Astroparticle Physics

Summerstudent Lecture 2010

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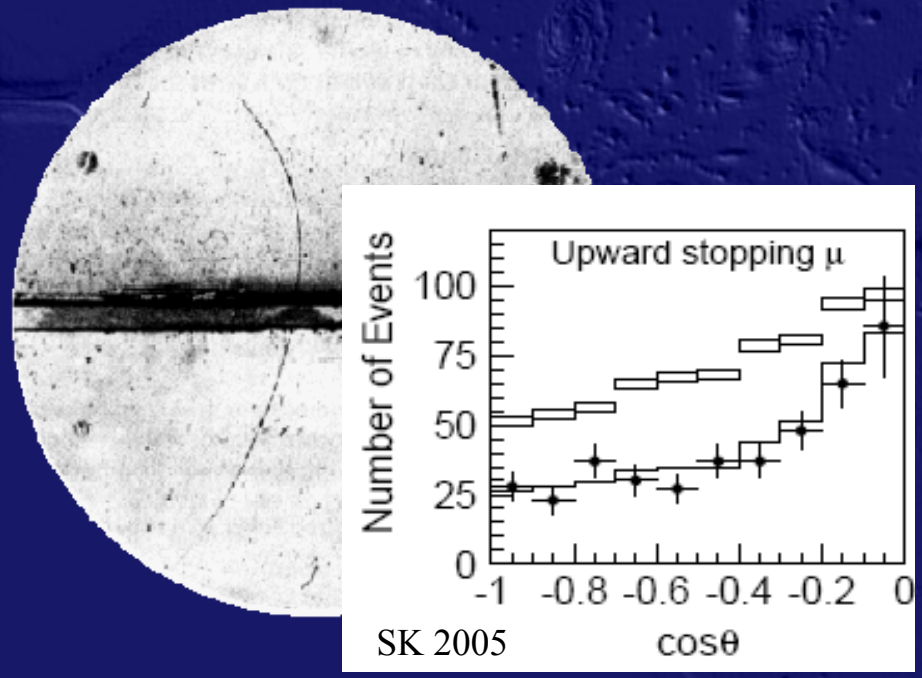
Astroparticle Physics: History

High energy physics started with discoveries and analysis of particles generated by the cosmic radiation in the atmosphere.

- 1932: Positron
- 1937: Muons
- 1947: Pions, Λ, K
- 1952: Ξ^-, Σ^+
- 1971: Charm (?)
- 1998: Neutrino oscillation



Astroparticle Physics: Cosmic Laboratory

Really high energies are only provided by the cosmos:

- particles beyond 10^{20}eV
  (10^7·LHC beam energy)
- Access to physics at the Planck scale via indirect observations of the very early universe

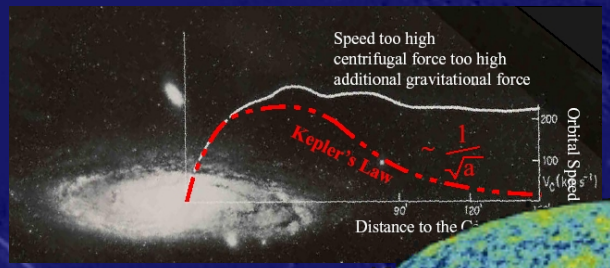
Really long baselines are only provided by the cosmos:

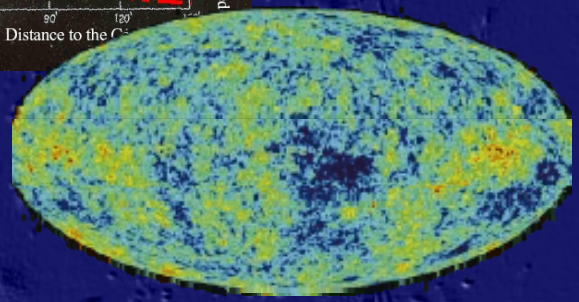
- Oscillation of υ from the sun: $150 \cdot 10^9$ m
- υ from SN 1987A (LMC): 150.000 light-years

Astroparticle Physics: Phenomena

There are many natural phenomena waiting for explanation:

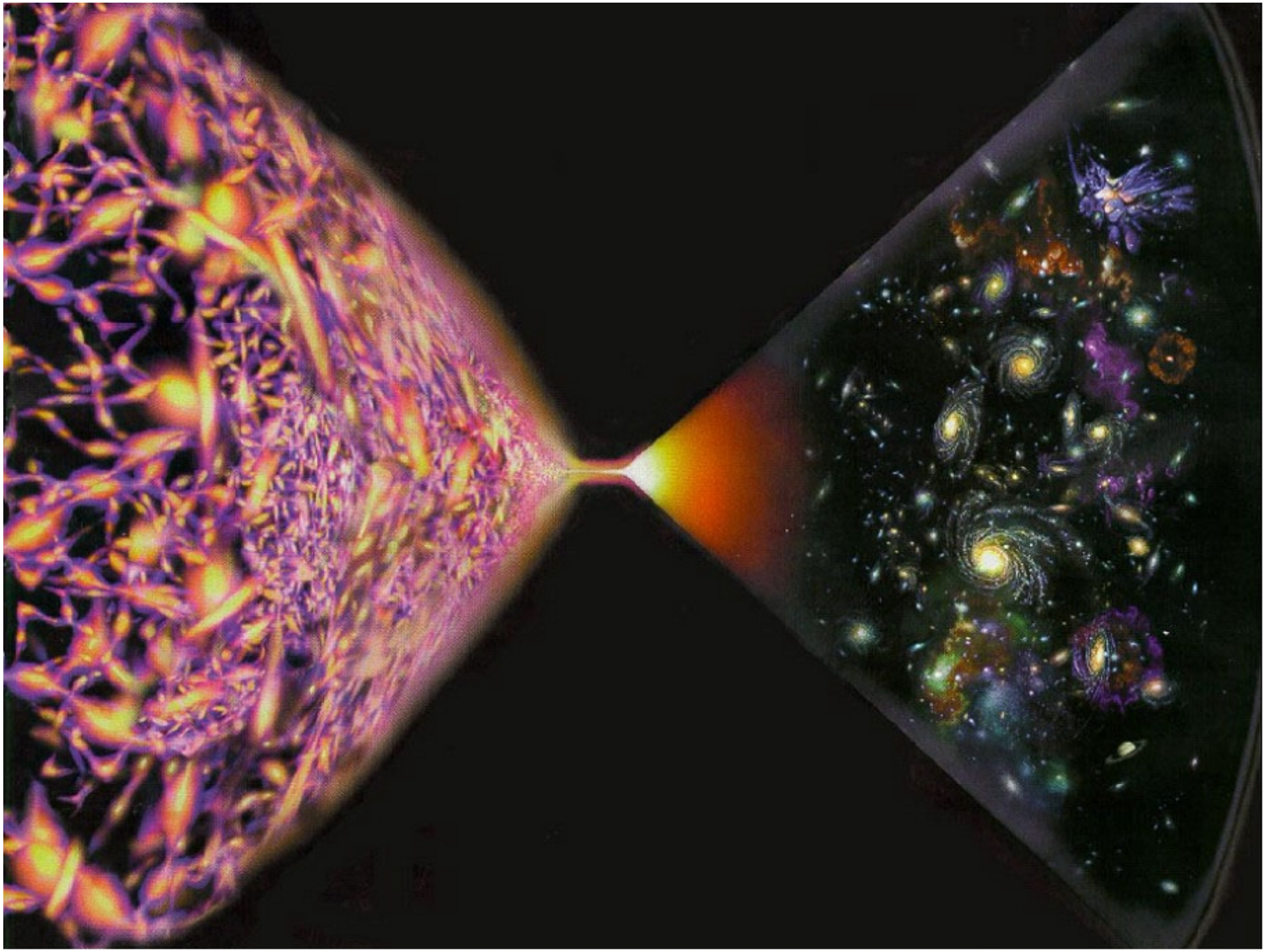
- Cosmic Radiation
- Dark Matter
- Cosmic Microwave Background Radiation





The cosmic connection:

- The development (and origin?) of the cosmos can only be addressed with HEP knowledge



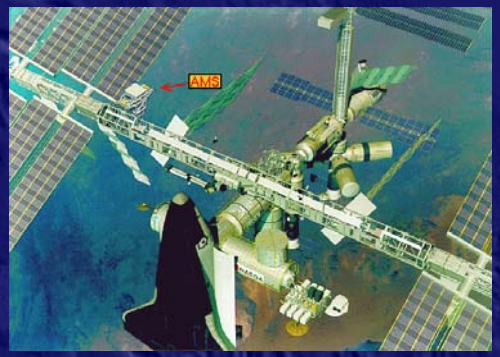
A Definition of Astroparticle Physics

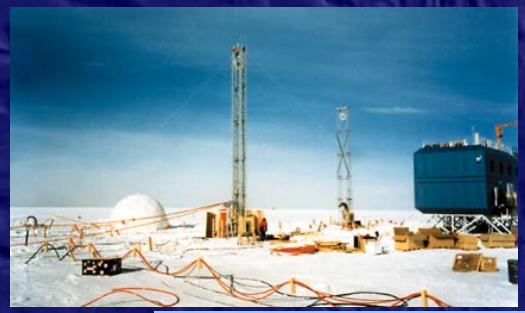
Three Aspects:

- Learning HEP from astrophysics:
  Neutrino properties, cross sections at ultra high energies, new forms of matter (dark matter and dark energy), time variation of fundamental constants, space-time structure
- Applying HEP techniques to astrophysics:
  calorimetry and tracking detectors onboard satellites and balloons, ground based scintillators and Cherenkov detectors, handling of large volume data sets, astronomy with neutrinos
- Cosmology with cognitions of HEP:
  Big Bang theory, nucleon synthesis, candidates for dark matter

Tools and Sites of Astroparticle Physics

(the real motivation?)





Unusual laboratories ...

... and a little adventure.

Collaborations in Astroparticle Physics

Size about an order of magnitude smaller than in HEP

MAGIC ("Cherenkov-Telescope")

ATLAS @ LHC

Astroparticle Physics

Topics for today:

- High Energy Particles from the Cosmos.
- The new Astronomy.

On Friday:

in context with the ALPS experiment some discussion of Dark Matter in the Universe.

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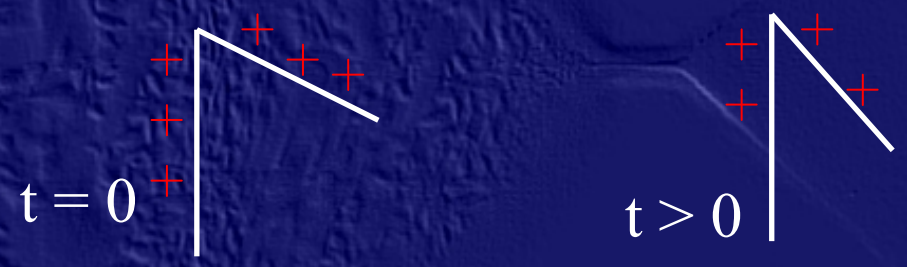
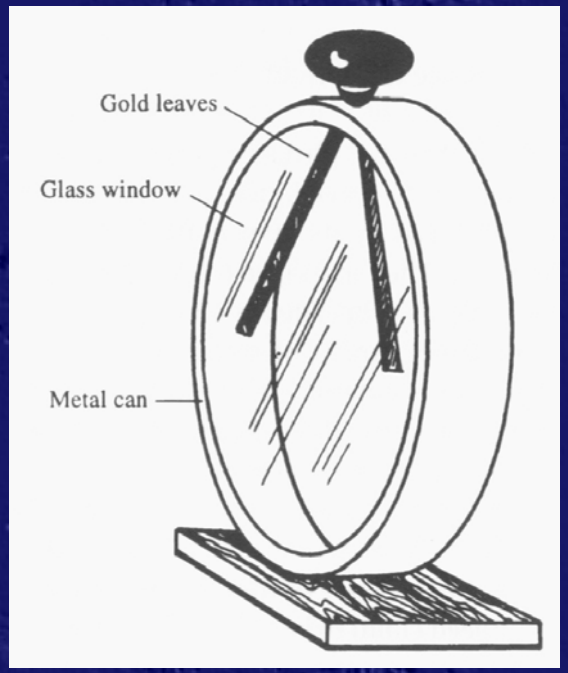
A simple Experiment

What happens to a charged electrometer?

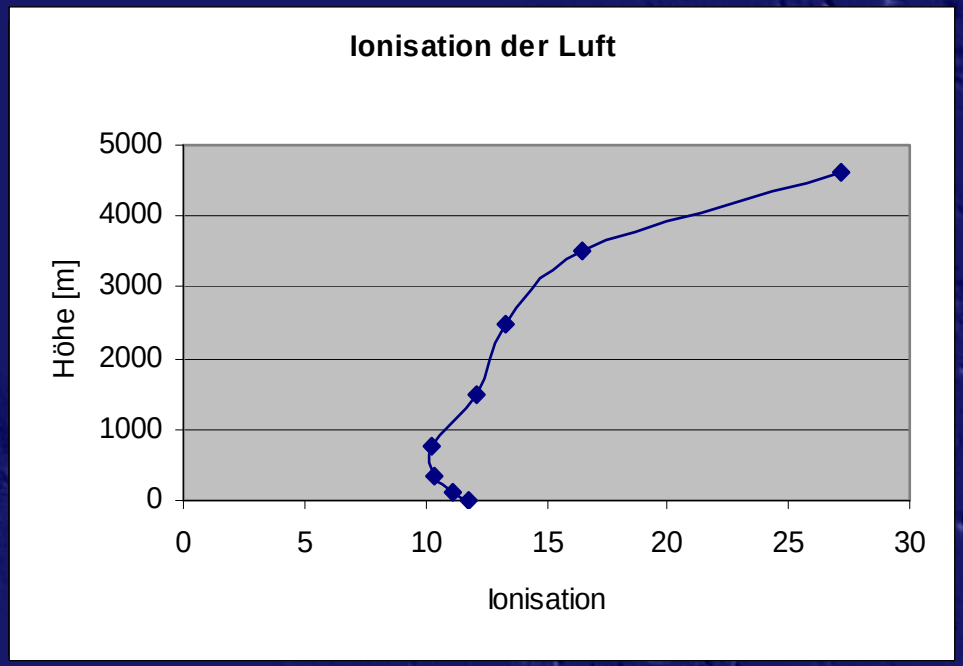




The charge is carried away by ions of the air.

Why is a fraction of the air ionized?

Discovery of Cosmic Rays



Viktor F. Hess 1912:
Ionisation of air increases with increasing altitude
↳ Radiation from the cosmos hits the atmosphere ("Cosmic Rays")

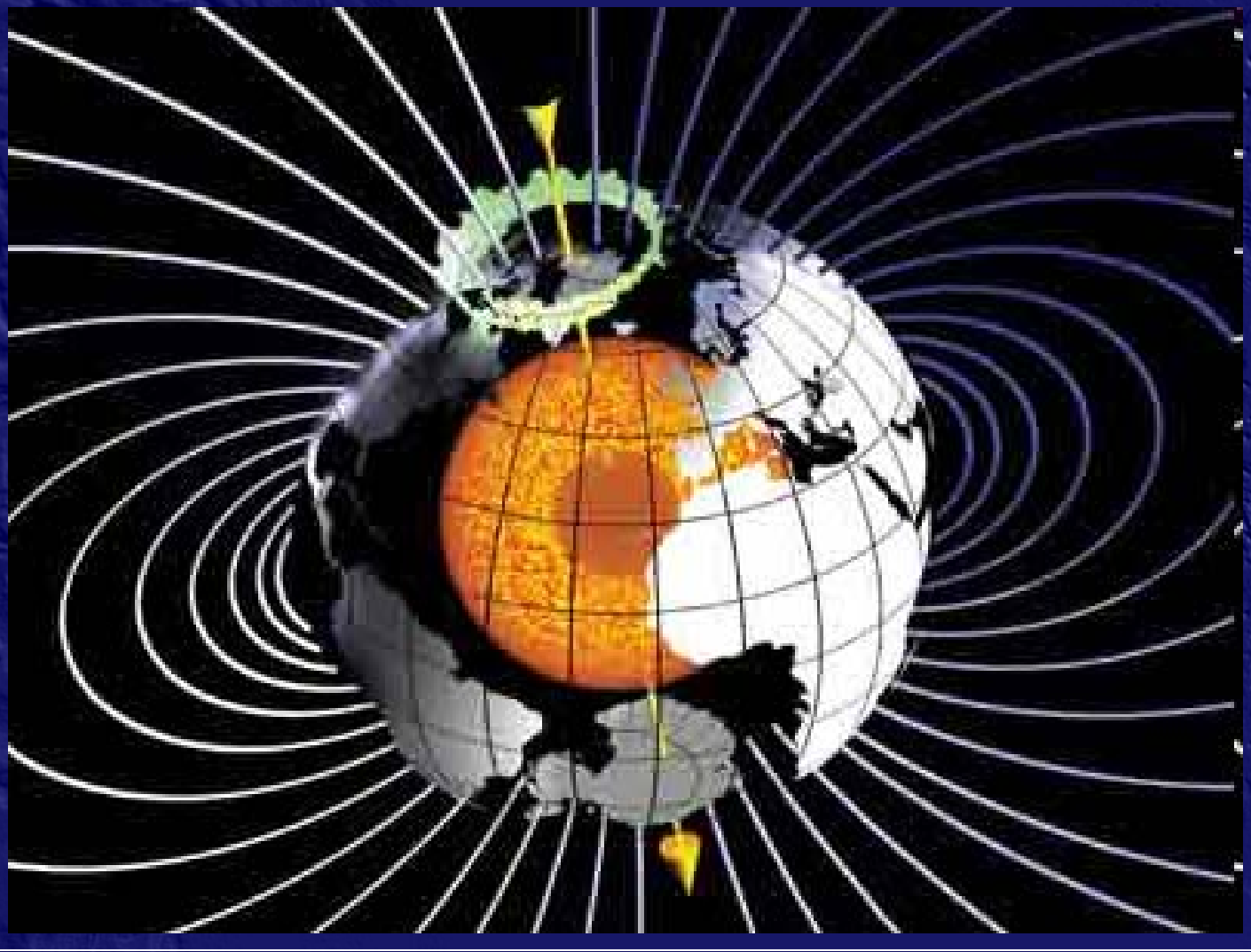
http://helios.gsfc.nasa.gov/cosmic.html
http://ik1au1.fzk.de/KASCADE/KASCADE_general.html
http://www.auger.org/

Viktor F. Hess

Die Ergebnisse der vorliegenden Beobachtungen scheinen am ehesten durch die Annahme erklärt werden zu können, daß eine Strahlung von sehr hoher Durchdringungskraft von oben her in unsere Atmosphäre eindringt, und auch noch in deren untersten Schichten einen Teil der in geschlossenen Gefäßen beobachteten Ionisation hervorruft. Die Intensität dieser Strahlung scheint zeitlichen Schwankungen unterworfen zu sein, welche bei einstündigen Ablesungsintervallen noch erkennbar sind. Da ich im Ballon weder bei Nacht noch bei einer Sonnenfinsternis eine Verringerung der Strahlung fand, so kann man wohl kaum die Sonne als Ursache dieser hypothetischen Strahlung ansehen, wenigstens solange man nur an eine direkte γ-Strahlung mit geradliniger Fortpflanzung denkt.

Physik. Zeitschr. 13, 1084 (1912)

A. H. Compton, 1932: What are the Constituents of CRs?



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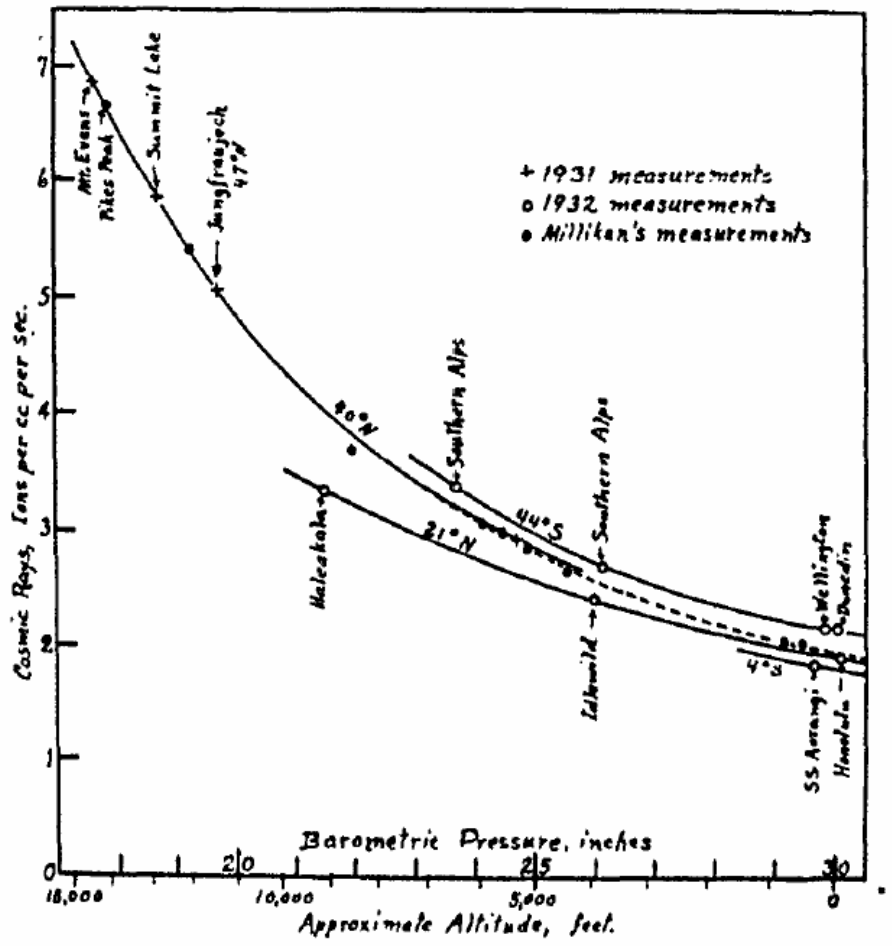


Fig. 1.

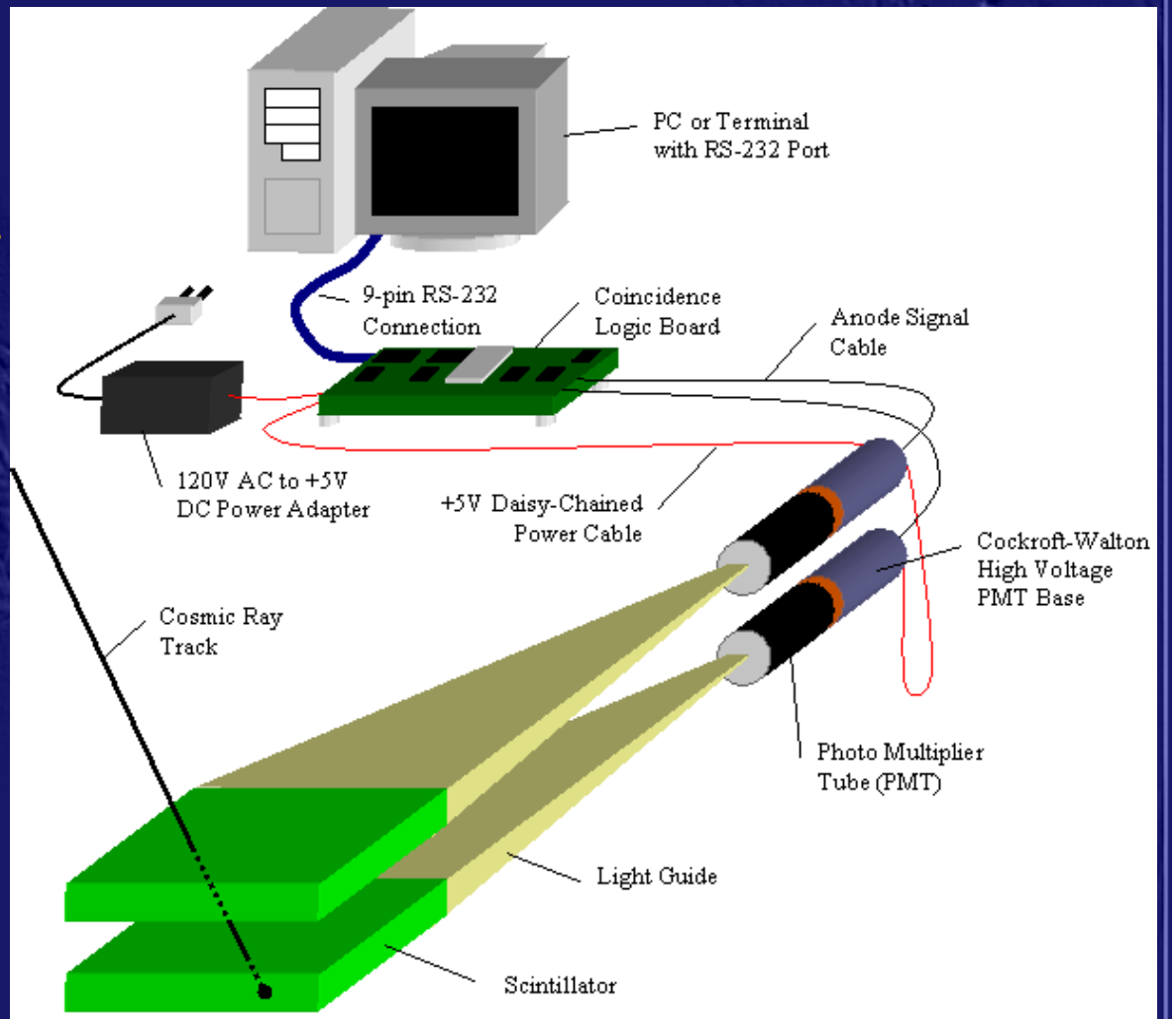
The CR flux varies as function of the latitude:

The CRs consist of charged particles!

ARTHUR H. COMPTON
University of Chicago,
The Tasman Sea,
May 7, 1932.

A more sophisticated CR Detector

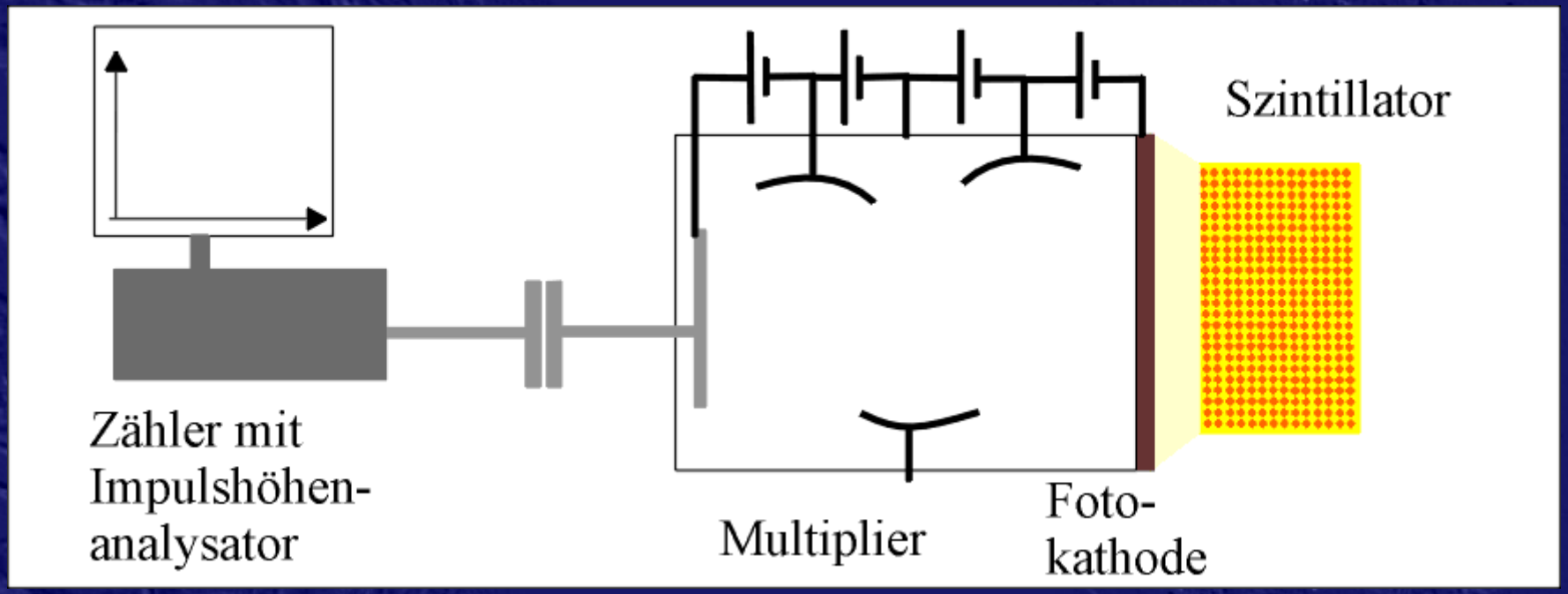
- Charged particles pass a szintillating material: molecules are excited and emit light.
- This light is guided to a photo multiplier tube (PMT) which converts the light into an electric signal.
- To get rid of the PMT noise usually two or more detectors are operated in coincidence.



http://research.fit.edu/quarknet/documents_qnet_detector_reference.htm

A more sophisticated CR Detector

Measurement principle:



http://leifi.physik.uni-muenchen.de/web_ph12/versuche/09szintil/szinti_zaehl_ani.htm

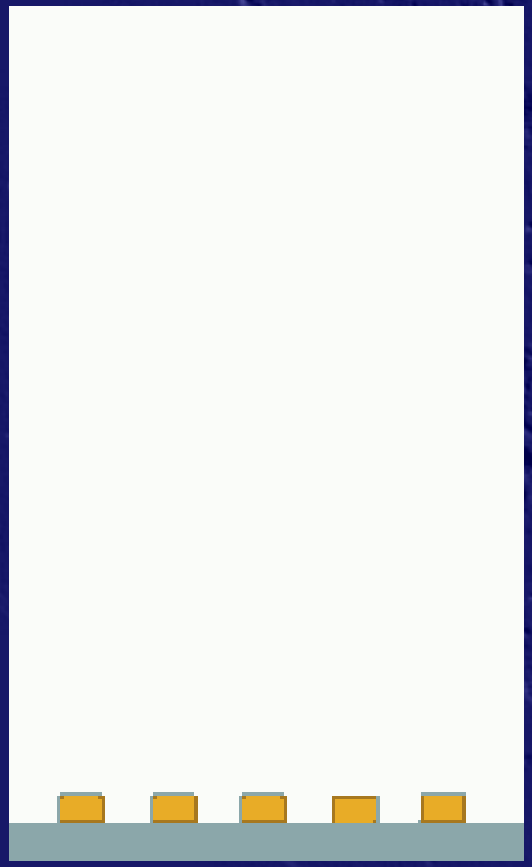
CR induce Extended Air Showers (EAS)

Pierre Auger 1938:

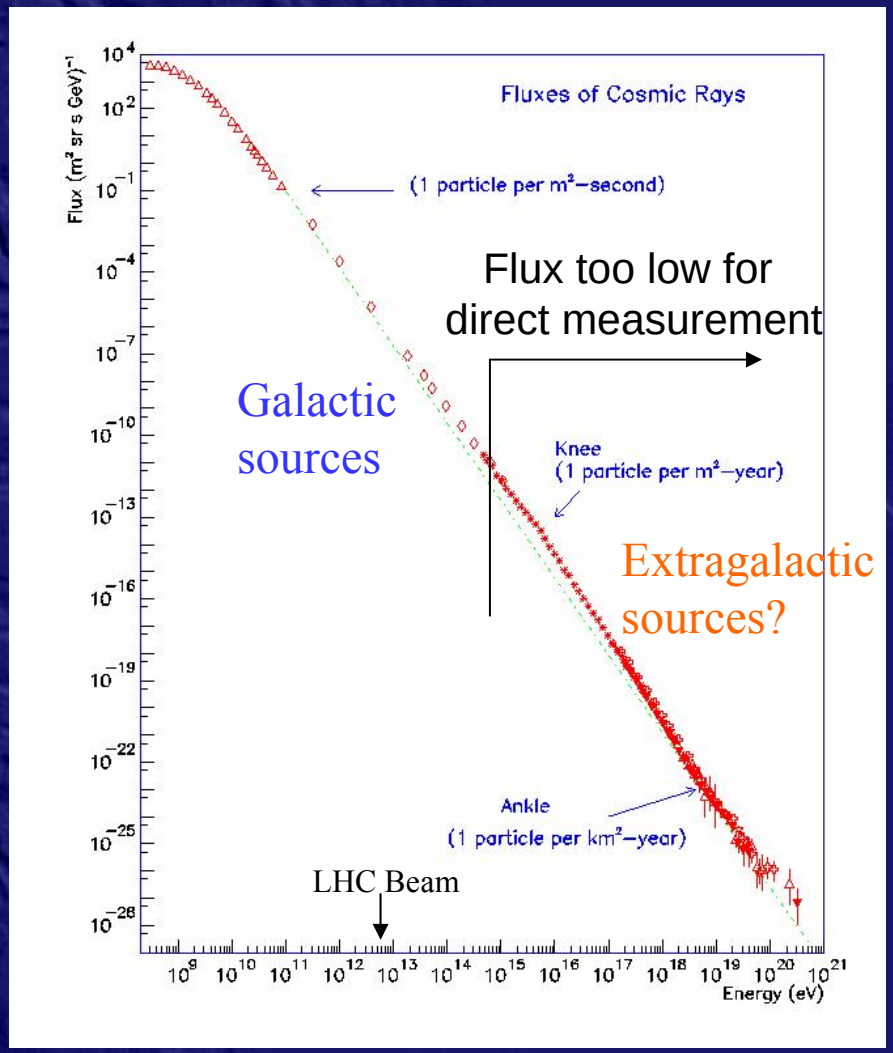
Observation of CR induced coincidences in widely separated detectors at the Jungfrau Joch.

