FRAM – The Robotic Telescope in the Pierre Auger Observatory

PIERRE AUGER OBSERVATORY

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Outline

Introduction to cosmic rays

Description of the Pierre Auger Observatory

The robotic telescope FRAM

Interesting results of FRAM

Conclusion

Cosmic rays

Charged particles (hadrons, electrons, positrons)

Neutral (gammas, neutrinos)

Flux decrease by about 3 orders of magnitude each order of energy

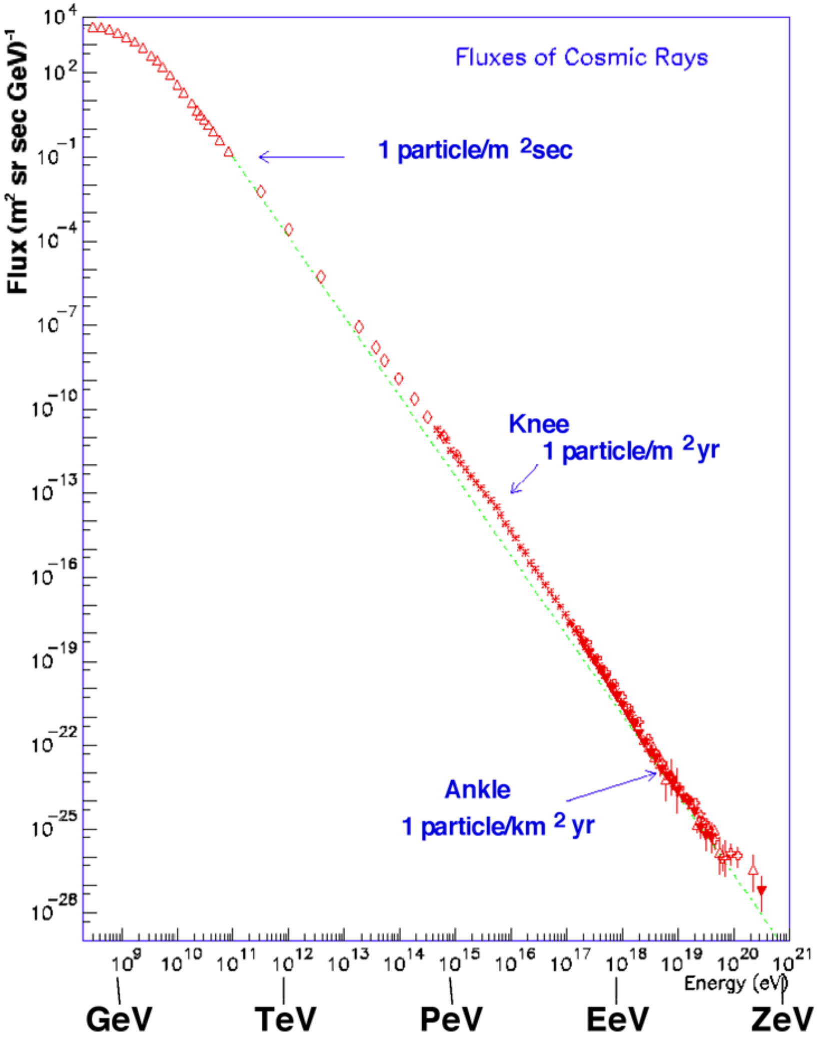
Direct observation (satellites, balloons) possible only below ~10^{14} eV

Probably the extragalactic origin above ~10^{16} eV

Mysterious origin of the ultra-high energetic cosmic rays (UHECR)

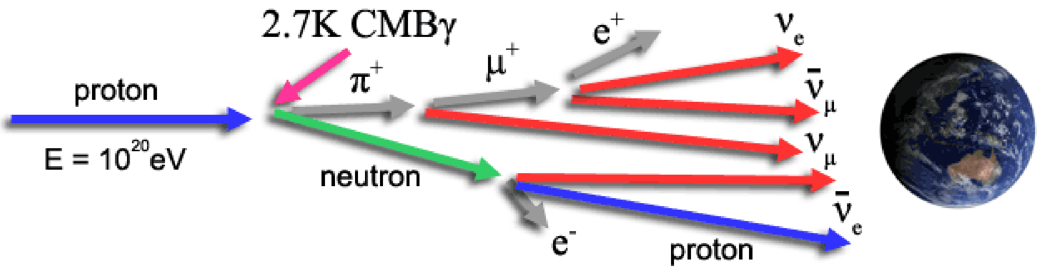
Particularly above 4*10^{19} eV

Is there a cutoff in the energy spectrum?



Greisen–Zatsepin–Kuzmin cutoff

Prediction of significant energy losses for particles above ~ $4 \cdot 10^{19}$ eV soon after the discovery of the Cosmic Microwave Background (CMB)

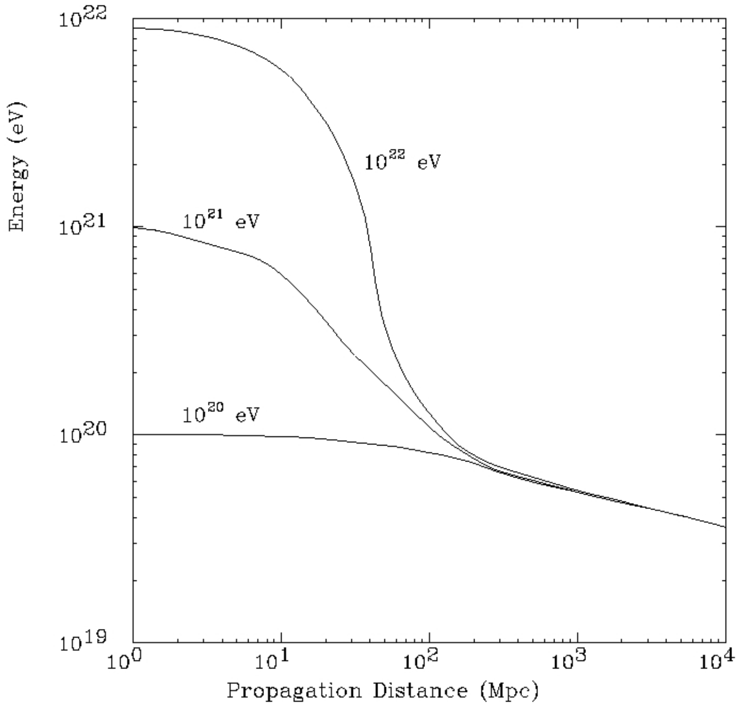


1) Interaction with microwave and IR photons (photodisintegration of nuclei)

