The Beginning and Construction of the MAGIC Telescopes

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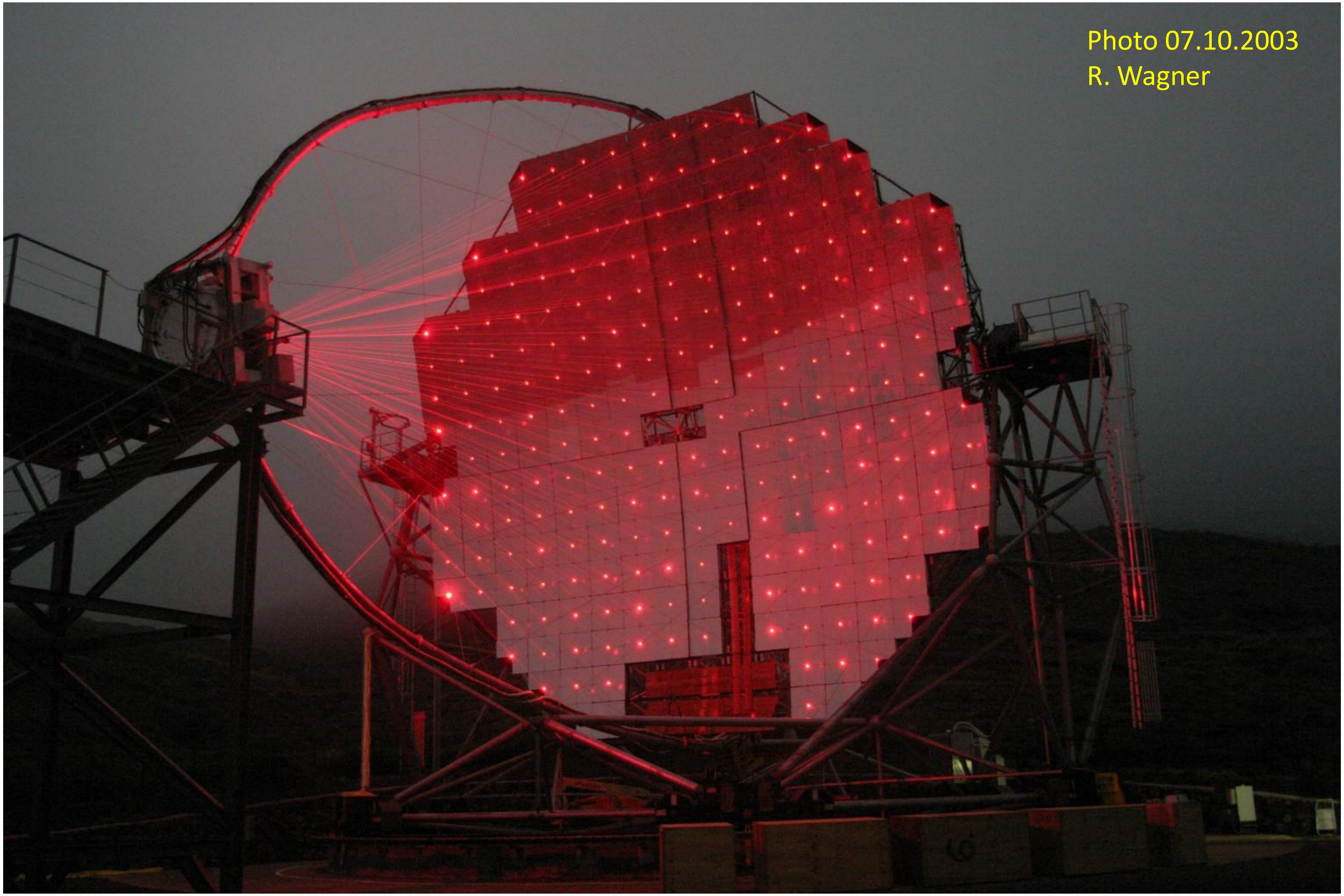
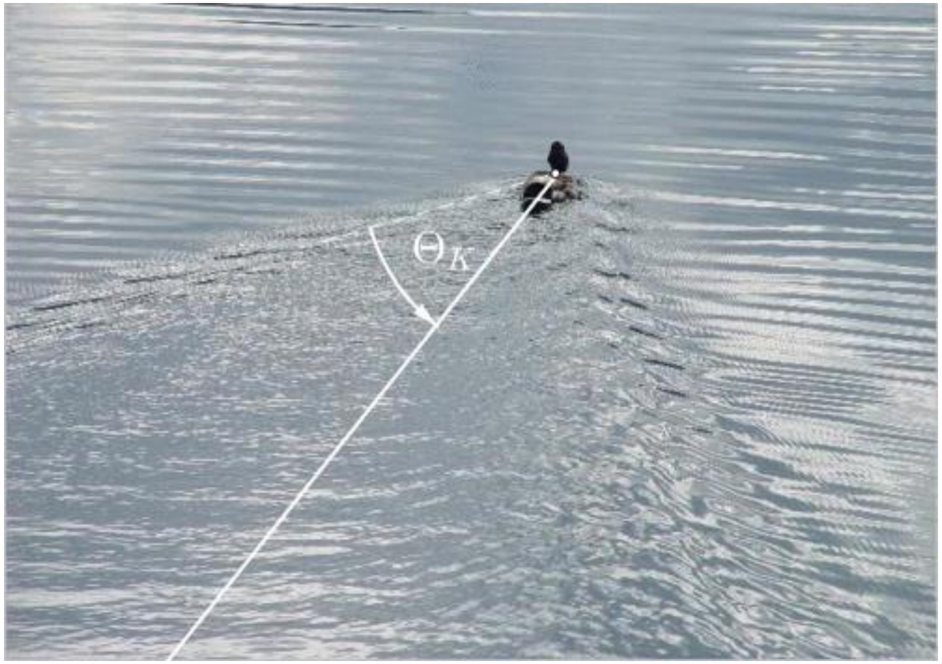
H 10 TABURIENTE PLAYA
MAGIC TELESCOPE
INAUGURATION
SEMINAR ROOM – BREÑA BAJA SALON
COFFEE BREAK – LOUNGE AREA
9 OCTOBER 2003