Explanation:

Primary cosmic particle interacts with atoms in atmosphere, secondary particles undergo further interactions
↳ avalanche of particles (EAS)



Energy Spectrum of CR



At high energies very large detector installations necessary:
10^4 m^2 (knee) to 10^9 m^2

Effect of $3 \cdot 10^{21}$eV:

Full Name
Height: 6-
Bats: Righ
Born: Sep
College: U
2004 Sala

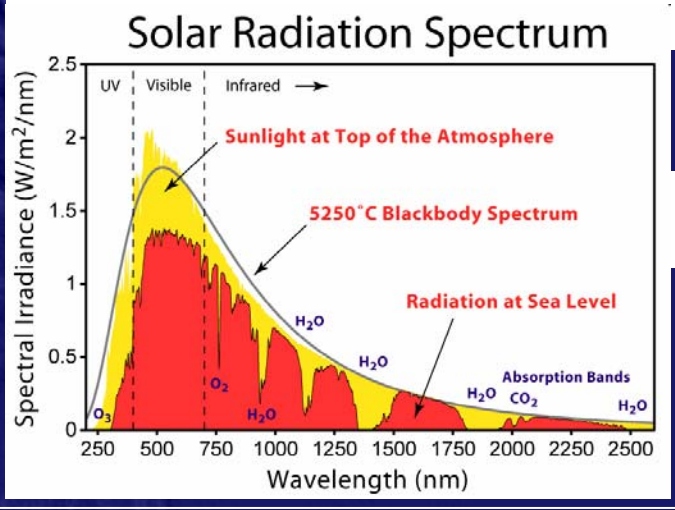
reek, CA,

The origin of CRs: Temperatures and Energies in the Cosmos

The hotter a material, the shorter the wavelength where the maximum intensity is radiated:

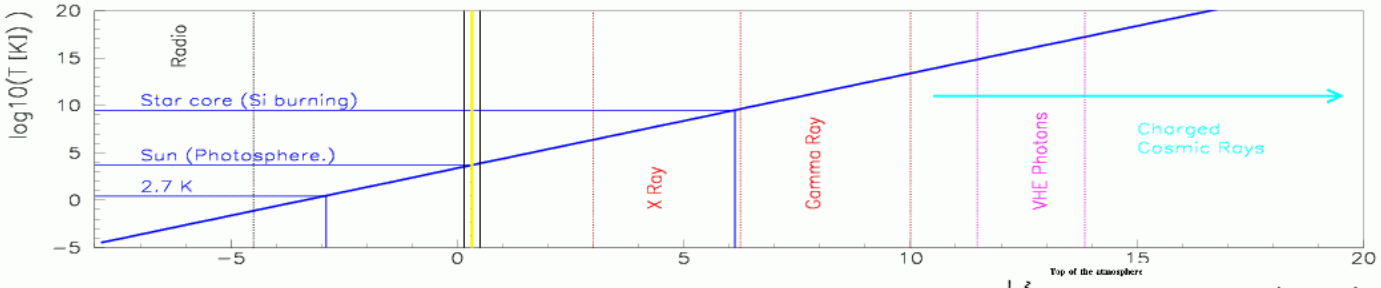
Wien's law: $E_{max}[eV] = 0{,}000427 \cdot T[K]$

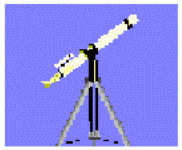
$\lambda_{max}[nm] = 2903611 / T[K]$

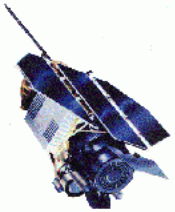


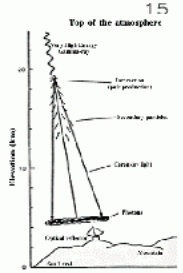
$\lambda_{max} = 526$ nm $= 2903611$ nmK / 5523 K

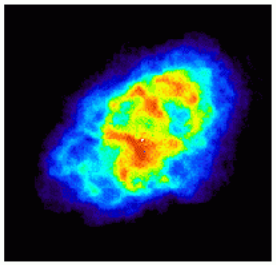
Temperatures and Energies in the Cosmos

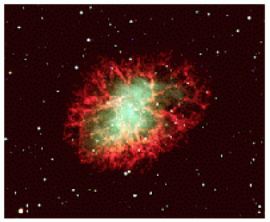








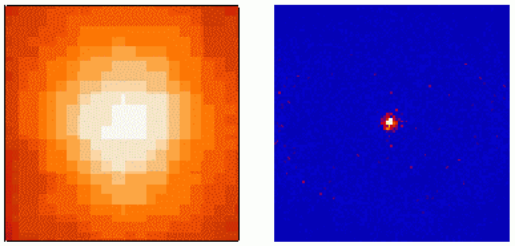




0.1 deg 0.1 deg 0.1 deg

γ- Rays from the Crab Nebula

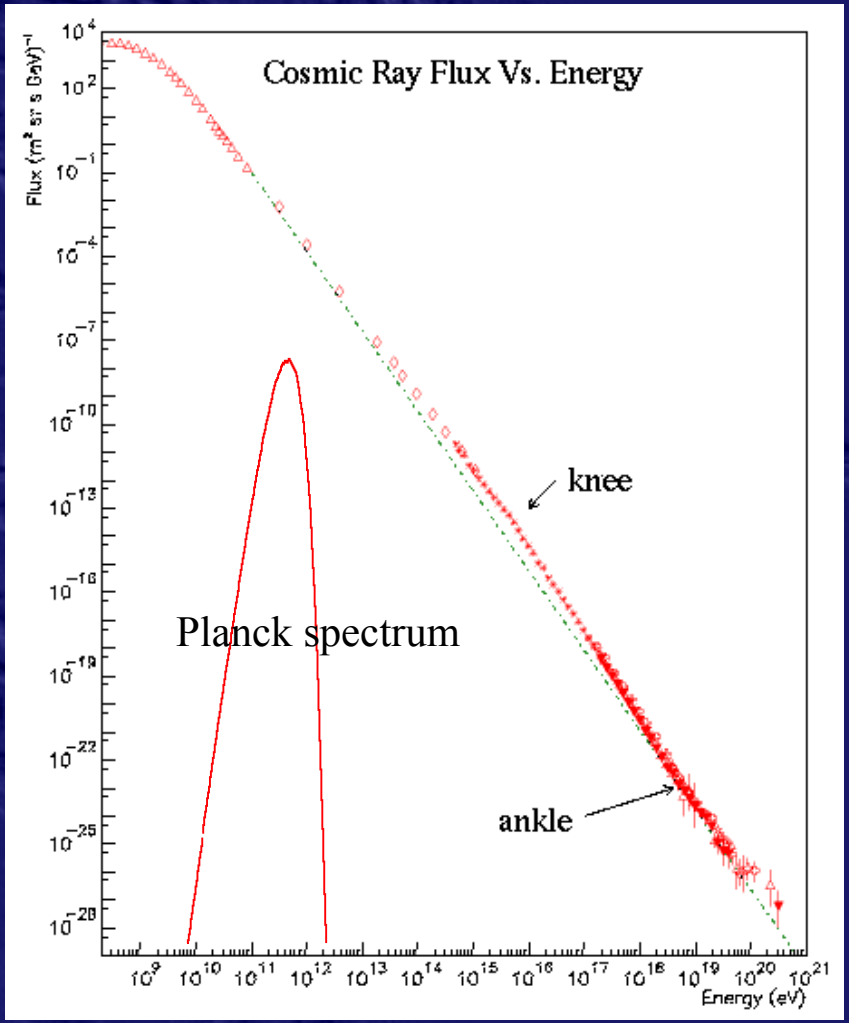
EGRET (>100 MeV) **HEGRA CT (TeV)**



4 deg 4 deg

CR energies: the cosmos is not hot enough!

CR Energy Spectrum ⇔ Thermal Radiation



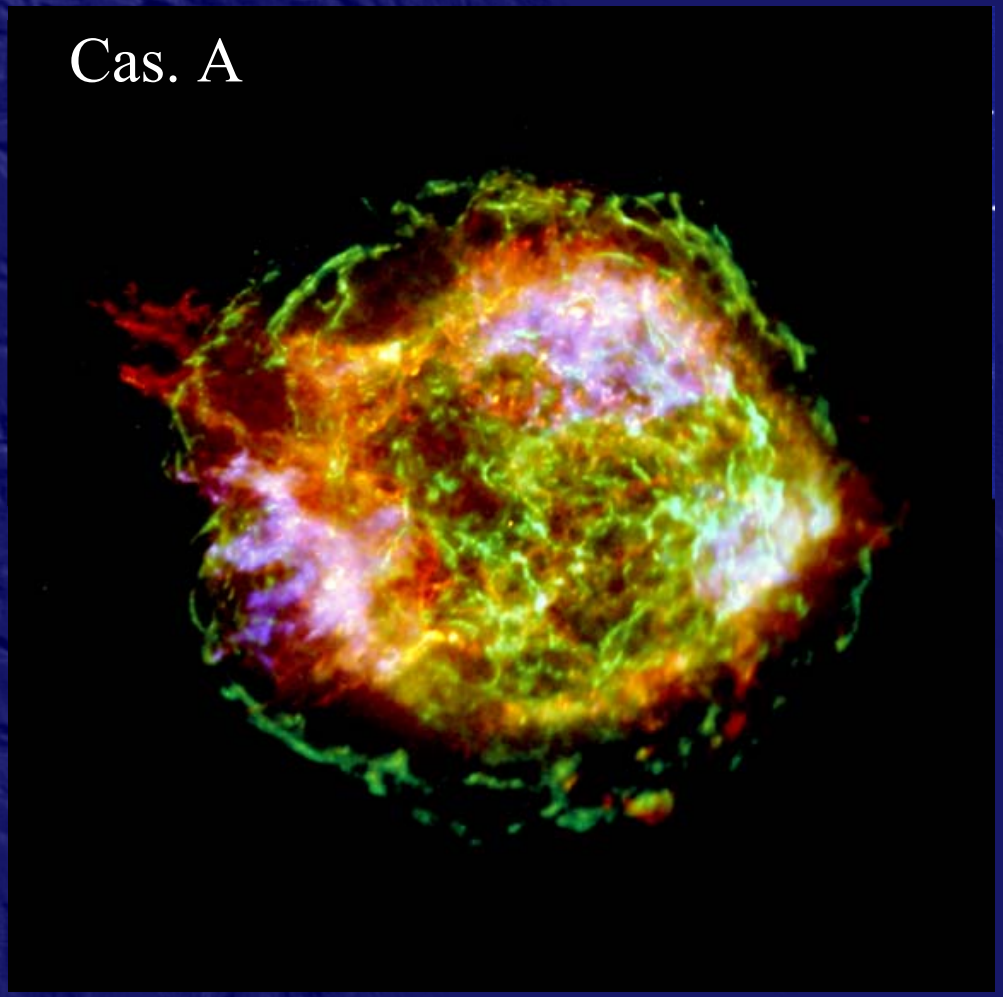
The energy spectrum of CRs is not a Planck spectrum.

Hence CRs do not originate from thermal processes.

CR gain their energies in cosmic accelerators.

They offer a view into the non-thermal universe.

Possible galactic Accelerators

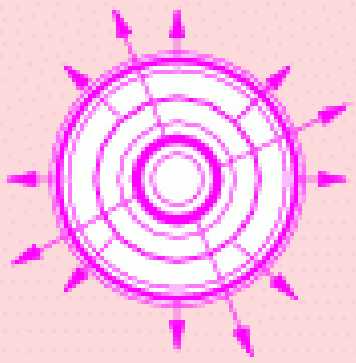


- Supernova remnants develop shock fronts in the interstellar medium.
- Turbulent processes in the shock fronts are visible in radio and X-rays.

Are these the cosmic accelerators?

Acceleration by interstellar Shock Fronts

Supernova explosion



Proposed by E. Fermi 1949:

- Energy gain per crossing:
  $\Delta E = E \cdot (1+d)$
- Probability to escape from shock region:
  P_{esc}

☞ Many crossings:
$N(E) \sim E^{-\alpha}$
with $\alpha = \ln(1/(1- P_{esc}))/\ln(1+d) + 1$

☞ power law with $\alpha \approx 2$ (Cas. A)

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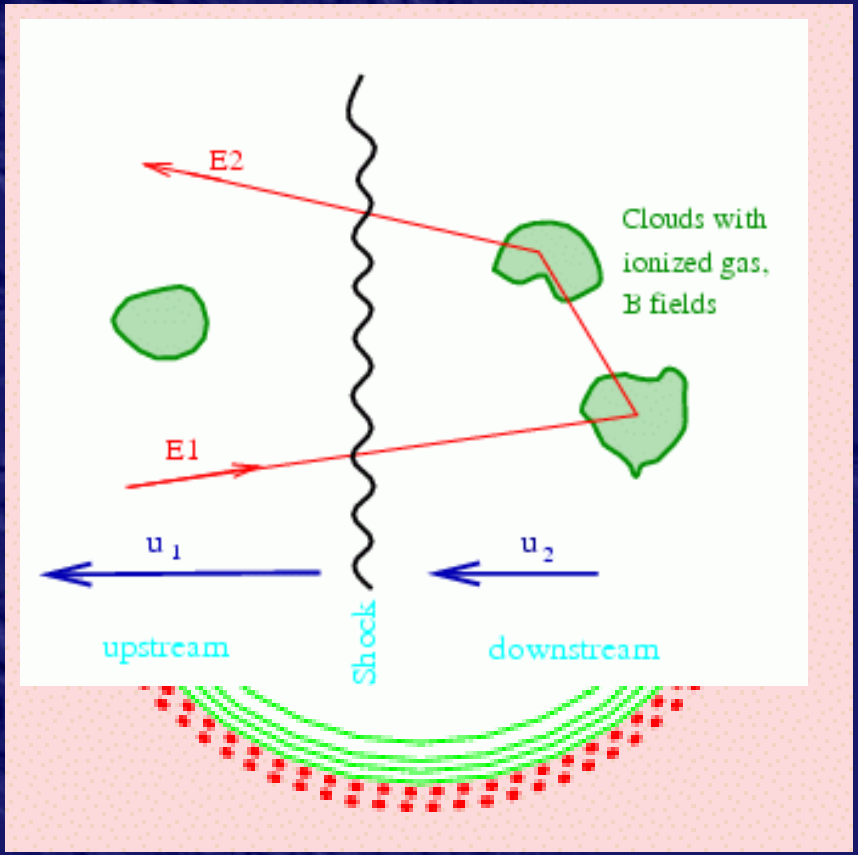

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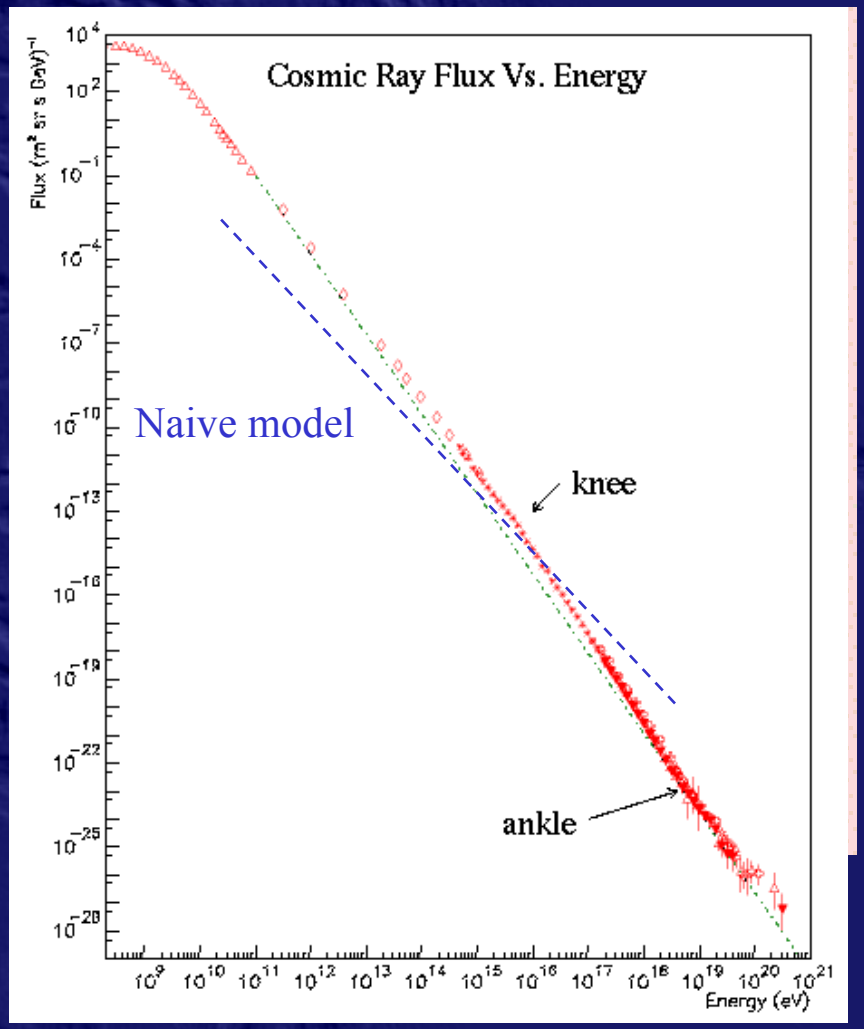

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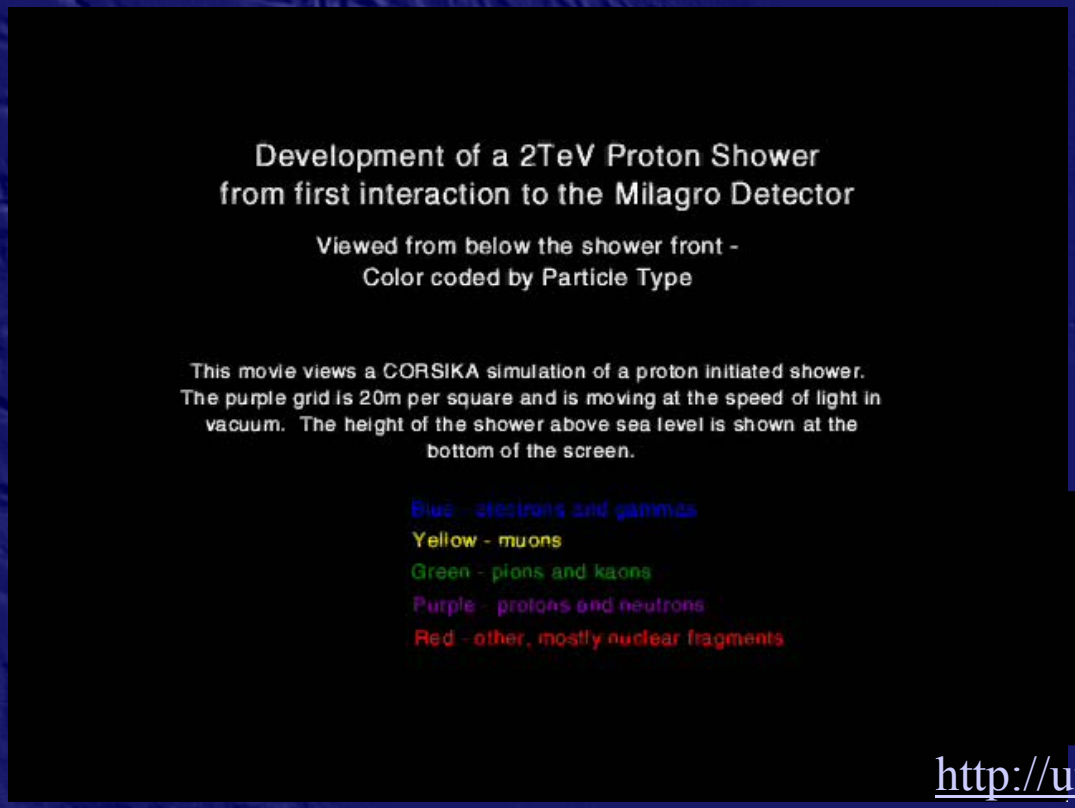
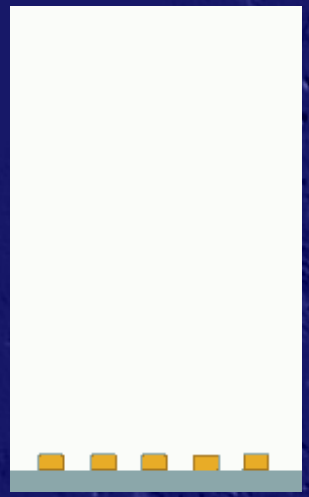
The experimental Challenge

From observation of extended air showers:

- direction, energy and mass range of the primary particle on a statistical basis





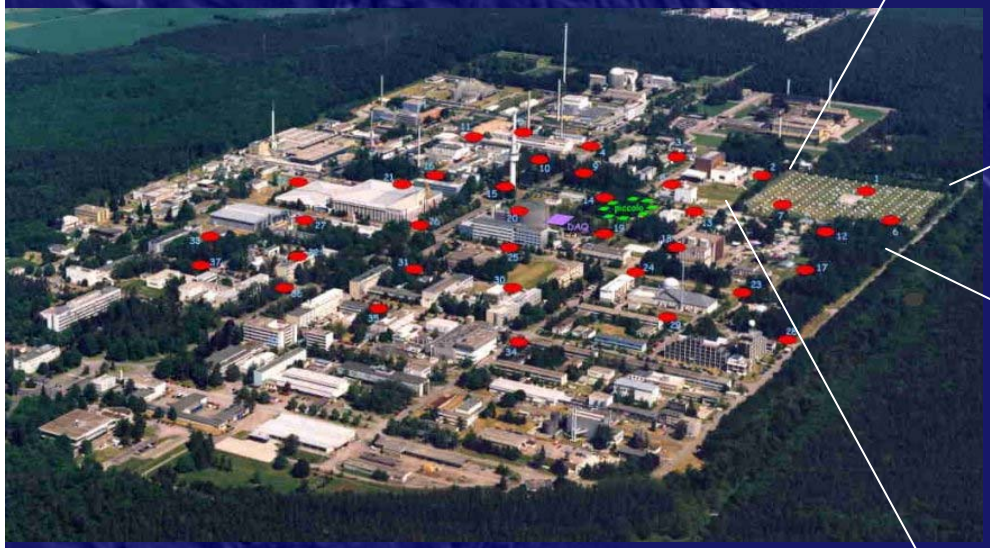
simulation of a EAS, observation from bottom, grid moves with the velocity of light

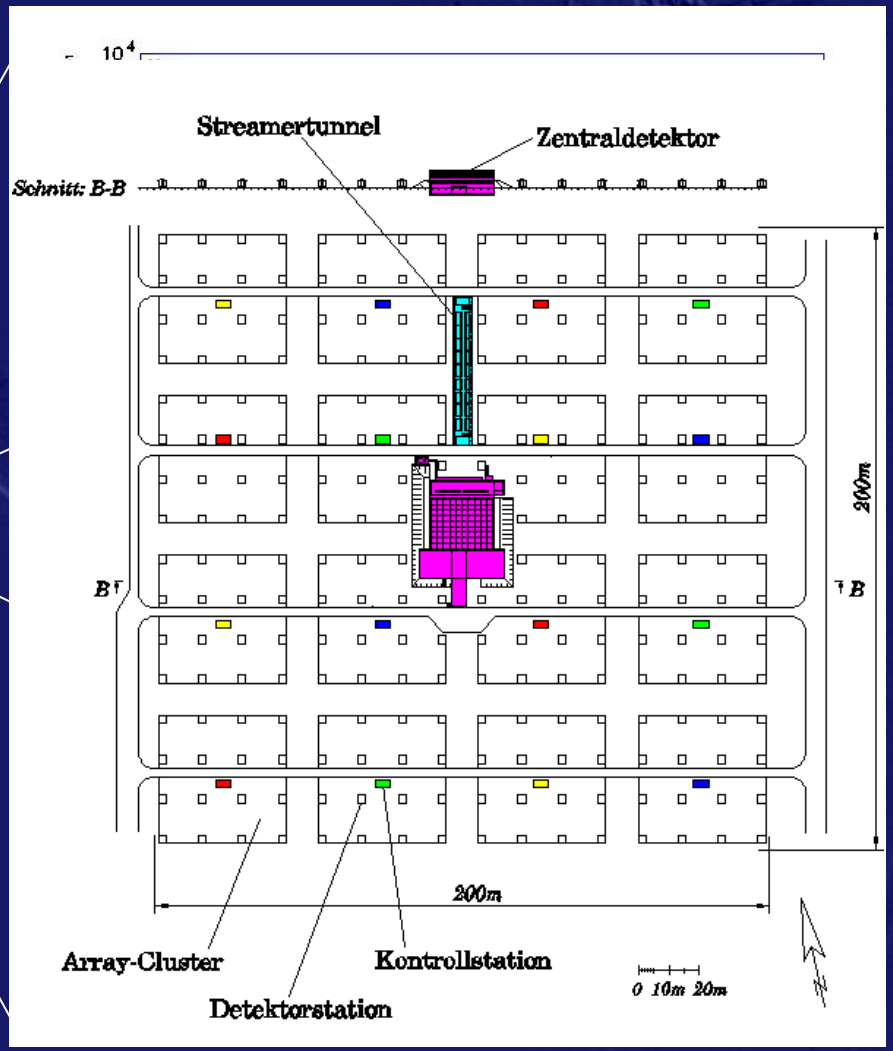
$e^{\pm}$, γ, $\mu^{\pm}$, π, K, p, n, N

http://umdgrb.umd.edu/cosmic/milagro.html

KASCADE-Grande: an Experiment at the CR-Knee

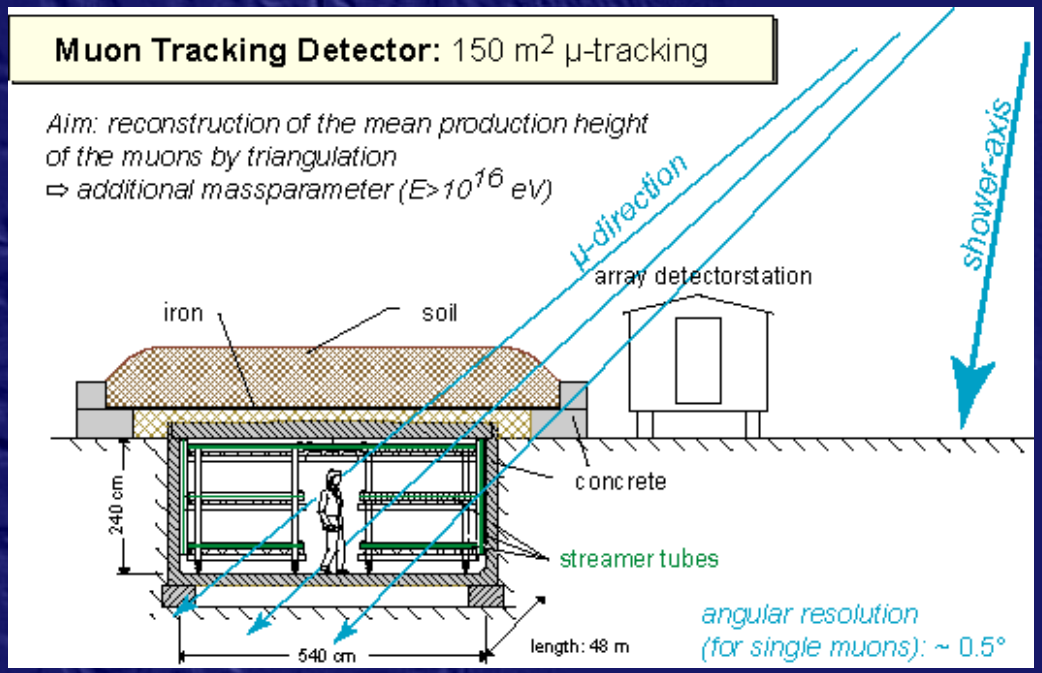
KArlsruhe Shower Core and Array DEtector





KASCADE (1)

Measure different EAS components:

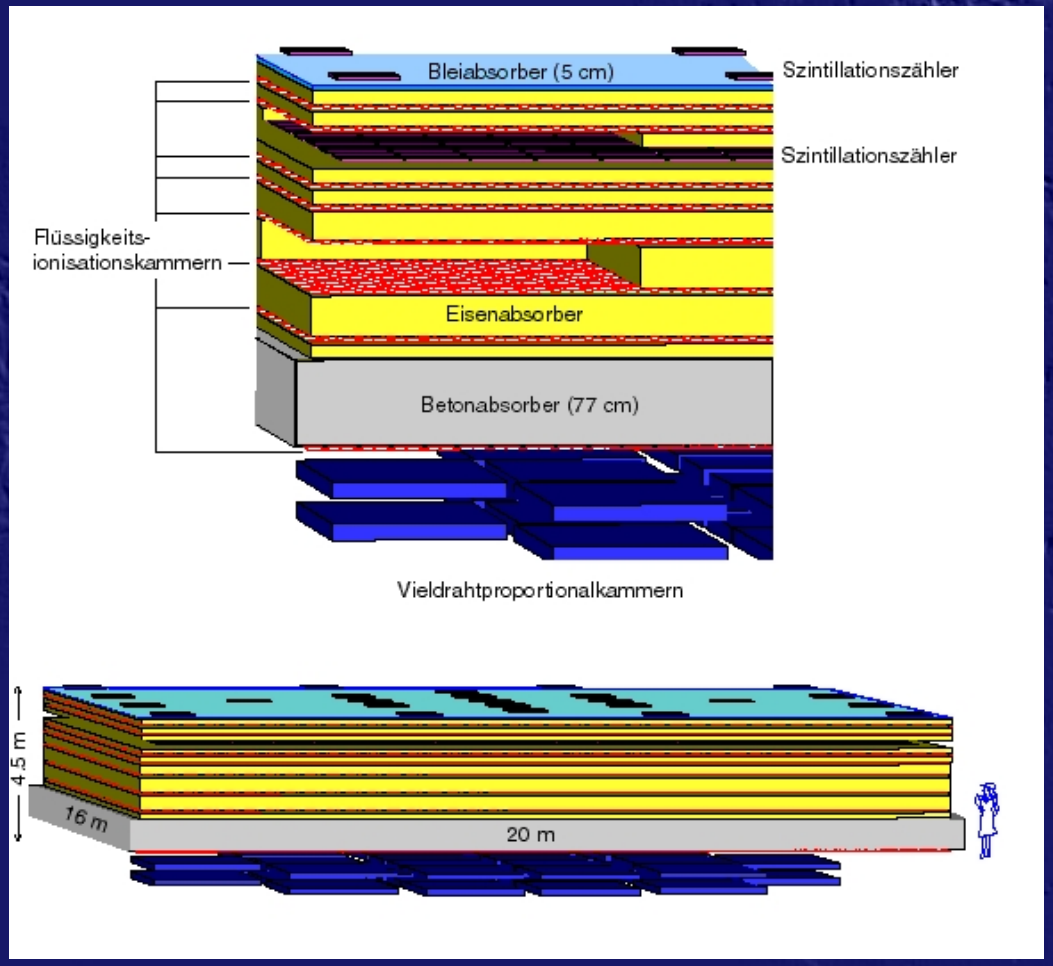


Muons

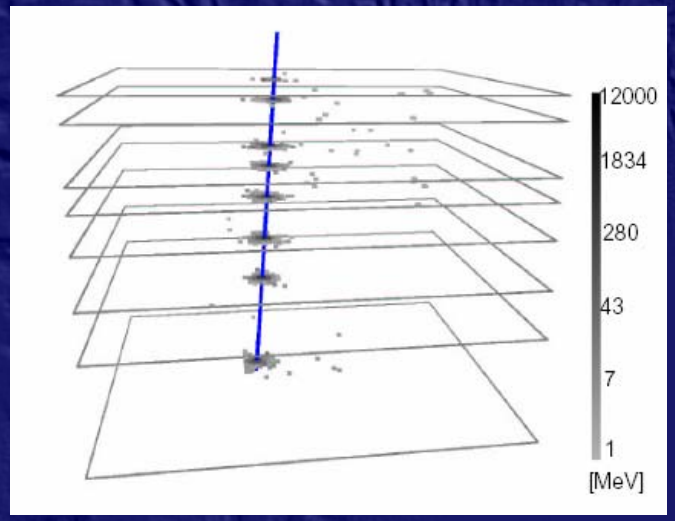
Electrons and photons

KASCADE (2)