2) Rapid decrease of the cosmic ray flux is expected

3) Limit on the distance of possible sources (must be located closer than about 100 Mpc)

4) And only protons and irons can survive travel longer than few tens of Mpc



Origin of UHECRs

A) Astronomical sources:

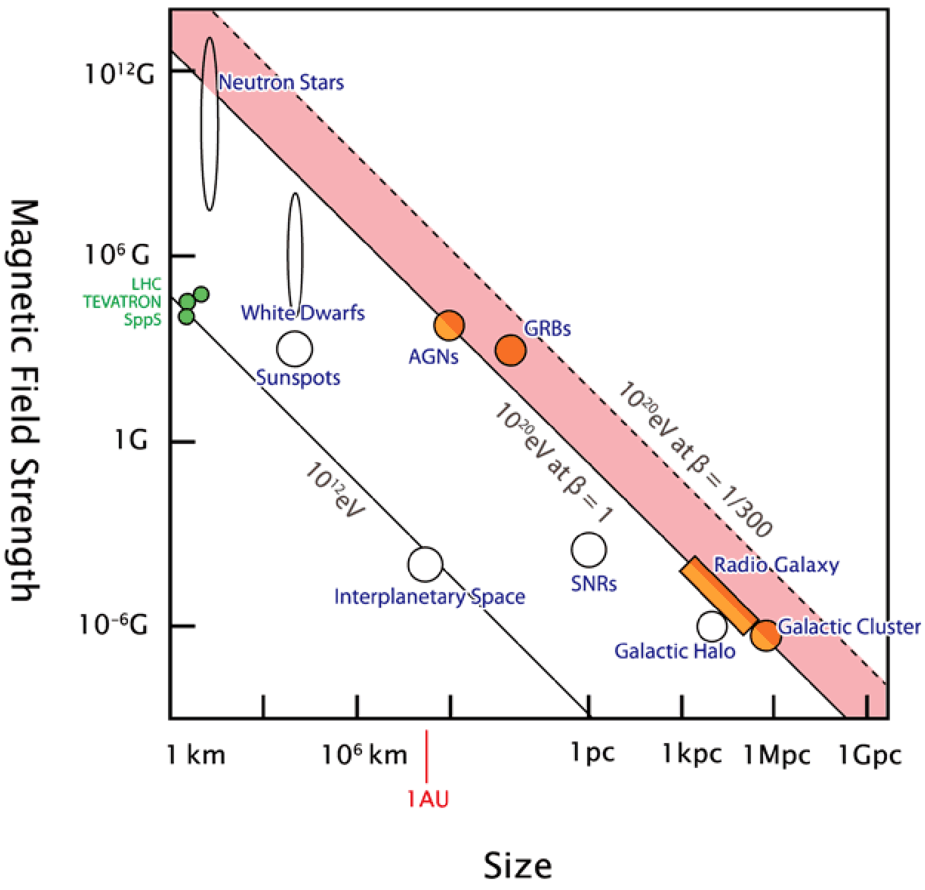
Cutoff might be caused by a lack of power in sources

Hillas diagram shows possible sources

Must be still local ones

No energy losses during acceleration are included

We still don't know any site of the origin



B) Exotic models:

Decay of superheavy particles

Large fraction of photons and neutrinos

Why to study UHECRs

What sources are so powerful to accelerate particles?
Arrival directions (e.g. correlation with active galactic nuclei)

Does any long-lived superheavy particle exist?
Dark matter
Flux of photons (< 2% above 10^{19} eV) and neutrinos

Information about the intergalactic space:
Energy losses
Magnetic fields

Particle physics:
Cross-section (proton – air)

