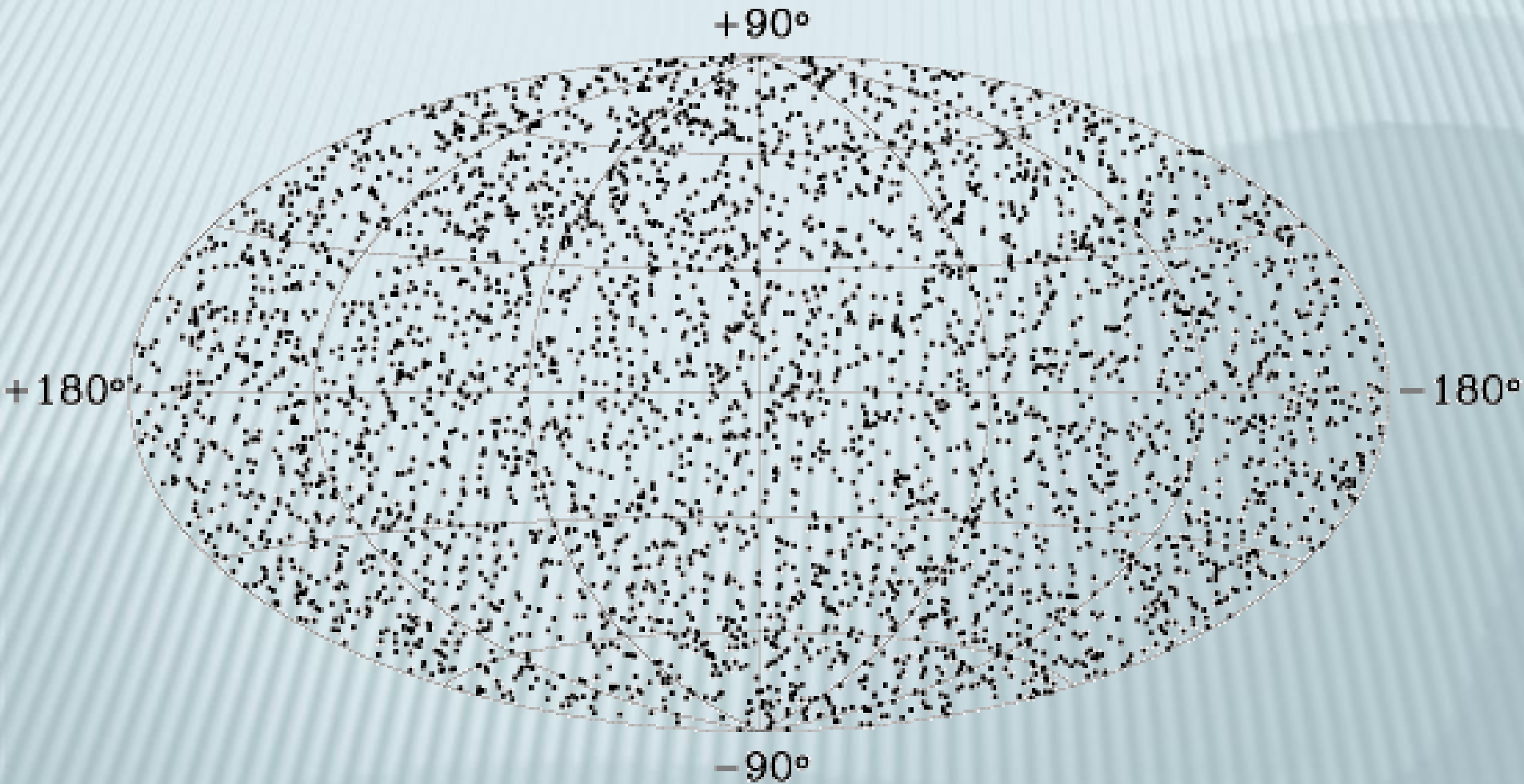
E. Strahler, et al.  
(IceCube Coll.),  
31<sup>st</sup> ICRC Lodz

# CR ELECTRON SPECTRUM

- Good agreement between Fermi and HESS!
- ATIC excess probably overestimated
- Explainable by nearby pulsar or dark matter annihilation



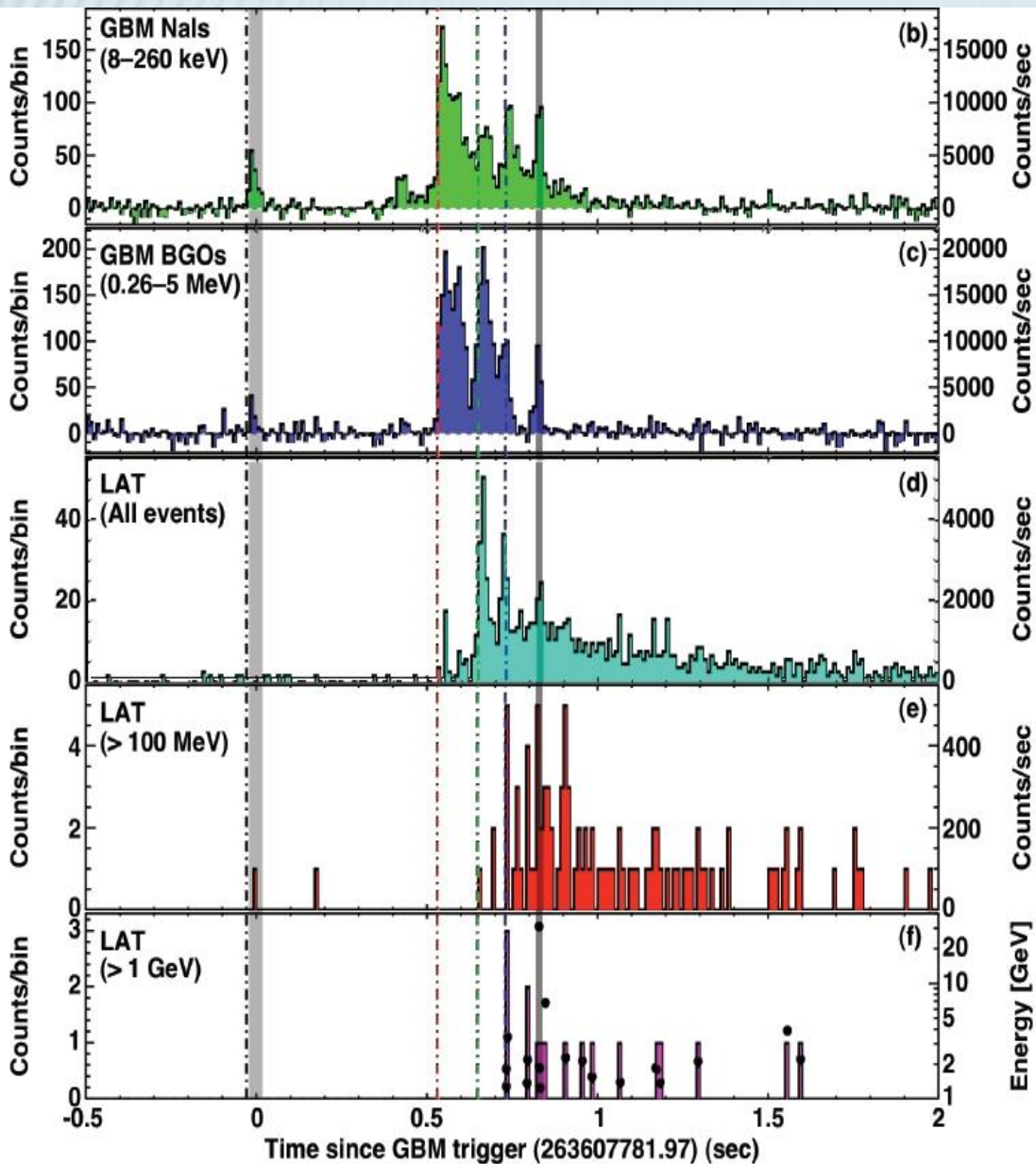
3906 GRBs  
(triggered & non-triggered)



