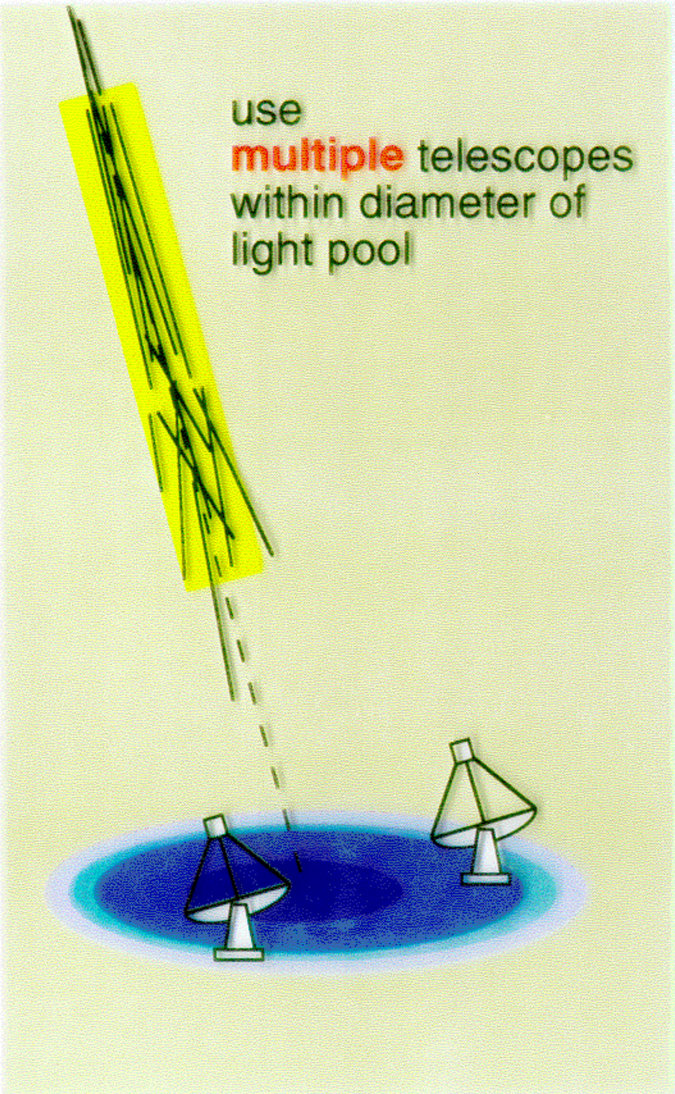
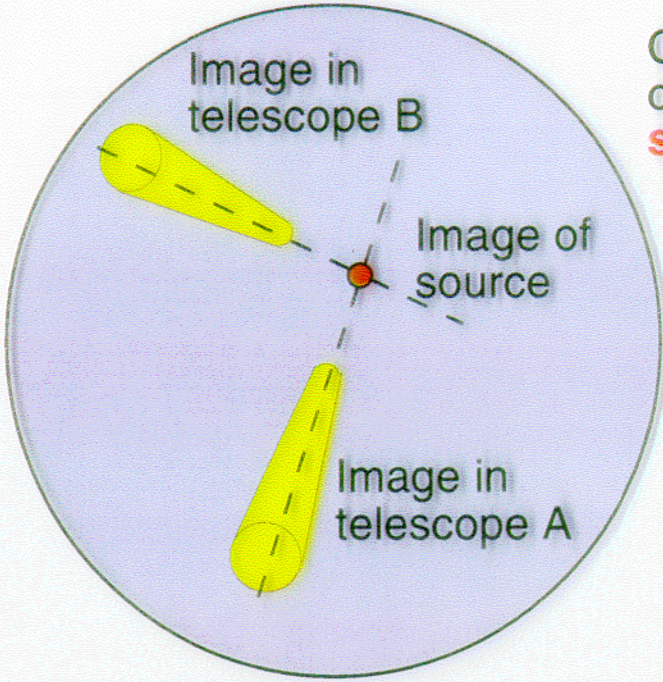
High Energy Stereoscopic System (H·E·S·S)

