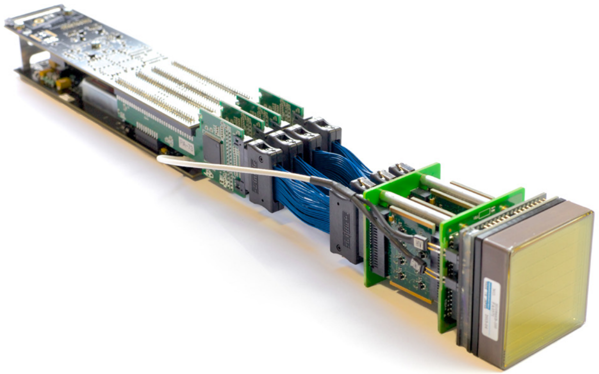

A CHEC module consisting of light sensor (multi-anode photomultiplier) and electronics: preamplifier, flexible cable connection, digitisation and signal processing as well as high-voltage supply.

ing whether to retain images or discard them based on the pattern of light in the photodetectors. The electronics are housed in a liquid-cooled, sealed enclosure. LED flashers in the corners of the camera provide a calibration source via reflection from the secondary mirror.

CHEC-M underwent preliminary laboratory tests in 2015. In November the camera was installed on a prototype telescope in Paris and was used to successfully record the first Cherenkov light for a CTA prototype, and the first Cherenkov light seen with such a dual-mirror optical system. CHEC-M is now at MPIK for further lab tests. A second full-camera prototype, CHEC-S, based on silicon photomultipliers is under construction.

Automated performance test of the CHEC prototype in the laboratory with the aid of a laser, mounted on a robot.

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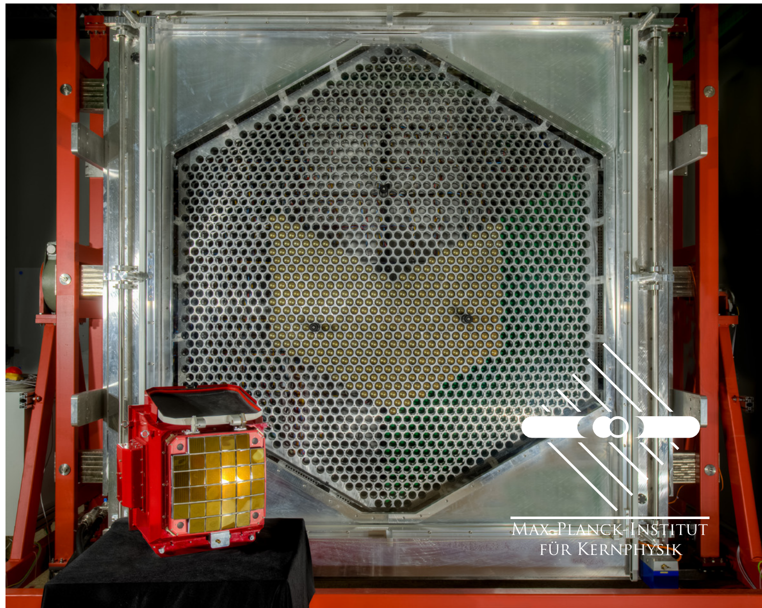
The Max-Planck-Institut für Kernphysik (MPIK) is one of 83 institutes and research establishments of the Max-Planck-Gesellschaft. The MPIK does experimental and theoretical basic research in the fields of Astroparticle Physics and Quantum Dynamics.

cherenkov telescope array

MAX-PLANCK-GESELLSCHAFT

High Performance Cameras

for the Cherenkov Telescopes of CTA

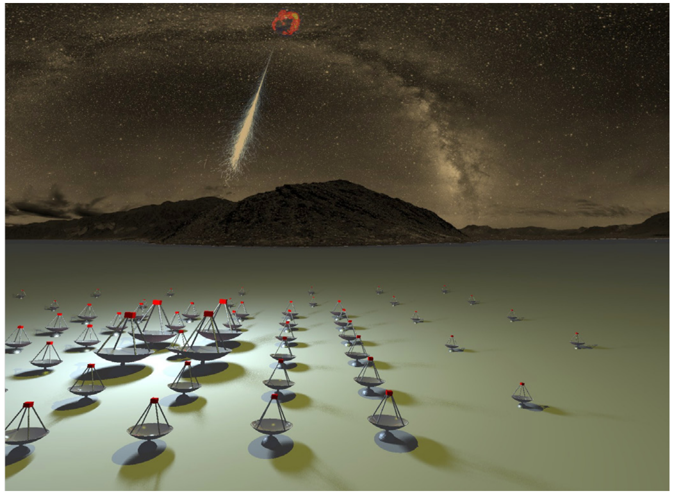


High Performance Cameras for the Cherenkov Telescopes of CTA

Despite – or in fact because of – the great success of gamma astronomy with Cherenkov telescopes, there are still numerous open questions. The Cherenkov Telescope Array (CTA) is a next-generation instrument for gamma astronomy at the highest energies. It will exceed the performance of instruments like H.E.S.S. by an order of magnitude and is to address these questions. Overall about 120 telescopes with three different mirror sizes of about 4 m, 12 m and 23 m diameter are planned for CTA at two sites in the northern and southern hemispheres, respectively, covering a large energy range from about 10^{10} to above 10^{14} eV.

