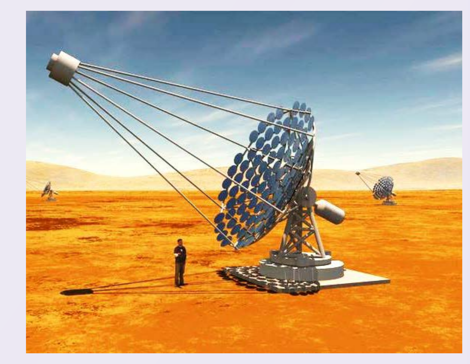
P125

R&D Studies for Very High Energy Gamma-Ray Astrophysics at Energies Greater than 10 TeV



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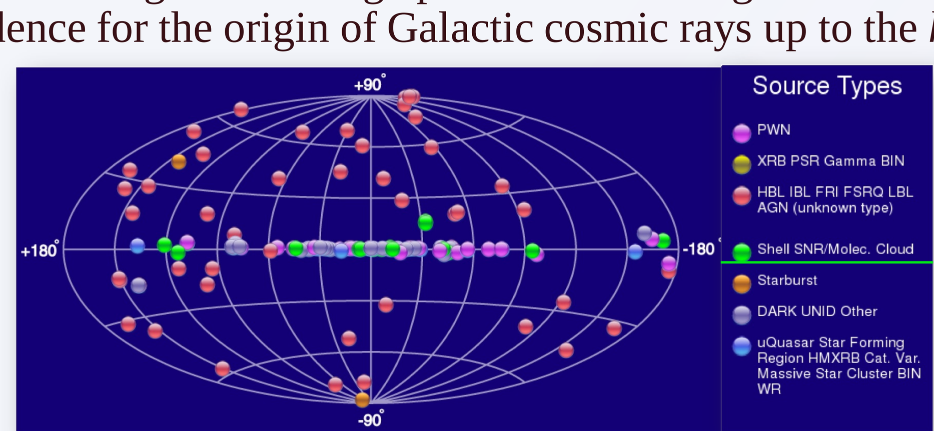
Abstract

Very high energy (VHE) gamma-ray astronomy has grown to a new branch of observational astronomy by the successes of the current imaging atmospheric Cherenkov telescope (IACT) arrays. In spite of the discoveries of more than 100 VHE gamma-ray sources by the current IACT arrays, the mystery of Galactic cosmic ray accelerators up to the cosmic-ray *knee* energy (~PeV, 10^{15} electronvolt) is still not fully resolved. PeV Explorer is a future project of a relatively small IACT array, optimized to detect gamma-rays of energies greater than 10 TeV and aiming to explore Galactic accelerators up to PeV energies. We present the status of our hardware R&D studies for this project and some extension plans.

Gamma-ray detection technique at energies > 10 TeV and concept of the mobile Cherenkov telescope array

PeV cosmic ray accelerators

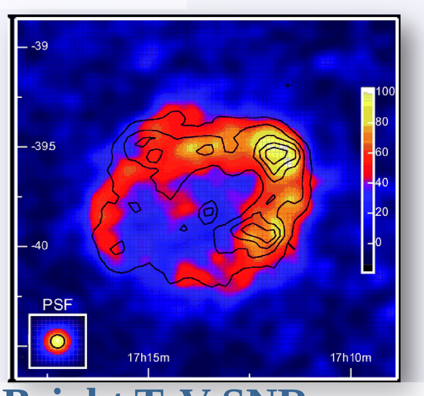
Imaging Atmospheric Cherenkov Telescopes (IACTs) have discovered more than 100 VHE γ-ray sources during the last 25 years. About 10 sources of them are associated with supernova remnants (SNRs) and expected to solve the long-standing mystery of the origin of Galactic cosmic rays. A γ-ray spectrum of a hadronic origin extending up to sub-PeV energies can be an evidence for the origin of Galactic cosmic rays up to the *knee*.



Current TeV source catalog by *TeVCat*
(http://tevcat.uchicago.edu/)

In spite of the expectation above, we have not found plausible evidences for a Galactic sub-PeV gamma-ray emitter. One of the brightest SNR in γ-ray RX J1713.7-3946, which associates with ambient molecular clouds, shows the γ-ray cutoff energy of 17.9 TeV, that is too low to explain the primary particle spectrum up to PeV.

There have been also found other darker Galactic sources which have hard TeV spectra with no cutoffs. We need deeper observations for them to determine spectral shape more precisely with good event statistics, by expanding the effective detection area in the *E*>10 TeV region.