MAGIC-I lasers of the Active Mirror Control system are On



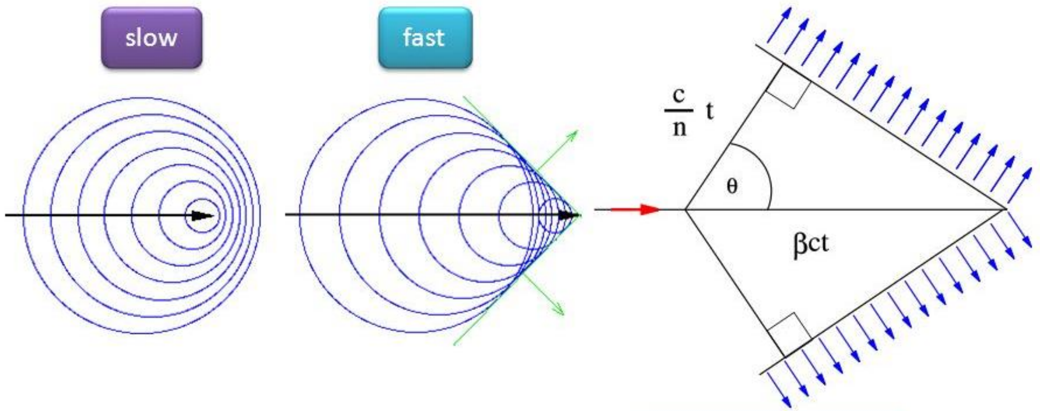


- A duck swimming in the lake leaves behind a cone-shaped water front
- The reason is that the speed of the duck exceeds that of the waves on the water surface