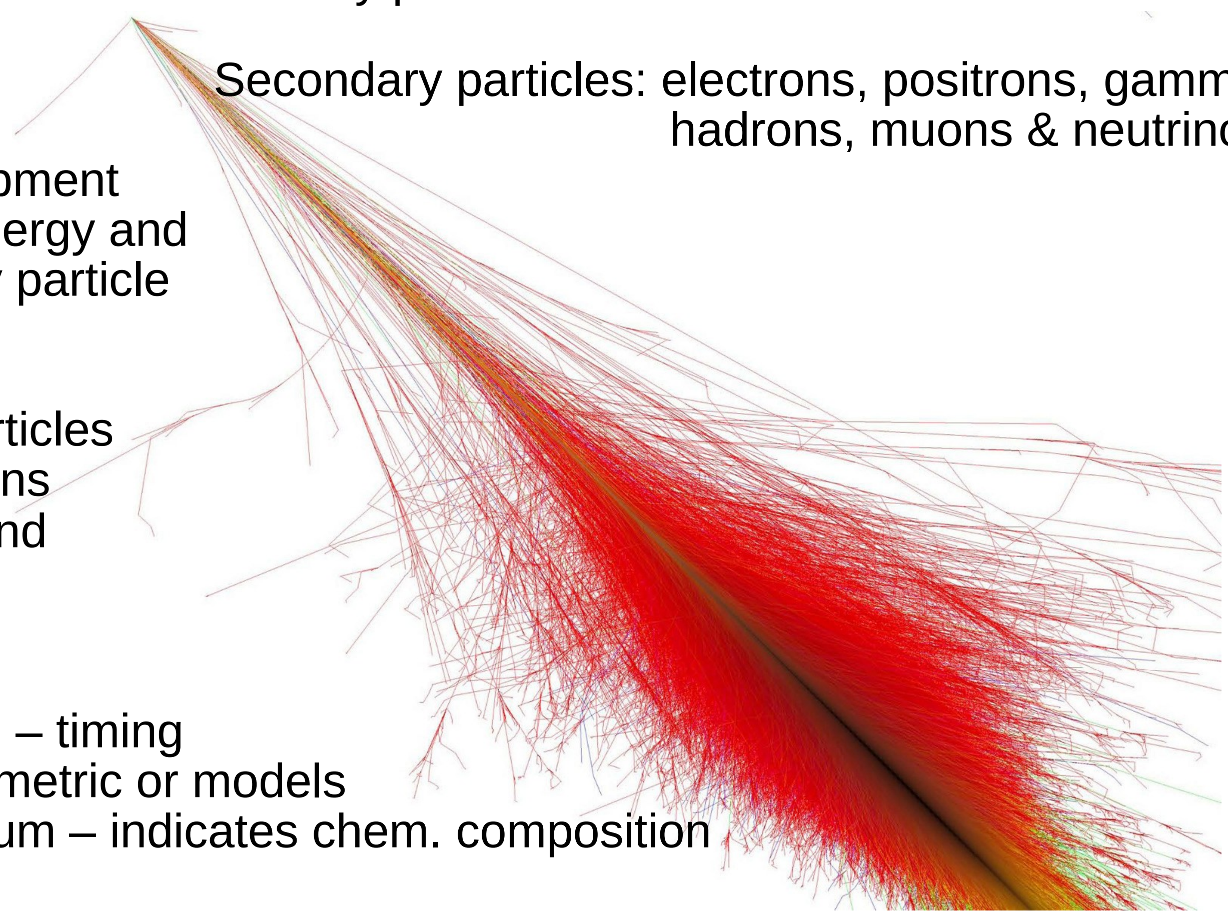
Composition of UHECRs:
Light (i.e. protons) or heavy (iron nuclei)?

Extremely steep and low flux above $4*10^{19}$ eV requires good energy resolution
Spillover from lower energies

Extensive air showers

The cosmic ray flux is too low above ~10^{14} eV for the direct measurement.

Interaction in the atmosphere discovered by P. Auger et al. in the late 1930s



Primary particle

Secondary particles: electrons, positrons, gammas, hadrons, muons & neutrinos

Air shower development depends on the energy and type of the primary particle

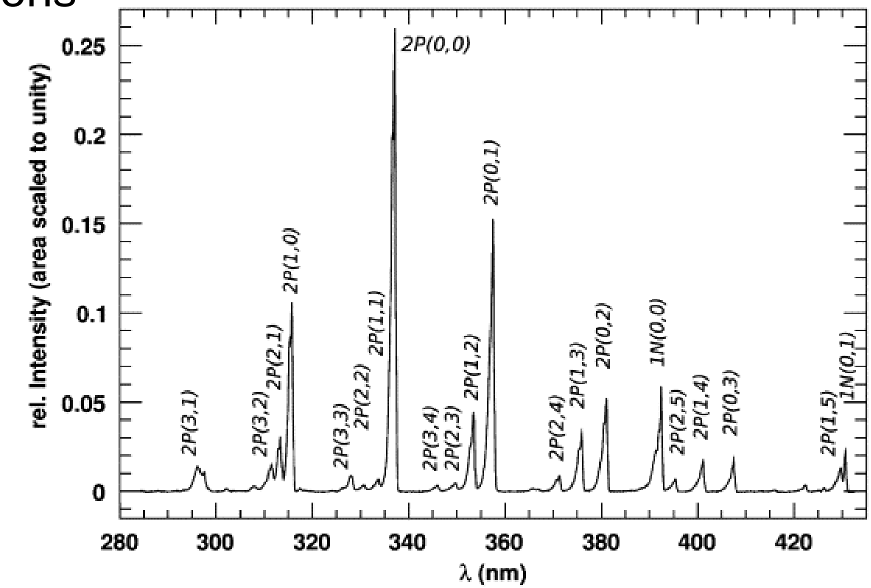
The secondary particles can extend over tens of km^2 on the ground

Reconstruction:

- Arrival direction – timing
- Energy – calorimetric or models
- Shower maximum – indicates chem. composition

Fluorescence light

Near UV light (300 – 400 nm) emitted during reionization of nitrogen molecules excited by the air shower electrons



Emitted isotropically

The shower development can be observed from side

Fluorescence yield measured in test beam experiments

Calorimetric measurement is possible

Visible during clear moonless nights

Signal is observable up to 40 km and the signal length is a few μs

Pierre Auger Observatory

The largest cosmic ray observatory

Collaboration of about 500 scientists from about 80 institutions in 18 countries

Close to town Malargüe in Mendoza province in Argentina (69° W, 35° S, 1400 m a.s.l.)