Swift, uniform distribution, high  
redshift!



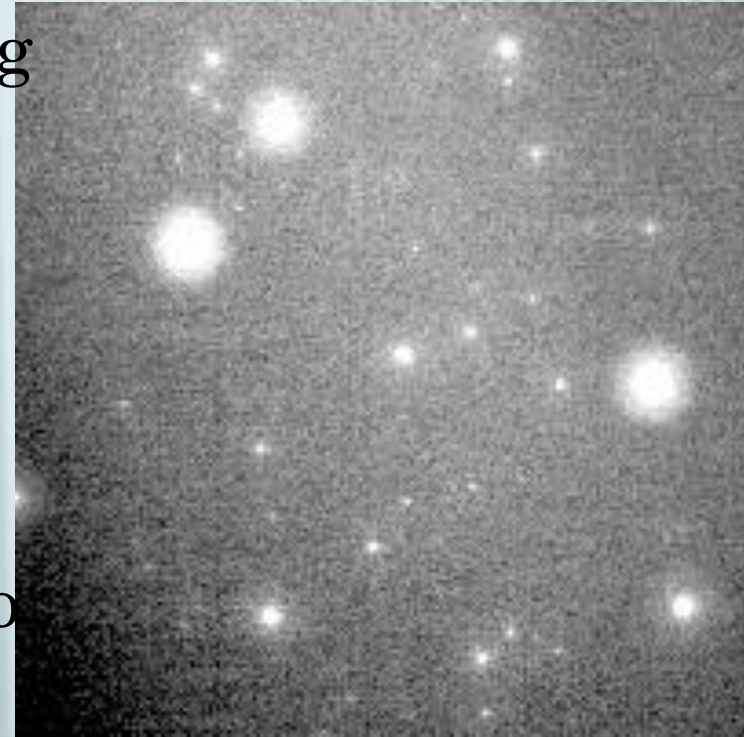
# GRB LIGHTCURVES: AN EXAMPLE



- ✘ Data from Fermi
- ✘ Cosmic distances
- ✘ Probe EBL, QG effects
- ✘ Most extreme explosions in the universe
- ✘ Still poorly understood
- ✘ Time delayed emission at higher energies

# WAITING FOR THE RIGHT GRB TO BE OBSERVED FROM GROUND

- Fermi discovered  $\gamma$ -ray emission of GRBs up to 30 GeV -> exciting prospects for detection with MAGIC (until now only upper limits)
- Fast slewing allows quick repositioning (< 20sec)
- Low zenith angles needed due to high redshift
- Why target GRBs from ground?
- Poor statistics at high energies -> cut off unknown -> important constraint for emission processes