Similarly, a speedboat leaves
behind conical traces

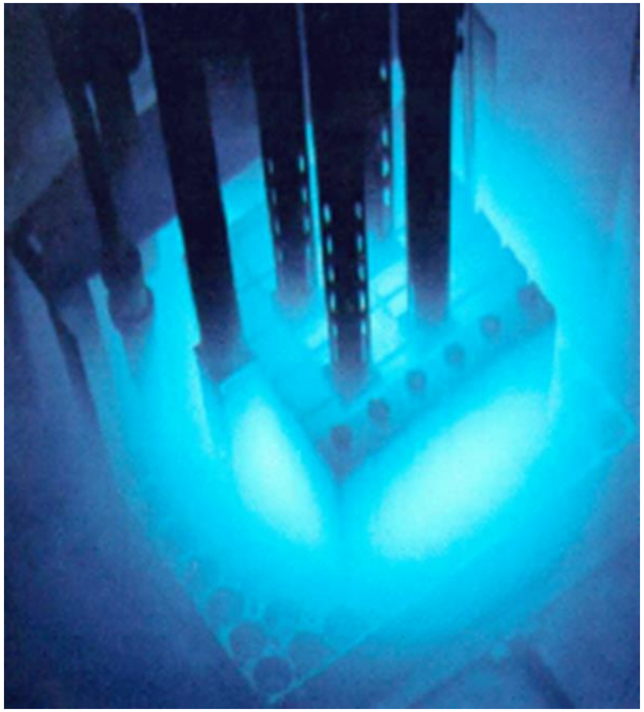
Čerenkov Radiation

In the figure, v is the velocity of the particle (red arrow), β; is v/c, n is the refractive index of the medium. The blue arrows are photons.