W. Hofmann, MPI Heidelberg

- The HEGRA experience
- Physics goals of HESS
  & The choice of the energy range
- The basic HESS design
- The HESS site
- The HESS telescopes
- The HESS collaboration
- Status & outlook

Stereoscopic viewing of air showers





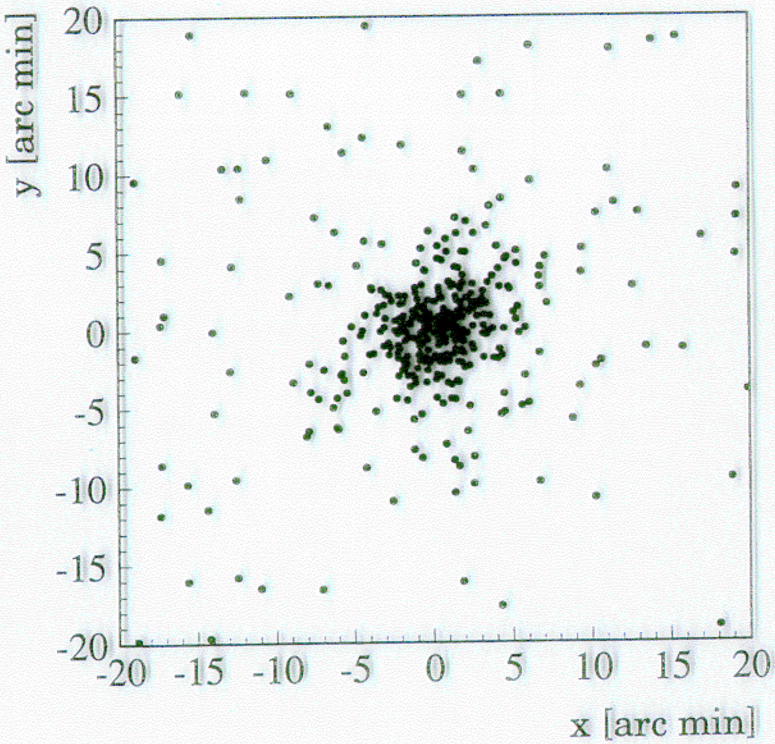
Camera images
of air shower,
superimposed

Benefits of stereo Cherenkov imaging

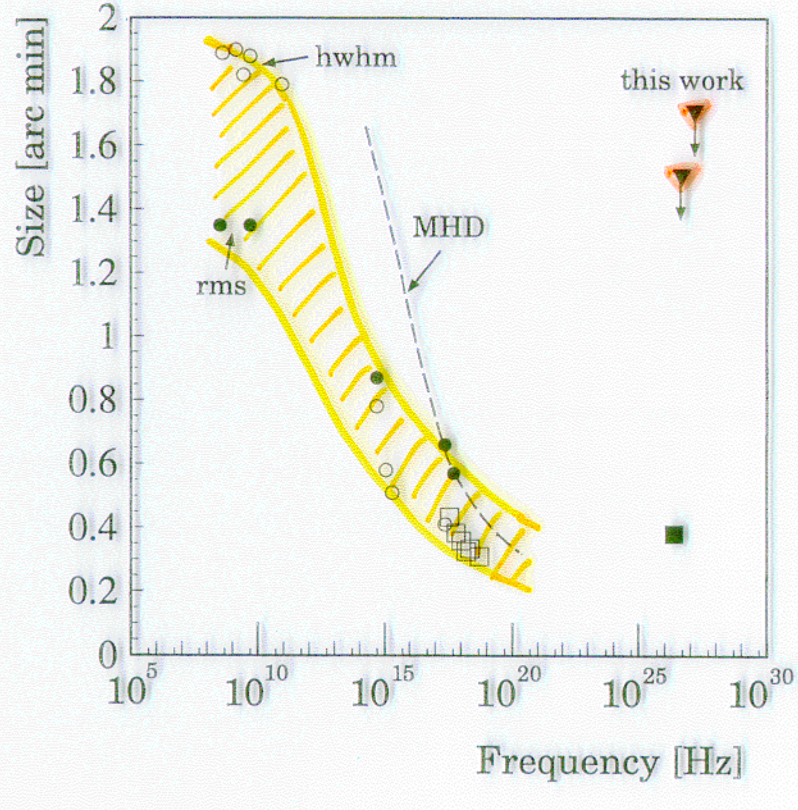
- **Unambiguous angular resolution**
- **Very good energy resolution (known core)**
- **High suppression of cosmic-ray background**
- **Reduced energy threshold**
- **Better control of systematics**