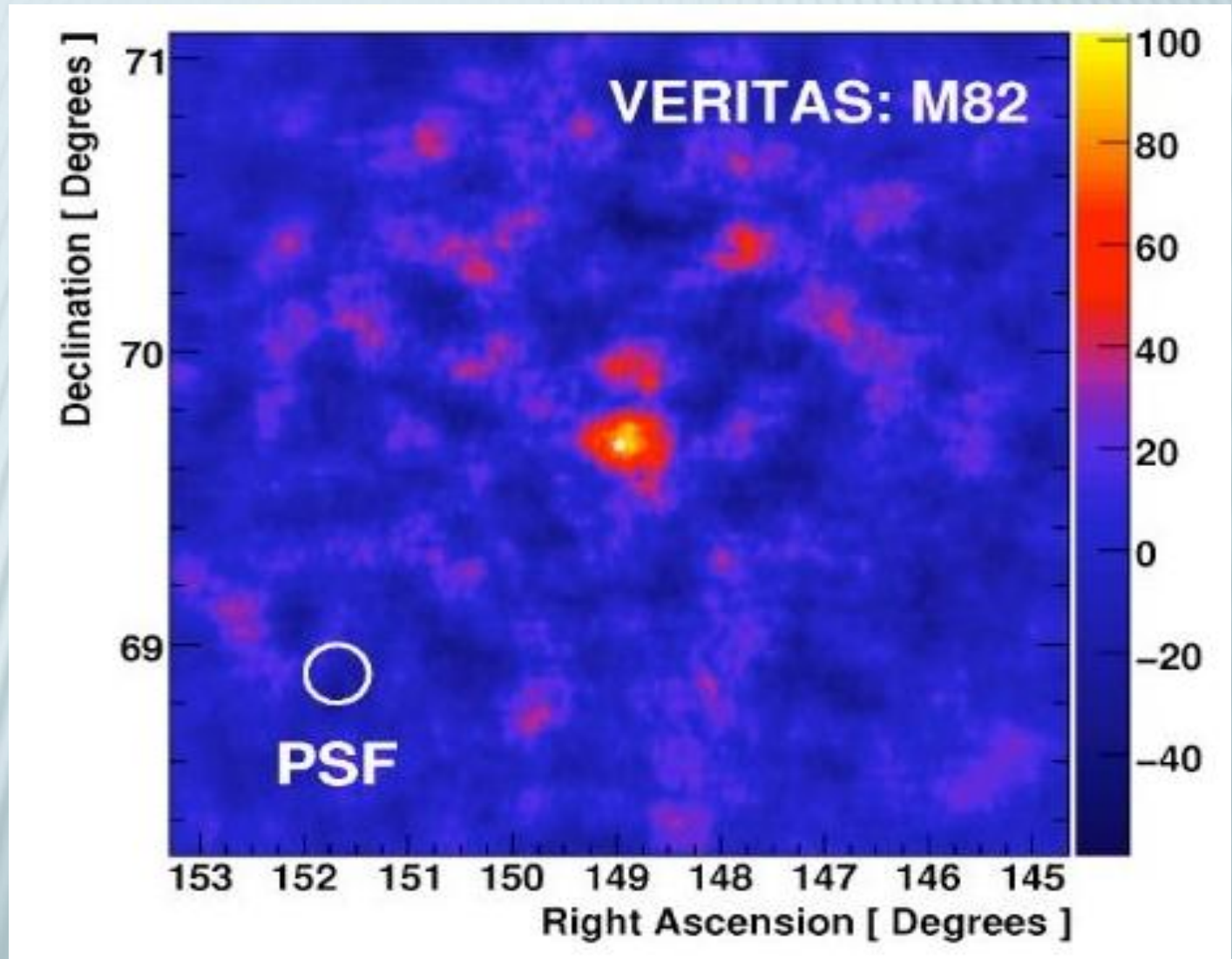


# STARBURST GALAXIES AS COSMIC ACCELERATORS



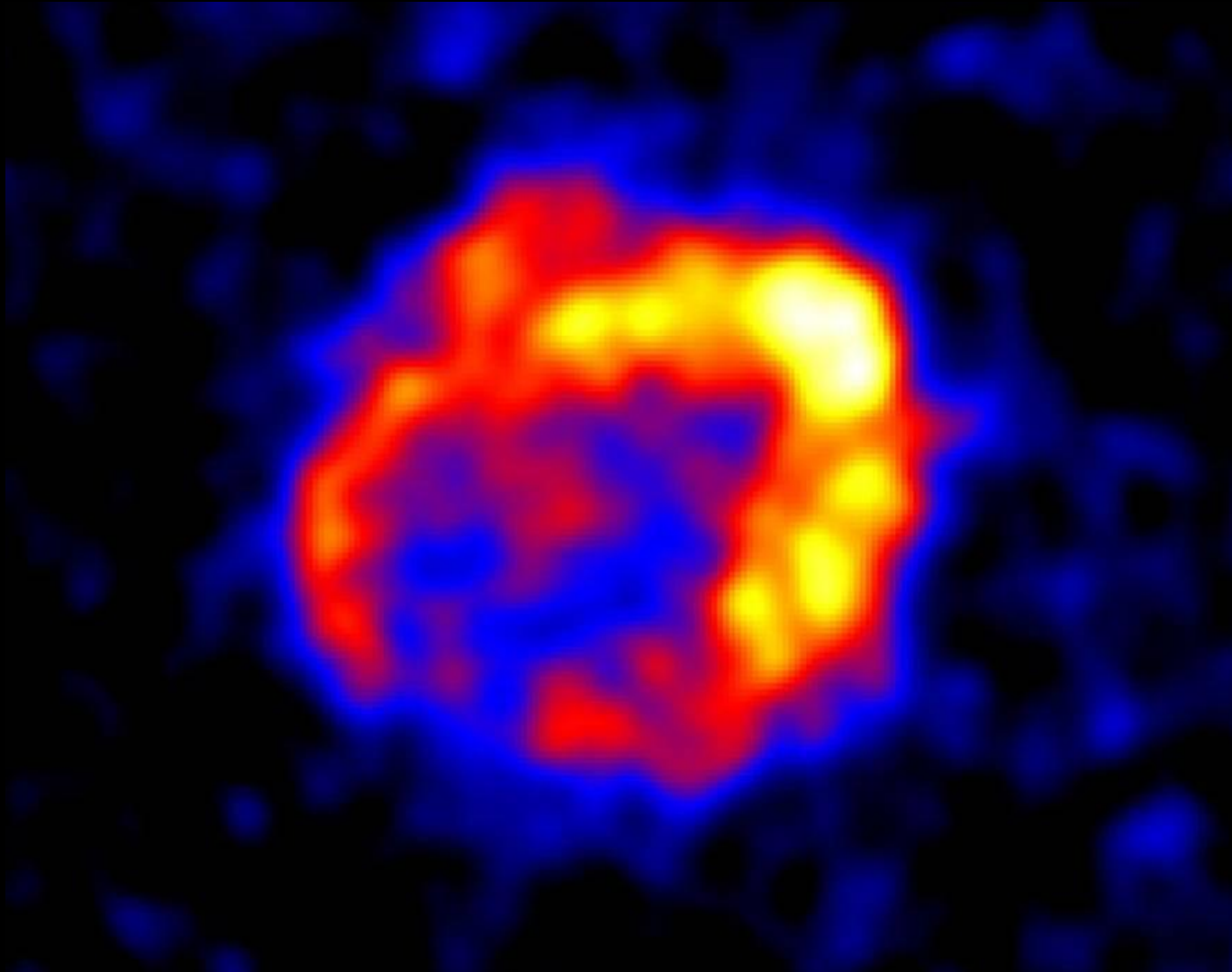
M82 HST

# STARBURST GALAXIES AS COSMIC ACCELERATORS



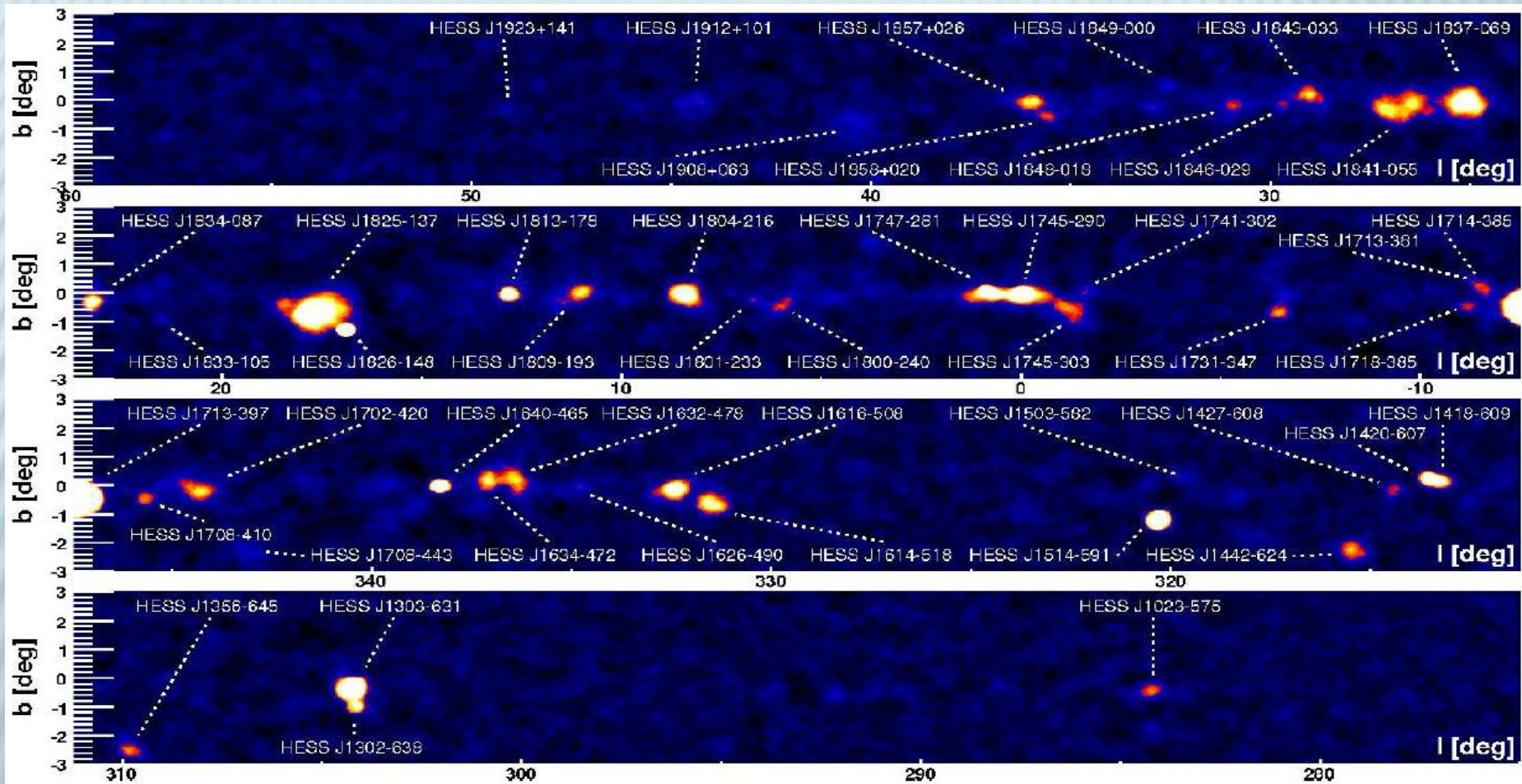
M82 Veritas  
VHE  $\gamma$ -rays

# Supernova Remnants are our best guess galactic cosmic ray producers



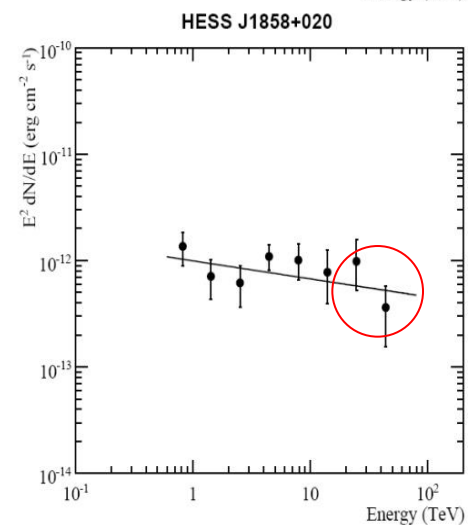