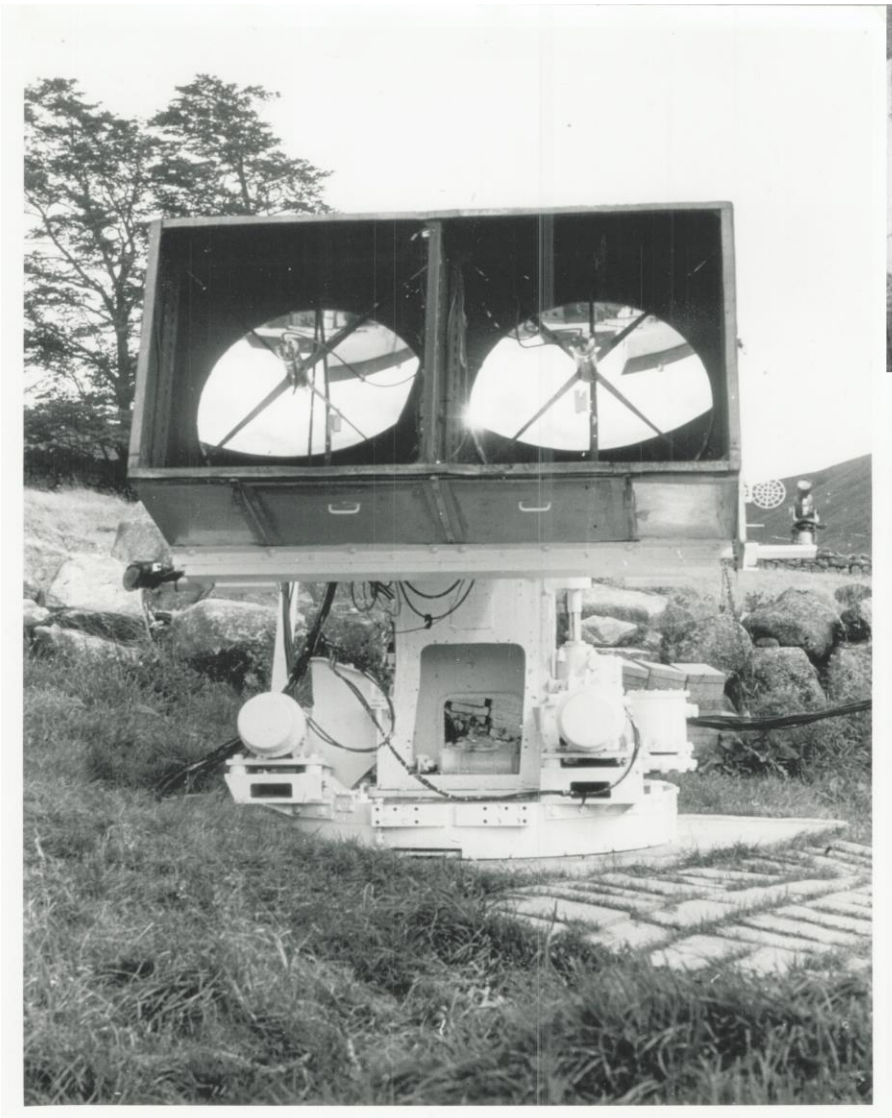


$$\cos\theta_c = 1/\beta n$$

A particle reactor glowing in Č light



Example: 1st generation telescope

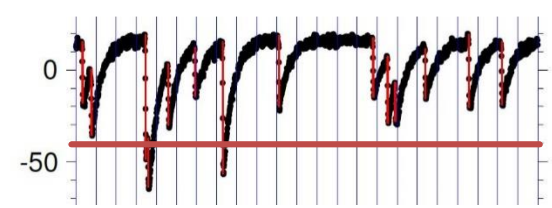


Neil Porter
Glencullen,
Ireland
1962---66

A 1st generation telescope consisted of a PMT in the focus of a parabolic (searchlight) mirror

Typically the PMT subtended a field of view of ~ 2° in ø in the sky

Fluctuations of Light of Night Sky (LoNS) within that solid angle define the threshold



The Early Days of Č light measurements at the 1280-m Level of Mt. Hopkins in Arizona (1967-68)

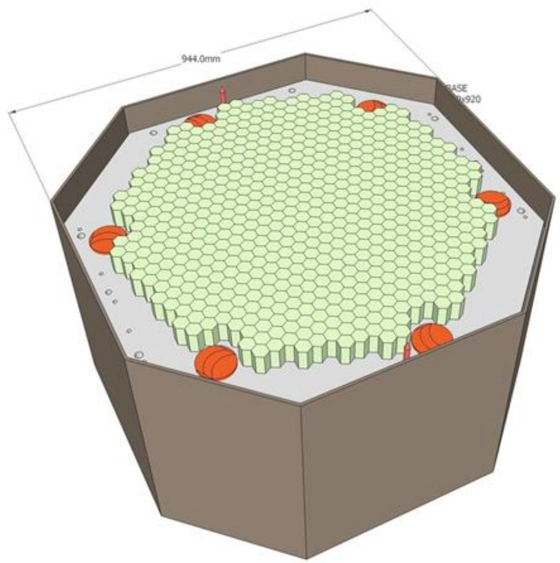
Trevor Weekes, PhD 1966 George Rieke, Ph.D. 1969

A non-imaging vs. imaging camera in the focal plane of a Č telescope

Imagine this is a single PMT „camera“

a)

An image camera of an IACT



b)

- Assume in a) single PMT integrates LoNS within a field of view 2°
- In case b) same LoNS is split among 100‘s of pixels, put into a fast coincidence
- LoNS fluctuations are independent, → one can almost „kill“ it in case b)
- A threshold ≥ 100 p.e. allows one to recognize and measure image
- Signal strength (i.e. amount of measured Č light) depends linearly on the E, i.e. on mirror area

1st Č telescope our group built in Armenia, 1989

The 1st (prototype) IACT of HEGRA in La Palma

- This telescope produced results in a record-short time in 1992
- After only 2-months of operation we were the first to confirm the gamma-ray emission from the Crab Nebula, measured by the team led by Trevor Weekes in Arizona, USA, in 1989


HEGRA *(1992-2002) provided wonderful*
results in cosmic- and VHE gamma-rays

The issue with the energy threshold

- Up until the mid-1990s, it was believed that to lower the threshold energy of a given telescope by a factor of *N*, one would need to increase its mirror area by a factor of N^2 [K.E. Turver and T.C. Weekes, Phil. Trans. R. Soc. Lond. A 301, (1981) 615]. One can read there, "*The energy threshold of a simple detector is inversely proportional to the diameter of the light collector. An energy threshold of 10^{11} eV requires an effective aperture of 5-10 m. To get to 10^{10} eV requires an aperture of 50-100 m; such apertures would have been out of the question a few years ago but the development of large concentrators for solar energy research makes this energy threshold a realistic possibility*".
- Note that in the early 1990s the threshold energy of what was then the largest 10m Whipple telescope with a reflecting surface of ~75m² was estimated to be ~300GeV.
- Thus, to reduce its threshold by a factor of 10, to the range of 30 GeV, it was necessary to increase the area of its reflector by a factor of 100, i.e. mirror area 7500 m² → and that was not realistic.