320 m^2 central calorimeter

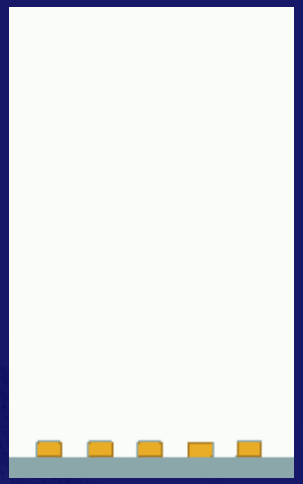


Single 12 TeV hadron:

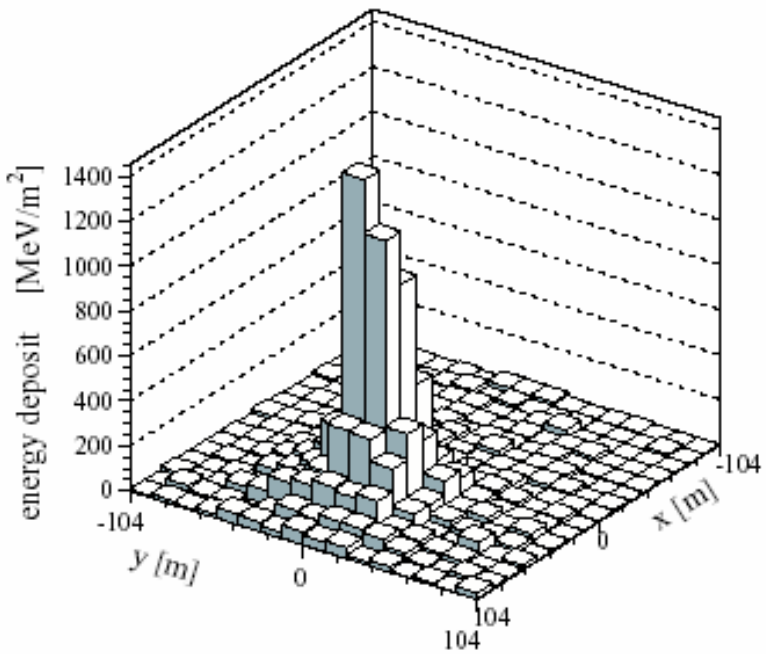


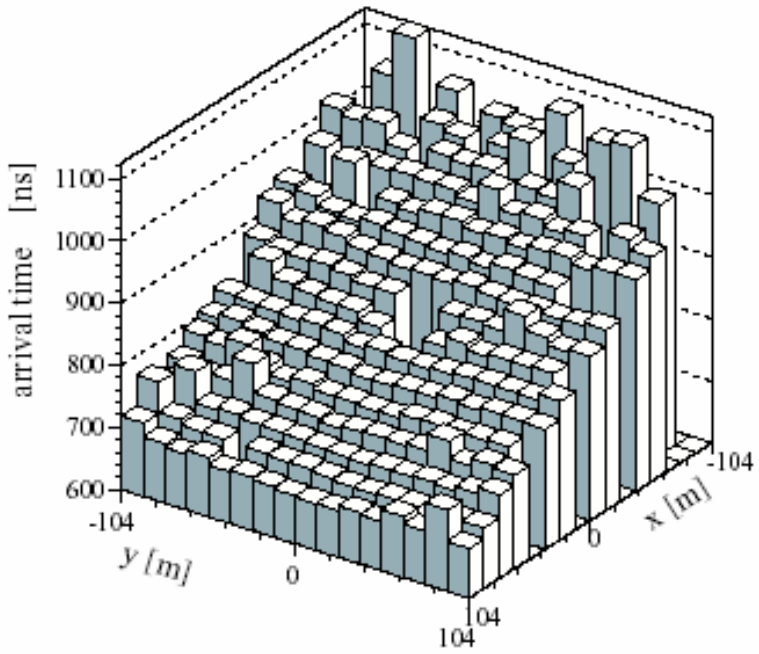
EAS Event

Particle distribution
↳ energy

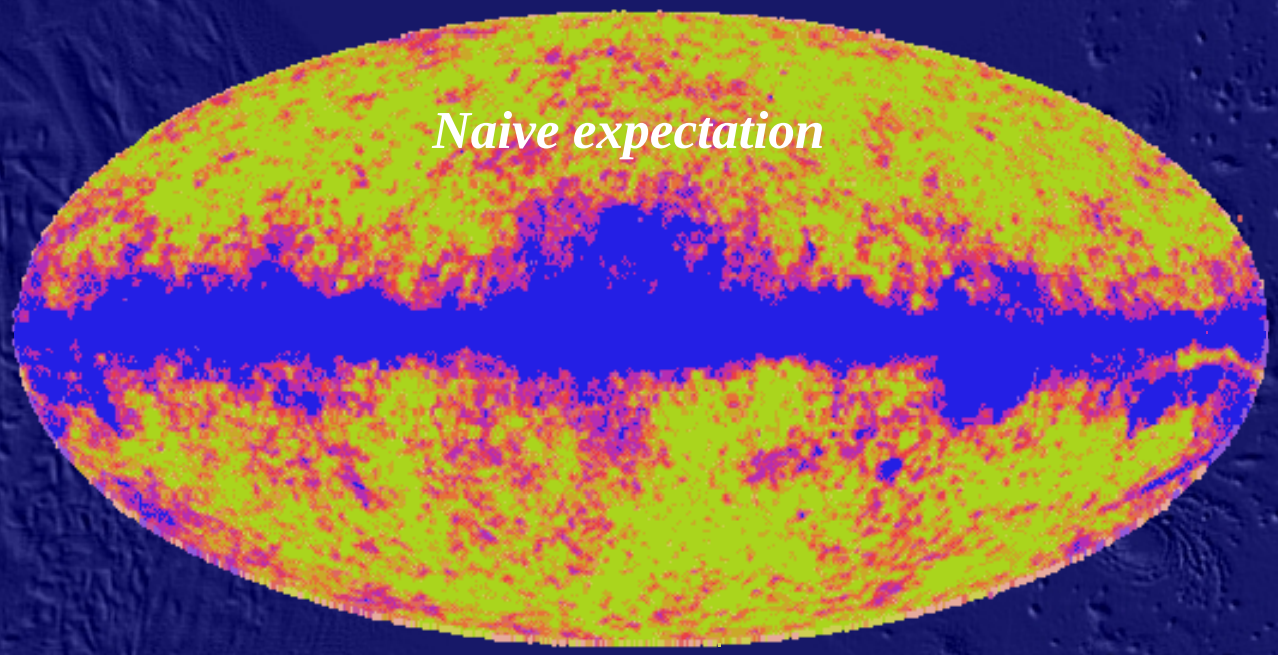


Arrival time of shower front
↳ direction





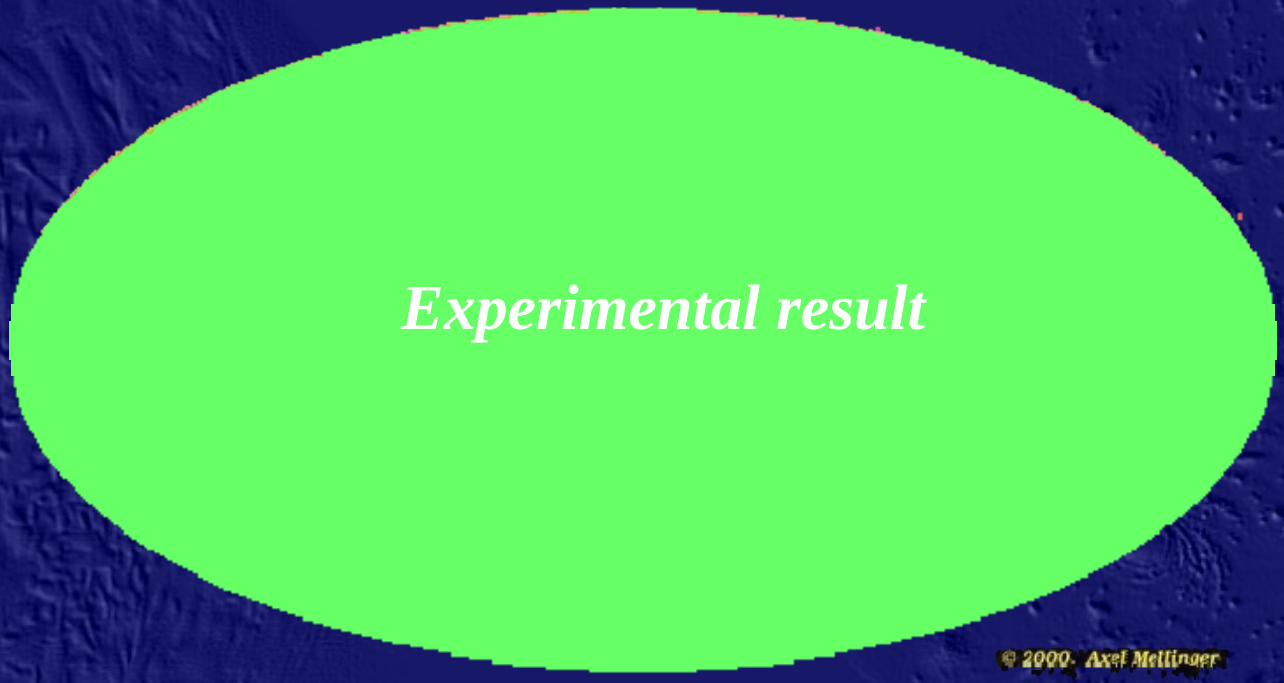
“Sky map“ with Cosmic Rays



From direction of (charged) CR:

No cosmic accelerators visible!

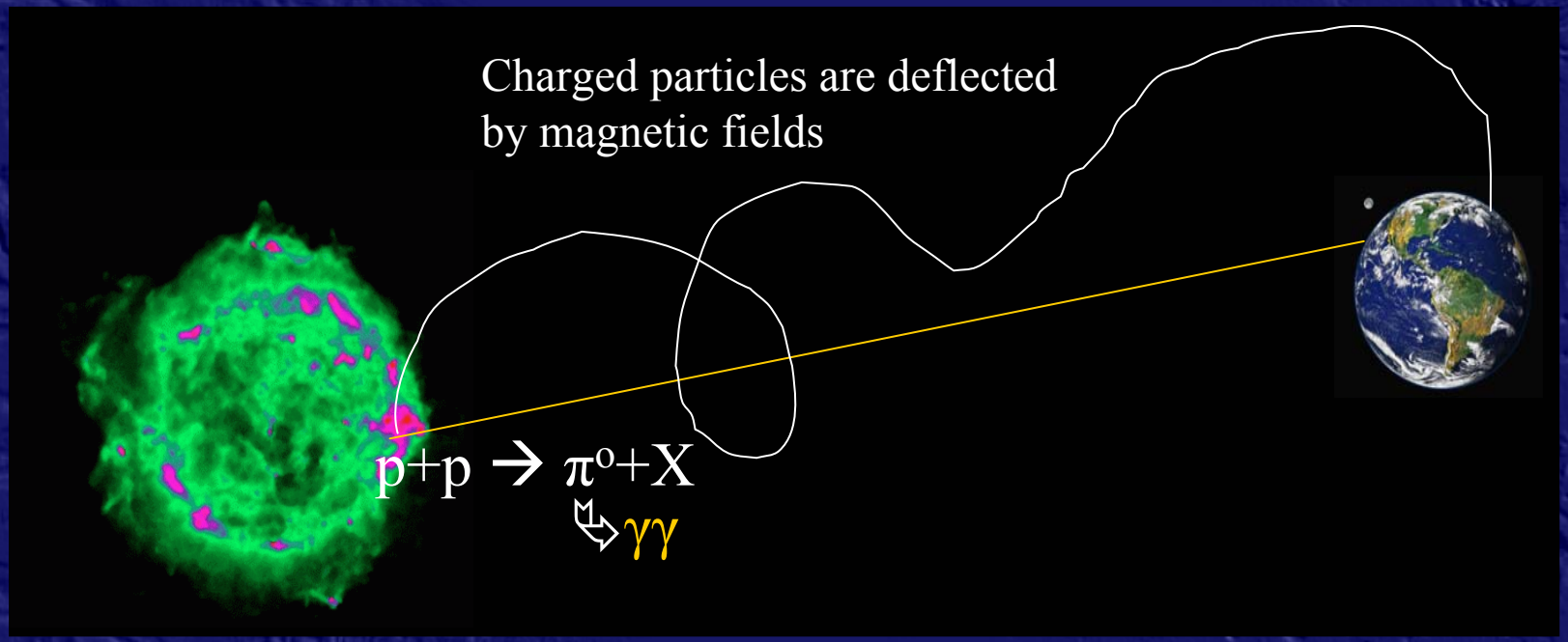
“Sky map“ with Cosmic Rays



From direction of (charged) CR:

No cosmic accelerators visible!

Why are CR isotropic?



- Charged CR do not point back to accelerators
- Number of neutral CR too small to identify accelerators with KASCADE type experiments.

What to do??

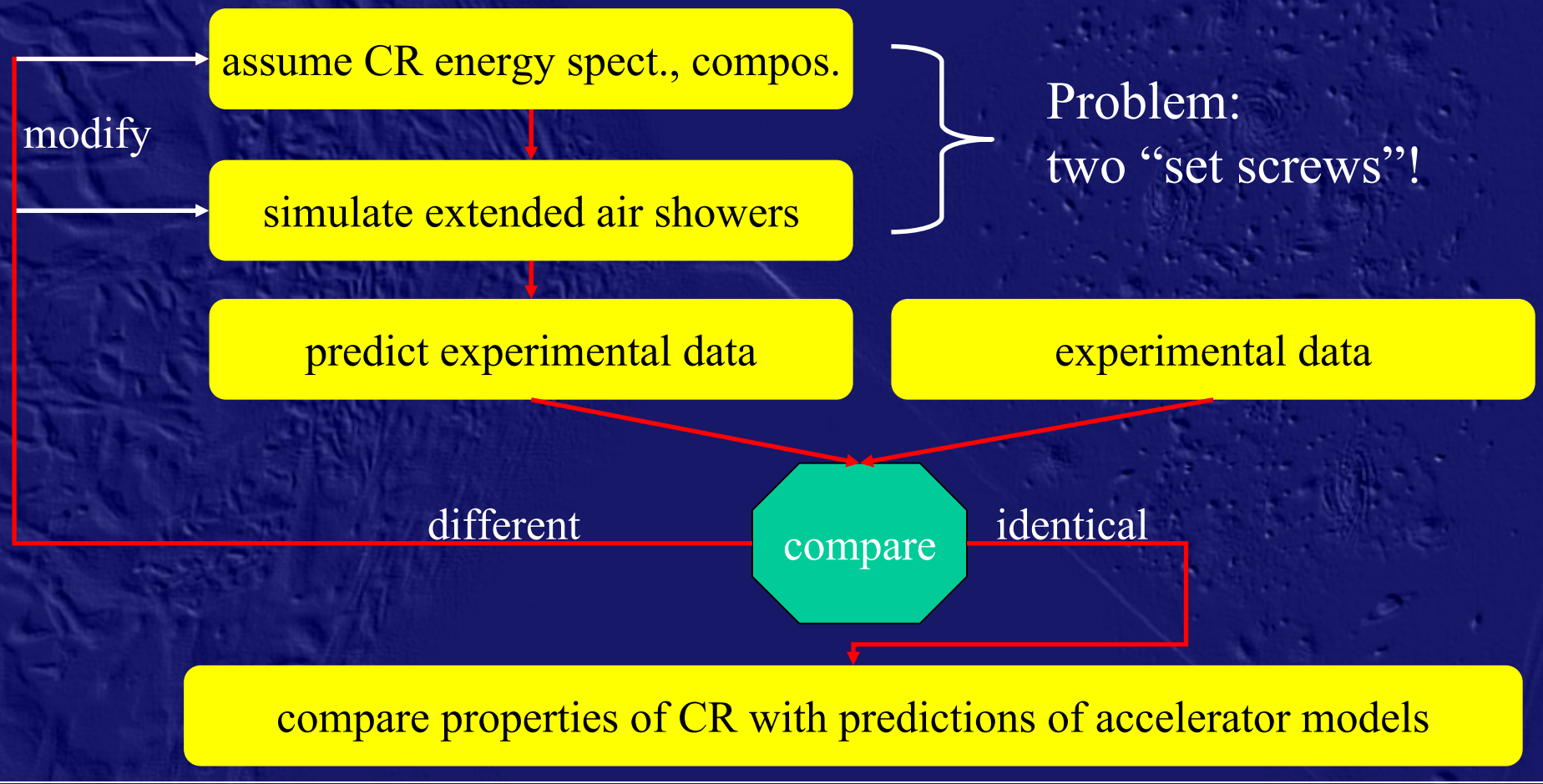
Strategies to identify the cosmic Accelerators

1. select photons (not charged) out of the CR ☞ later

2. compare detailed measurements of the energy spectrum and mass composition of CR with accelerator models

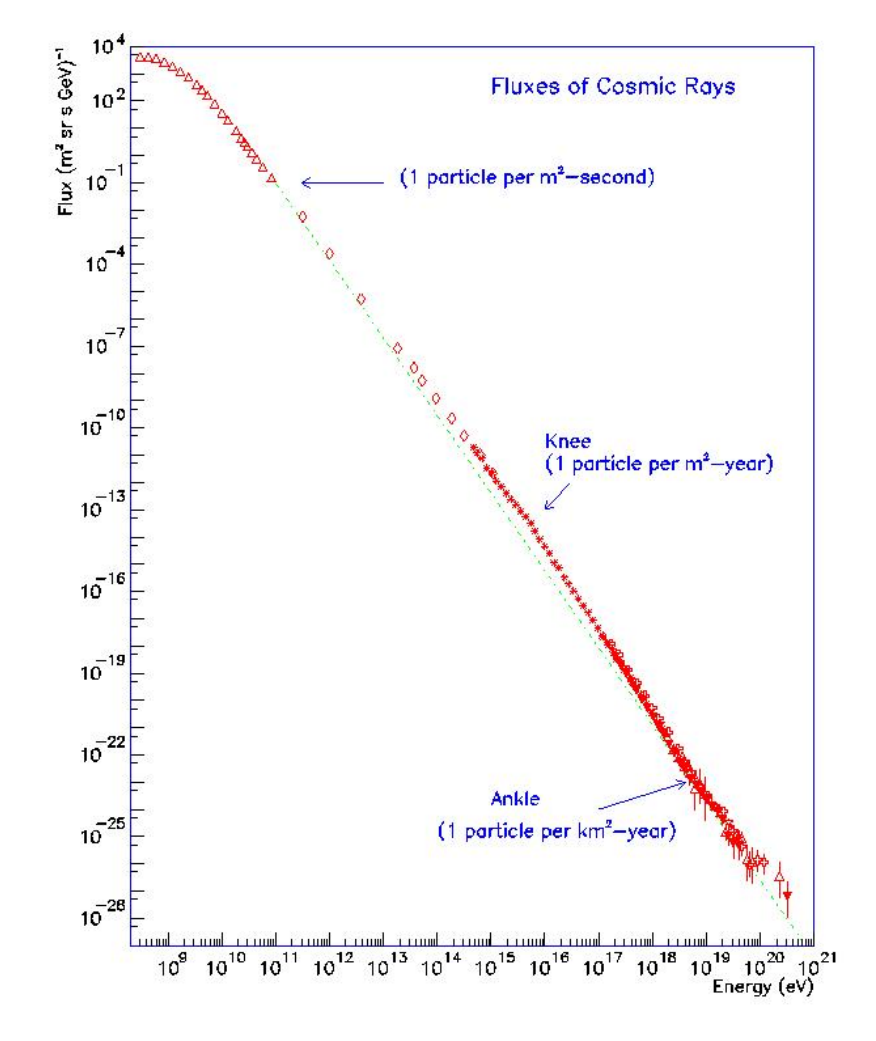
Analyses of Energy Spectrum and Composition

Compare measurements with models

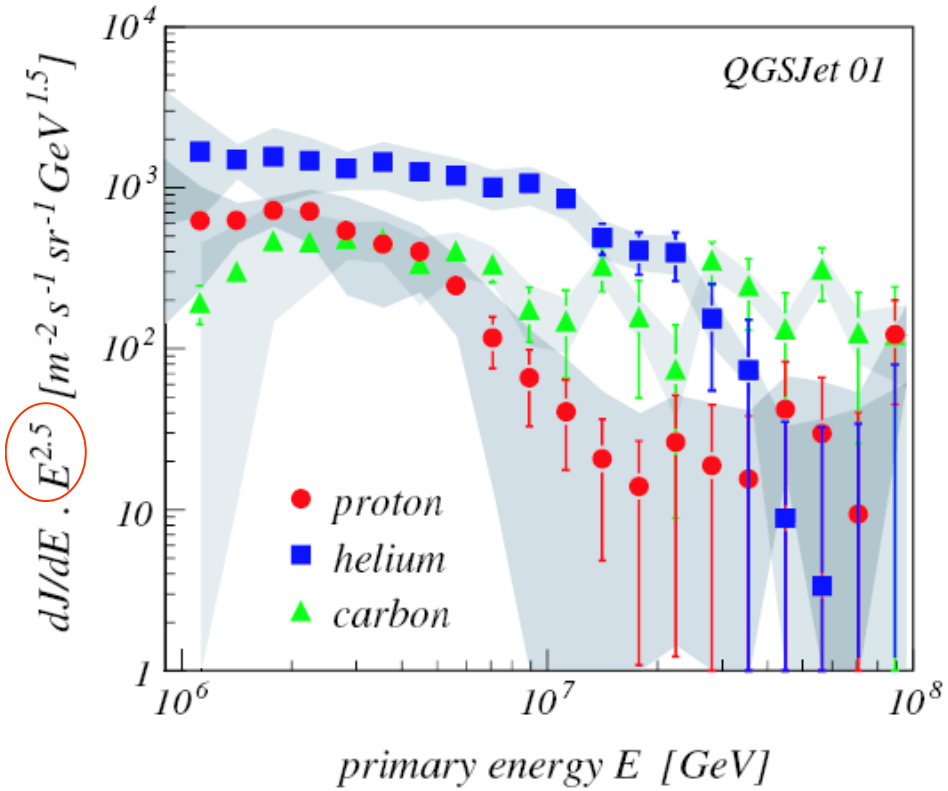


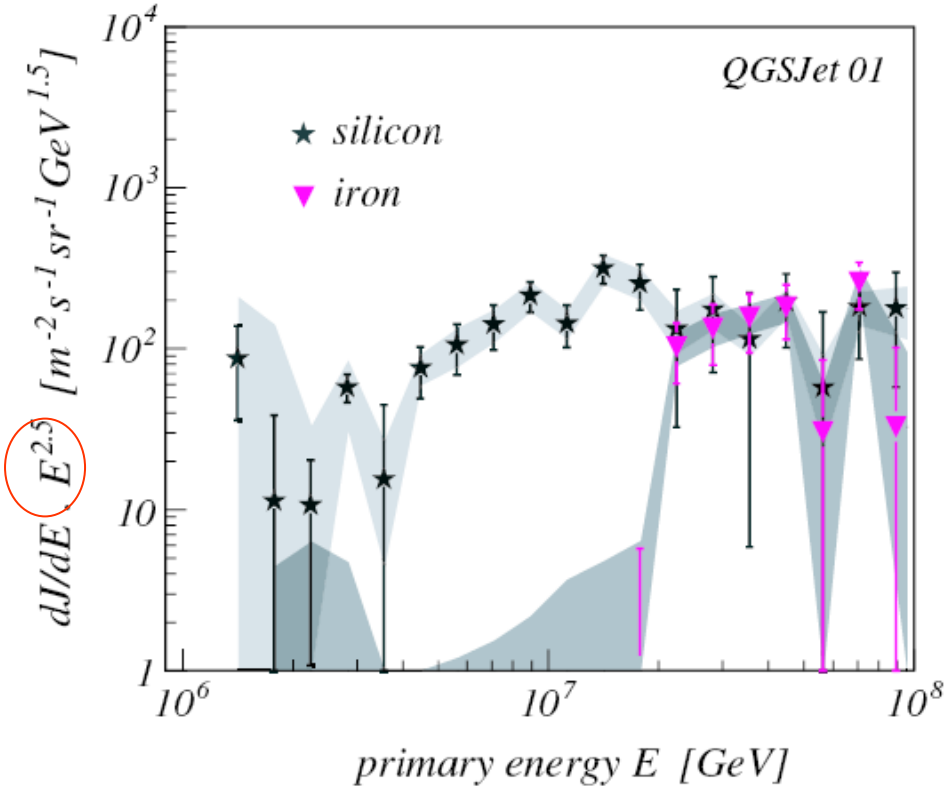
Results of CR Analyses around the Knee

KASCADE collaboration,
Astroparticle Physics 24(2005)1-25

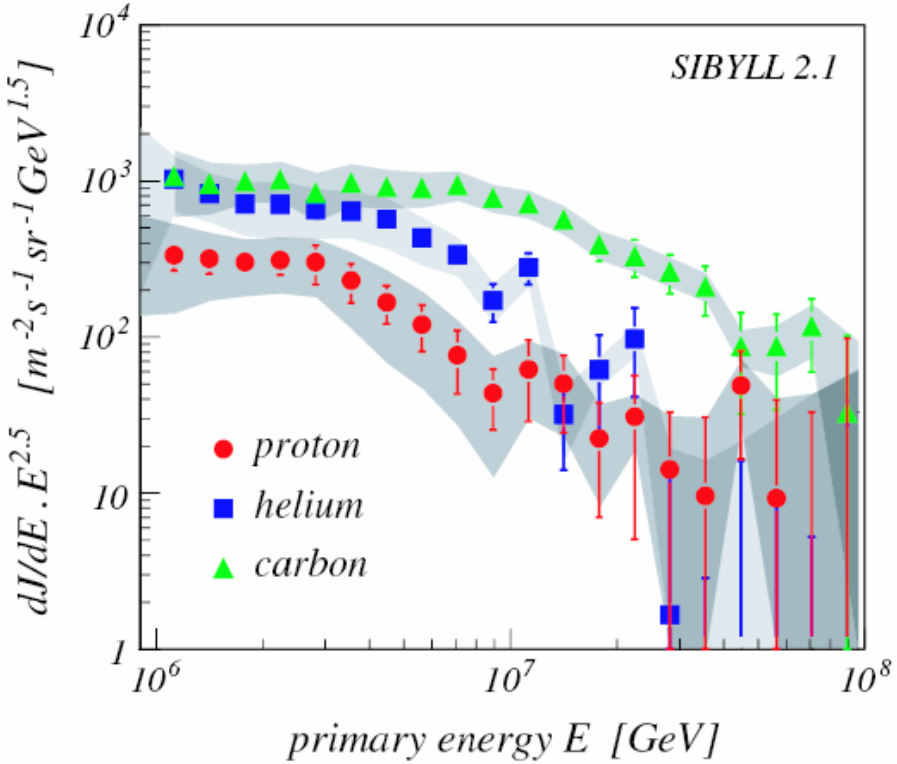


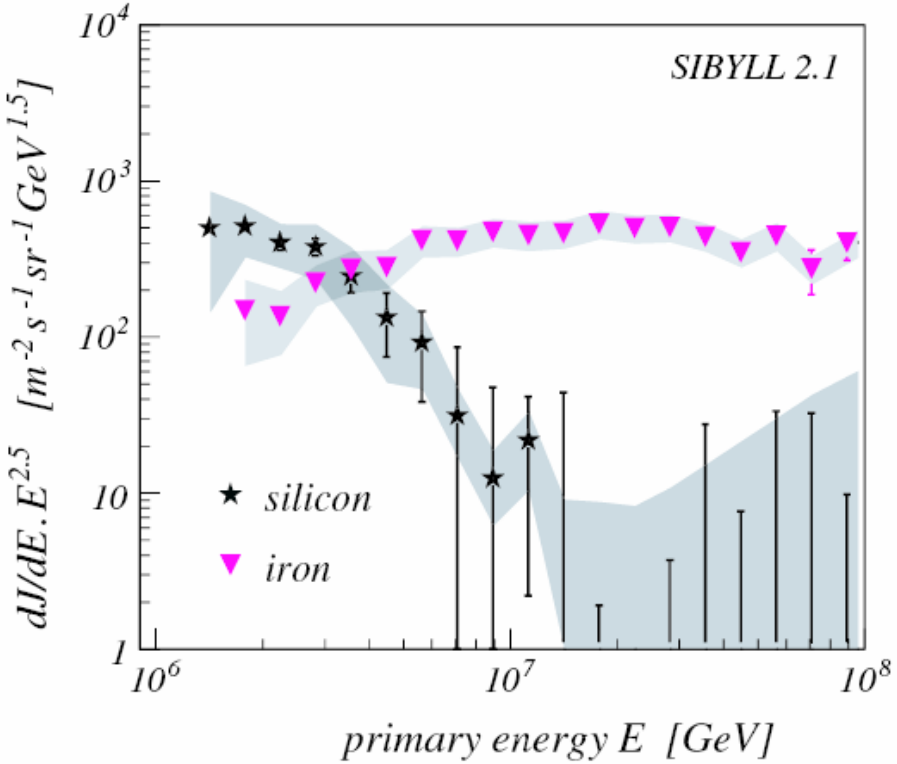
Results of CR Analyses around the Knee





Results of CR Analyses around the Knee





Results of CR Analyses around the Knee

Details of the results depend on the EAS simulation used.

Common features are:

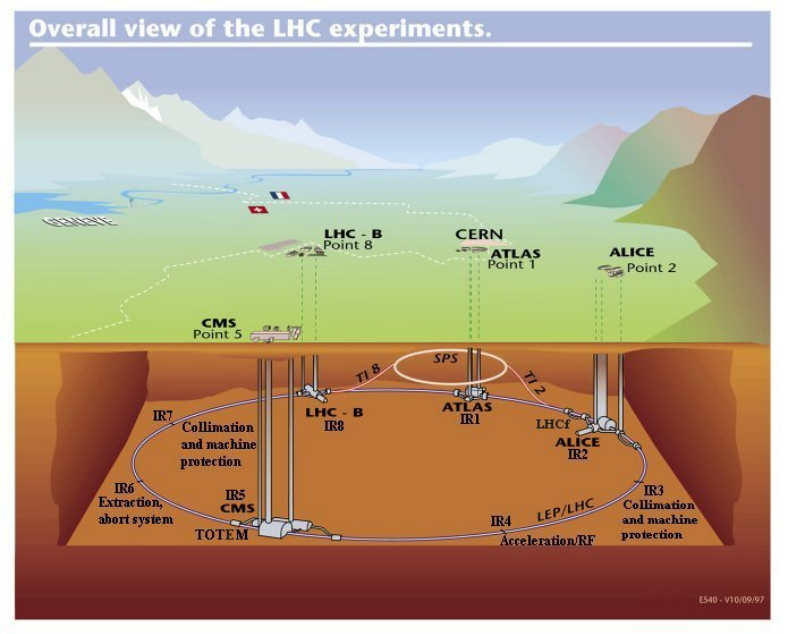
- The composition becomes heavier after the knee
- The knee-energies of CR mass groups are proportional to their electric charges $E_{max} \approx Z \cdot B \cdot L$
- ↳ Consistent with acceleration in supernova remnants

However …

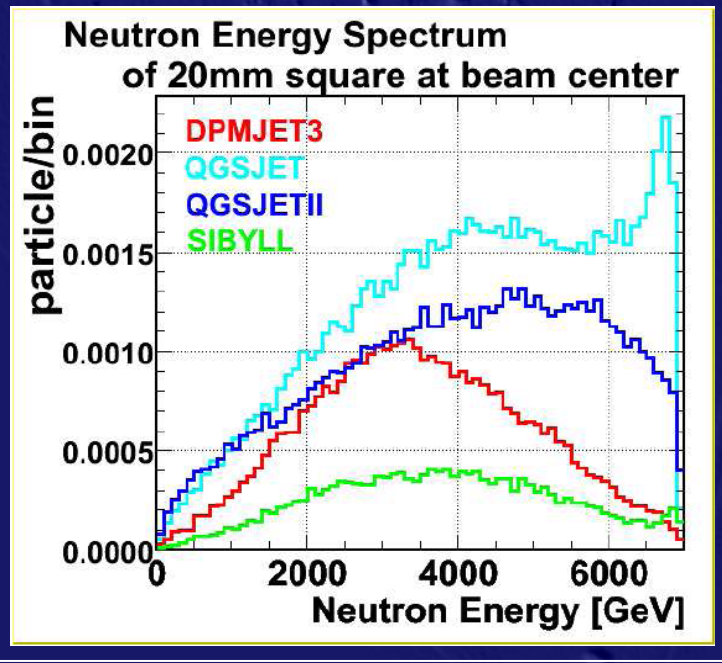
KASCADE collaboration, **Astroparticle Physics 24(2005)1-25**

- "... none of the two interaction models is capable of describing the measured data consistently …"
- "At present, the limiting factors of the analysis are the properties of the high energy interaction models used and not the quality or understanding of the KASCADE data."

Answers from the LHCf- Experiment at LHC?