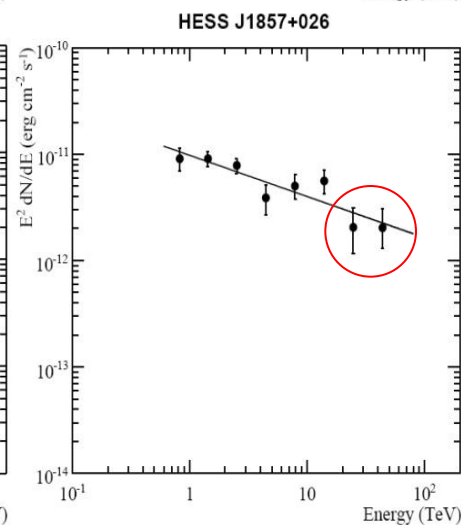
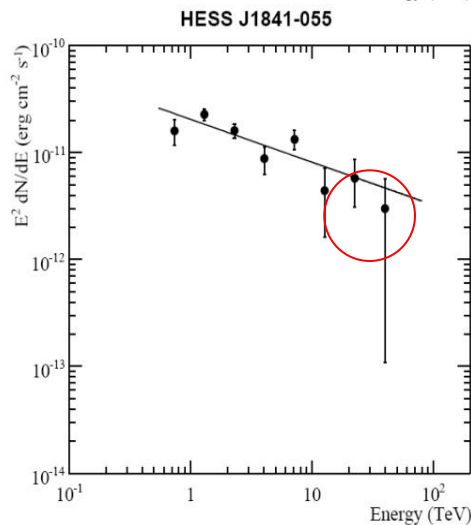
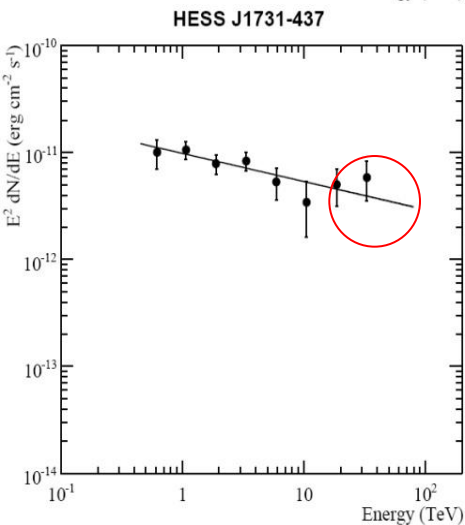
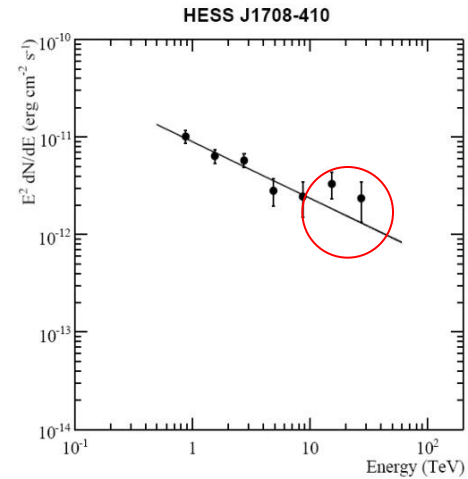
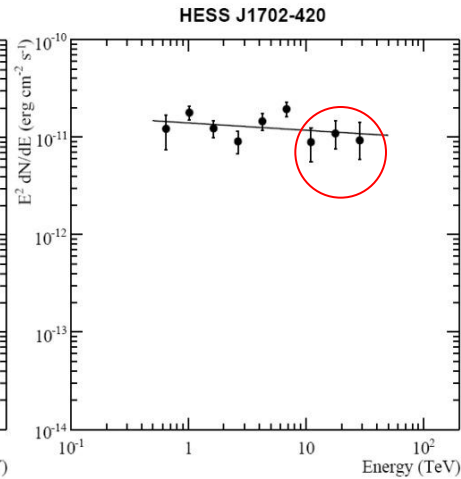
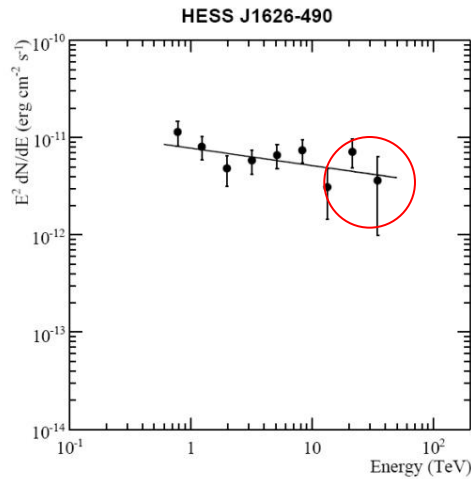
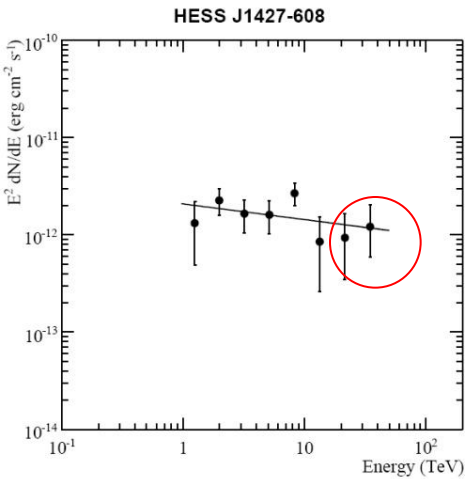
SNR RX J 1713.7-3946 in VHE  $\gamma$ -rays (HESS Collaboration)