Cameras for Cherenkov telescopes

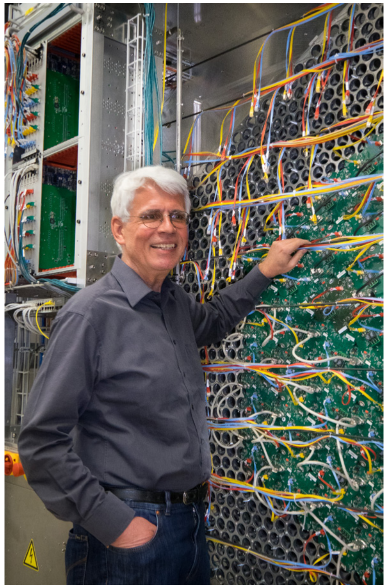
Cameras for Cherenkov telescopes must be able to resolve the faint flashes of atmospheric Cherenkov light from gamma- and cosmic-ray initiated particle cascades, which last only a few tens of nanoseconds, against the background of ordinary starlight. In addition, they must be capable of capturing many thousand exposures per second.



An artist's view of the southern CTA array with the Milky Way, a gamma source, and a particle shower.

Of the medium-sized telescopes, 24 are planned at the southern and 15 at the northern site. About 70 small-sized telescopes distributed over an area of several square kilometres will be deployed at the southern site only. Given their large number, CTA cameras must be cost-effective as well as high performance. In addition, cameras must be easy to maintain, spend few power, and at the same time work reliably and safe.

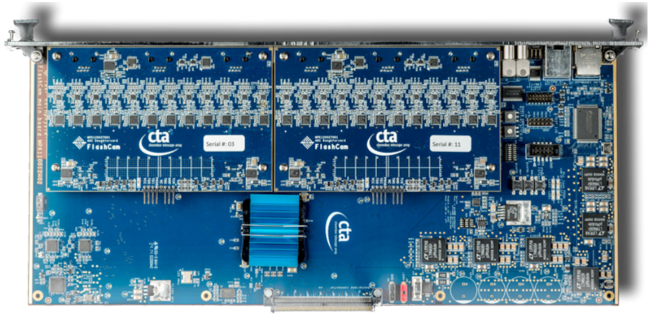
FlashCam: for the medium-sized telescopes



Werner Hofmann at the back side of the FlashCam light sensor plane partly equipped with photomultipliers. The read-out electronics is located within the camera case.

Together with several European partner institutes, the MPIK is developing a novel camera, FlashCam, which fulfils these requirements and is designated for use in the medium-sized telescopes. The central functional elements of FlashCam are a light sensor plane and digital high-speed read-out electronics, which are both designed in a highly modular manner.

The light sensor plane consists of 147 identical electronics modules each equipped with 12 photomultiplier tubes as light sensors. These are capable of resolving ultrashort light pulses of a few nanoseconds duration, consisting of single up to several thousand photons, and to convert them into a measurable electronic signal. These signals are then continuously digitised by the read-out electronics with a sampling rate of 250 MHz and a resolution of 12 bits, and are available for subsequent digital signal processing and storage. This takes place in parallel in several steps on up to 96 FPGA-based processors which extract events (Cherenkov images or “exposures”) from the digital raw-data flux of up to ~7 TBit/s. Therefor, it is required that within a few nanoseconds several nearby light sensors detect a signal which exceeds the light of the night sky. Subsequently, the digital information of the ex-



Electronics “motherboard”, developed at the MPIK, with FPGA and 2 plugged-on analogue-to-digital converter boards for each 12 photomultipliers.

tracted exposures is buffered on the FPGA's, and is ready for read-out via ethernet to a standard computer. The electronics, firmware, and software, developed at the MPIK, make it possible to capture and process without loss of information more than 30 000 exposures per second.

The camera case housing the light detector and electronics has dimensions of $2.9 \times 3.0 \times 1.1$ m^3. It is a closed insulating body with an entrance window and a cooling system for the electronics. FlashCam has a total weight of about 2 tonne.

CHEC: for the small-sized telescopes

The Gamma Cherenkov Telescope (GCT) is of a design that incorporates dual-mirror optics. This design results in compact telescopes with good image quality and a large field of view. A novel camera type, named CHEC (Compact High Energy Camera) is designed specifically for these telescopes. Together with Jim Hinton, the first camera prototype, CHEC-M came from the University of Leicester to the MPIK and is being developed into a production-ready instrument together with partner institutes from Europe, Japan, Australia and the United States. The GCT optics require the camera detectors follow a convex surface with a radius of curvature of 1 m and a diameter of about 35 cm, approximated by tiling the focal plane with 32 modules. The weight of CHEC is only about 40 kg.

The first prototype, CHEC-M, is equipped with multi-anode photomultipliers each containing 64 pixels, resulting in 2048 pixels in total. Each pixel measures 6×6 mm^2 to provide the required angular scale. Signals from the photodetectors are shaped, amplified and then digitised by custom electronics. The camera is self-triggering, decid-