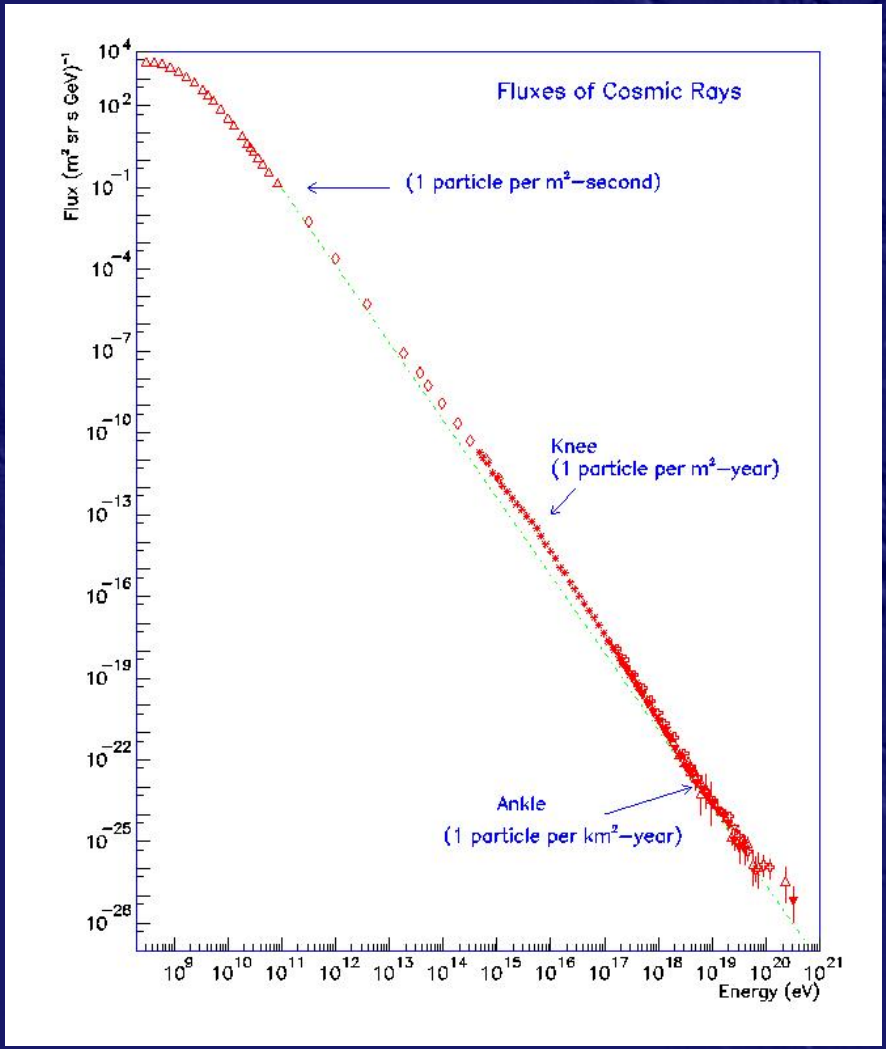
Technical Design Report LHCf



Measure energy flux in the very forward region to constrain air shower simulations:

- 7TeV + 7TeV correspond to 10^{17}eV CR, beyond the "knee"!

From the "Knee" to the highest CR Energies

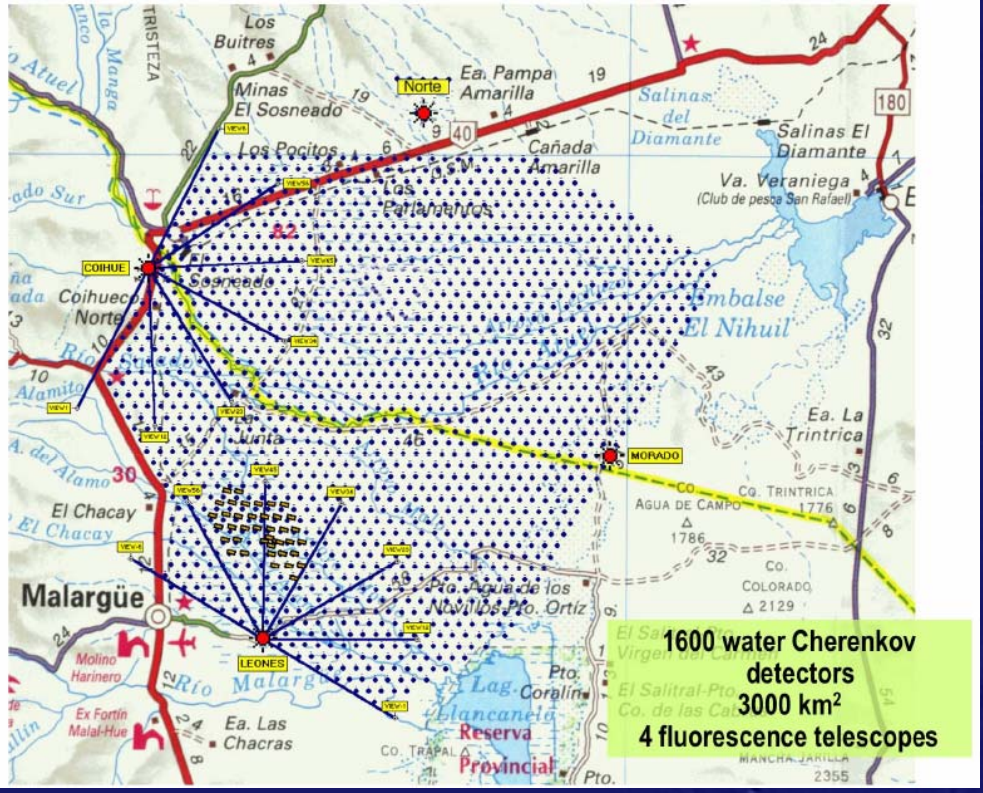


New Challenges …

10^4 m^2 Detector Area ⇨⇨⇨⇨ 10^9 m^2 Detector Area

KASCADE

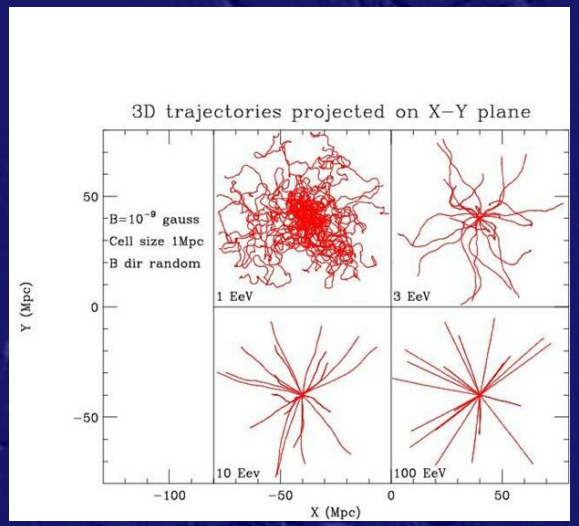
AUGER



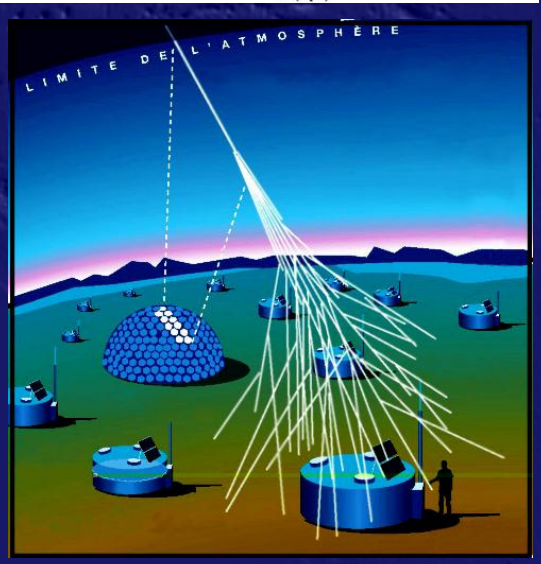
fully operational since end of 2007

… and Chances

- CR at highest energies are hardly deflected by magnetic fields.
  Possibility of "astronomy"?



- New measurements possible: scintillation light, initiated by the air shower in the atmosphere.
  ☞ measure the whole shower development!



From Karlsruhe to the Pampa Amarilla

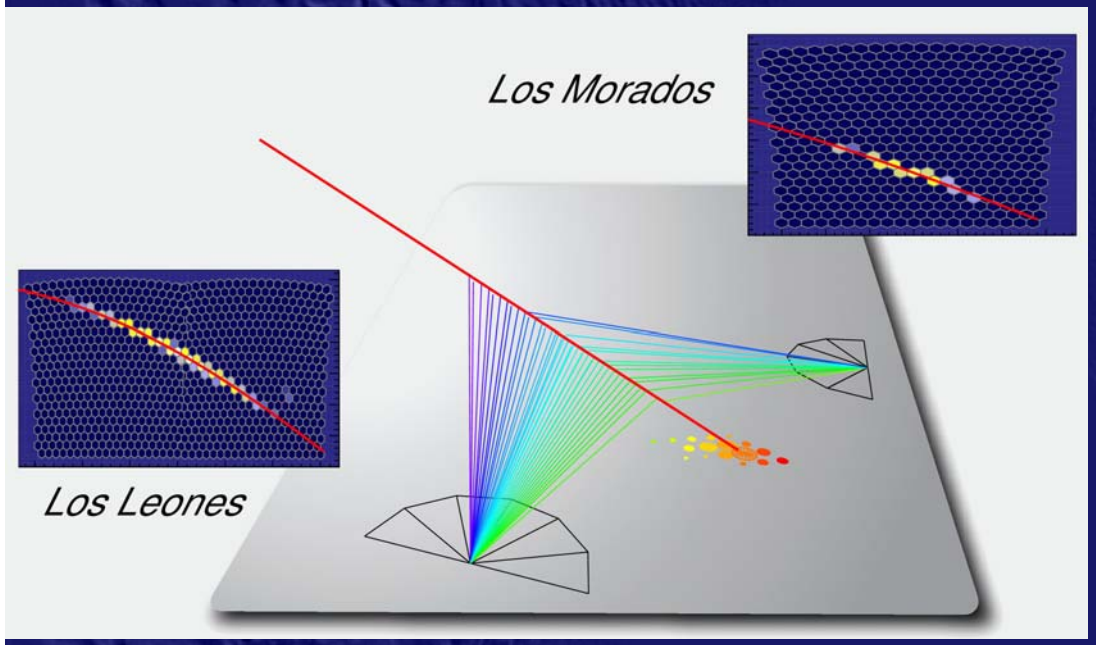
- Large flat area
- Clear nights
- Only few villages
  ↳ dark nights

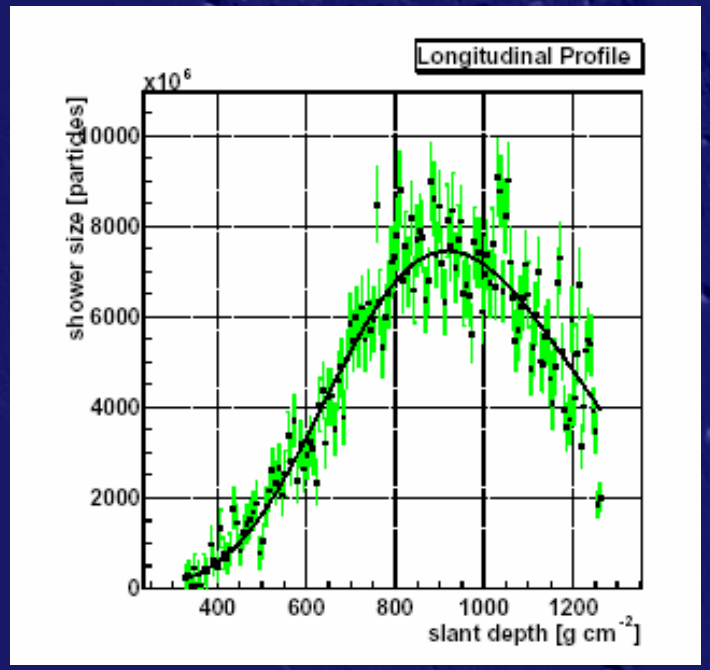
Use the atmosphere as a "fully active" calorimeter!

KASCADE:
only one active layer at ground level

The Pierre AUGER Observatory

air shower development





Physics with much better systematics!

Physics with the Auger Observatory

- Energy spectrum of highest energy CR
- Composition of highest energy CR
- Sources of highest energy CR
- Neutrino physics
- Air shower physics
- Tests of simulations
- …

Energy Spectrum: the GZK-Cutoff

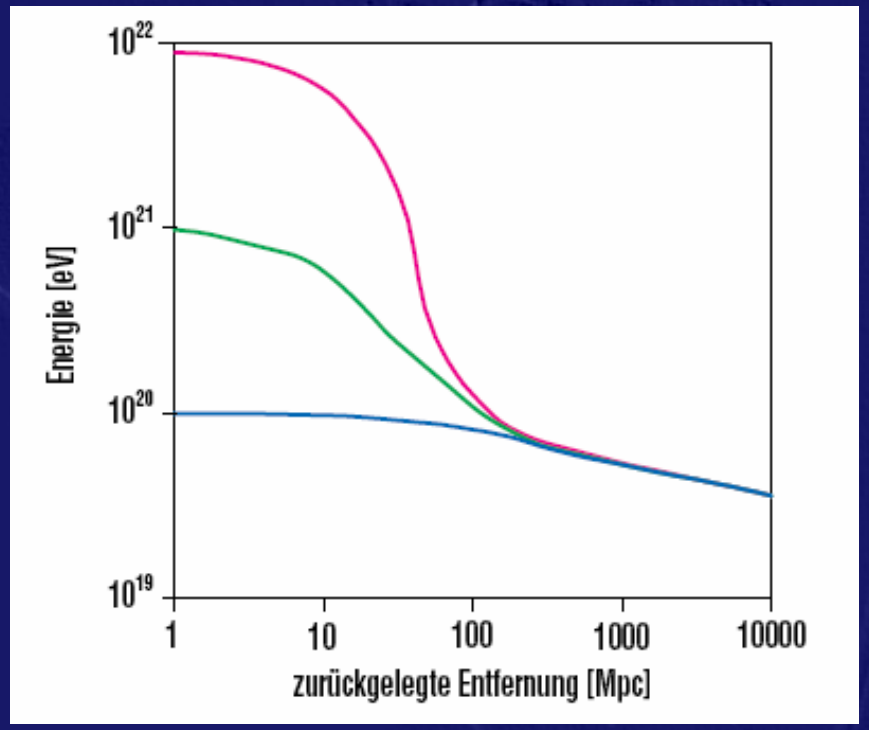
Greisen-Zatsepin-Kuz'min:

The universe appears opaque to CRs of highest energies due to photoproduction of pions

$N + \gamma \rightarrow N' + n \cdot \pi$

with CMBR-photons ($E_\gamma = 10^{-3}$eV):

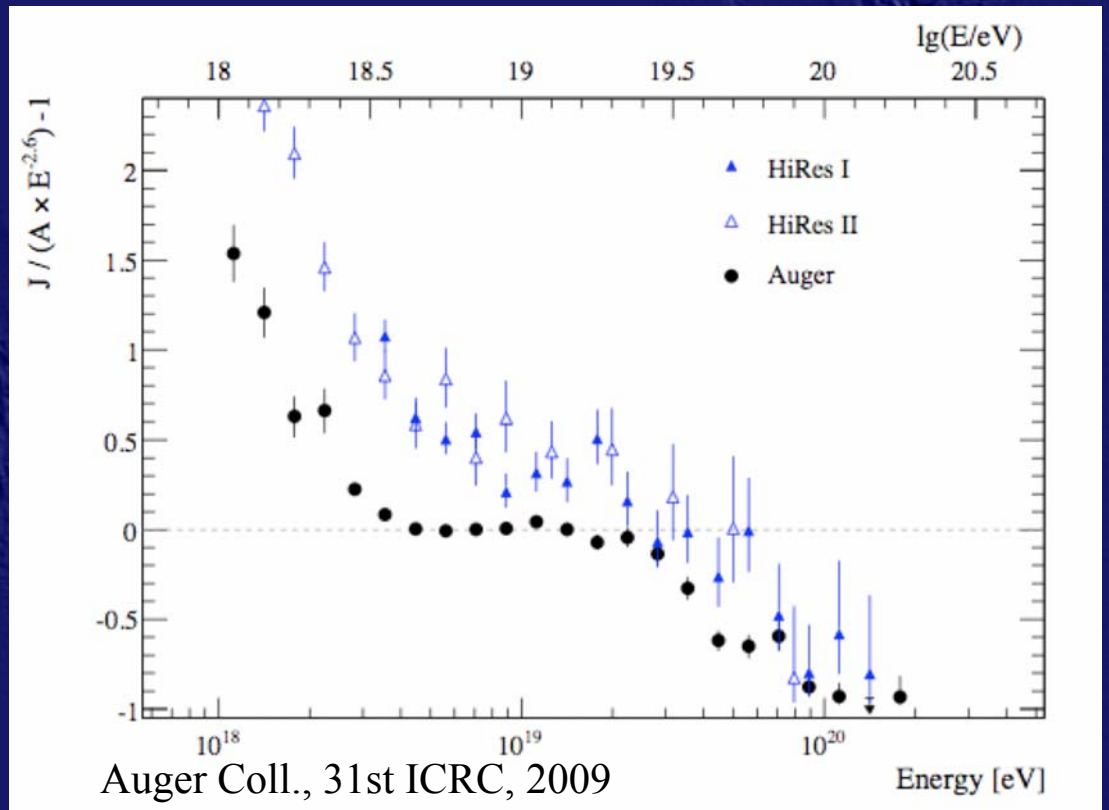
photoproduction for
$E(N) > 5 \cdot 10^{19}$eV
mean free path length:
"only" 30 million light years



AUGER: Energy Spectrum

- The GZK-cutoff is present in the measured energy spectrum. However, the origin of the particles with highest energies is unclear!

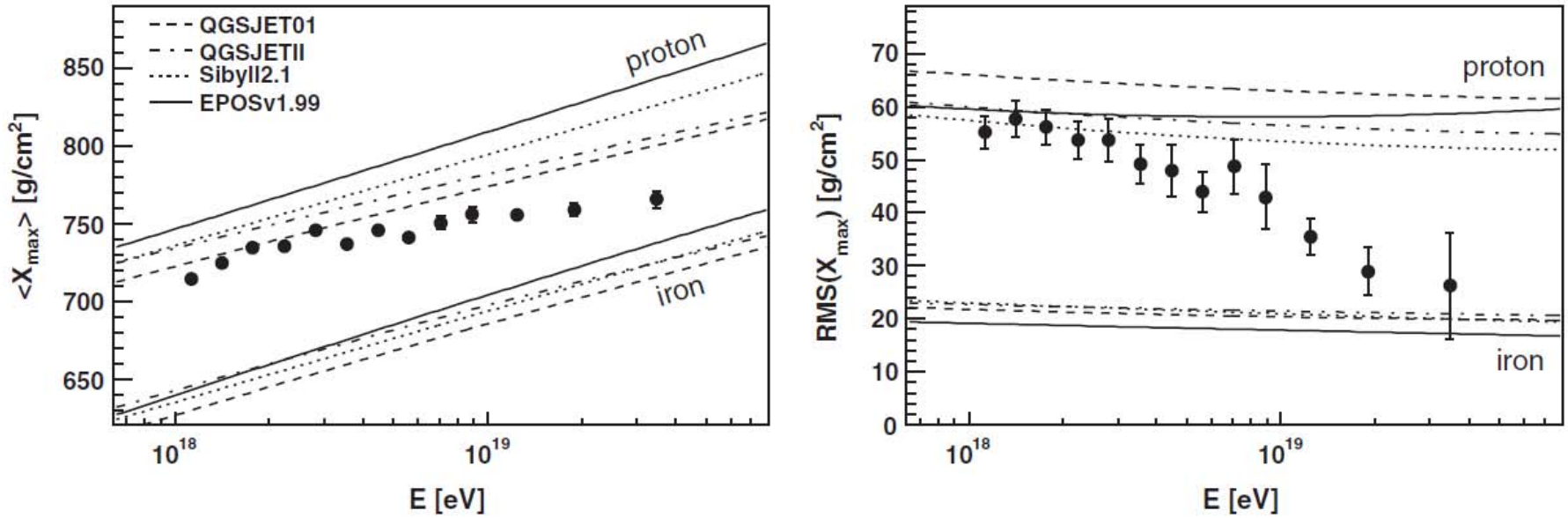
Conclusion:
The bulk of cosmic ray accelerators lies at cosmological distances!



Auger Coll., 31st ICRC, 2009

AUGER: Composition

PRL **104,** 091101 (2010) PHYSICAL REVIEW LETTERS week ending 5 MARCH 2010



- Highest energy CR seem to be dominated by iron-like nuclei! This is hard to understand because nuclei tend to disintegrate in the cosmos.
- Are our models of hadronic interactions appropriate at these energies?

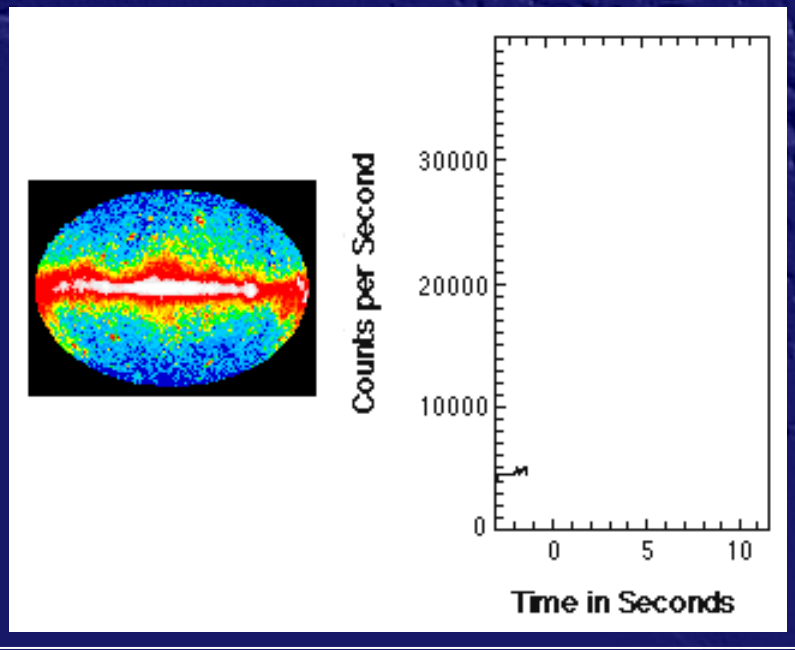
Possible Origins of highest Energy CR

Above $5 \cdot 10^{19}$eV CR not bound to galaxy (gyroradius > galaxy)

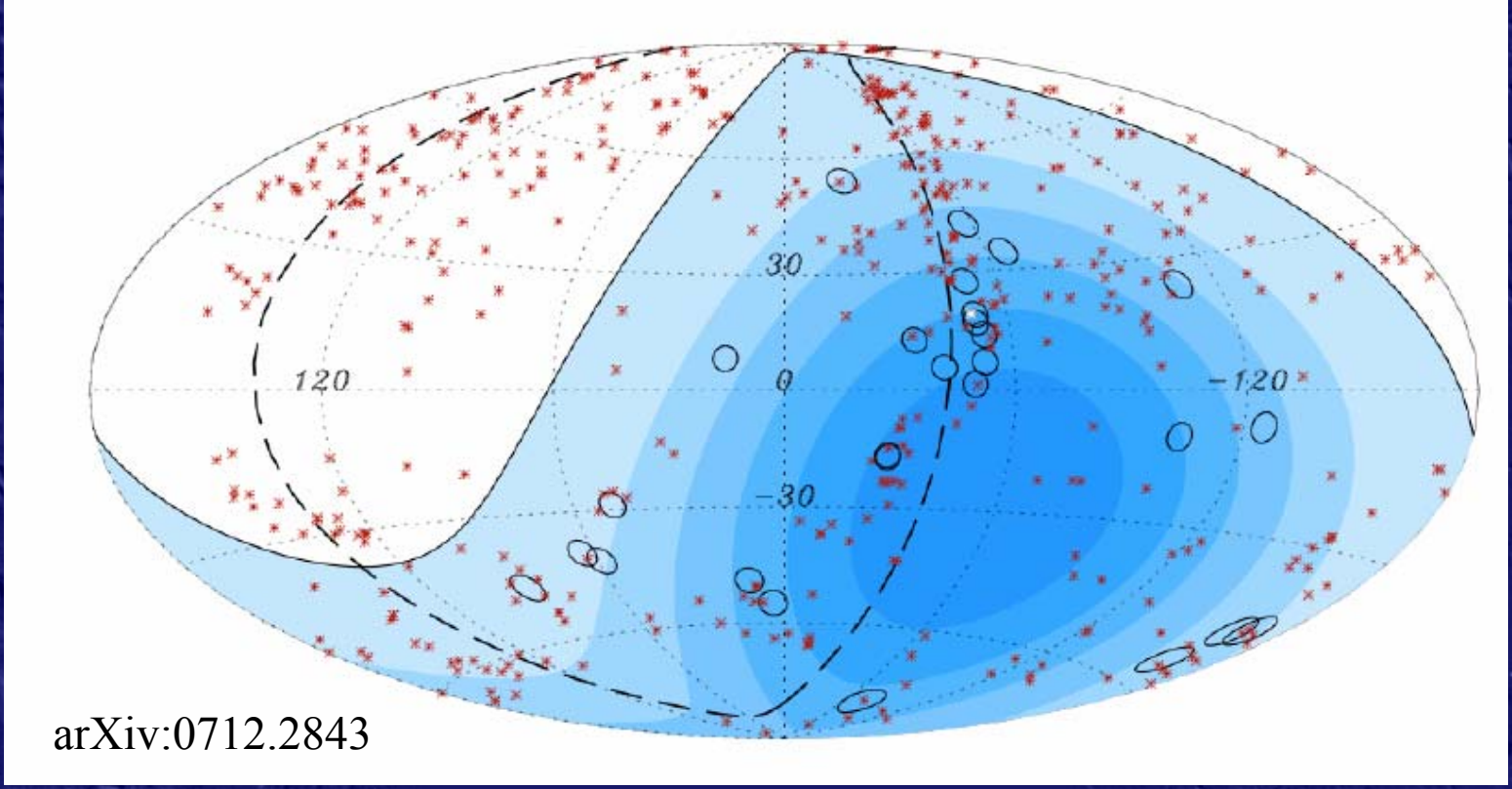
- Extragalactic sources at cosmological distances likely

Active Galactic Nuclei
active black holes with more 10^{10} solar masses

Gamma Ray Bursts
extremely violent supernovae (?) at cosmological distances



AUGER: Accelerators of Cosmic Rays



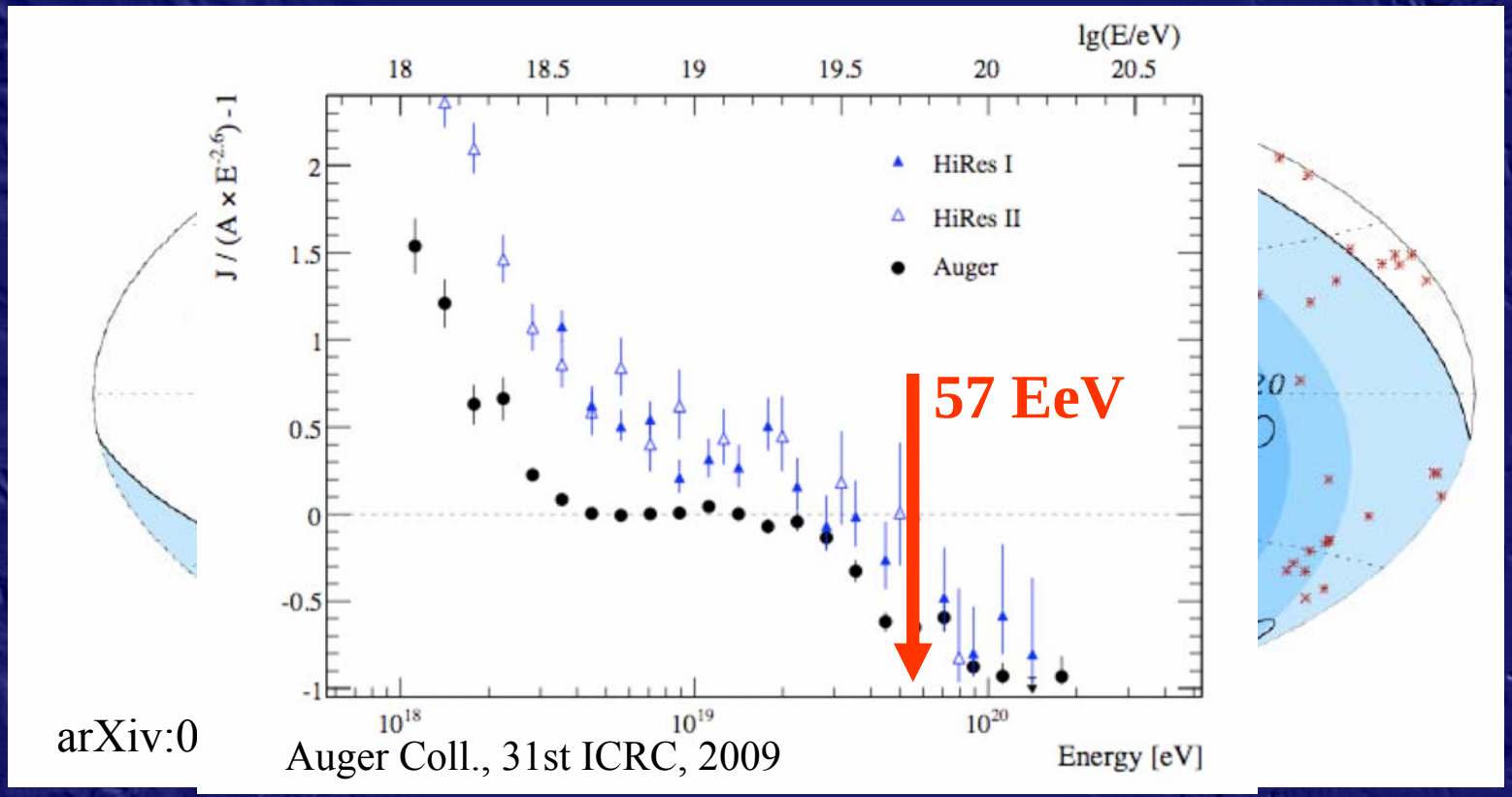
arXiv:0712.2843

Circles: CR with E > 57 EeV *(= 8,000,000 · LHC-beam)*

asterisks: AGNs with z < 0.017 (< 71 Mpc, within GZK horizon)

blue areas: exposure time

AUGER: Accelerators of Cosmic Rays



arXiv:0

Auger Coll., 31st ICRC, 2009

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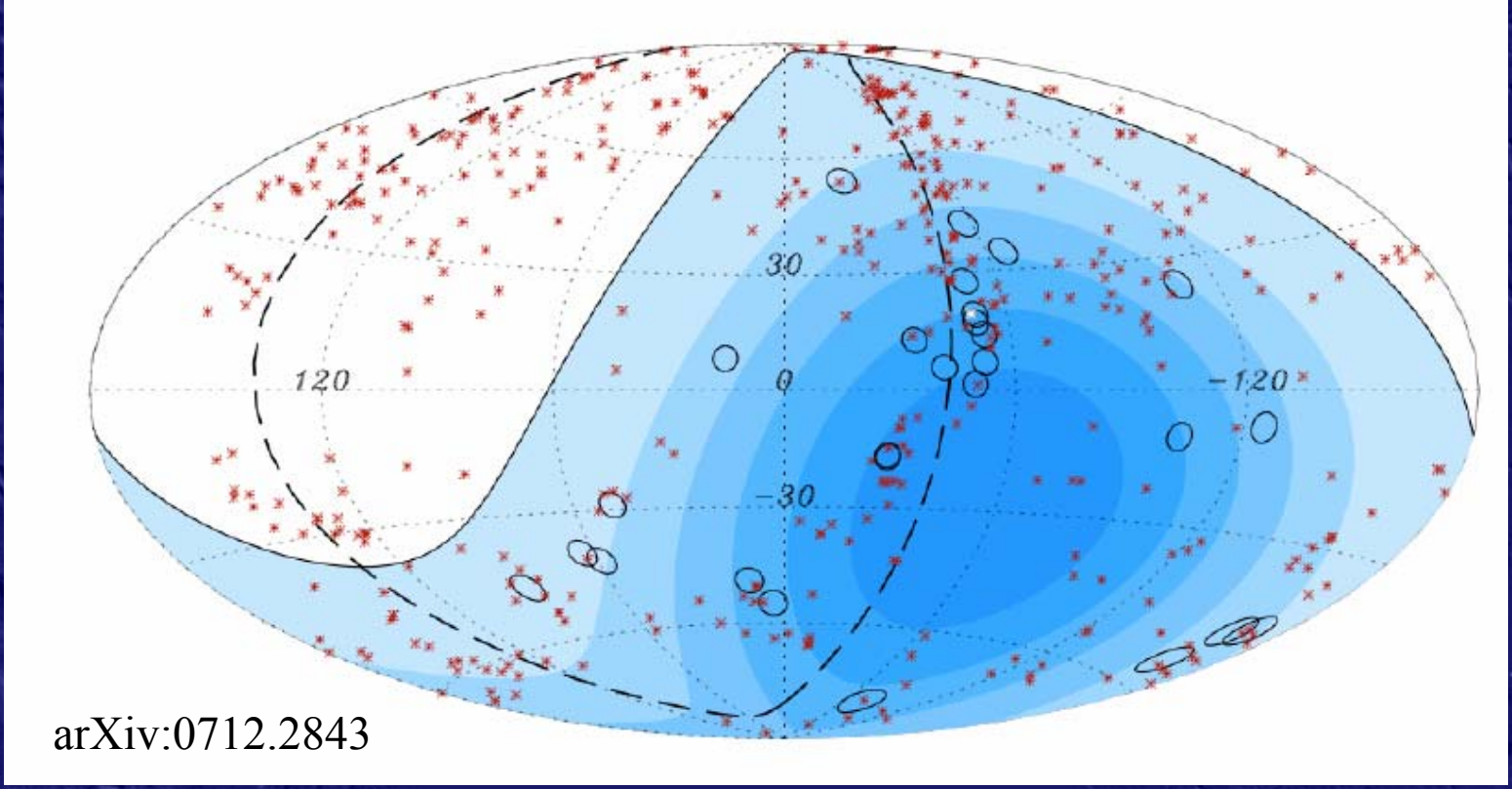