# H.E.S.S. GALACTIC PLANE SCAN



Galaxy full of VHE  $\gamma$ -ray emitters -> many candidate cosmic ray sources

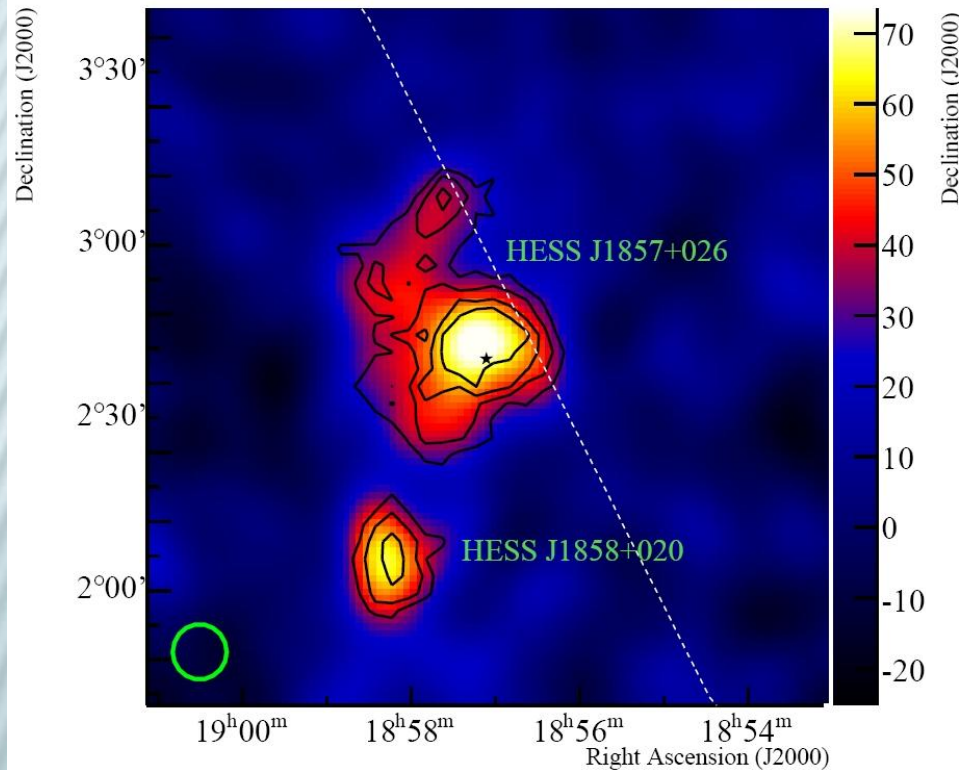
# MANY VHE G-RAY SOURCES ARE UNIDENTIFIED



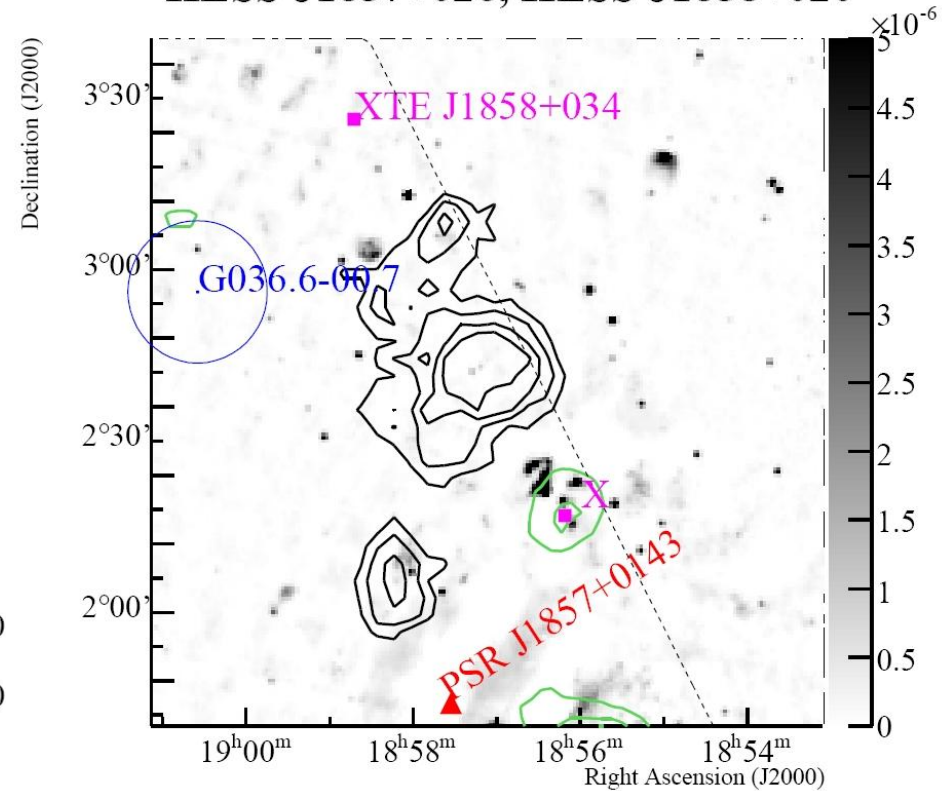
No cut-off visible! Flat spectra, flux >100 TeV???