The very beginning of MAGIC

- I realized that IACT operation is in contrast to non-imaging technology, which operates on the edge of the fluctuations of the light of night sky. It became clear that the usual consideration that the threshold energy E of an IACT is proportional to

$$1/\sqrt{A_{mirror}}$$

  is wrong
- The correct dependence should be

$$E \sim 1/A_{mirror}$$

- The 1^{st} HEGRA IACT with 10 m^2 mirror had a threshold of ~1 TeV
- A telescope with a mirror area 20 times larger (~200 m^2) should have a threshold value ~20 times smaller, i.e. 1 TeV/20 ~ 50 GeV - and this is how the idea of what will be called the MAGIC telescope was born

The very beginning of MAGIC

- In August 1994 just by a chance I saw on a cover of a solar energy journal issue the picture of the 17m diameter solar telescope of DLR @Lampoldhausen
- The optical quality of this telescope was poor for our purposes, it collected sunlight (0.5°) at a highly aberrated, diffuse picture in the focal plane
- Well, we thought we could build our own IACT, with a better optics
- 1995 we made 3 presentations @ conferences on the future telescope, which later on got dubbed MAGIC (Major Atmospheric Gamma Imaging Cherenkov) telescope
- This happened at a really “hot time” for HEGRA, IACTs # 3, #4 were under construction, #5 #6 under planning

- German Ministry for Education and Science (BMBF) document about the review of HEGRA by a representative international review committee

Date: February 1-2, 1996

Reviewers:

- J. Cronin
- D. Fegan
- G. Schatz
- J. Trumper
- A. Watson

Report on the Review of the HEGRA Experiment
held at the
Bundesministerium für Bildung,
Wissenschaft, Forschung und Technologie (BMBF)

Bonn, February 1 - 2, 1996

Members of the Review Committee (henceforth called the Committee) were J. W. Cronin (Chicago), D. J. Fegan (Dublin), G. Schatz (Karlsruhe; Chairman), J. Trümper (Garching), A. A. Watson (Leeds). The HEGRA Collaboration (henceforth the Collaboration) was represented by G. Heinzelmann (Hamburg), W. Hofmann (Heidelberg), E. Lorenz (Munich), H. Meyer (Wuppertal), M. Samorski (Kiel), W. Stamm (Kiel), and H. Völk (Heidelberg). In addition H. Blask (BMBF), K. S. de Boer and G. Morfill (present and former chairman of the funding committee, respectively) attended.

Members of the Committee had received written material on the results and future plans of the Collaboration shortly before the meeting and heard reports by G. Heinzelmann, W. Hofmann, E. Lorenz, H. Meyer, and H. Völk. The Committee outlined its conclusions to H. Blask and K. de Boer during the afternoon of February 2.

The HEGRA experiment in its present form consists of two major parts which are only loosely coupled and could operate separately: the arrays of scintillation counters, wide angle integrating Cherenkov detectors and the muon towers on the one hand (called the Hybrid Array by the Collaboration) and the system of Cherenkov telescopes the other hand. This report therefore considers these parts consecutively and then discusses the proposed MAGIC telescope as a possible future development.

The Hybrid Array

The Hybrid Array consists of 243 scintillation counters for registering the electromagnetic component of extensive air showers (EAS), 77 wide angle integrating detectors for the Cherenkov light emitted by the relativistic particles of the EAS in the atmosphere, and 17 towers which measure mainly the muon component.

Different components of HEGRA were critically reviewed

Hybrid Array beyond 1997 should therefore be rediscussed in late 1996 or early 1997 on the basis of the results then available.