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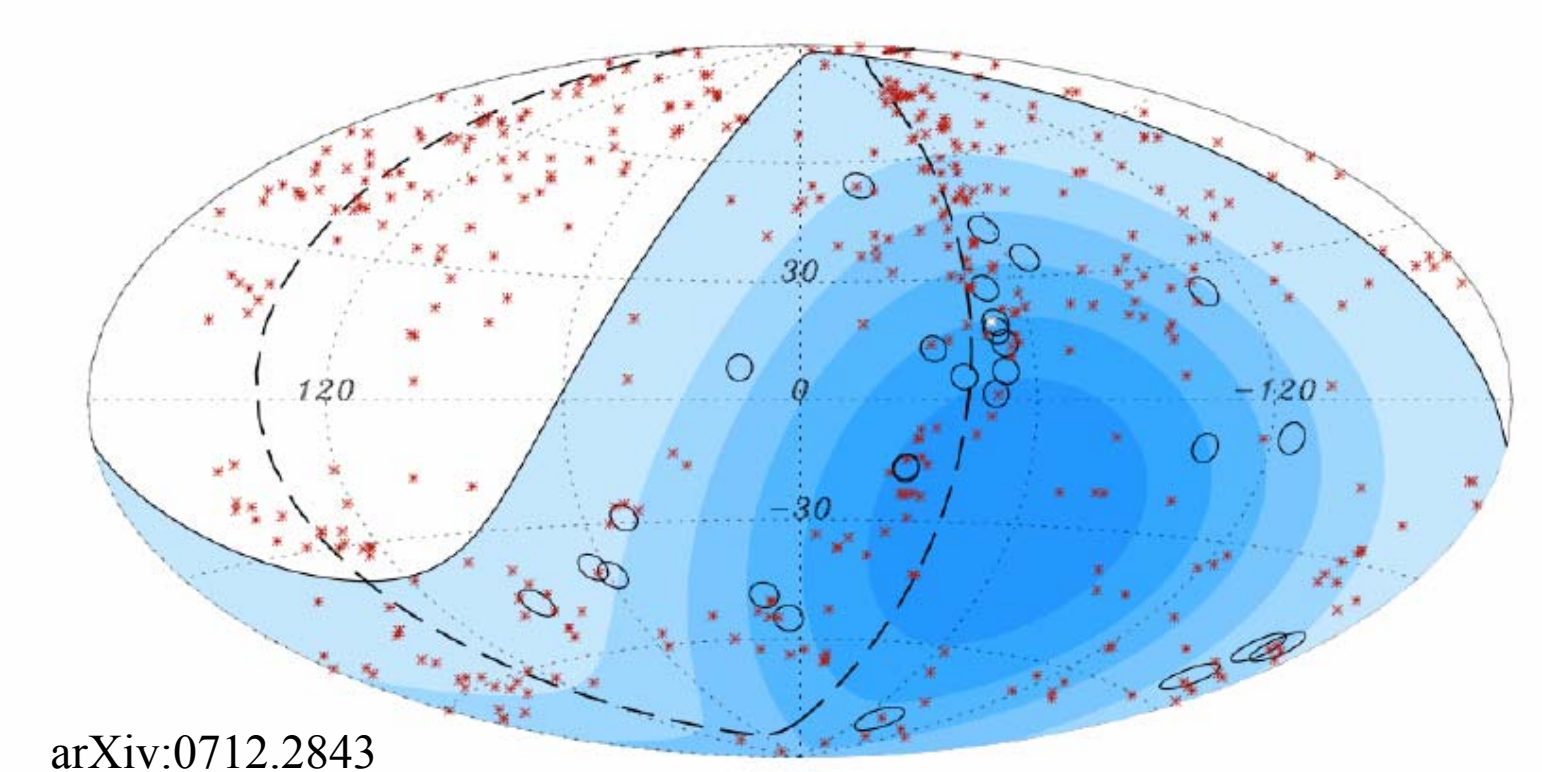


arXiv:0712.2843

Statistical analyses show a 99% confidence level for a correlation of the arrival direction with AGNs ($5\sigma = 99.994\%$).

More data needed to prove "high energy CR astronomy"!

Conclusions on highest Energy Cosmic Rays

- The GZK cut-off exists. If CRs reach earth from cosmological distances, they should preferably consist of proton-like nuclei.
- At highest energies (above the GZK cut-off) CRs seem to point back to AGNs as their acceleration sites. If this is confirmed, CRs should be proton-like, because nuclei with larger charges would be deflected too much by intergalactic magnetic fields.
- However, analyses hint at an iron-like composition of highest energy CRs.

Something seems to be wrong!

Cosmic Rays: Topics for Discussion

- How do we know that CR are charged?
- How do we know the composition of CR at lower energies?
- Why is the simulation of extended air showers doubtful and hence problematic?
- How to improve interaction models for high energy air showers?
- Would a detector for CR above the knee located at the moon be meaningful?
- How to do neutrino-physics with a CR detector?

Astroparticle Physics

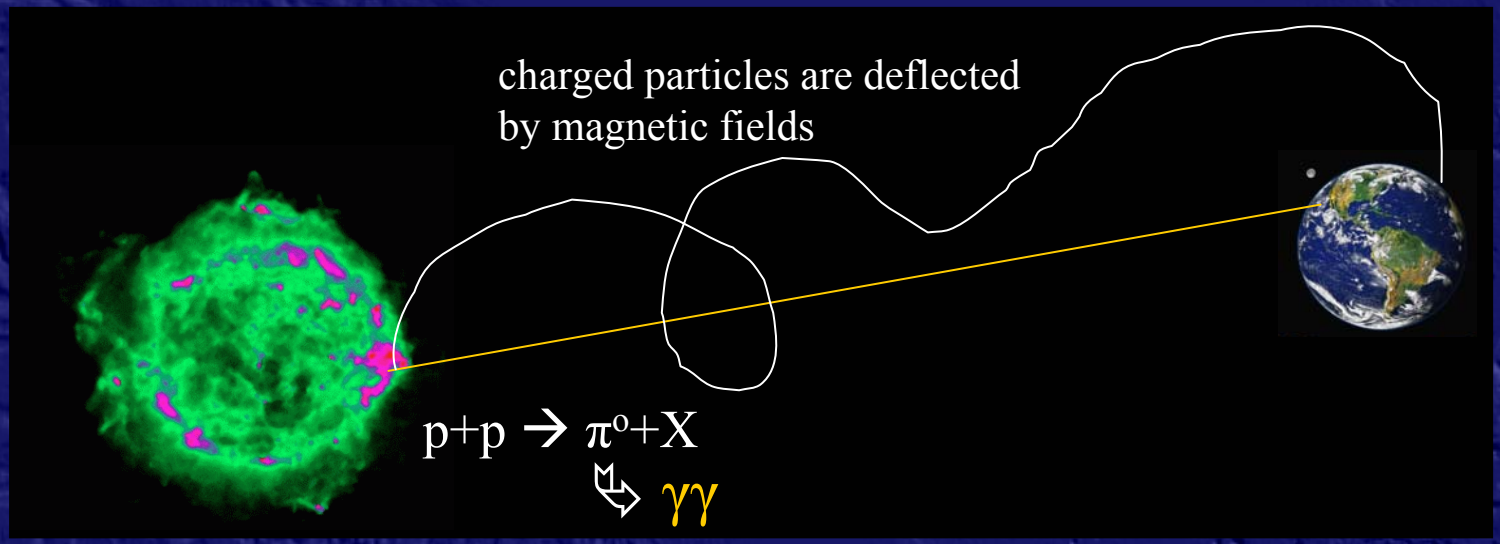
Topics for today:

- High Energy Particles from the Cosmos.
- The new Astronomy.

On Friday:

in context with the ALPS experiment some discussion of Dark Matter in the Universe.

Motivation for Astronomy with E > 100 GeV



- Indirect identification of CR accelerators via analyses of the charged CR problematic
- Look for high energy photons which are produced at the accelerator

New experimental methods required!

Instruments for GeV-TeV Photons

The challenge:

Flux of photons of the crab nebula
(brightest galactic source in the GeV-TeV range)

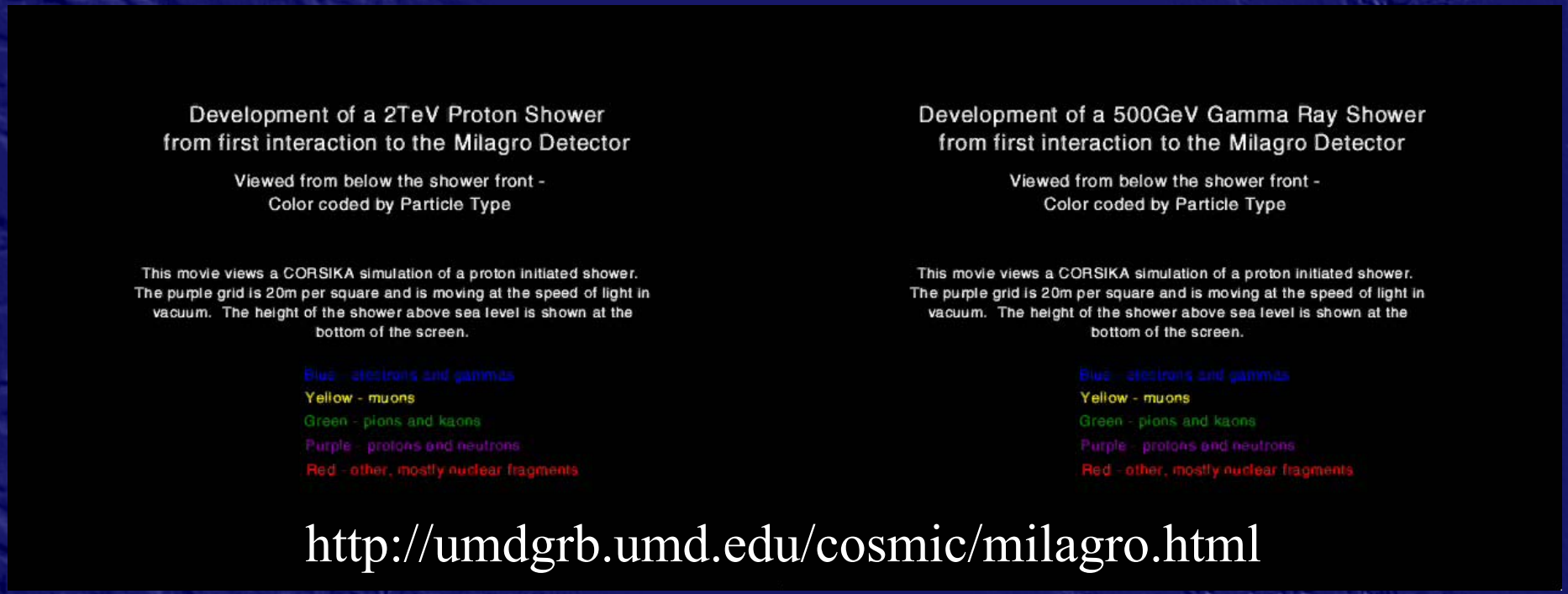
$F(E_\gamma > 500\text{GeV}) = 10\ /\text{m}^2/\text{year}$

↳ Not detectable with satellites!

The solution:
register air showers initiated by photons!

- select photon induced air showers
- aim for lowest possible energy threshold to maximize number of detected photons.

Proton and Photon induced Air Showers



http://umdgrb.umd.edu/cosmic/milagro.html

simulation of a EAS,
observation from bottom,
grid moves with the velocity
of light

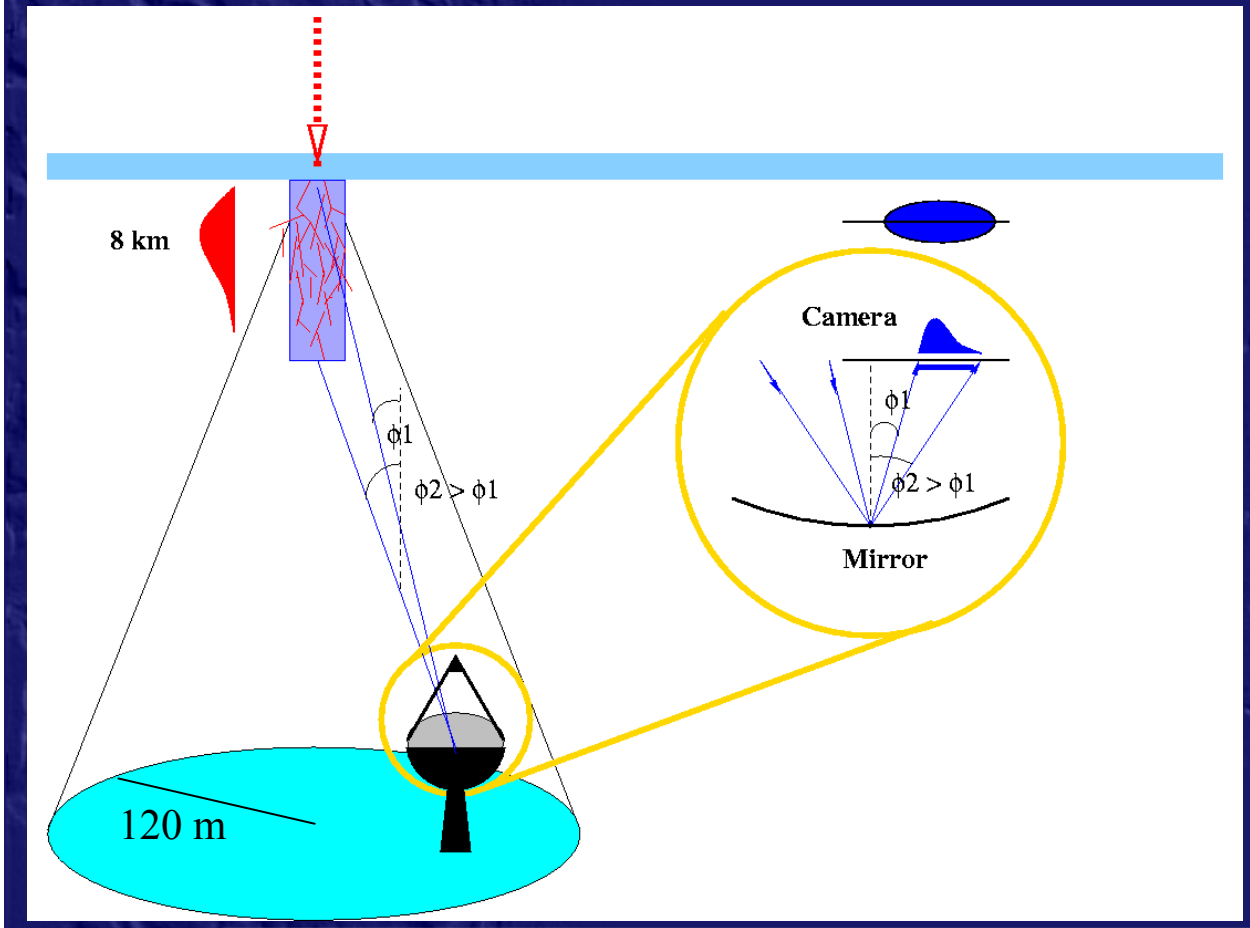
$e^{\pm}$, γ, $\mu^{\pm}$, π, K, p, n, N

Proton and Photon induced Air Showers

Compared to proton induced showers photon induced showers

- contain only electrons, positrons and photons,
- are more compact,
- are more uniform,
- decay faster.

Imaging Air Cherenkov Telescopes (IACTs)



http://www.mpi-hd.mpg.de/hfm/HESS/HESS.html
http://veritas.sao.arizona.edu/
http://magic.mppmu.mpg.de/index.en.html

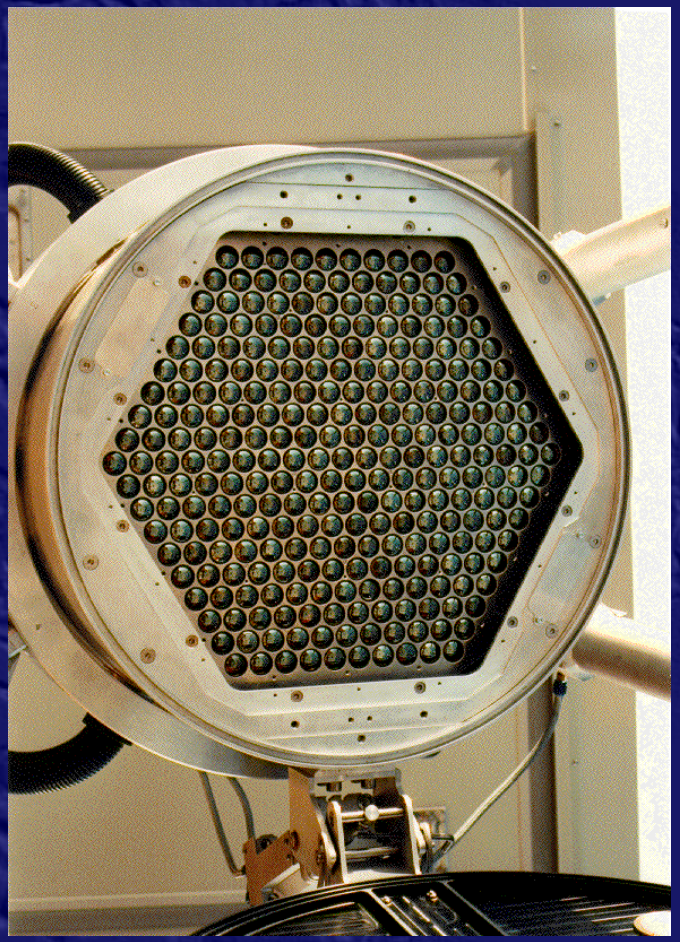
Register Cherenkov light emitted by the air shower:

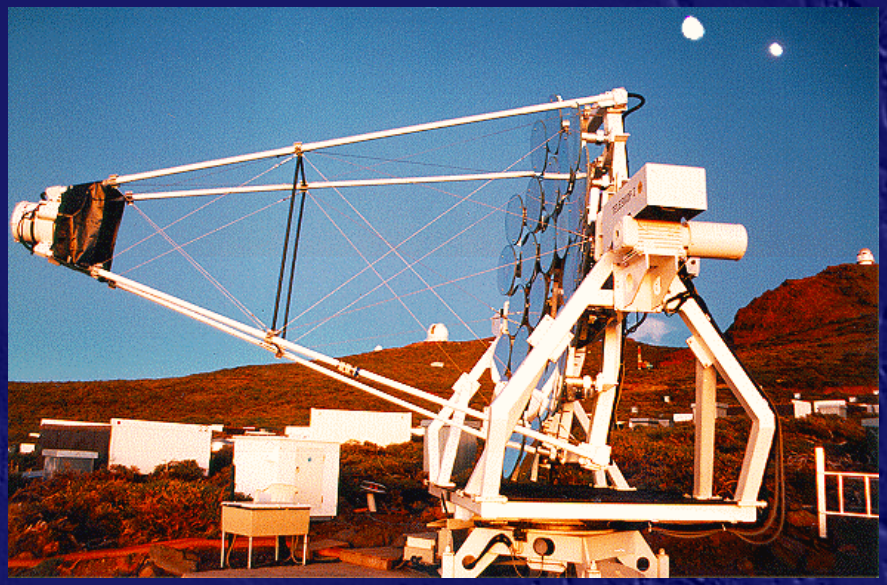
by nature
sensitive area of 10^4 m^2

secondary shower particles do not have to reach ground level
☞ low energy threshold

But operation only in clear moonless nights!

A Pioneer: The HEGRA Experiment





- Segmented mirror
  (optical demands much less than for optical astronomy)
- Camera made of several hundred photomultipliers
  (register ns signals, high amplification)

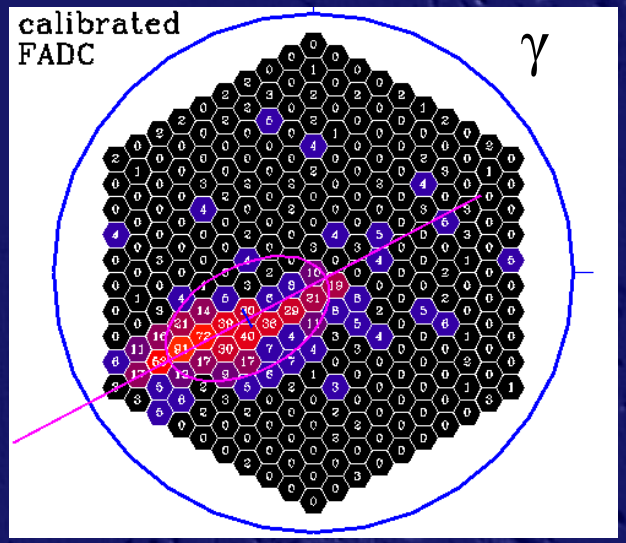
Selection of Photon induced EAS

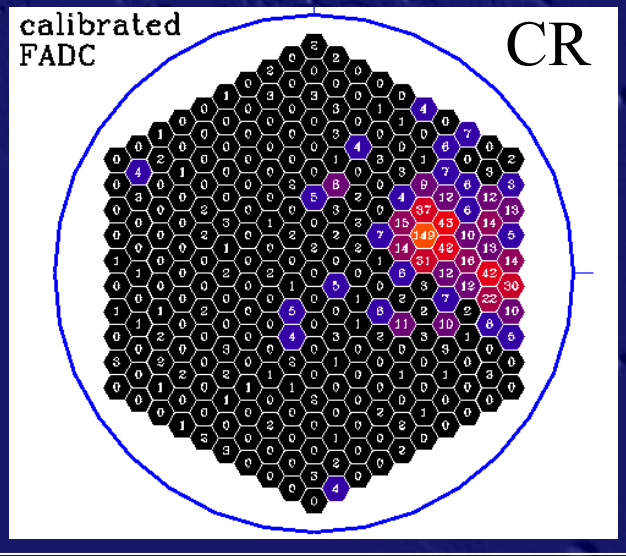
Images of EAS

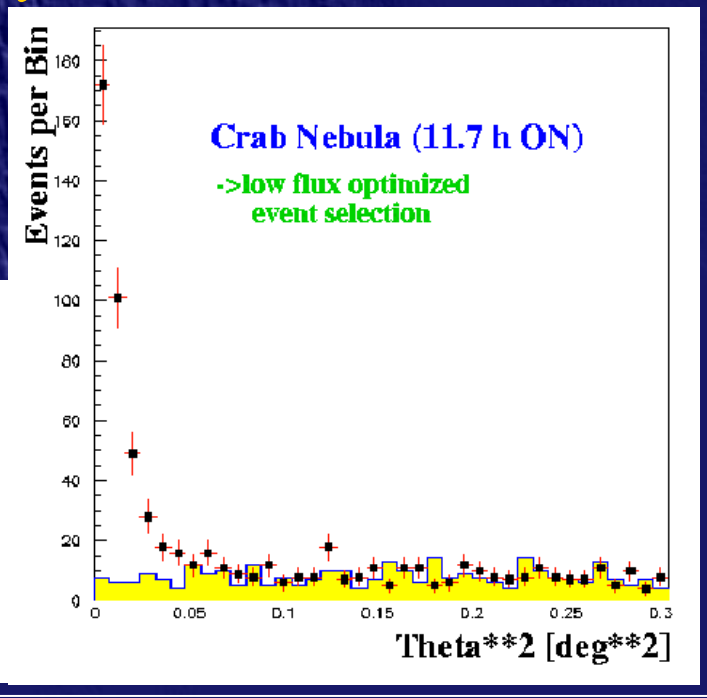
Photon showers: only em. interaction

↳ Photon induced EAS more compact and homogeneous than showers of CRs

↳ Image analysis!



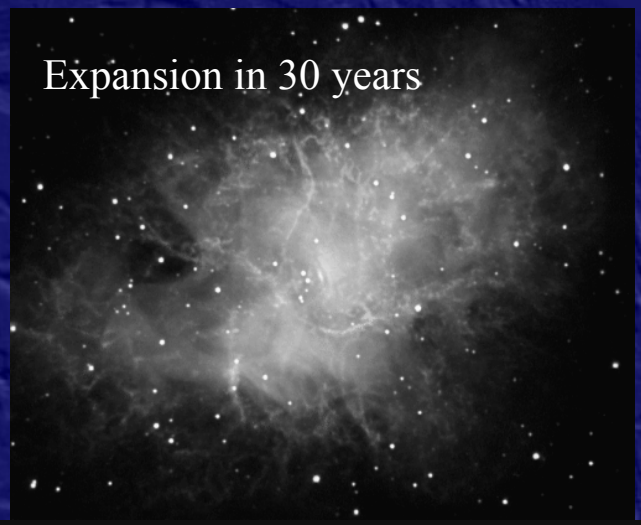


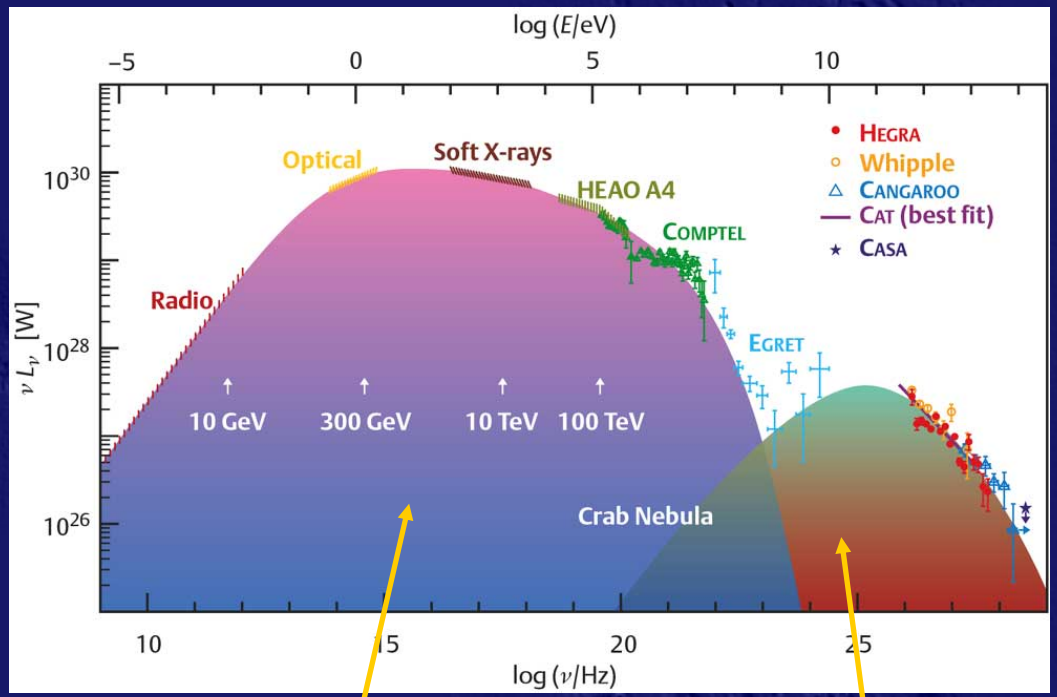


- Strong CR suppression
- Very good angular resolution

Crab nebula (M1): the TeV Standard Candle

Remnant of a supernova in the year 1054 with a central pulsar



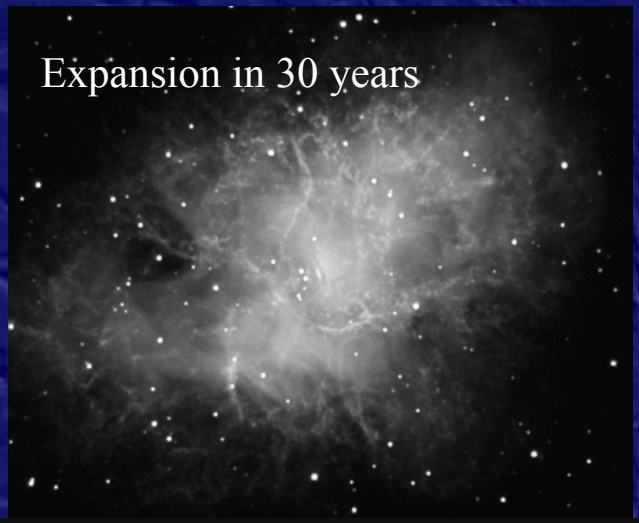


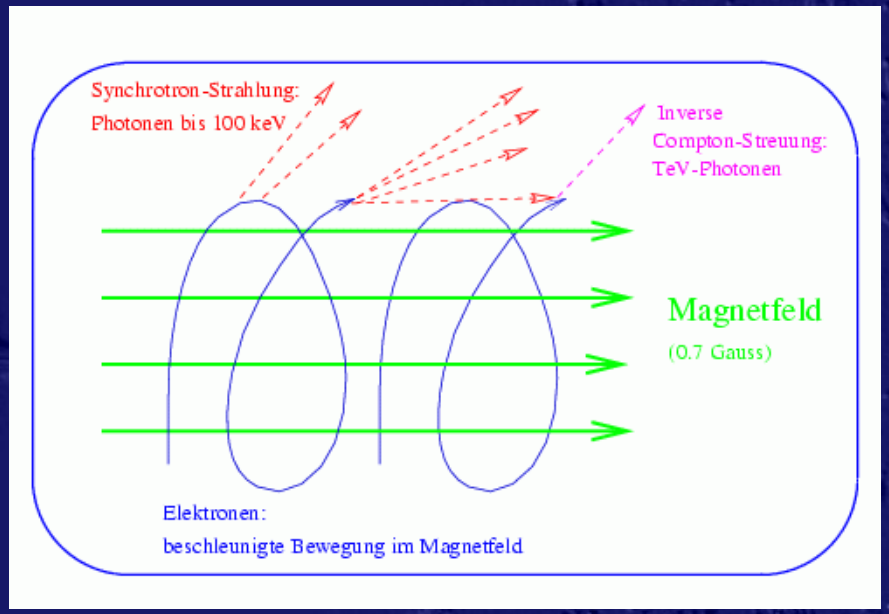
Synchrotron radiation from electrons

Compton-scattered photons

Crab nebula (M1): the TeV Standard Candle

Remnant of a supernova in the year 1054 with a central pulsar

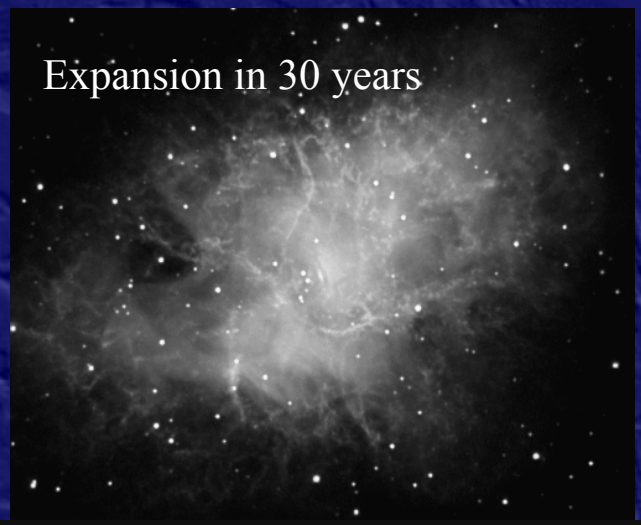


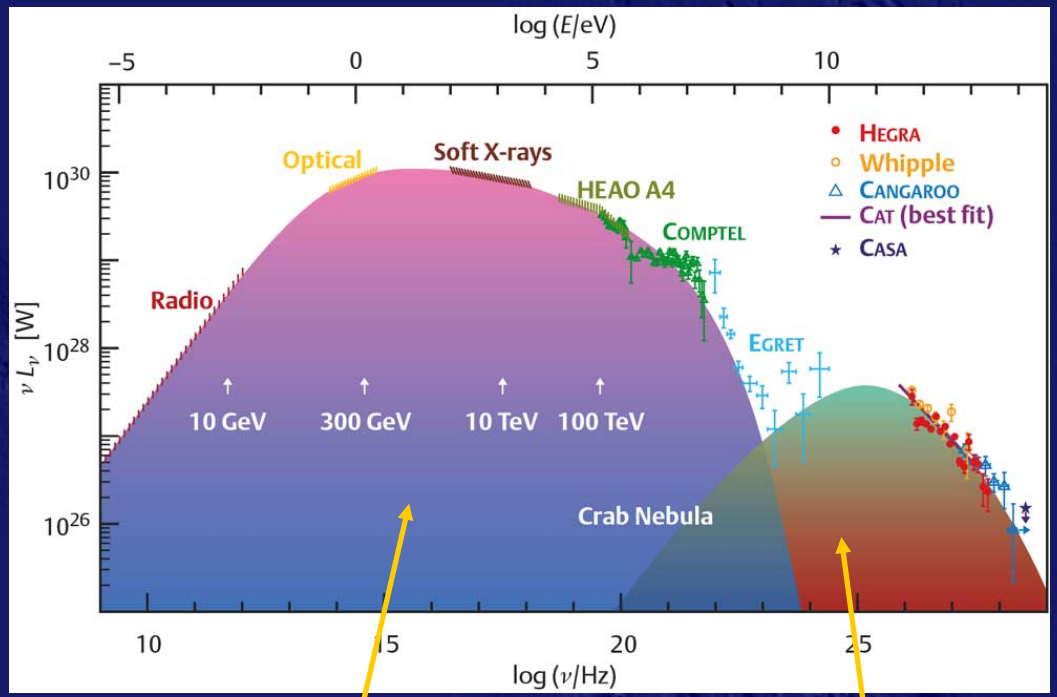


- synchrotron emission of X-rays
- inverse Compton-scattering of X-rays to TeV energies
- Parameters:
  - strength of magnetic field
  - energy of electrons

Crab nebula (M1): the TeV Standard Candle

Remnant of a supernova in the year 1054 with a central pulsar





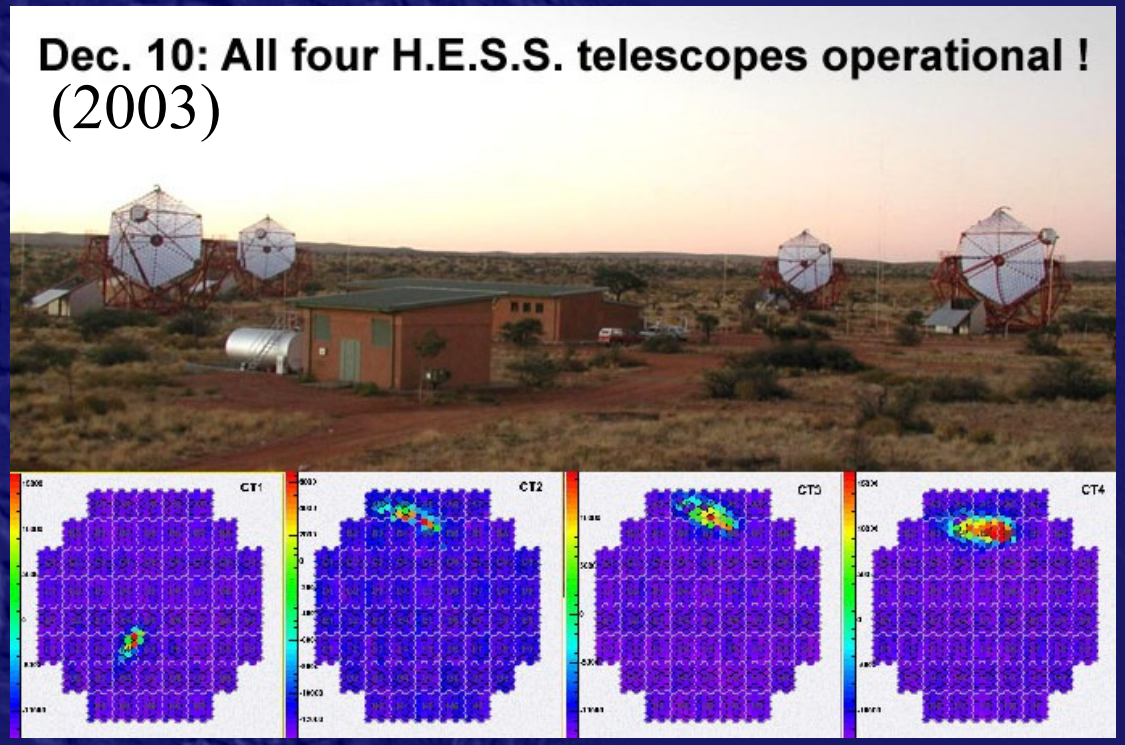
Synchrotron radiation from electrons

Compton-scattered photons

no CR accelerator!