# UNIDENTIFIED TEV G-RAY SOURCES: DARK ACCELERATORS?

HESS J1857+026, HESS J1858+020



HESS J1857+026, HESS J1858+020

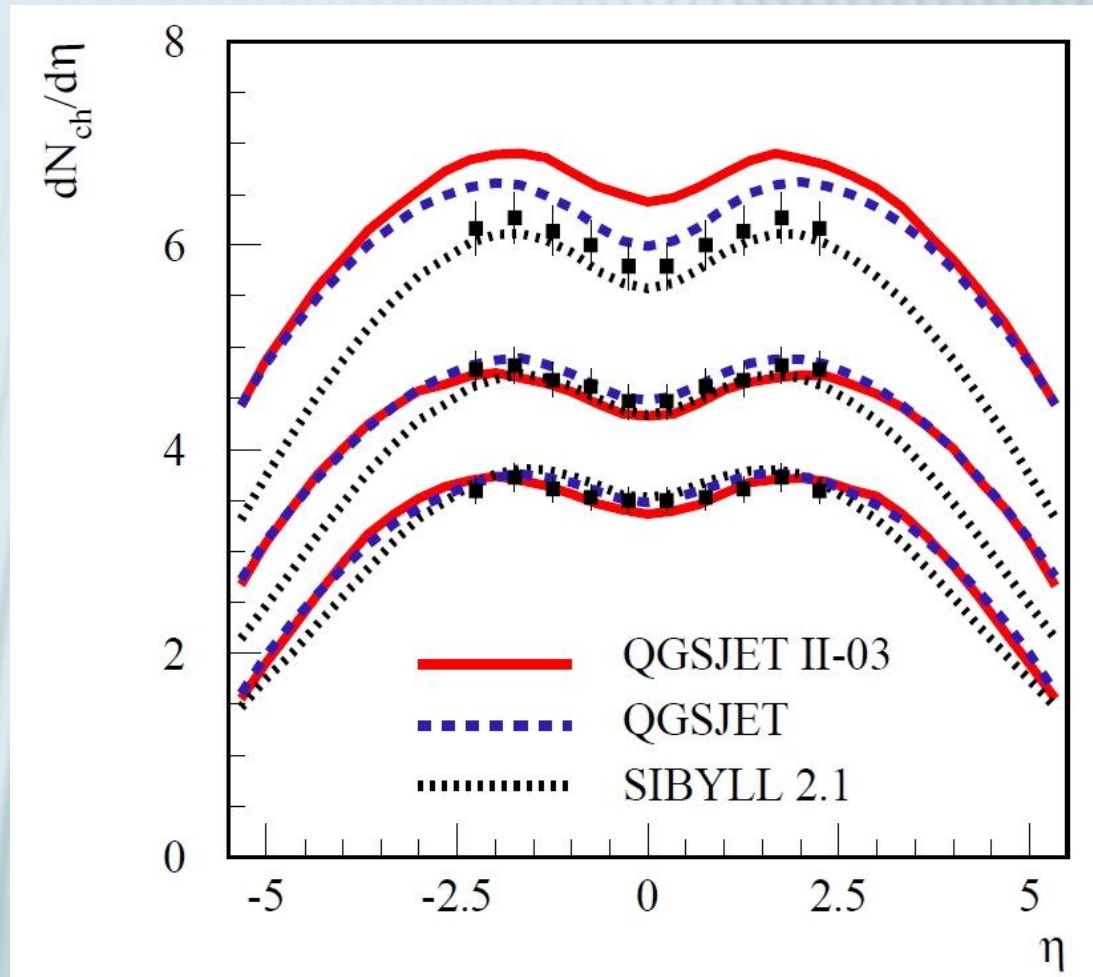


No obvious counterpart in radio or X-rays! PWN from unknown pulsars? Pulsations seen by Fermi? E.g. TeV 2032  
-> pulsars could be large contributors to cosmic rays