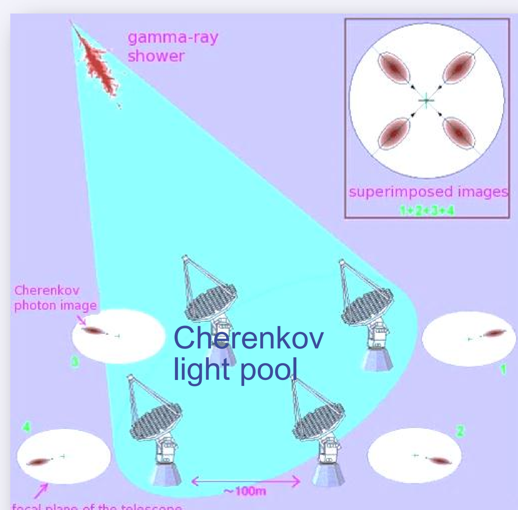
Bright TeV SNR RX J1713-.7-3946.
Acceptance corrected γ-ray excess image by HESS. (Aharonian et al. 2007)

E>10TeV IACT array design

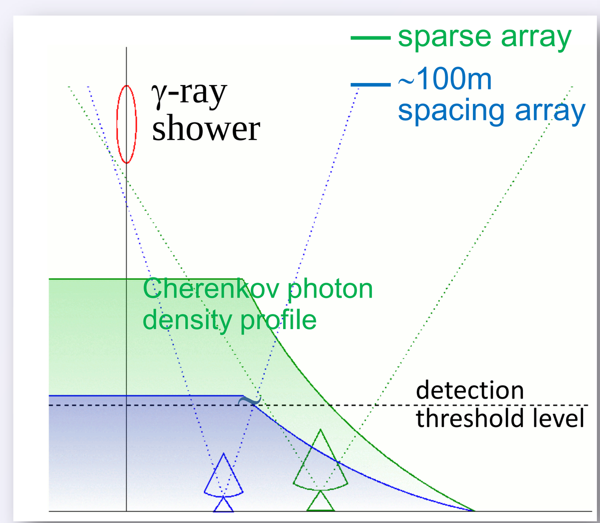
The *TenTen* IACT array concept has been proposed to explore various astrophysical phenomena in the E>10 TeV gamma-ray regime. It is a future project for an array of 30-50 IACTs of a relatively small aperture (3-5m diameter), which aims to achieve a 10km² effective area for E>10 TeV gamma-rays.

This concept is based on the simulation by Plyasheshnikov et al. (2000), which showed that the effective area can be expanded cost-effectively with large telescope spacing (~300m) and wide field of view (FoV) of the imaging camera such as ~8°. This method works as follows: In the existing IACT arrays, telescope spacing was determined by the size of Cherenkov light plateau (radius of ~100m), where the Cherenkov photon density is roughly flat. The plateau is accompanied with a wide skirt area where the photon density is lower than the plateau but still can exceed detection threshold level. By utilizing this skirt area with a sparse spacing array of wide FoV telescopes, the effective area can be expanded at low cost.

The optimum array configuration for TenTen must be determined using simulations so that the effective area per cost is maximized.



γ-ray detection principle of the present IACT arrays.



Concept of a sparse array for the E>10 TeV region.

PeV Explorer

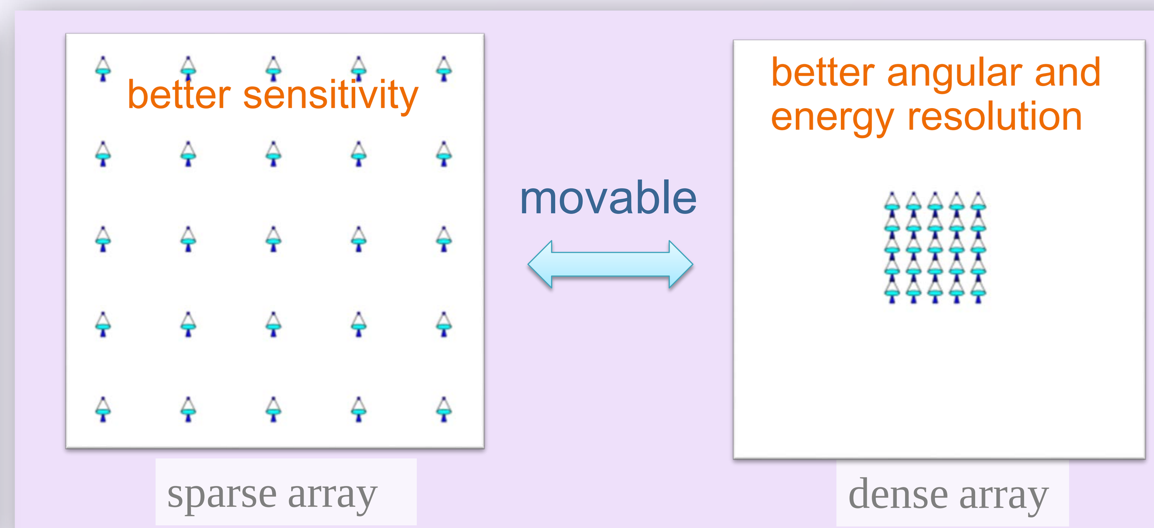
Before designing an array of 30-50 telescopes, R &D works for one "cell" of TenTen (which consists of 4 to 5 IACTs) have started as the "PeV Explorer" (or PeX) project.

One concern for this small array is that large core distance and low telescope multiplicity will bring a possible degradation of angular and energy resolution. In order to cope with this problem, a new analysis method using Cherenkov photon time gradient has been developed by the Adelaide group (Stamatescu et al. 2011).