Close to the Andes mountain

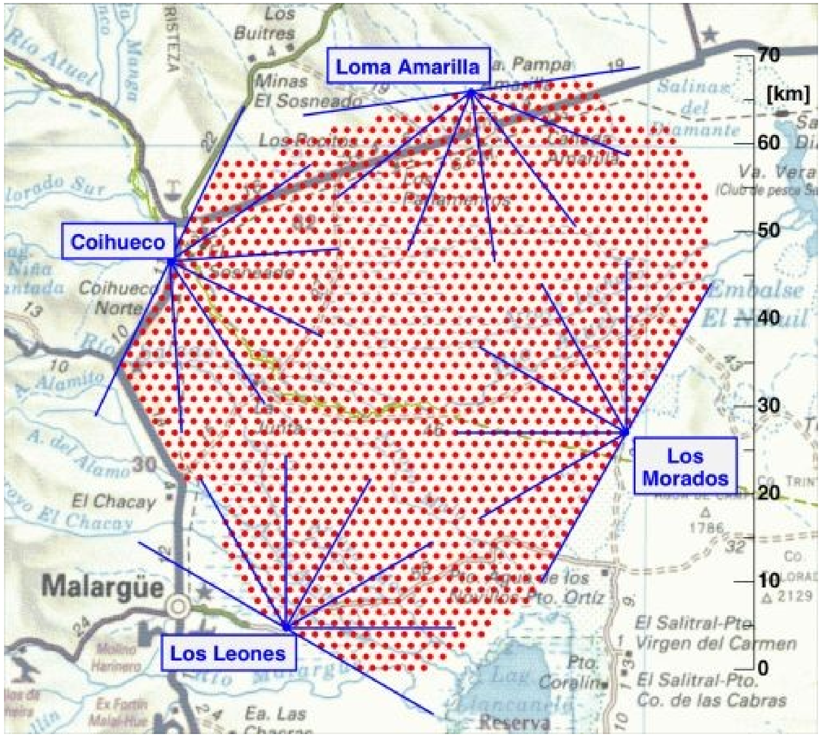
Experiment covers an area of 3000 km^2

Hybrid detector (combination of two well tested detection techniques)

Hybrid detector operated since 2004 and was finished in 2008

Enhancements (for lower energies)

Testing of new measurement techniques:
e.g. radio and microwave detection



Fluorescence detector

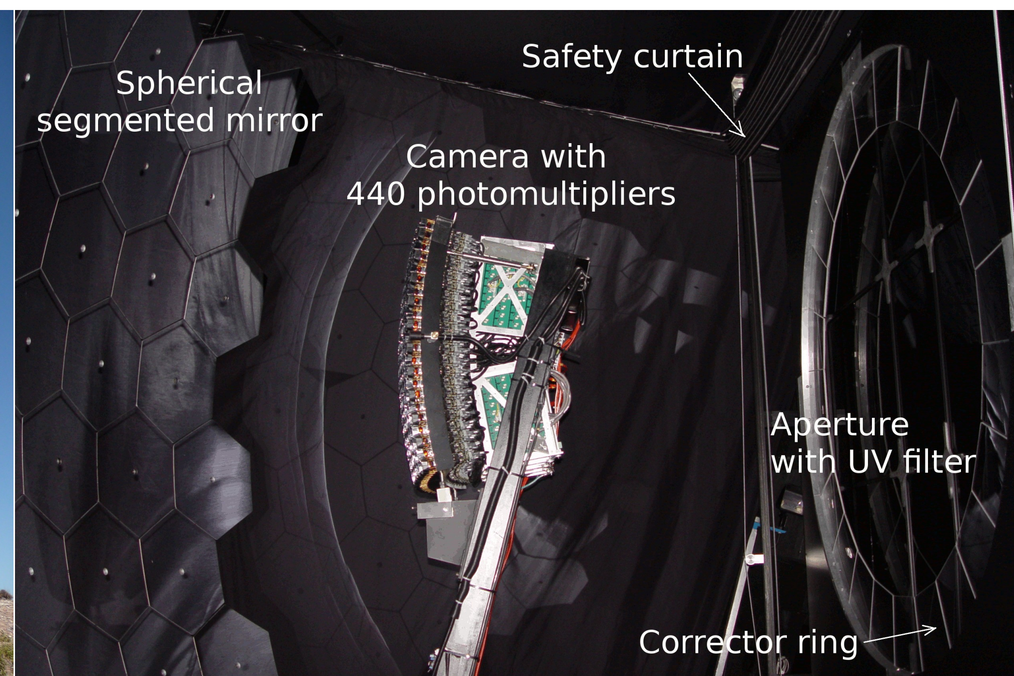
24 Schmidt telescopes in 4 buildings, f.o.v. / telescope = 30° * 30°

Observation only during moonless nights

15% uptime (lowers when quality cuts are applied)