# DIRECT CONNECTIONS BETWEEN LHC AND ASTROPARTICLE PHYSICS

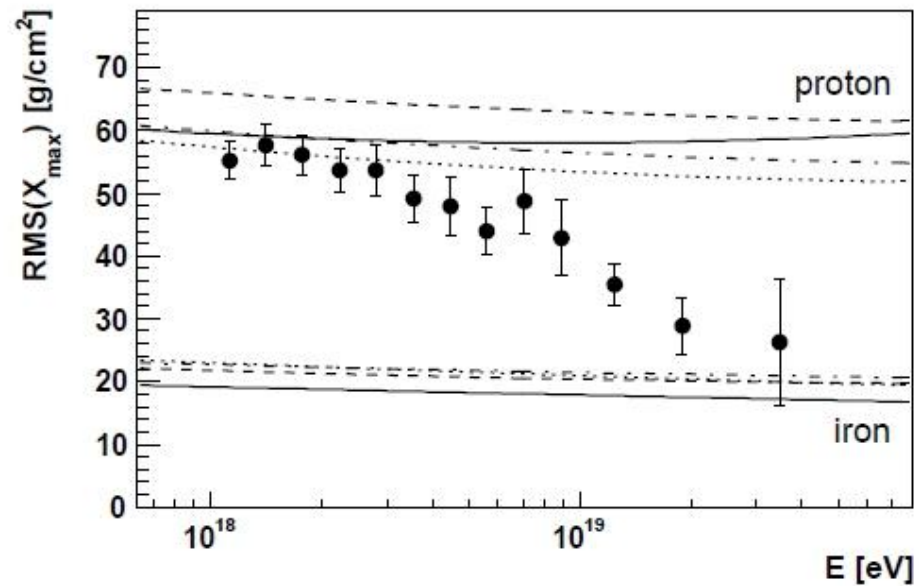
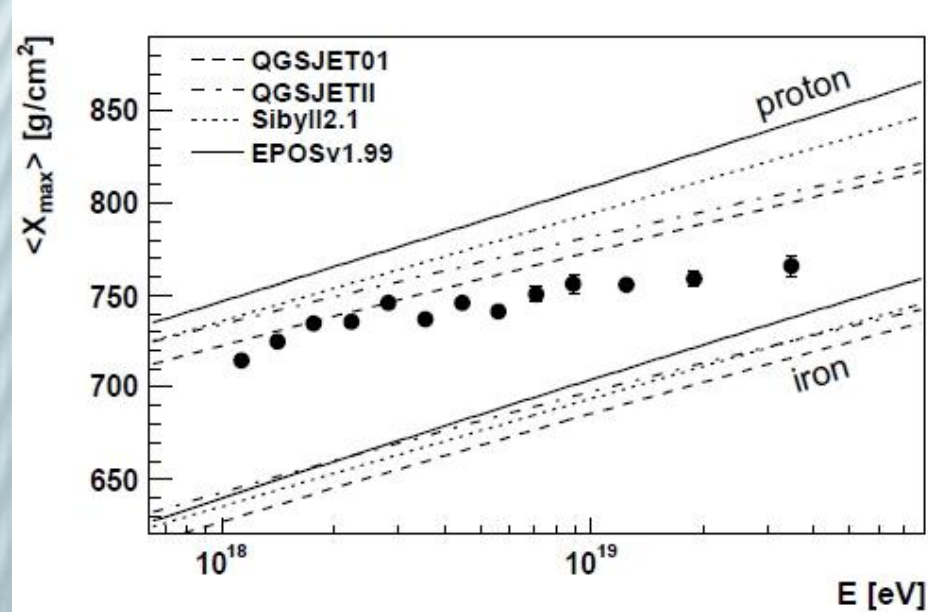
- ✗ LHC data constraints hadronic interaction models (e.g. measurement of secondary particle production)
- ✗ Puzzles: higher muon rate (factor 1.5) in EAS measured by AUGER, supported by IACT data
- ✗ would require increase of multiplicity of proton air and pion-air collisions by an order of magnitude over a wide energy range



Ostapchenko 2010: CMS data on pseudo-rapidity density of charged particles in pp collisions vs model prediction

# CHEMICAL COMPOSITION AT UHE

- ✗ Change to heavier composition at the highest energies?
- ✗ But decrease of RMS favours single component (proton)
- ✗ Deeper EAS penetration into the atmosphere?
- ✗ would require factor 2 decrease for inel. crosssection p-air compared to current models