State-of-the-art Experiments

HESS: 4 10m-IACTs, Namibia



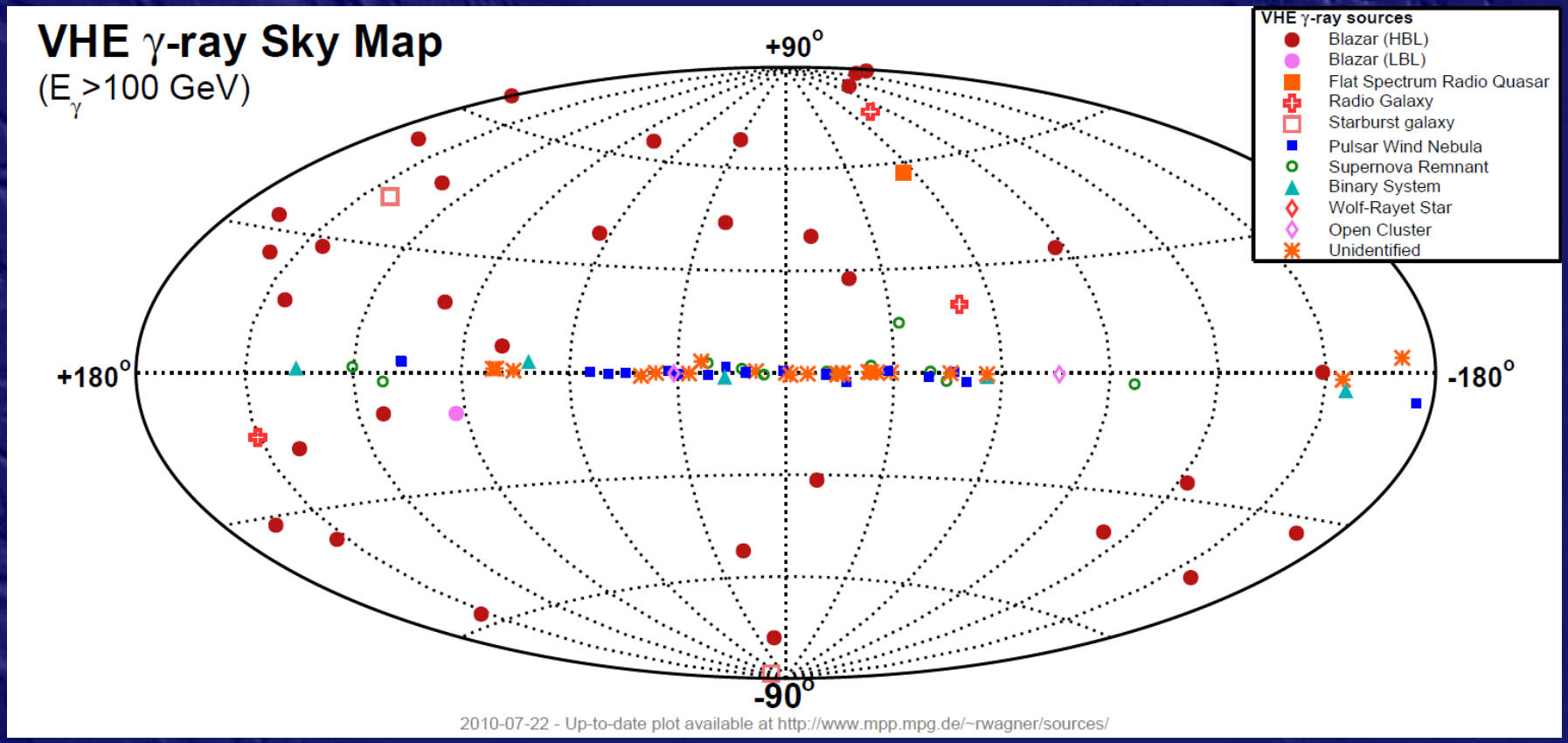
MAGIC: 17m IACT, La Palma

1989: First observation of the Crab nebula at TeV energies: 50h observation time needed (WHIPPLE, Arizona)

2003/2004: HESS and MAGIC measure the Crab in 30s!

Opening a new Window for Astronomy

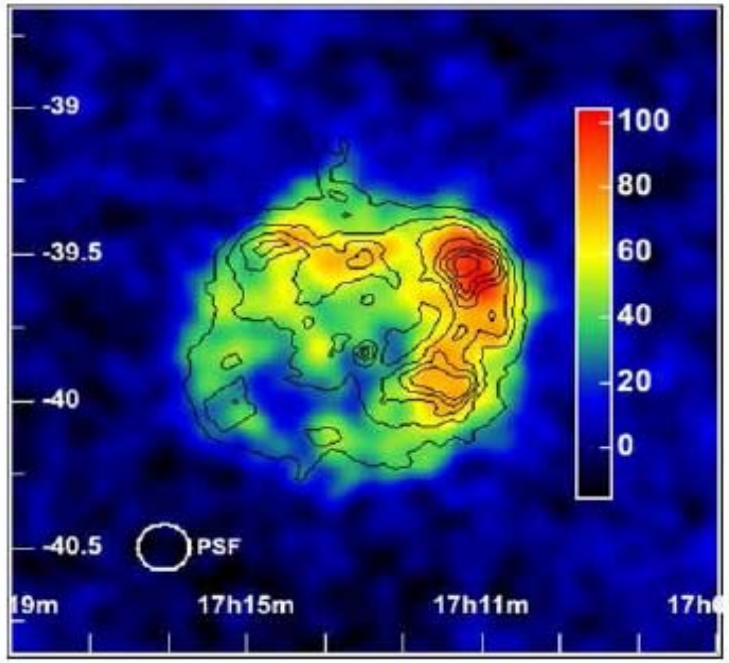
First TeV photon source in 1989,
now (July 2010) already 61 galactic and 41 extragalactic sources!

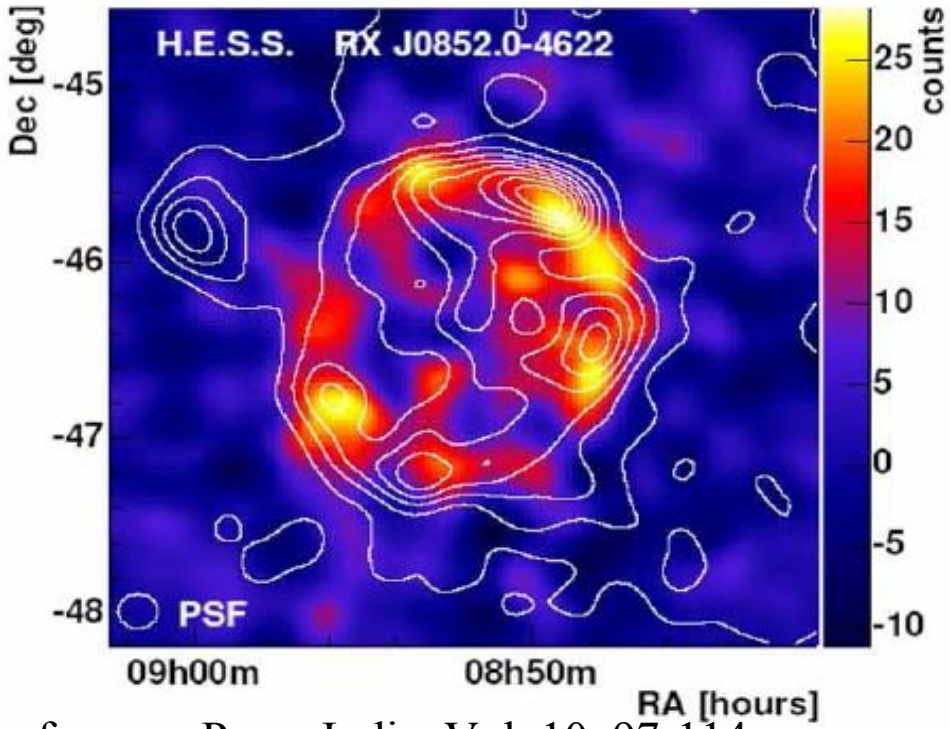


http://www.mppmu.mpg.de/~rwagner/sources, http://tevcat.uchicago.edu

Where are the Accelerators of galactic CR ?

With H.E.S.S. very detailed analyses of supernova remnants:

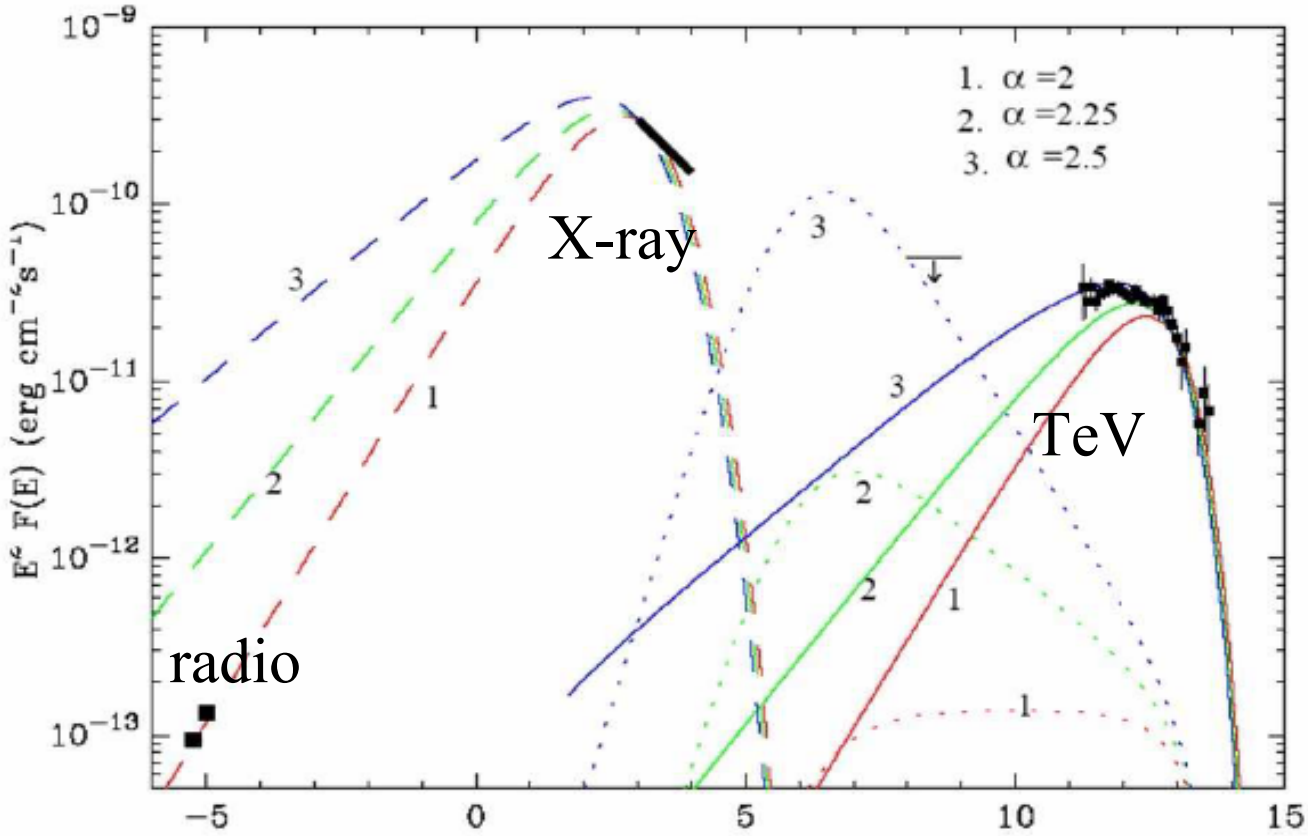




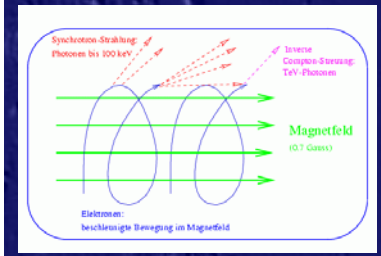
W. Hofmann, Proc. 29 Int. Cosmic Ray Conference, Pune, India, Vol. 10, 97-114

Where are the Accelerators of galactic CR ?

Multiwavelengths observation:

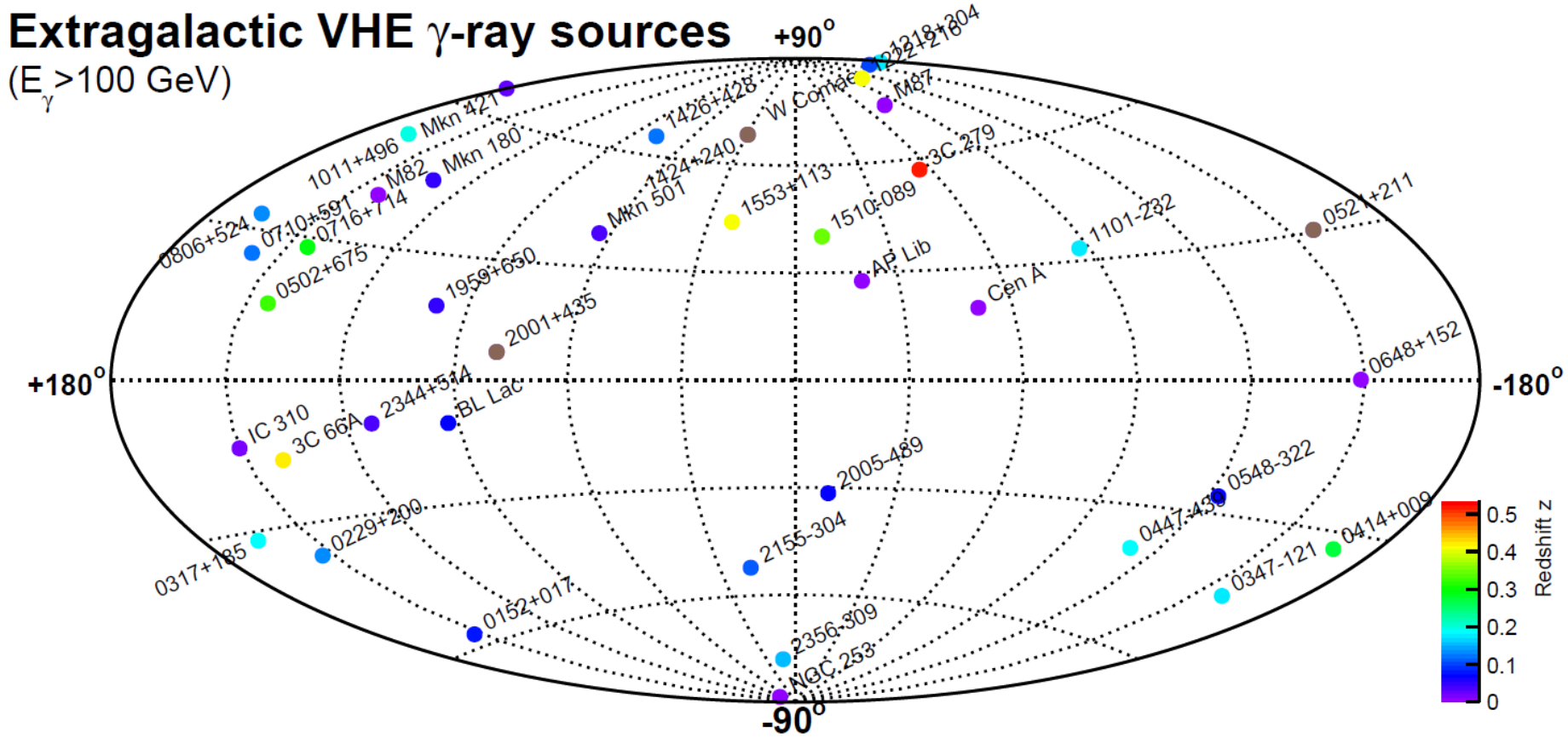


W. Hofmann, Proc. 29 Int. Cosmic Ray Conference, Pune, India



SSC models fail to describe the data:
hint to acceleration of CR (nuclei)?

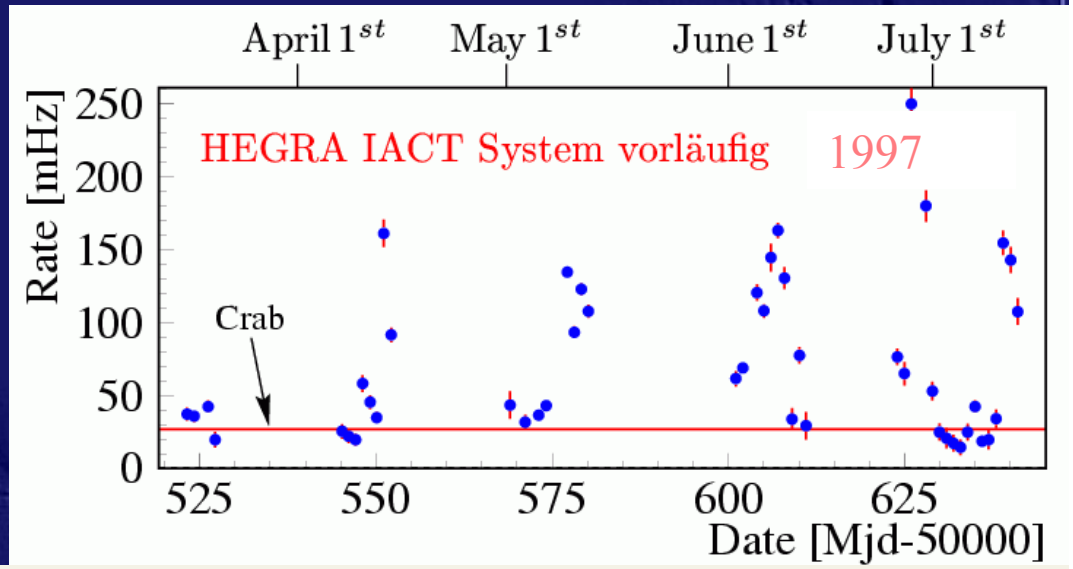
Surprise: TeV Photons from distant Galaxies

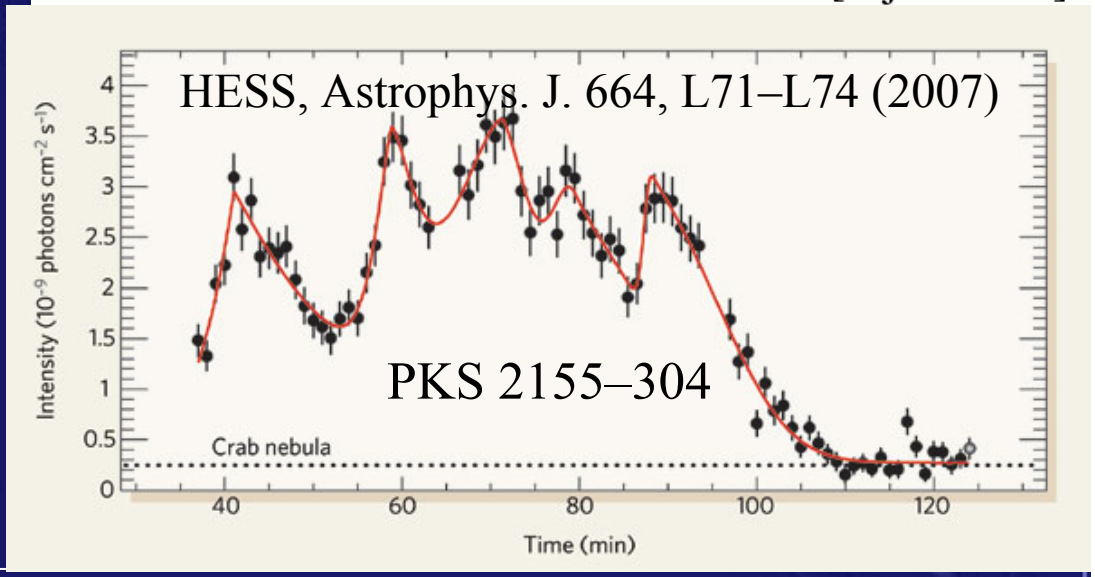


Surprise: TeV Photons from distant Galaxies

Extragalactic sources:

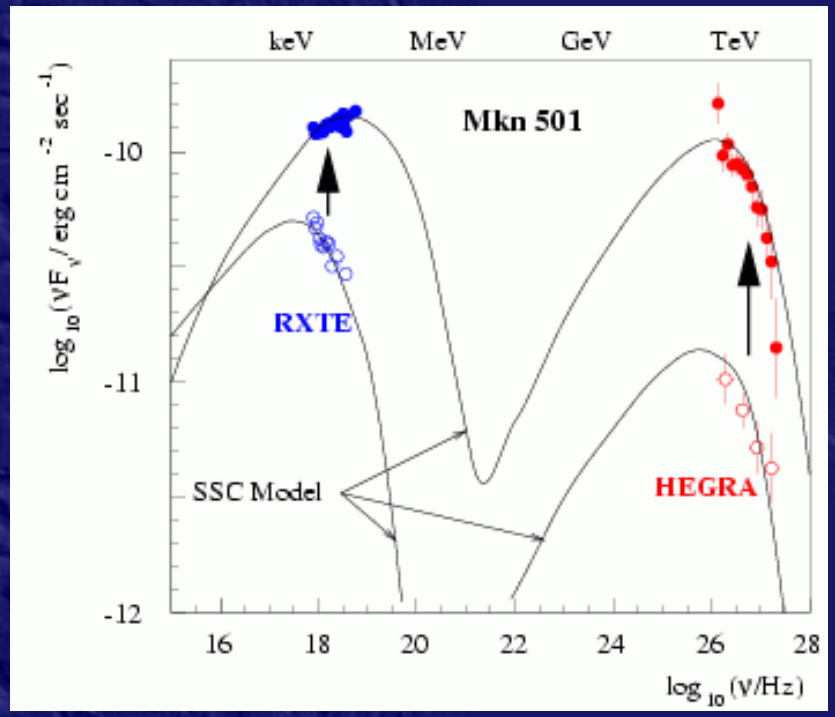
- Very large intensity fluctuations, sometimes brightest sources in the TeV-sky
- TeV intensity variations correlated with X-ray measurements
- All sources are galaxies containing an active galactic nucleus (AGN)
- Reminder: AGNs are the likely sources of highest energy CR!

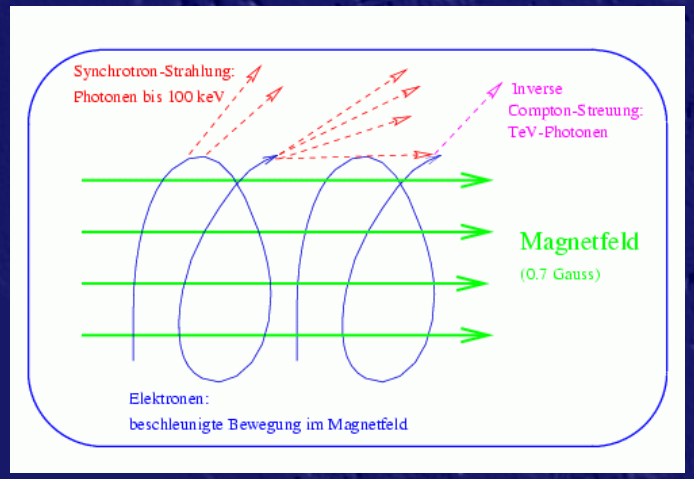




Which Particles are accelerated in AGNs?

Observation: tight correlation between X-ray and TeV emission of AGNs

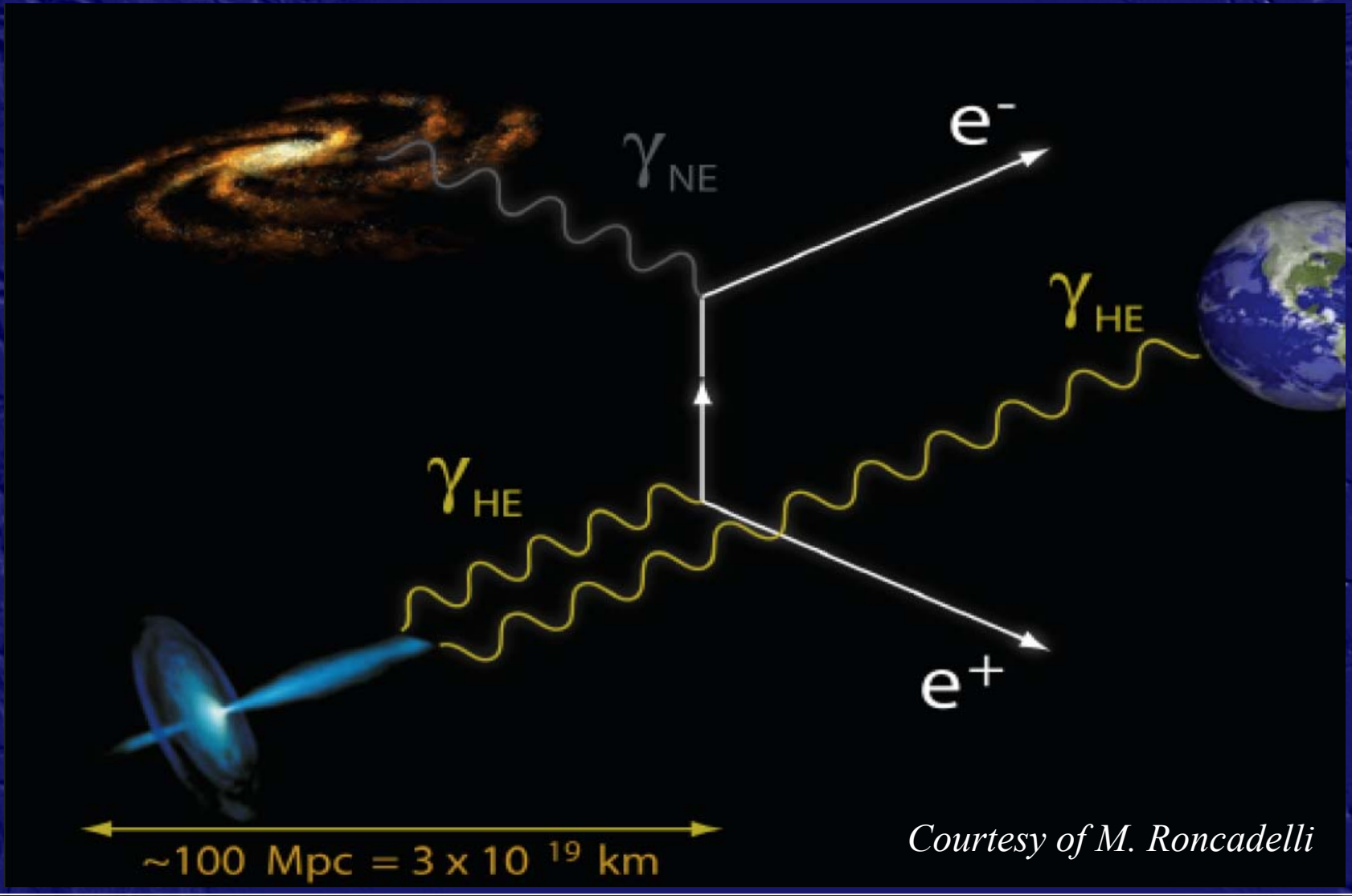




AGNs may accelerate electrons!

Do they also accelerate nuclei (protons)?

Absorption of TeV Photons in the Universe



Courtesy of M. Roncadelli

Probing intergalactic Radiation Fields

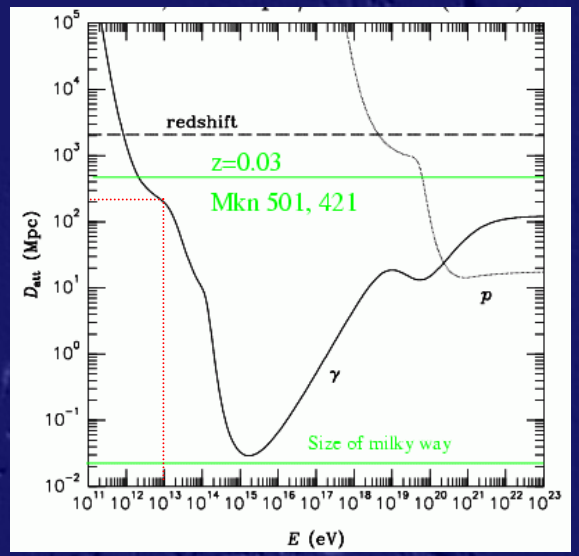
The universe is not transparent to high energy photons:

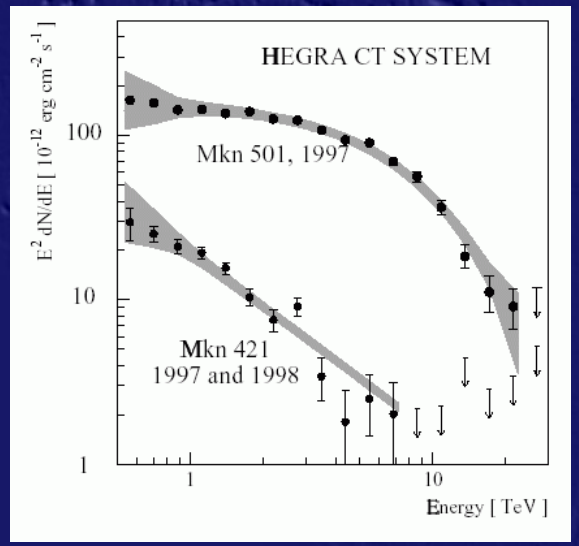
$\gamma_{TeV}\gamma_{background} \rightarrow e^+ e^-$

Photons above 10 TeV should hardly reach earth from cosmological distances!