440 photomultipliers in each camera, 1.5° / pixel

Aperture of 2.2 m diameter w/ corrector ring



Surface detector

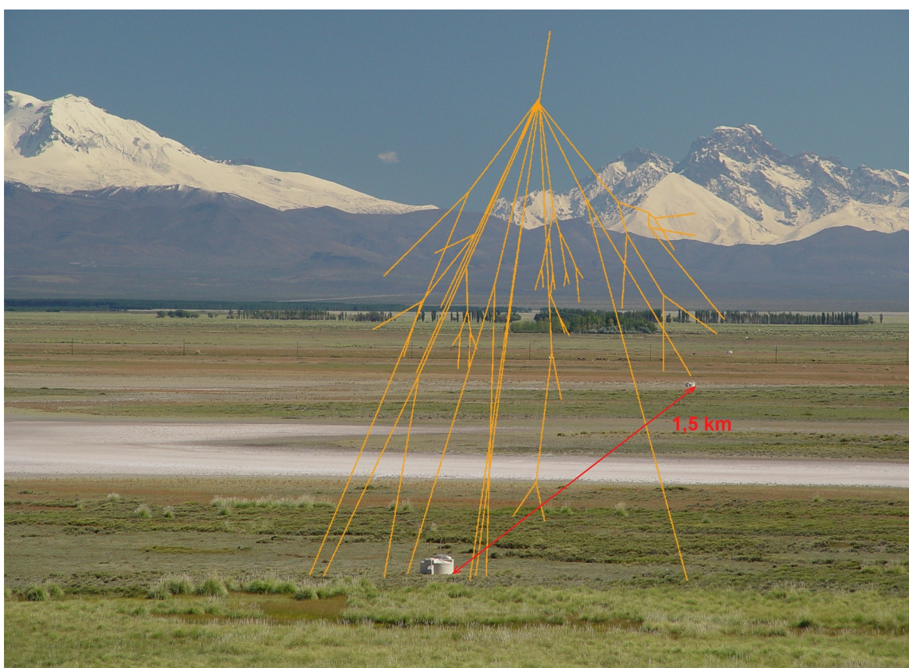
Water Cherenkov stations

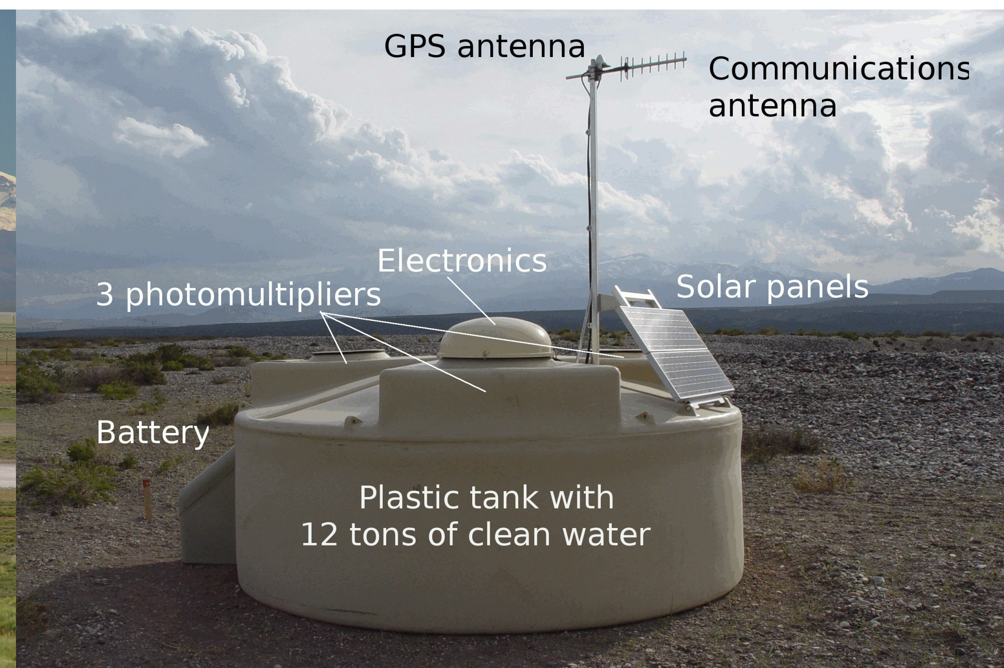
Sampling secondary particles on the ground