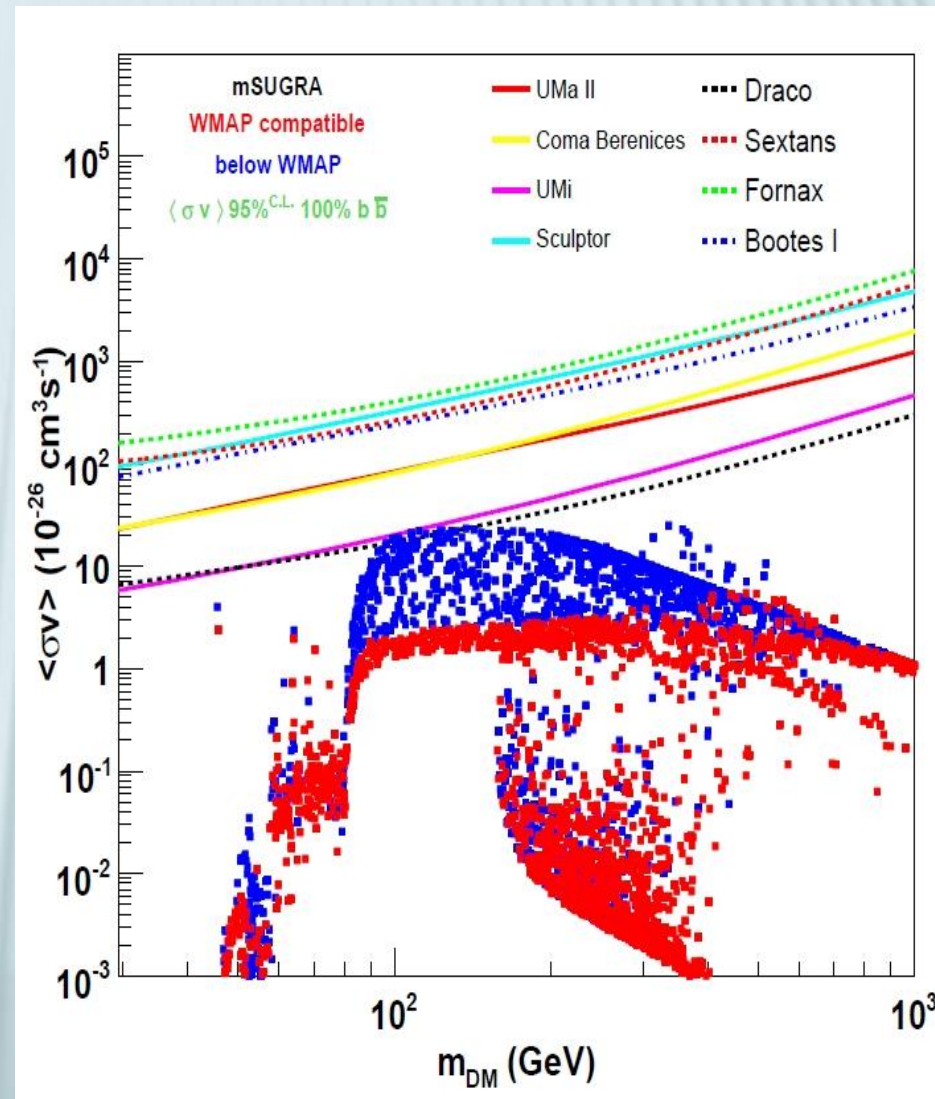
# DARK MATTER



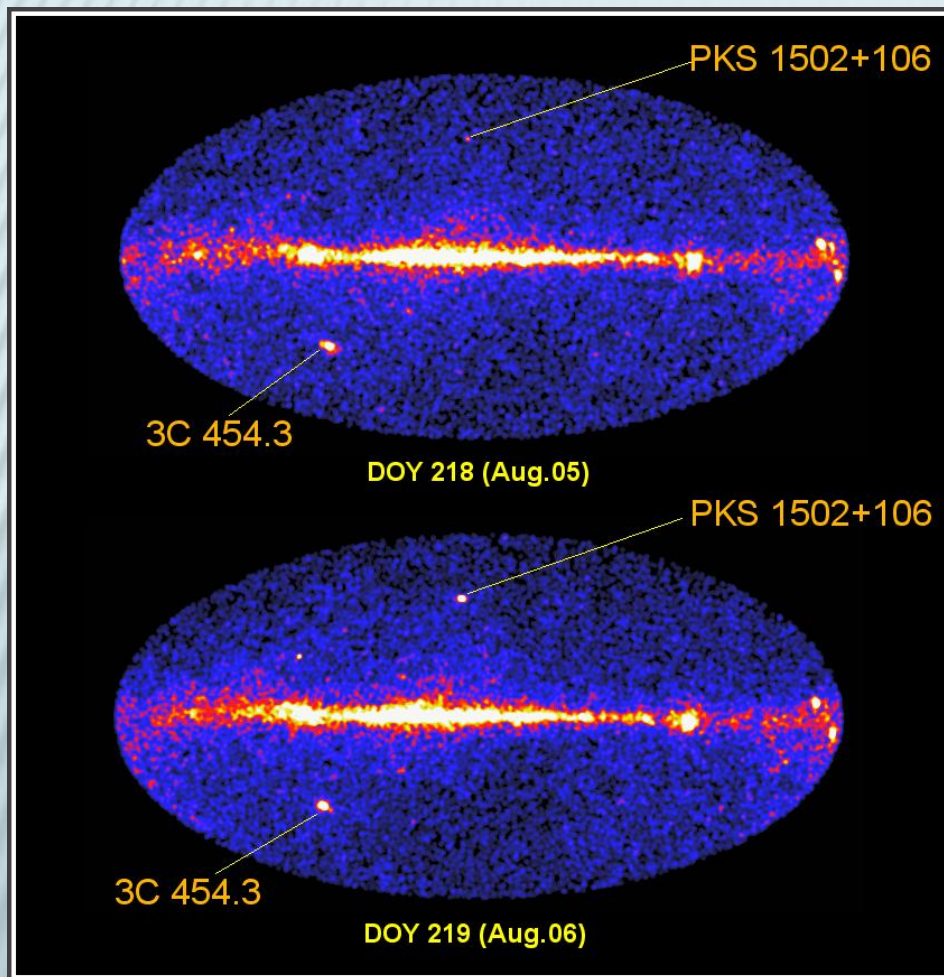
The Bullet Cluster (NASA): hot gas in red, dark matter in blue

# DARK MATTER

- ✘ A realistic explanation must satisfy astrophysical observations (rotation curves, clusters,  $\gamma$ -ray signature?) and results from particle accelerators
- ✘ And of course it would always help to know what we are searching for...



# EXTREME VARIABILITY

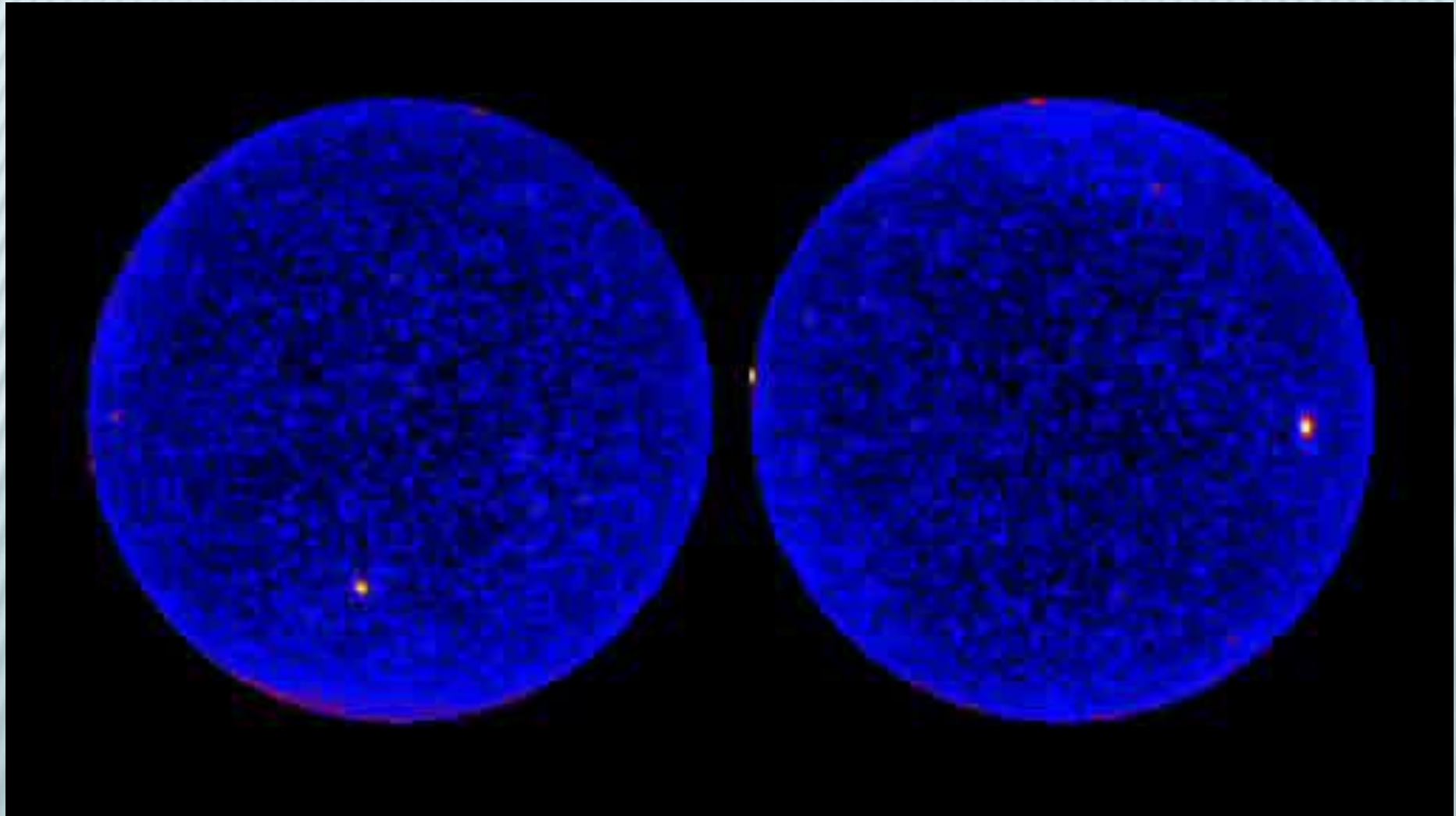


- × Sources are flaring rapidly
- × (V)HE  $\gamma$ -ray sky changes every day (every minute)
- × Variability time scale correlates with source extension -> important independent measurement of production process and region

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× Thank you!

# EXTREME VARIABILITY IN G-RAYS



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# × Backup



# M82 EXPLANATION