- Is there a contradiction between measurements of extragalactic background light (EBL) and TeV photons from AGNs?
- Does Lorentz invariance hold?

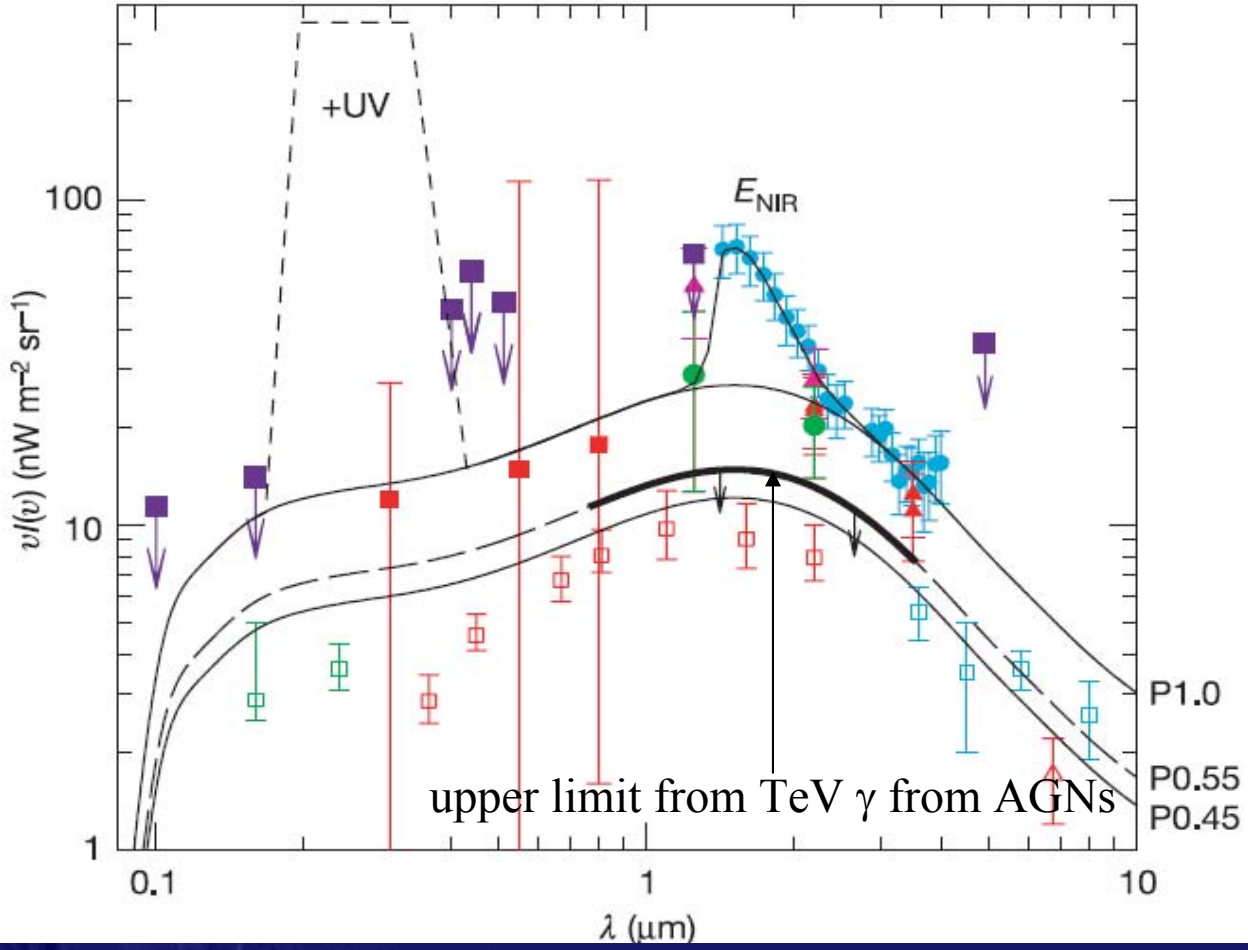
Need data from many AGNs at different distances (redshifts)!





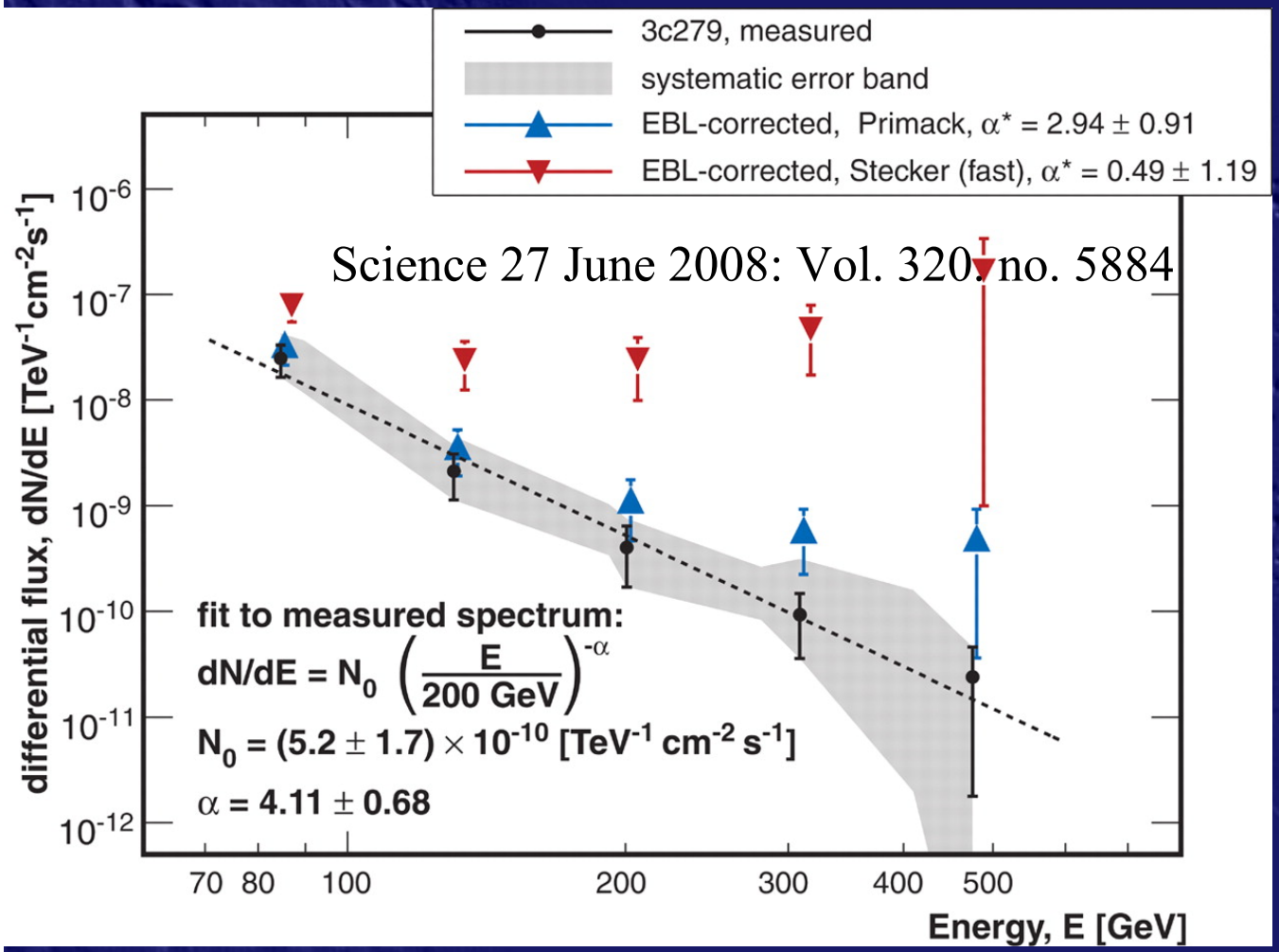
H.E.S.S.: 1ES 101-232 (z=0.186)

Nature 440 (2006)



- TeV photon non-absorption and EBL data just compatible?
- However: are the intrinsic features of AGNs sufficiently well known ?

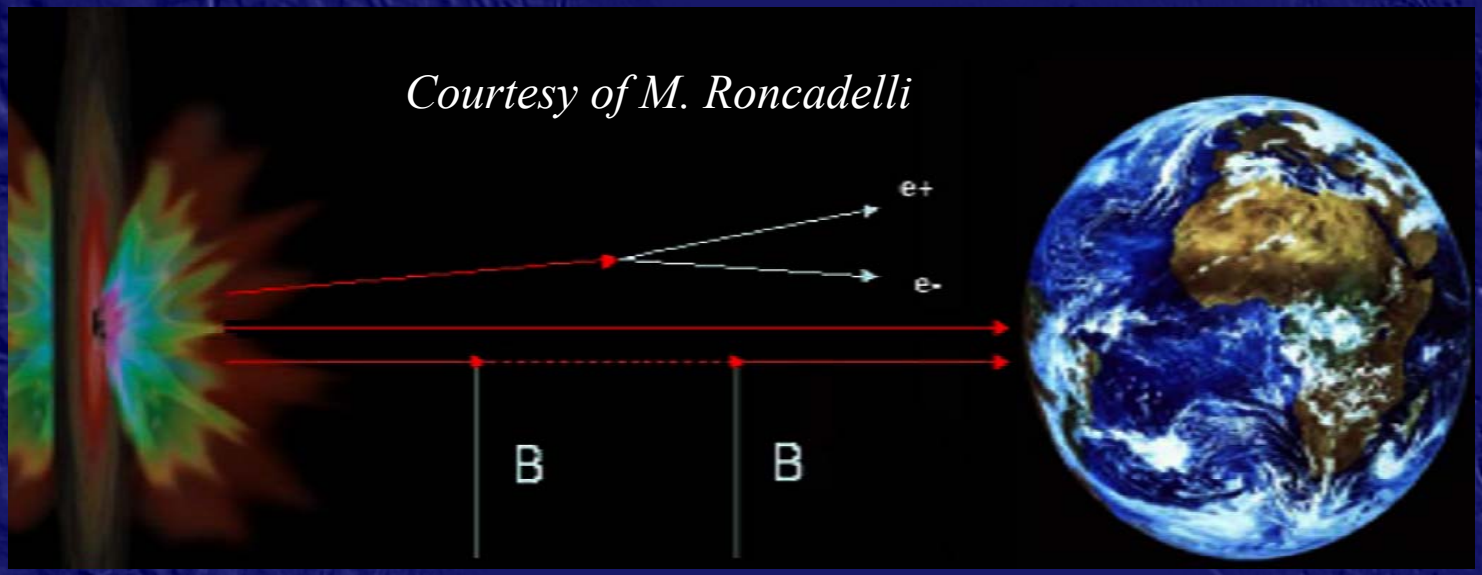
MAGIC: 3C 279 (z=0.536)



- TeV photon non-absorption and EBL data just compatible?
- However: are the intrinsic features of AGNs sufficiently well known ?

Way out: a new Kind of Particle?

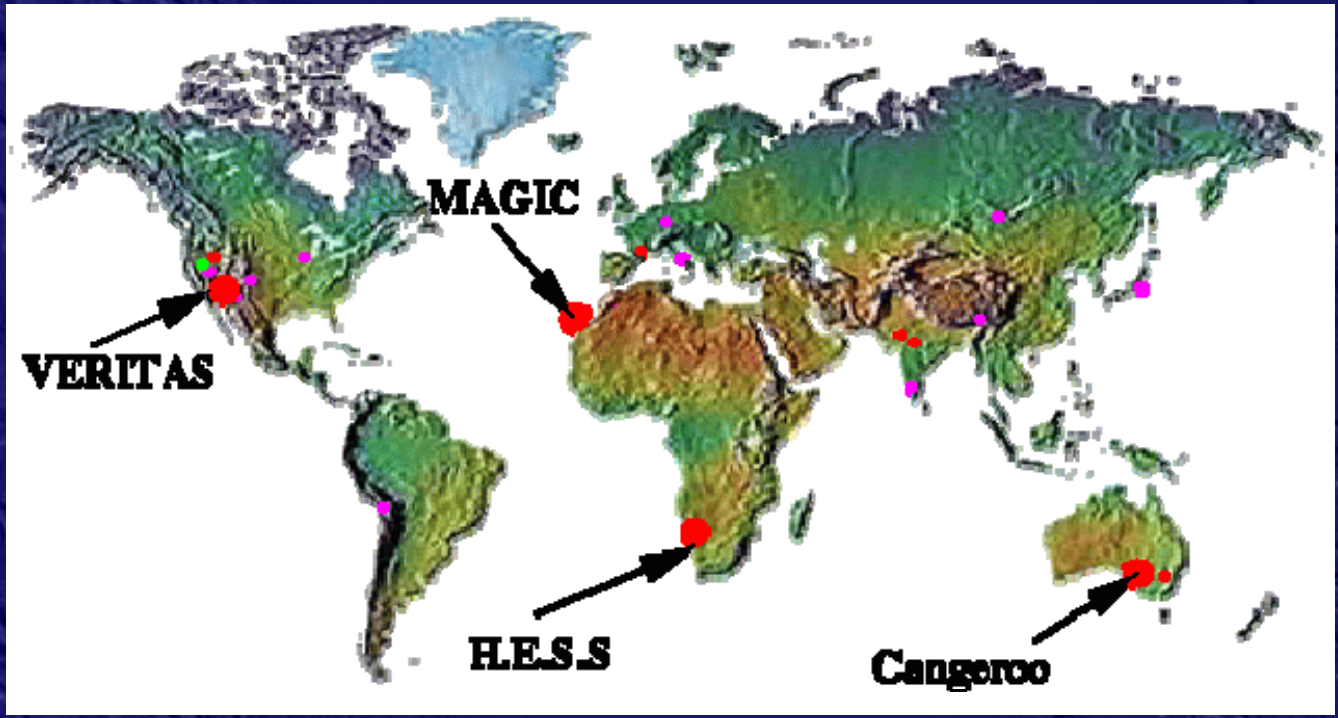
Photons may escape absorption by converting into hypothetical axion-like particles which later convert back into photons.



Simet et al., PhysRevD.77.063001 (2008)

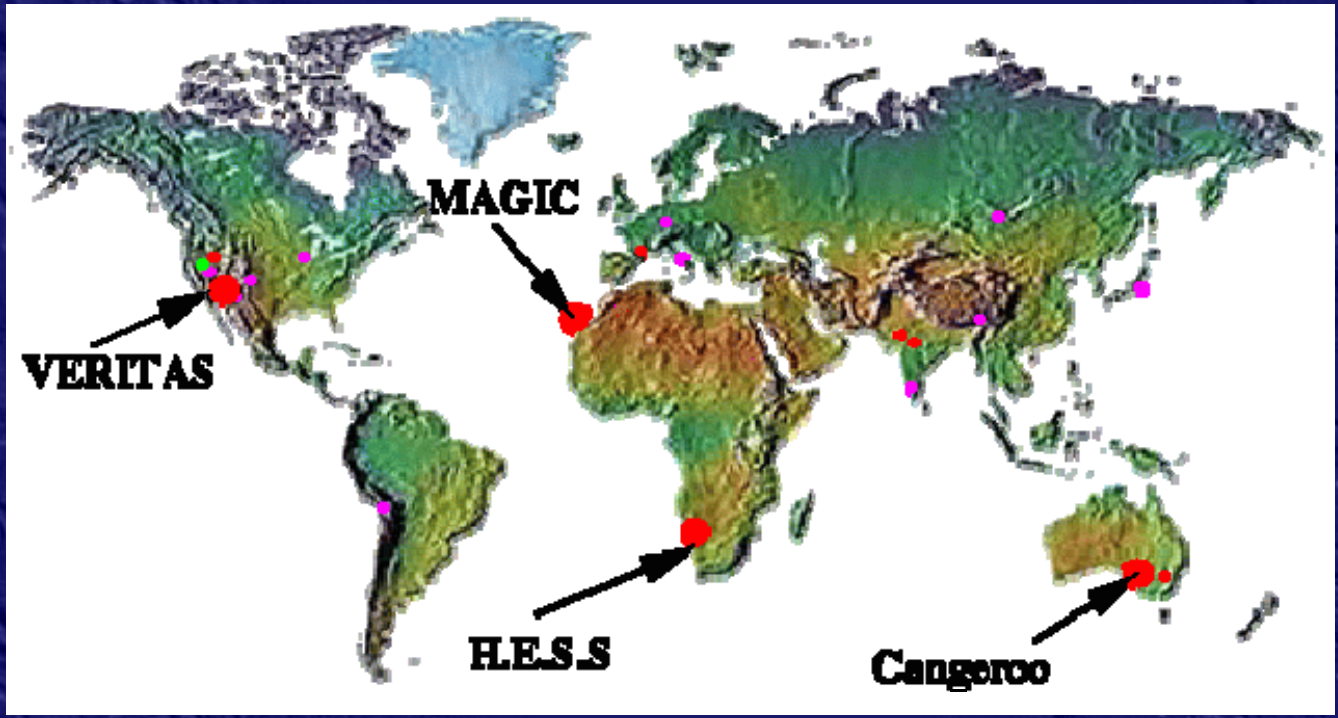
De Angelis et al., arXiv:0807.4246 (astro-ph, 2008)

A new Branch of Astronomy



- Discover galactic sources of CR
- Understand AGNs and intergalactic fields
- Search for photons from annihilation of Dark Matter
- More surprises?

A new Branch of Astronomy



HESS: http://www.mpi-hd.mpg.de/hfm/HESS/

MAGIC: http://wwwmagic.mppmu.mpg.de/

VERITAS: http://veritas.sao.arizona.edu/

CANGAROO: http://icrhp9.icrr.u-tokyo.ac.jp/index.html

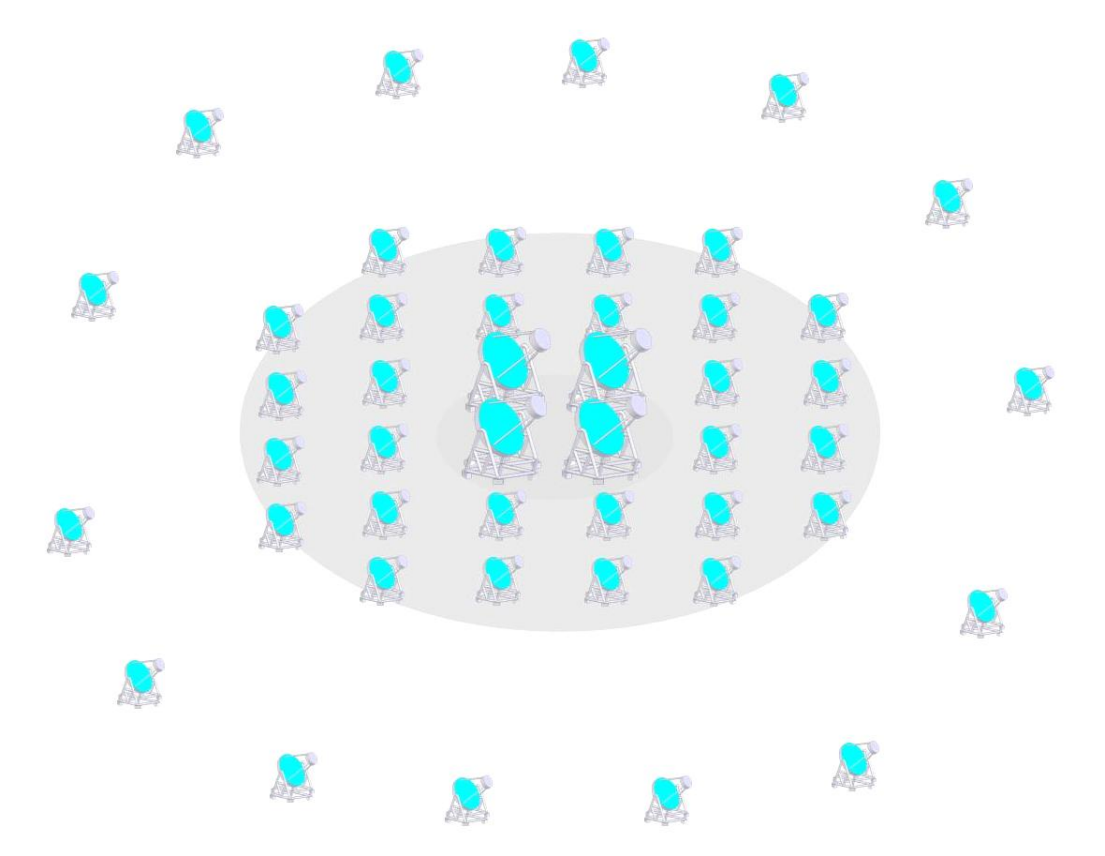
The future 2nd Phase of H.E.S:S.

Add IACT with 600 m^2 mirror (40 m high!)
to existing IACTs with 108 m^2 mirror.

http://www.mpi-hd.mpg.de/hfm/HESS/

The future Cherenkov Telescope Array

Presently under study: telescope array including 30m dishes



http://www.mpi-hd.mpg.de/hfm/CTA/CTA_home.html

A future new Branch: Neutrino Astronomy?

Advantage:

- Neutrinos travel on straight lines like photons
- Neutrinos are produced in hadronic environments
- Neutrinos are hardly absorbed
  ↳ direct look into the cosmic engines!

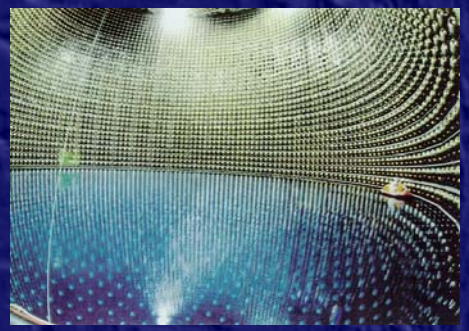
Disadvantage:

- Neutrinos are hardly absorbed
  ↳ very large detectors necessary

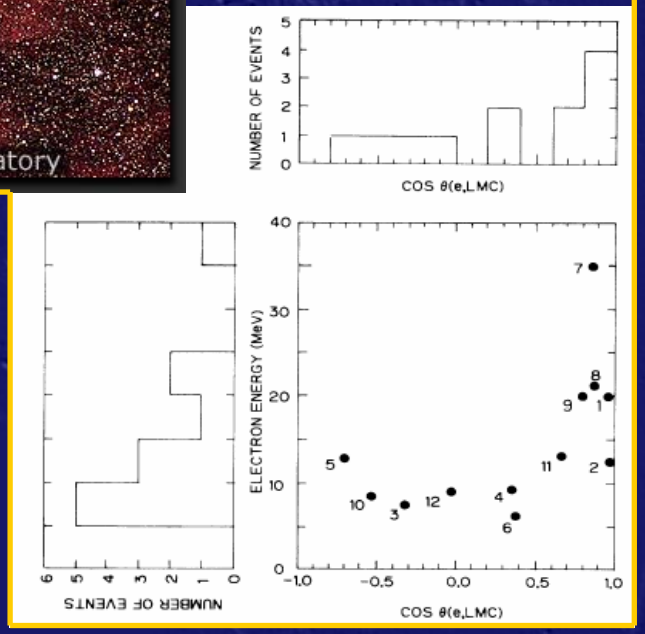
http://amanda.uci.edu/
http://icecube.wisc.edu/
http://antares.in2p3.fr/

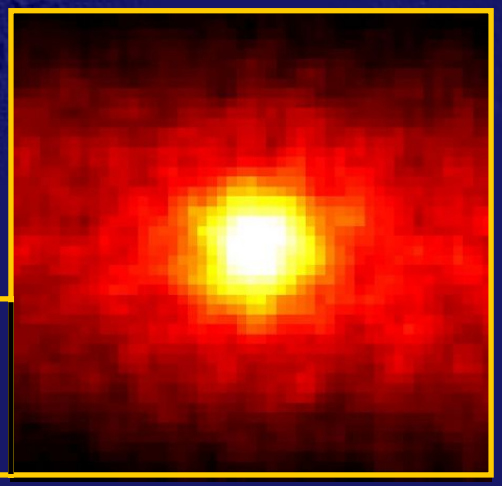
Two Sources in the Neutrino Sky

Super Kamiokande Experiment: 50,000 t of water watched by photomultipliers



Neutrinos from SN1987A
(with Kamiokande, 2000 t of water)

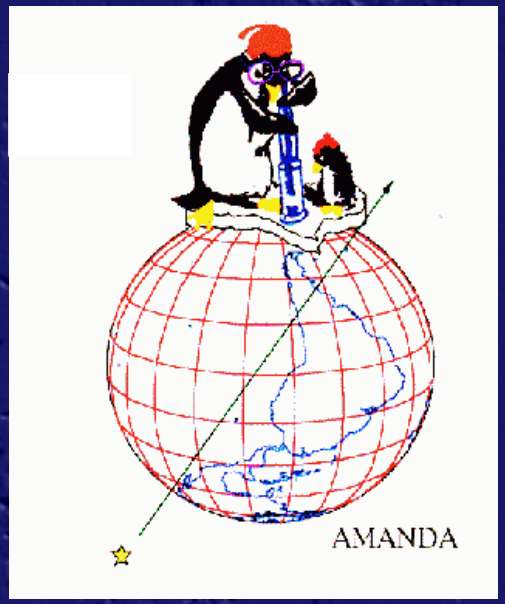


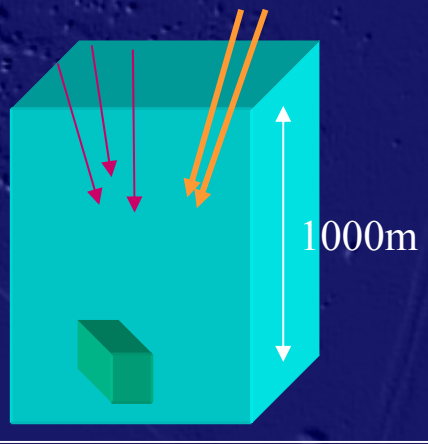


Neutrinos from the sun

Detector Basics to find more Sources

- Use the whole earth as a shielding (background mainly from interactions of CRs in the atmosphere, also υ!)
- Search for "upward" going muons from υ-interactions close to the detector
  Detect muons by their Cherenkv light emission
- Install detectors at depths of about 1000m to shield from "downward" going CRs
- Build detectors of several 10 M tons
  ↳ Install detector elements in natural water, ice at the south pole





Performance and Physics

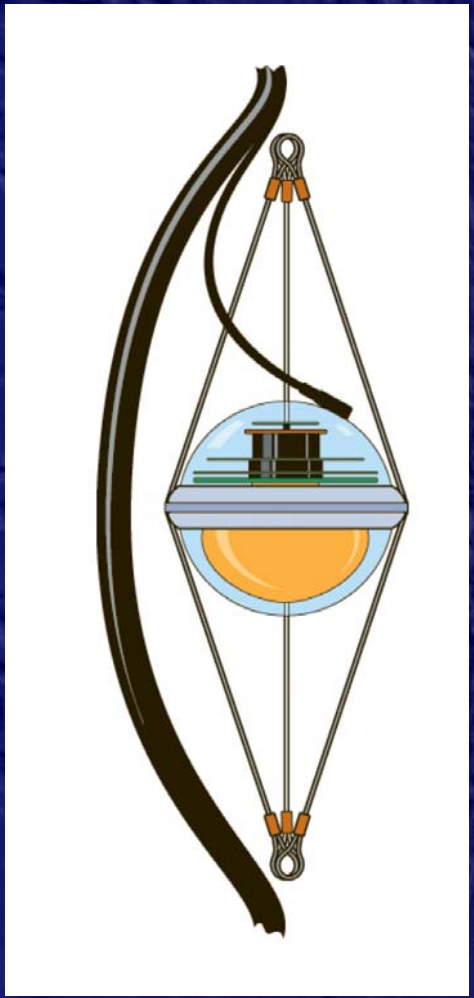
- Neutrino Energy > 50 GeV
- Angular resolution < 10°

Physics Questions:

- Galactic Supernovae
- Gamma Ray Bursts
- Active Galactic Nuclei
- Dark Matter Annihilation
- Topological defects
- Surprises?

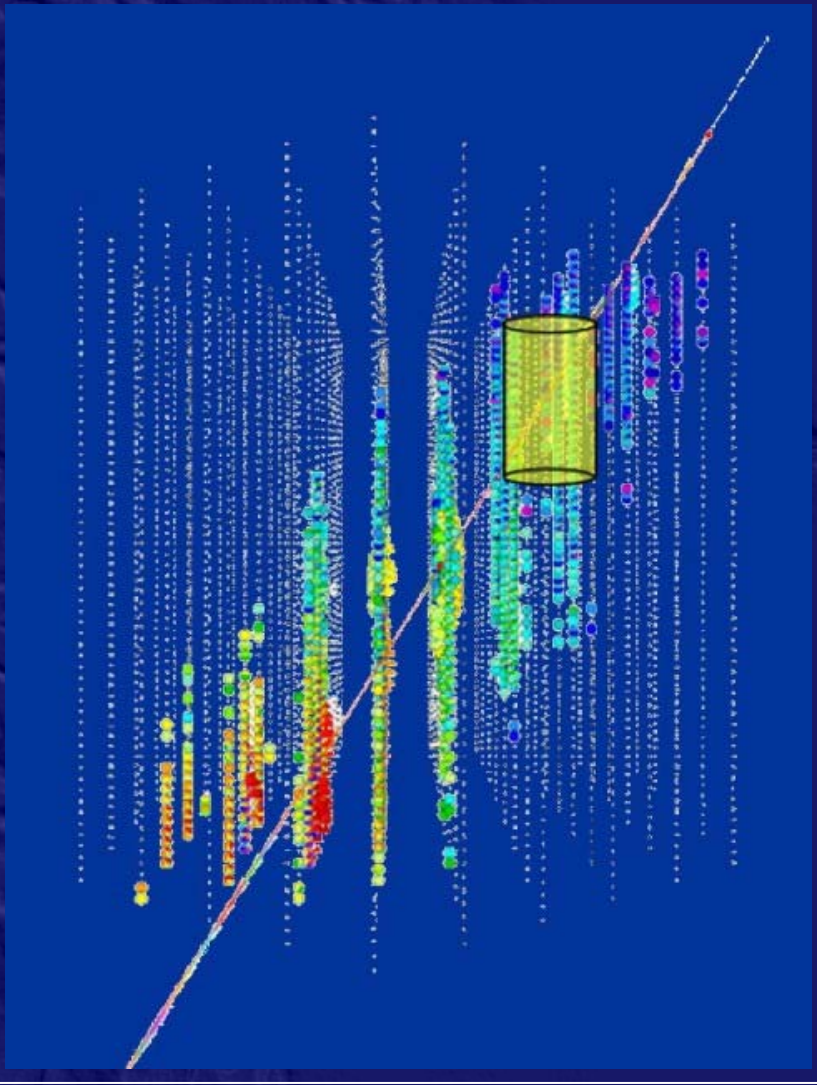
ICECUBE

The optical modules of ICECUBE



Photomultipliers attached to long cables are deployed in km-deep holes drilled with hot water into the Antarctic ice shield.