100% uptime and well defined exposure

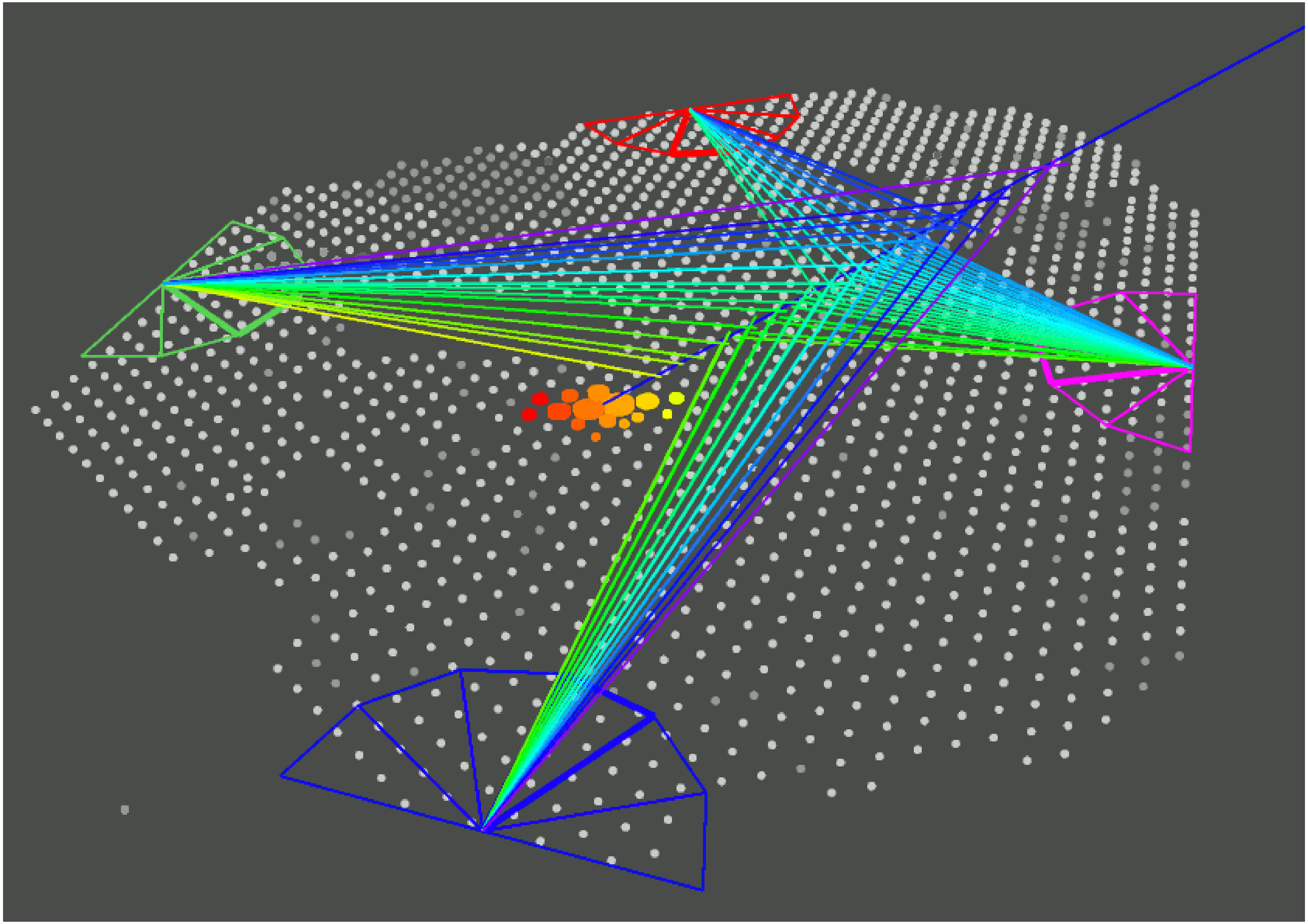
Arrival direction < 1°

Must be calibrated by the FD





Beautiful event



Atmospheric monitoring

To obtain precise knowledge about the immediate status of the atmosphere

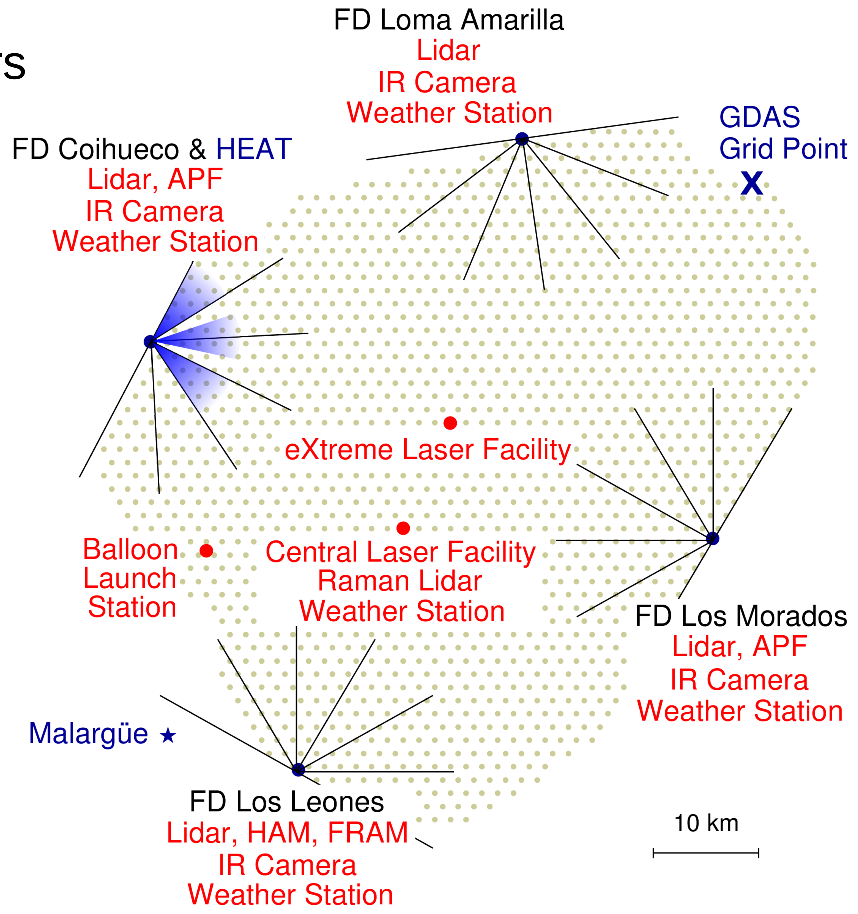
A whole range of different atmospheric monitoring instruments

1) Dependence of the fluorescence emission on the atmospheric conditions

2) UV light propagation from (distant) showers

3) Presence of clouds (position of the shower maximum)

4) Cross-check of the detector



Interference with the FD measurement:
- Invasive (active light source)
- Non-invasive

Mode of operation:
- a) Continuous
- b) Rapid monitoring system (online reconstruction for interesting events: very deep, high energetic, etc.)

FRAM – overview

Located 30 m in front of the Los Leones FD building
Only air showers measured by Los Leones are monitored

Installed during 2005, routinely taking data since mid 2006, upgraded in July 2009

Enclosure made of laminated glass fiber epoxy with inner iron frame

FRAM is operated as a passive scanner (no dead time into the FD DAQ)

Both measurement modes:
continuous and rapid monitoring

Operating in fully autonomous mode
or remotely controlled

Remote Telescope System – 2nd version (RTS2) under Linux:
Details on http://rts2.org/

Weather data from the FD building (closing roofs if it is raining or too strong wind)

FRAM – telescopes

1) Wide-field (WF):

Finger Lake Instrumentation MaxCam CM8

Carl Zeiss Sonnar telephoto lens
(f = 200 mm, max. aperture = f /2.8)

4° (azimuth), 2.7° (elevation)

Goal: measurement the atmospheric extinction along shower-detector plane

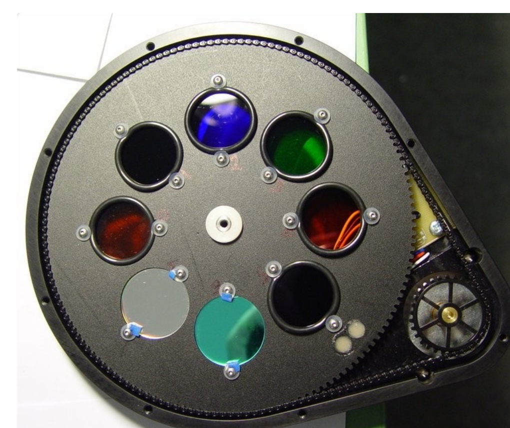
2) Narrow-field (NF):

Moravian Instruments CCD camera G2 (since June 2010)

Meade 30 cm Schmidt-Cassegrain telescope

0.4° * 0.3°

Goal: calibration the wide-field camera images



Both cameras are equipped with a filter wheel including Johnson-Bessel filters

FRAM – performance

From the Pierre Auger Observatory is observable the whole southern sky and part of northern sky (reasonable are objects up to declination +30°)