HEGRA: Angular resolution

Crab Nebula at TeV energies,
events selected for < 3' resolution

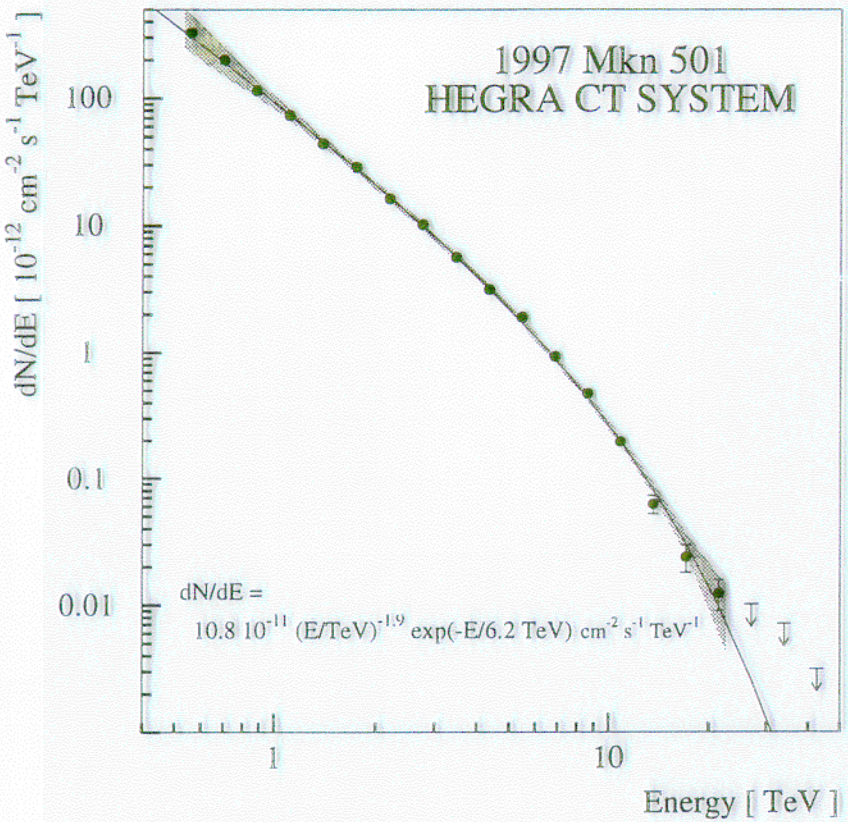


(Rms) radius of the emission region in the Crab Nebula



HEGRA: Energy resolution, reconstruction of spectra

Mrk 501 energy spectrum



Energy resolution (1 - 30 TeV range)