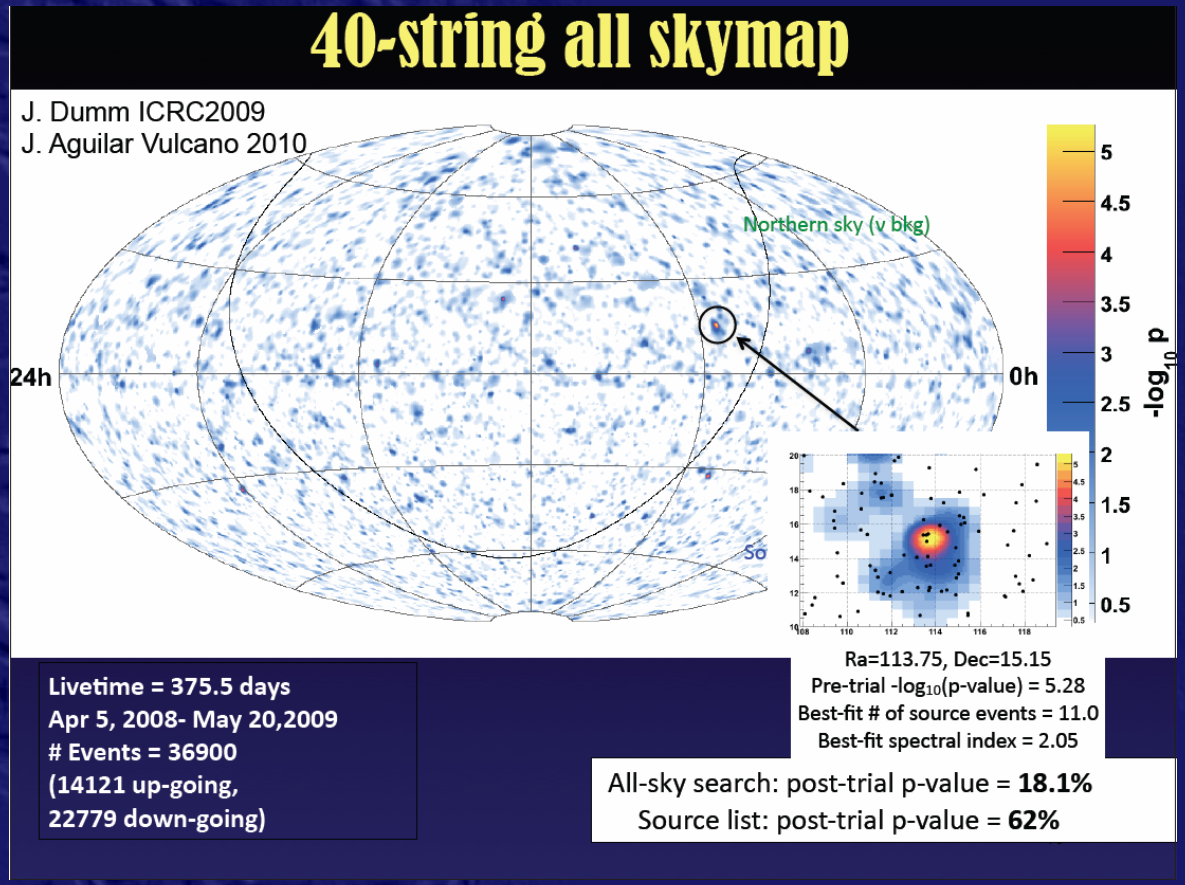
ICECUBE



DESY in AMANDA/IceCube:

- optical modules
- data analysis
- data “hub” to universities
- R&D for future extensions

First Results: the Sky seen with Neutrinos!



T. Montaruli, 6th Patras workshop, 2010

- No evidence yet for a neutrino source in the sky.
- The measured events are compatible with neutrinos produced in the air by cosmic ray interactions.
- More data will come soon!

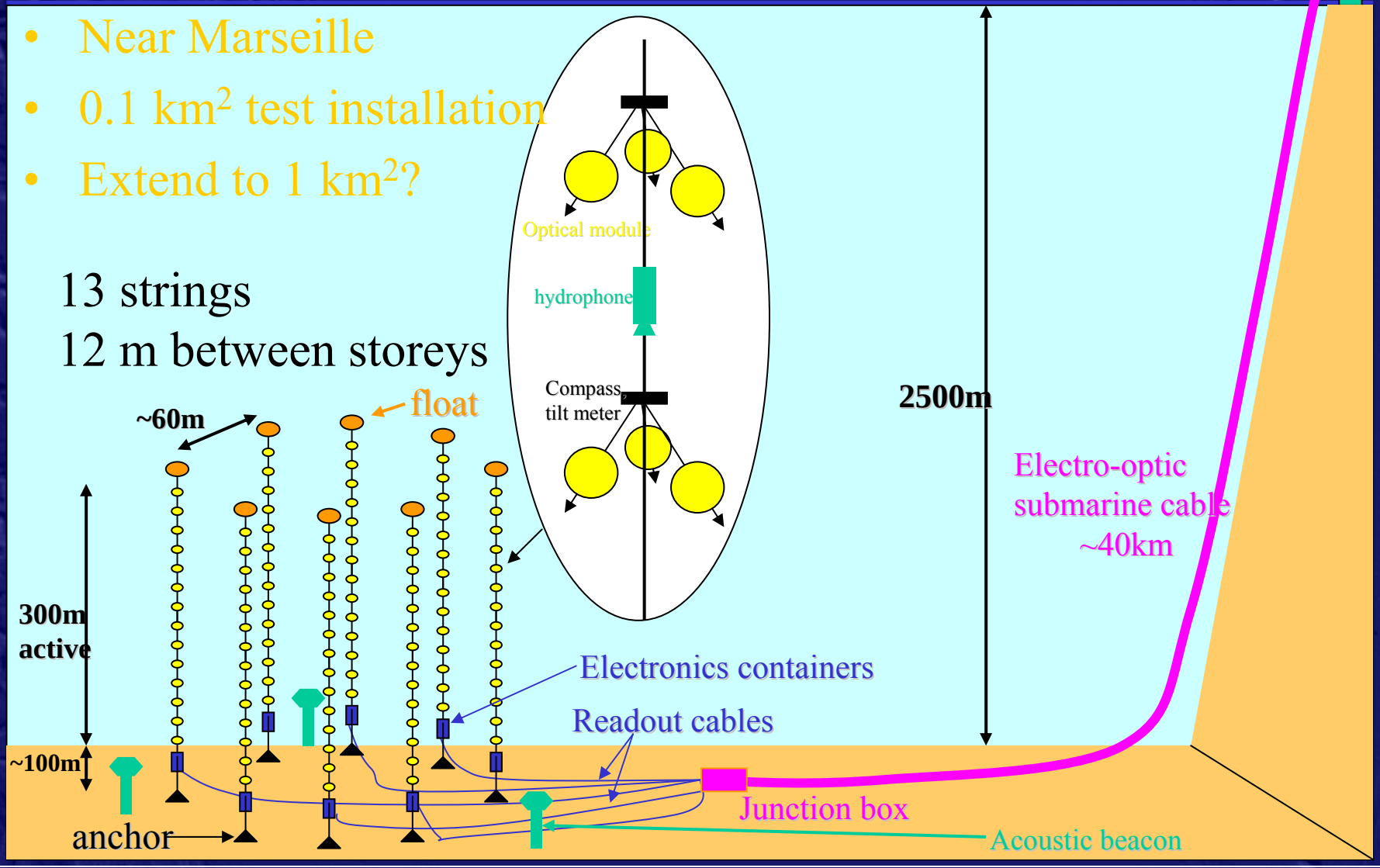
The ANTARES Experiment

Mediterranean water instead of Antarctic ice.

The ANTARES Experiment

- Near Marseille
- 0.1 km^2 test installation
- Extend to 1 km^2?

13 strings
12 m between storeys



New Astronomy: Topics for Discussion

- Why may the discovery of neutrino sources in the sky be crucial to solve the riddle of cosmic ray accelerators?
- Which effect limits the low energy threshold of the IACT technique?
- Why did hardly anyone expected 15 years ago to find TeV photon sources beyond our galaxy?
- How to understand the extremely small doubling times of TeV emission from AGNs?
- Can you imagine techniques to extend neutrino detectors far beyond the km^3 scale?

Summary on Cosmic Rays

from

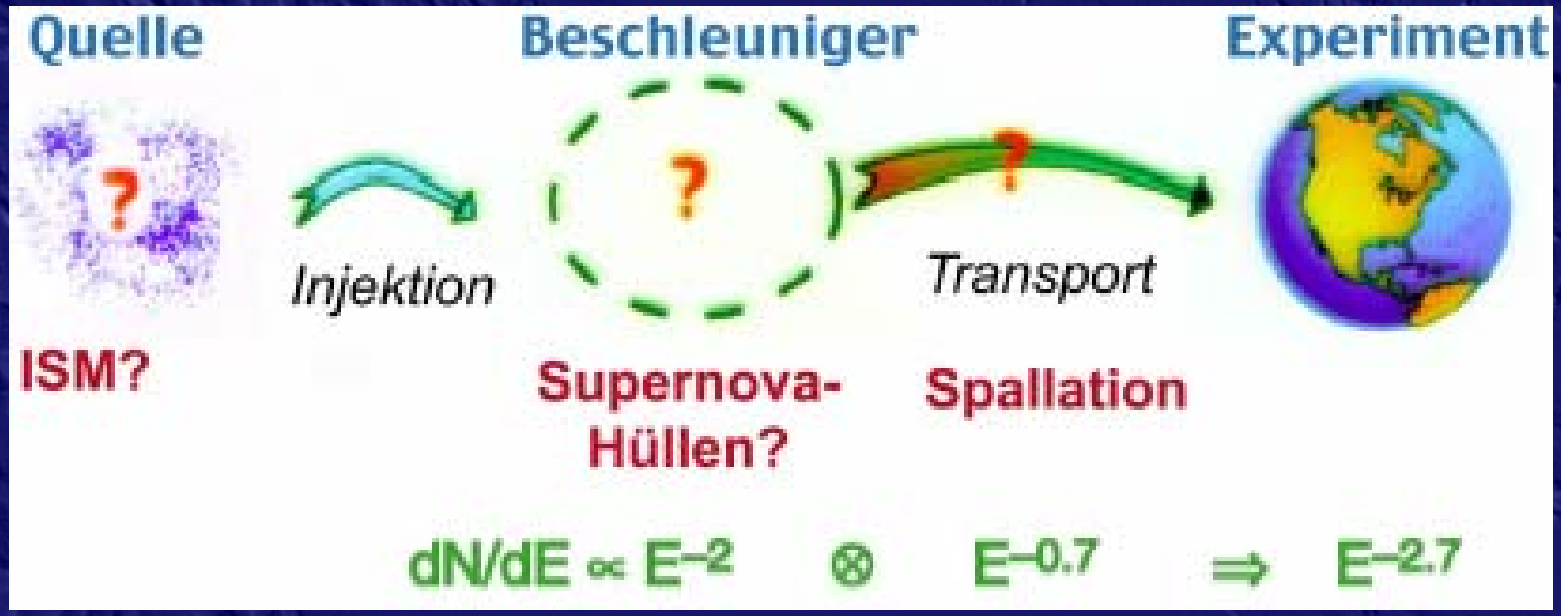
Measurements of Cosmic Rays (Nuclei) and TeV Astronomy

The Origin of Cosmic Rays

Our model:

atomic nuclei are accelerated to highest energies at shock fronts.

Candidates for such accelerators (shock fronts):

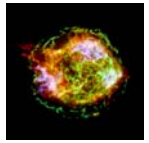
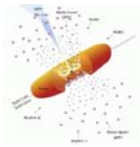
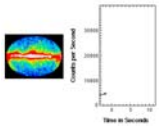


The Origin of Cosmic Rays

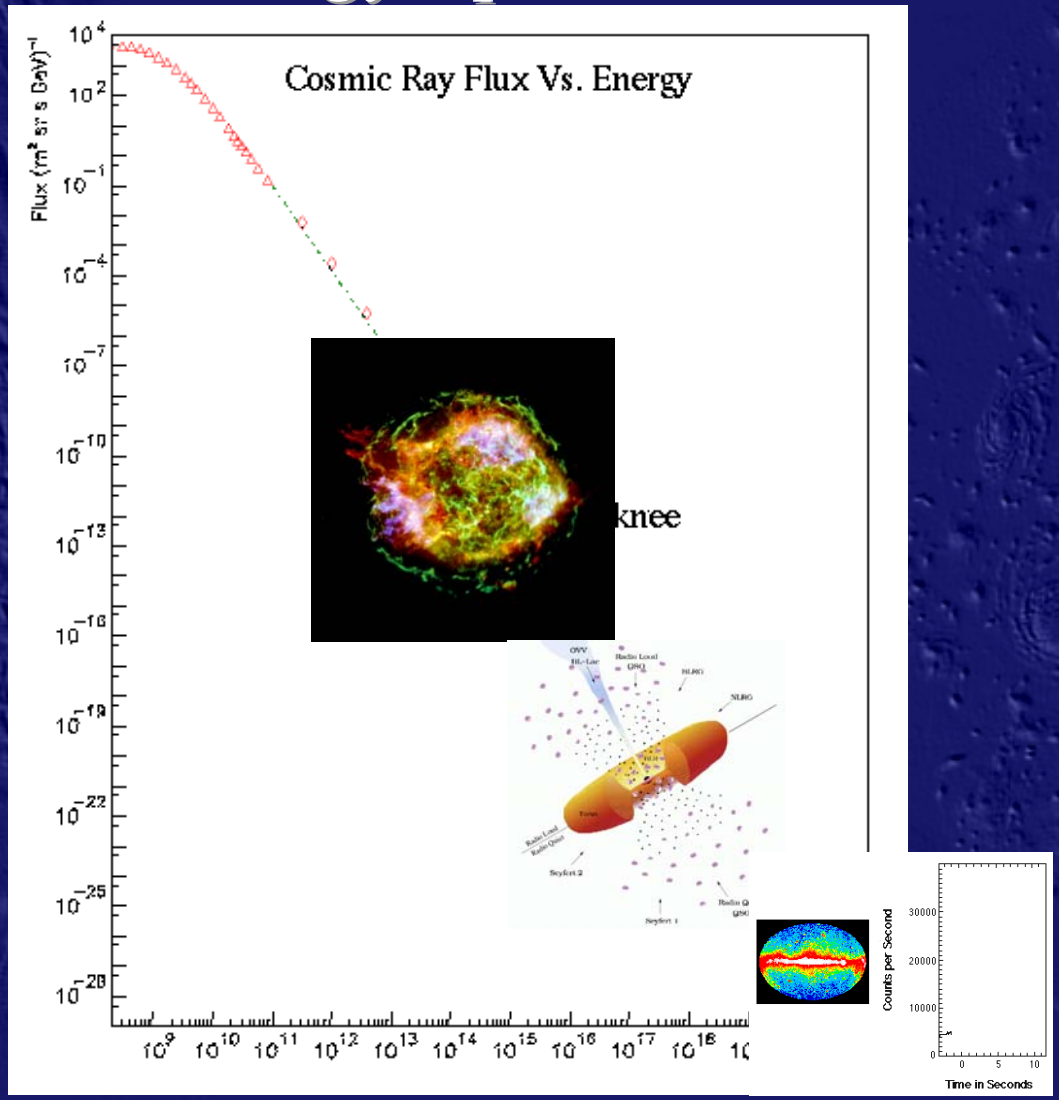
Our model:

atomic nuclei are accelerated to highest energies at shock fronts.

Candidates for such accelerators (shock fronts):

Accelerator		Extension	B-Field	Max. Energy	
Supernova-remnant	✓	100 pc	10^{-3} G	10^{17} eV	
AGN Jets	?	0,01 pc	10 G	10^{18} eV	
Gamma Ray Bursts (GRB)	??	100 km	10^{10} G	10^{20} eV	

The Energy Spectrum of Cosmic Rays



However …

See first, think later, then test. But always see first. Otherwise you will only see what you were expecting. Most scientists forget that.

Douglas Adams

English humorist & science fiction novelist (1952 - 2001)

http://www.quotationspage.com/quotes/Douglas_Adams

Applications

news feature

Pyramid power

Archaeologists have failed to learn the secrets of Mexico's largest ancient monument. Particle physicists might save the day, says Michael Hopkin.

It's not the kind of place you'd expect to find a particle-physics laboratory. The ancient Pyramid of the Sun at Teotihuacán is an hour's drive from Mexico City at the end of a bumpy jeep track. But deep inside this massive monument a state-of-the-art particle detector is being assembled, and my companions, both physicists, have brought me here to see how it's getting on.

The project is the brainchild of researchers from the National Autonomous University of Mexico (UNAM) in Mexico City, who hope to succeed where traditional archaeology has failed. Instead of taking up pickaxes and shovels to get at the pyramid's secrets, they will use their machine to detect the cosmic rays that continually pass through this mass of stone and dirt. With patience, the researchers believe, the rays will generate a picture of what is inside the monolith.

"The mass of the pyramid is so huge that we need twenty-first-century technology to study it," concedes UNAM archaeologist Linda Manzanilla, who is collaborating with the physicists.

The Pyramid of the Sun is believed to be the third largest pyramid in the world, with a base that is roughly 200 metres on each side. Built some 2,000 years ago, it formed the centrepiece of a bustling city for five centuries until Teotihuacán was abandoned. When archaeologists first dug into it in 1922, they hoped to find the bones of Teotihuacán's rulers. But unlike the neighbouring Pyramid of the Moon, which contains numerous stone chambers, the Sun pyramid is filled with earth and volcanic debris. Further digging seemed likely only to damage the structure.

Going underground

The physicists didn't need to dig. A cramped tunnel just below ground level that leads to several chambers at the heart of the pyramid was discovered in 1971. Although it provided scant clues for archaeologists as to what lies above, it made a perfect, if humid, spot for a particle detector.

As tourists admire the views from the top of the pyramid some 65 metres above us, we don hard hats and open a rusting metal door at the base of the great structure. My guides, UNAM particle physicists Arturo Menchaca and Ernesto Belmont, lead me down an iron staircase beyond the door to the tunnel opening. After several minutes of walking stooped through the stifling humidity of the tunnel we come to the metal shed that the researchers have set up to house their instrument.

Menchaca's team has been working on the detector for more than a year. Once this is ready, the group will begin looking for muons, charged particles that rain down on Earth at a rate of about 12,000 per square metre every minute. Muons penetrate most things, including rocks, earth and people, but the denser the medium, the less likely they are to get through. This means that a pyramid that contains burial chambers or other cavities will absorb fewer muons than one without.

The detector itself is a metre-square sandwich of several layers, each strung with tiny tungsten wires like a miniature piano. The wires, each thinner than a human hair, sit in an electric field. A muon passing through the detector charges the gas inside it, and the wires pick up the tiny current. With different layers strung in different directions, the researchers can build up a picture of the muon's direction, and hence the position of any rooms in the pyramid above.

The set-up should spot any cavity larger than about 80 centimetres across, Menchaca says, gesturing at the hundreds of thousands of tonnes of rock and earth above our heads.

M. HOPKIN

Catching rays: Arturo Menchaca (right) and Ernesto Belmont hope their muon detector will let them see inside the Pyramid of the Sun (above).

But he warns that even if something that looks like a room is spotted, it could simply be the result of subsidence over the centuries, rather than architectural design. "Everyone's expecting Tutankhamun," he says, "but we may find something that means nothing."

Subterranean blues

Doing science down here creates unusual problems. The researchers had to install their own power supply and encase it in a metal pipe to protect it from thieves. Once the detector is running, they will have to ventilate the chamber and tunnel before entering to avoid suffocating on the mix of carbon dioxide and noble gases used in the instrument.

No one should expect results any time soon. The researchers are testing parts of the detector in the lab and installing them underground piece by piece, a process they hope to complete within the next two months. They will then collect data for at least a year before releasing it to archaeologists. Should any of the tiny wires break, as has been known to happen, everything gets set back a week.

Perhaps there's no rush. As we emerge blinking into the sunshine to the curious stares of camera-clutching sightseers, the baking sun reminds me that it's better not to hurry in this climate. "This problem has been waiting 2,000 years," Menchaca says. "Nothing's going to happen if we're delayed another month." ■

Michael Hopkin is a reporter for news@nature.com.

nature Vol 447|24 May 2007

RESEARCH HIGHLIGHTS

Cosmic rays peek inside

Nucl. Instrum. Methods Phys. Res. A **575**, 489–497 (2007)

Researchers in Japan have taken advantage of cosmic rays to image the inside of an active volcano. This approach has previously been used to search for chambers inside pyramids.

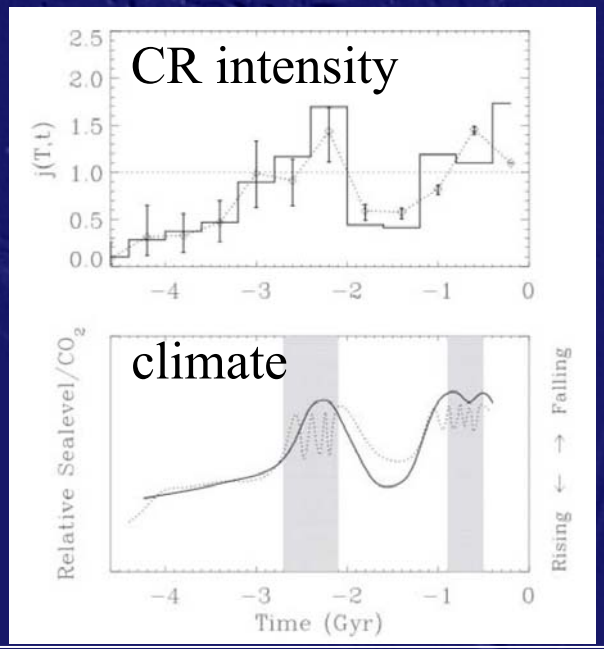
Hiroyuki Tanaka of the University of Tokyo and his colleagues placed an instrument that detects particles known as muons on the side of Mount Asama (pictured). Muons are sent off in all directions when cosmic rays hit Earth's atmosphere.

Some muons reach the detector having passed through the rocks of the volcano. By calculating the number of muons absorbed en route, the researchers determined the density of the volcano's innards. With more devices and real-time readings, the method may help in predicting eruptions.

KYODO NEWS/AP

Climate and Cosmic Rays

H. Svensmark, arXiv:physics/0311087v1 [physics.space-ph]



Outreach

nature

17 June 2004 Volume 429 Issue no 6993

Schools at 10^{20} eV and beyond

A project that explores a research frontier, attracts high-school students of both sexes and diverse ethnicities and that can be scaled up to international level deserves not only celebration but also the €1-million support that it has just won.

Where do the highest-energy cosmic rays come from? Where did all the science students go? In the Netherlands, where physics undergraduate numbers are taking a dive, experimentally addressing the first question is hopefully countering the problem reflected in the second, thanks to an imaginative scheme in which universities and schools are collaborating in particle astrophysics.

The "high-school project on astrophysics research with cosmics" (HISPARC) seems to fire up the enthusiasm of school students in a way that few other schemes have done. And, encouragingly, this is just one entry among several in a competition, run by the Altran Foundation, that this year focused on innovative school projects. Announced this week as the winner, its technology and approach will within a year become accessible to schools in other countries.

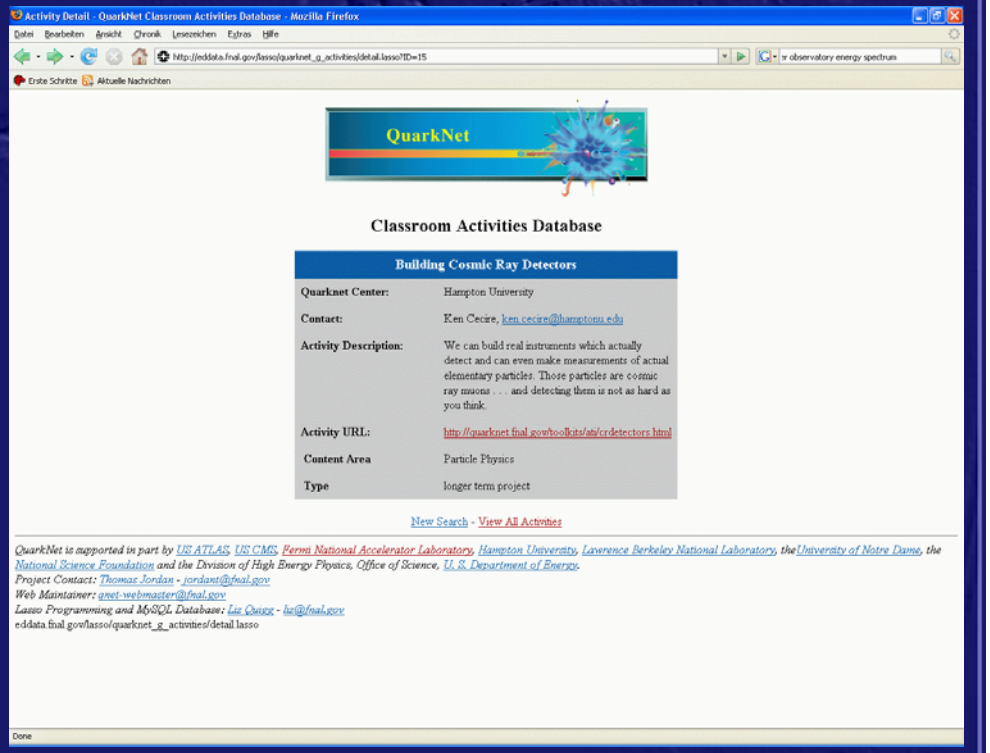
With its first detectors set up in 2002, HISPARC focuses on the air showers produced when cosmic rays hit the upper atmosphere, each stimulating a cascade of secondary particles travelling in the same direction. The higher the energy, the larger the area at the ground over which secondaries arrive. At the highest energies seen so far — more than 10^{19} electronvolts — the secondaries can be detected by an array of detectors spread over 100 km^2 or so. Such showers caused consternation when detectors discovered them in the early 1990s; the numbers of 'primaries' hitting the atmosphere had been expected to tail off below such energies.

Initiated by physicists at the University of Nijmegen, a cluster of schools was chosen to host a network of detectors of these extraordinary events. The detectors — more sensitive than those that made the original observations — consist of a pair of plastic scintillators that detect light given off as secondary particles arrive. Events that trigger coincident bursts of light in both detectors, timed with the help of the Global Positioning System, register within the network. Now tens of such detectors are being developed in schools in collaboration with several Dutch universities (see www.hisparc.nl/NL/english.shtml).

A key to the project's motivational success, according to its coordinators, is that the schools become stakeholders by working with researchers in constructing the detectors. Importantly, those who are motivated include an even balance of both sexes and a healthy representation across ethnic groups. And that motivation could grow further as the networks develop into a system capable of having a scientific impact, pursuing rare events for which only a few detectors exist.

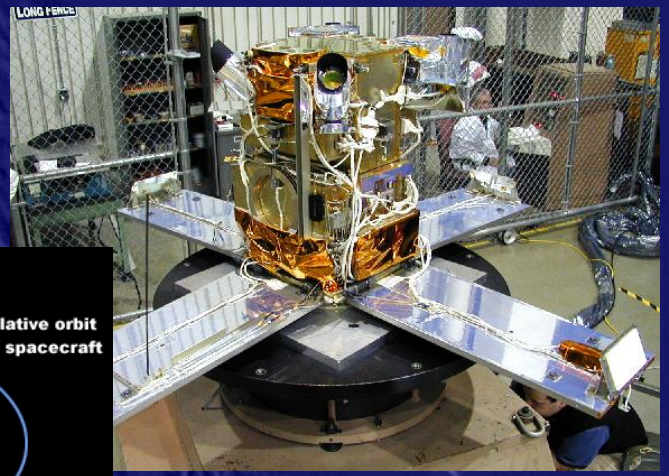
The project's impact will be magnified by its success in winning this year's Altran Foundation for Innovation Award. The prize money of €16,000 (US$19,000) will no doubt be useful. But much more useful will be an unusual and commendable feature of the awards, whereby the foundation, based in a major consultancy organization (see www.fondation-altran.org), will also provide €1 million of support-in-kind over 12 months. This support is intended to ensure that the technology and software become cheaper to build and that the project spreads to schools in other countries.

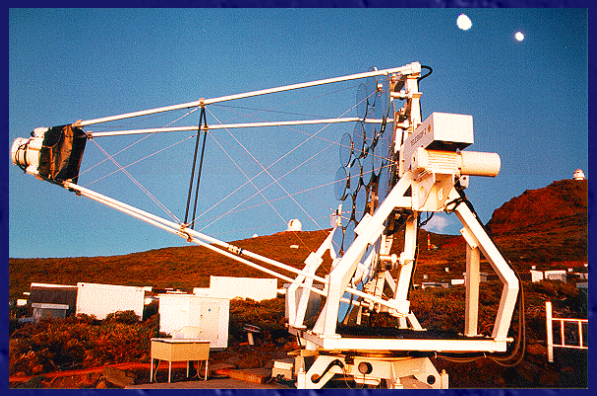
The short-listed entries show that physics is not the only area in which imagination is being deployed to involve schoolchildren in the ideas of science. Measurements of climate change, the development of hands-on mathematical instruments modelled on historical originals, and the use of easy-to-make fuel cells are among the other projects dreamt up by universities and museums, and already in action. At a time when everyone is agonizing about the dearth of interest in science among schoolchildren, such projects should not only be noticed but also nurtured. Wherever science students have been disappearing to, here's hoping that these schemes can encourage some of them back. ■

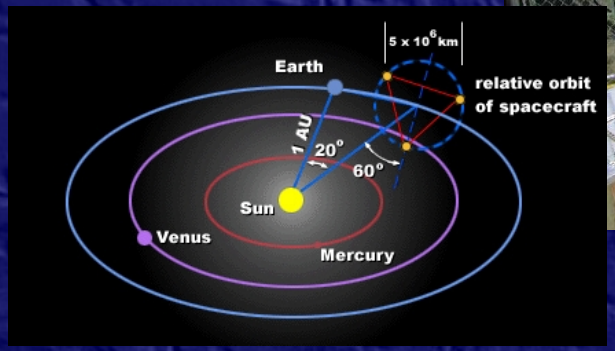


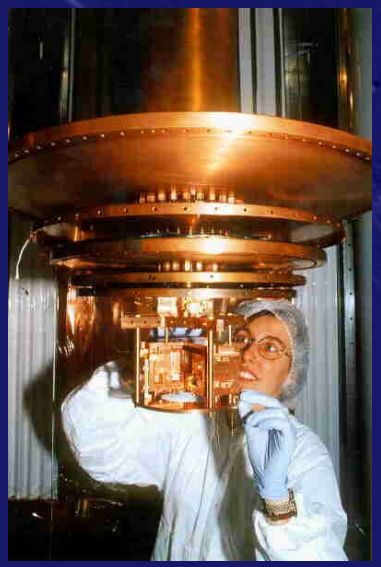
Astroparticle Physics

Multifaceted ...









Astroparticle Physics

... and thrilling!

Fire and ice at the HEGRA experiment on the Canary island La Palma

Astro and Particles

Particle physics detectors

⇓

Cherenkov Telescopes

⇓

TeV Astronomy with AGNs

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Hints for new elementary particles, quantum gravity?

Some results seem to be confusing or weird (Dark Matter, Dark Energy)

⇓

really basic questions are being addressed

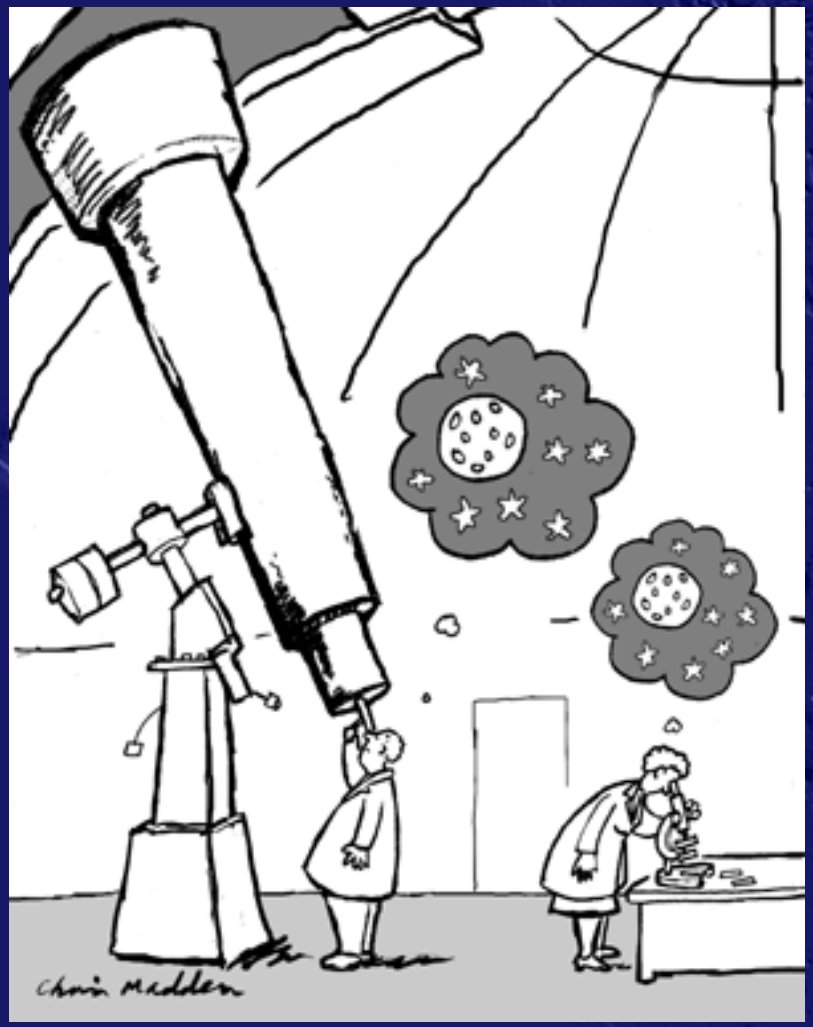
⇓

hope to understand fundamentals!

Astroparticle Physics

Most fascinating (to me):

If research on smallest and largest scales complement each other in the way most evident in astroparticle physics we can be confident to catch a glimpse of reality!



Suggestions for further Reading

- "Astrophysics" (M. S. Longair), Cambridge 1992
- "Cosmic Rays and Particle Physics" (T. K. Gaisser), Cambridge 1999
- "Very High Energy Cosmic Gamma Radiation (F. Aharonian), World Scientific 2004
- "Astroparticle Physics (Claus Grupen), Springer 2005