Telescope works in fully autonomous mode (including the dome control) using Remote Telescope System 2 (RTS2) software

Continuous – info about the atmospheric attenuation

Rapid monitoring – scanning track of interesting events

The observing queue: object, length of exposure, number, what filter to use

Storing and processing CCD images, reduction with dark frames and flat fields

Magnitude limits:

16 – 17 mag for 60 s for single exposure of NF camera for unfiltered frames
(on compositions can be seen stars fainter than 20 mag)

In case of WF camera the limit is near 14 mag on single frames

FRAM – photometry

Atmospheric attenuation is caused by scattering of light from small particles (aerosols) or water droplets suspended in the atmosphere and by absorption

Primarily, FRAM observations are used to obtain the wavelength dependence of the immediate light extinction by measuring fields with standard stars (i.e. stars w/ precisely known and tabulated intensities in various filters)

The extinction coefficient can then be transformed to optical depth using the expression:

$$\tau = \frac{\sqrt[5]{100}}{e} k = 0.924\, k, \;\; k = (m_{\text{obs}} - m_{\text{tab}})/AM$$

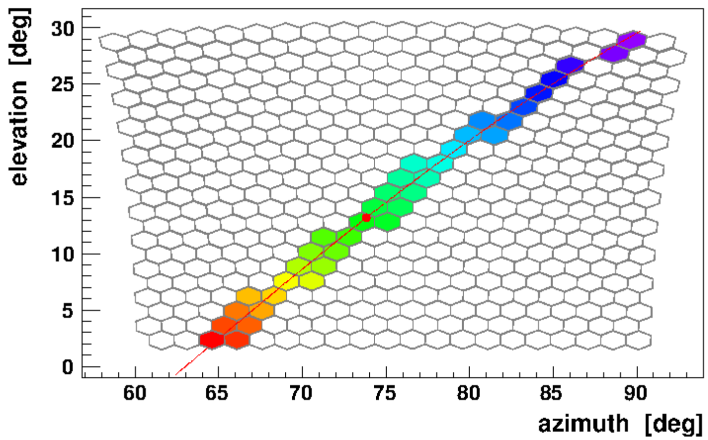
Our main goal is to provide the so-called Angstrom exponent, which is used for parametrization of wavelength dependence of aerosol optical depth:

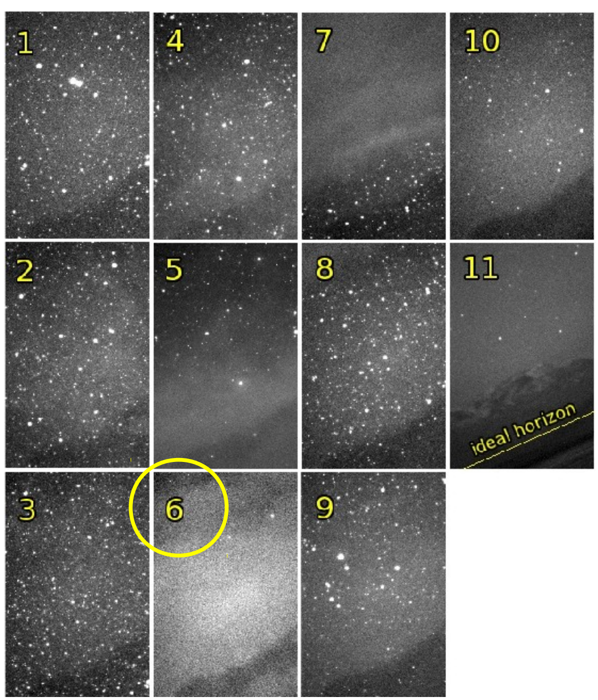
$\tau_A(\lambda) = \tau_{A0} \cdot (\lambda_0/\lambda)^{\gamma}$, λ_0 is the reference wavelength
τ_{A0} is the aerosol optical depth measured for this wavelength

The disadvantage of this instrument is its limited capability of only integral measurements through the whole atmosphere