To conclude the Committee gives highest priority to obtaining a larger and homogeneous data set for studying the problem of primary cosmic ray composition. This goal could be achieved by continuous operation of HEGRA during the next two years. These data would also allow a better founded assessment of the prospects of investigating the topics mentioned in the preceding paragraph. The Committe does not see a convincing reasons for enlarging the present AIROBICC array. Although the proposed expansion appears reasonable and would improve the quality of the installation, it was not thought to be decisively so. Instead, the resources, both human and financial, should be concentrated on potentially more promising future developments.

The Cherenkov Telescopes

Construction of the system of Cherenkov telescopes is pursued with a high degree of expertise. The Collaboration was among the very first groups to observe cosmic ray events with two Cherenkov reflectors operating in stereoscopic mode, using the first pair of telescopes. The system, when completed, will not reach the sensitivity of the best Cherenkov telescopes now existing (Whipple) or soon coming into operation (CAT). Its potential to discover new gamma ray sources will therefore be limited. However it will have strong astrophysical potential as it permits the detailed investigation of known sources of gamma rays in the TeV region with much higher spatial and energy resolution than single Cherenkov telescopes. In this respect the arrangement will be unique at least in the northern hemisphere and for the next three to five years. These features are especially important because the production mechanisms of high energy gamma rays in astrophysical objects are frequently unclear or controversial and spatially and spectrally resolved observations constrain theoretical models much more effectively. The close cooperation of the experimental group with theoretical astrophysicists is especially promising in this respect.

The Committee recommends to proceed with the construction of the telescopes as planned.

Conclusions and recommendations of the committee:

Future Plans

The Committee heard two reports about possible future expansions of the HEGRA experiment by E. Lorenz on the MAGIC telescope and by W. Hofmann on an improved more sensitive system of Cherenkov telescopes in the TeV region. The latter plans appear to be in a very early stage of consideration, not surprisingly in view of the present status of the Cherenkov telescopes. This report will therefore discuss only the first project.

The planned MAGIC telescope consists of a single Cherenkov dish of 17 m diameter. It would have considerably higher sensitivity and lower threshold than existing arrangements. The scientific objective of the MAGIC telescope would be quite different from that presently under construction at La Palma. It would offer a unique opportunity to push the operating threshold of the Cherenkov technique down below 50 GeV, a threshold which is not currently attainable by existing or planned installations. MAGIC would be therefore constitute the largest area Cherenkov reflector in either hemisphere, offering unique survey opportunities at low threshold energies.

The project takes advantage of technology developed for solar energy applications and proposes a number of innovatory and challenging approaches, especially with respect to

- the mechanical structure of the mounting
- mirror fabrication
- mirror alignment procedures
- the use of novel light detectors.

Successful realization of any of these objectives would represent a considerable improvement of technology in the field of Cherenkov telescopes and therefore be beneficial for a much wider community. The Committee therefore recommends pursuit of these developments and subsequent construction of the telescope without delay, the latter also in view of plans for new gamma ray satellites with much improved angular resolution and sensitivity which will become available in the long run and whose energy range will probably overlap with that of MAGIC.

This report was approved by all members of the Committee.

G.Schatz, Chairman

Criticizm because of the suggested too many novel technologies

- The initial criticism about MAGIC from some members of the evaluating MAGIC representative committee was about too many new technologies which we planned to introduce
  - carbon-fibre frame of the telescopes,
  - all-Al diamond mirrors,
  - sytem of Active Mirror Control,
  - 20s fast rotation of the telescope,
  - fast analog signal transmission via optical fibres by using VCSELs,
  - hemispherical fast PMTs from EMI,...
- The history showed that indeed, we needed relatively long time for „polishing“ the novel technologies, but then, once these became operational, the majority paid off

Our dear colleagues and friends with whom we were lucky to work and share our lives, to make the MAGIC real

Eckart Lorenz,
1938-2013

Rudy Bock,
1935-2015

Florian Goebel,
1972-2008

Daniel Kranich,
1966-2014

Leo Takalo
1952-2018

Installation of the 1st MAGIC reflector frame

- MAGIC extended the sensitivity window of the IACT technique from 300 GeV down towards 20 GeV
- Discovery of 25 GeV pulsed gamma emission from Crab pulsar at E ≥ 25 GeV (*Science*, *2008*) marked the begining of high-sensitivity gamma astrophysics @ few tens of GeVs