Future mobile telescope array concept

The optimum array spacing of TenTen/PeX may vary in wide range depending on the target of interest. An array of "movable" telescopes (like ALMA) has a capability to cover various array spacing pattern with flexibility.

In order to realize such mobile telescopes, there are some technical challenges to solve (such as power supply means and optical axis calibration method etc.) R&D works for this future mobile telescope array have started in Japan.



Concept of the mobile Cherenkov telescope array

Hardware R&D and a test bench at the Akeno Observatory

Future mobile IACTs in our concept will run on their own local power supply and automatically calibrate their optical axis direction. In order to achieve this goal, we have been developing low power consumption electronics and a telescope pointing calibration system using GPS.

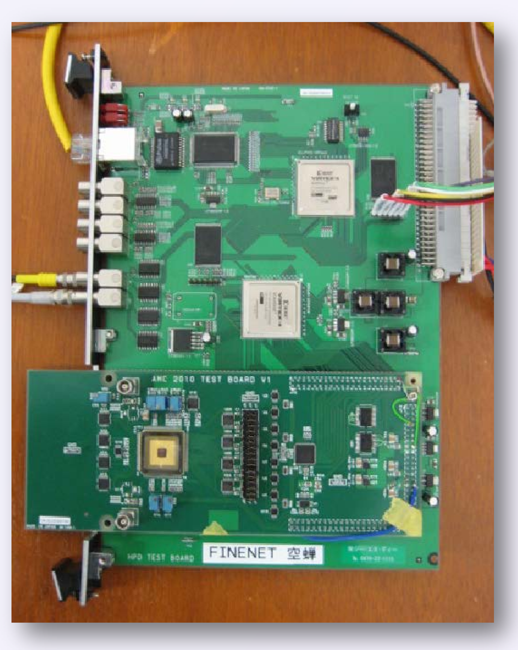
Analog Memory Cell (AMC)

An AMC circuit is a parallel circuit of capacitors and sampling switches, which can record signal voltages with fast time sampling.

- Sampling speed >500 MHz
- Analog bandwidth up to 500 MHz

are required for our telescopes in order to apply the Cherenkov photon time gradient analysis described above. The present sample depth of 64-128 cells (which corresponds to 64-128ns time window for 1GHz sampling) is regarded to be sufficient considering the time dispersion of Cherenkov photons at large core distances.

Performance of some prototype AMC chips has been checked with a test board. The analog cutoff frequency is a factor of 2 or 3 smaller than 500 MHz, which should be improved in the next prototype. The power consumption was ~180mW for 64 cells and suppressed to be a reasonable level.



Prototype AMC chip test board

Telescope pointing calibration system

We have tested an automatic telescope direction measurement system using GPS compass. It consists of two GPS antennas and a GPS compass board and can measure the direction of the line connecting the two antennas using the real time kinematic (RTK) technique.

Some long-time continuous measurements of 24 hours have been done and we confirmed that the accuracy better than 1 arcmin was achieved by accumulating data for 100 minutes (in the case that the distance between antennas is 4.5m). This system can be used in rough measurements before fine tuning using star images by a CCD camera.

The GPS antennas (Novatel GPS-701-CG) **and compass board** (Hemisphere Crescent Vector OEM)

A test bench at the Akeno Observatory

3m diameter telescope installed at the Akeno Observatory, ICRR

We obtained a used 3m-diamter Cherenkov telescope which can be used as a test bench for future IACT projects. It has been installed at the Akeno Observatory of ICRR .

Basic parameters of this telescope are:

- 3m diameter
- Davis-Cotton type tessellated reflector with a focal length of 3m (f/D=1)
- Reflector area of 5.7×10^4 cm²
- Hexagonal facet mirrors made of glass (will be recoated soon)
- Altazimuth mount

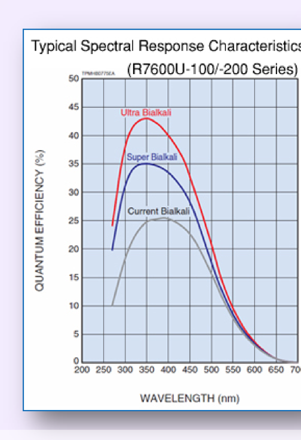
The telescope drive system has been repaired and the imaging camera and the electronics (already shown in this poster) will be installed soon. We plan to do some test observations with this system. A portion of electric power will be supplied by a lithium-ion battery, to demonstrate as the first battery-powered IACT system.

Photodetector for the imaging camera

The imaging camera for this telescope will consist of ~32 photomultiplier tubes. We are planning to adopt Hamamatsu R11265 for its compactness and high quantum efficiency.

- 23mm square pixel (resolution of 0°.43 for f=3000mm)
- High quantum efficiency (~35% at peak) by the super bialkali photocathode

Photomultiplier tube



Quantum efficiency of some types of photocathode

Summary

We are developing instruments for the future projects of very high energy γ-ray astrophysics at energies >10 TeV. The low power-consuming electronics and the automatic telescope pointing calibration system have been built and tested. These developed systems will be installed to a test bench telescope placed at the Akeno Observatory in Japan and we will have some test observations with this telescope.

Acknowledgements

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