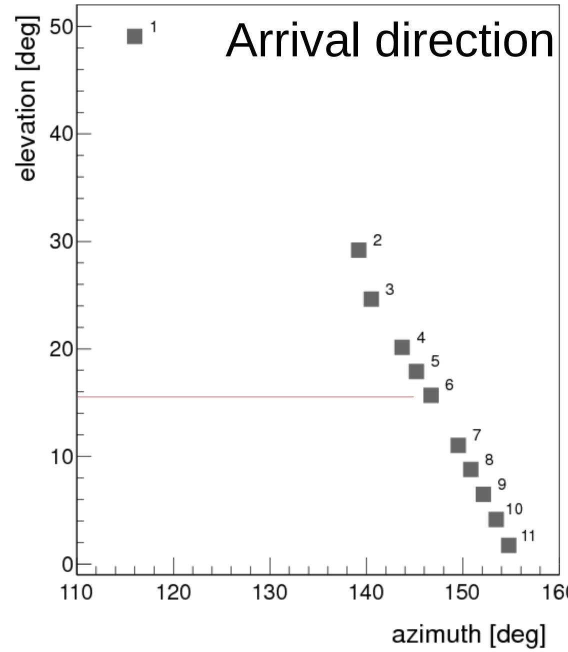
"FRAM"-the-shower

FD camera

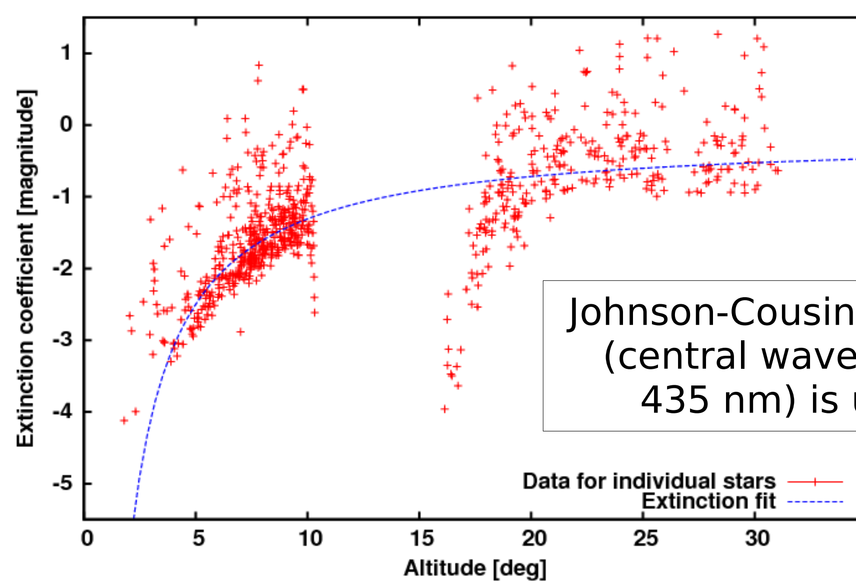




Arrival direction (optical counterpart?)



The shower-detector plane of an interesting shower



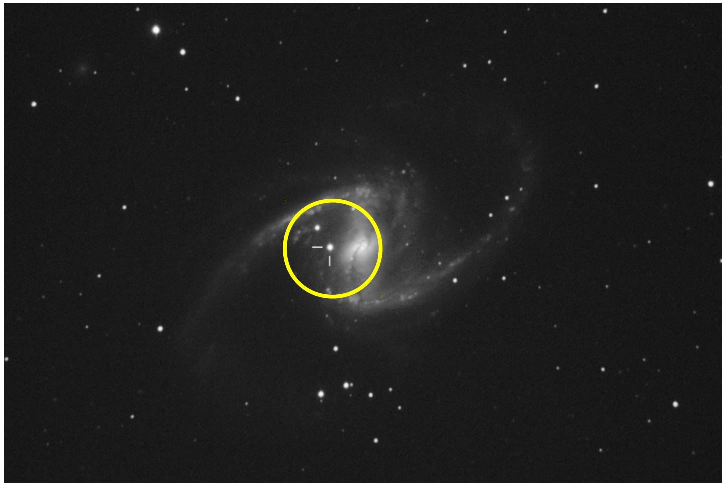
Johnson-Cousins B filter (central wavelength 435 nm) is used

Astronomical observations

Examples of astronomical targets:

1) Optical counterparts of gamma-ray bursts
2) Selected variable stars
3) Accurate photometry of comets in V and R bands for International Comet Quarterly
4) Measurements of afrho parameter of comets for CARA project (Cometary ARchive for Afrho)
5) Confirmation observations of newly discovered small solar system bodies and providing their astrometry for Minor Planet Center

Minor planet Apophis on Jan 16, 2013 (left), NGC1365 w/ SN2012fr (right)



GRB 060117

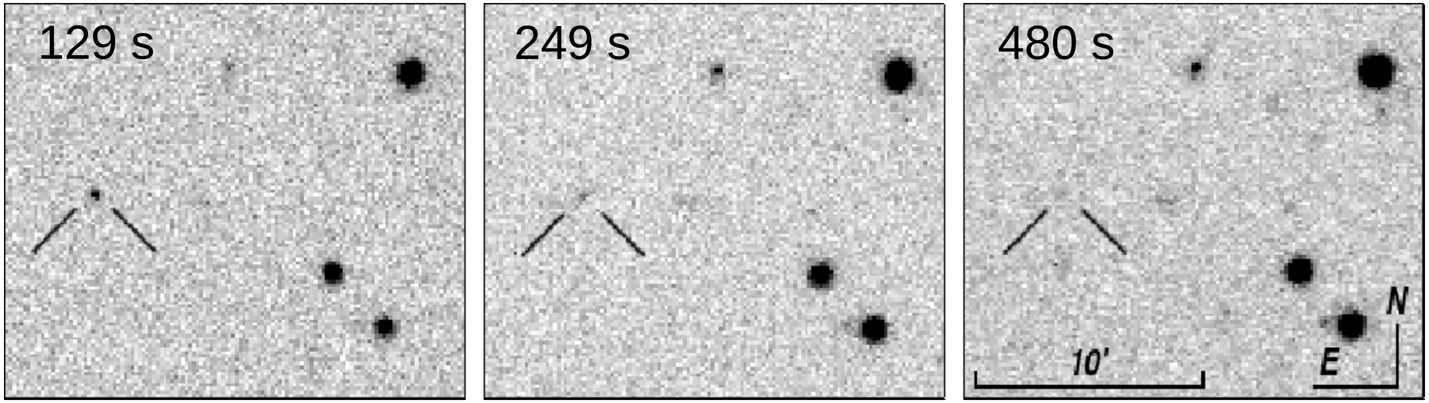
Discovery of an extraordinarily bright prompt optical emission of the GRB 060117

GRB 060117 detected by Swift satellite on Jan 17, 2006
FRAM received msg 19.2 s later, the 1st exposure started 123.8 s after the GRB
(and it was only 5° above the horizon) [M. Jelínek et al., A&A 454, 2006]

Sequence of wide-field CCD camera shots (2 to 10 minutes after GRB)

Optical counterpart: rapid temporal flux decay
peak brightness of 10.1 mag in Bessel R filter

Later observations by other instruments set a strong limit on the optical and radio transient fluxes, unveiling an unexpectedly rapid further decay.



Conclusion

The fully autonomous telescope FRAM is located in the southern hemisphere

It's main purpose is the study of the atmospheric conditions for the events measured by the Pierre Auger Observatory

FRAM has been successfully working since mid 2005

Measuring the standard stars is a non-invasive method for getting actual atmospheric transparency

FRAM is useful for the rapid search of optical counterparts of the interesting cosmic ray events and also gamma ray bursts

Any trigger can be implemented into its operation