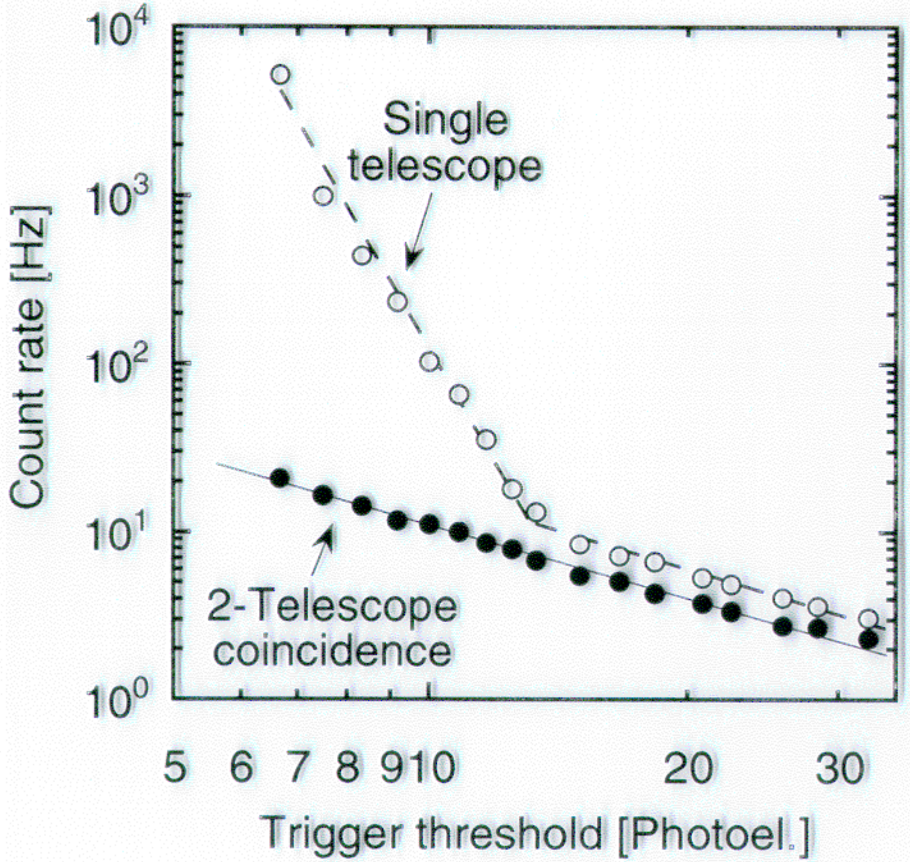
"Classical reconstruction" of direction and energy:
18 - 22%

Improved algorithms for direction and energy:
12 - 14%

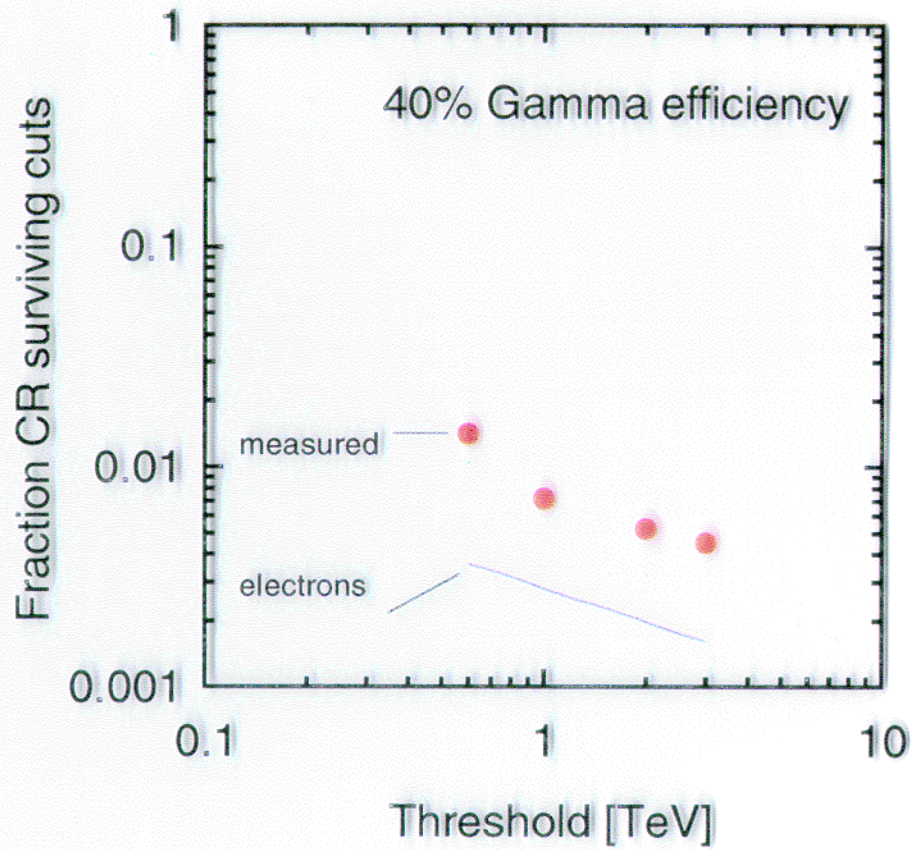
Improved algorithm, assuming known source
9 - 12%

Background suppression for stereo IACT systems

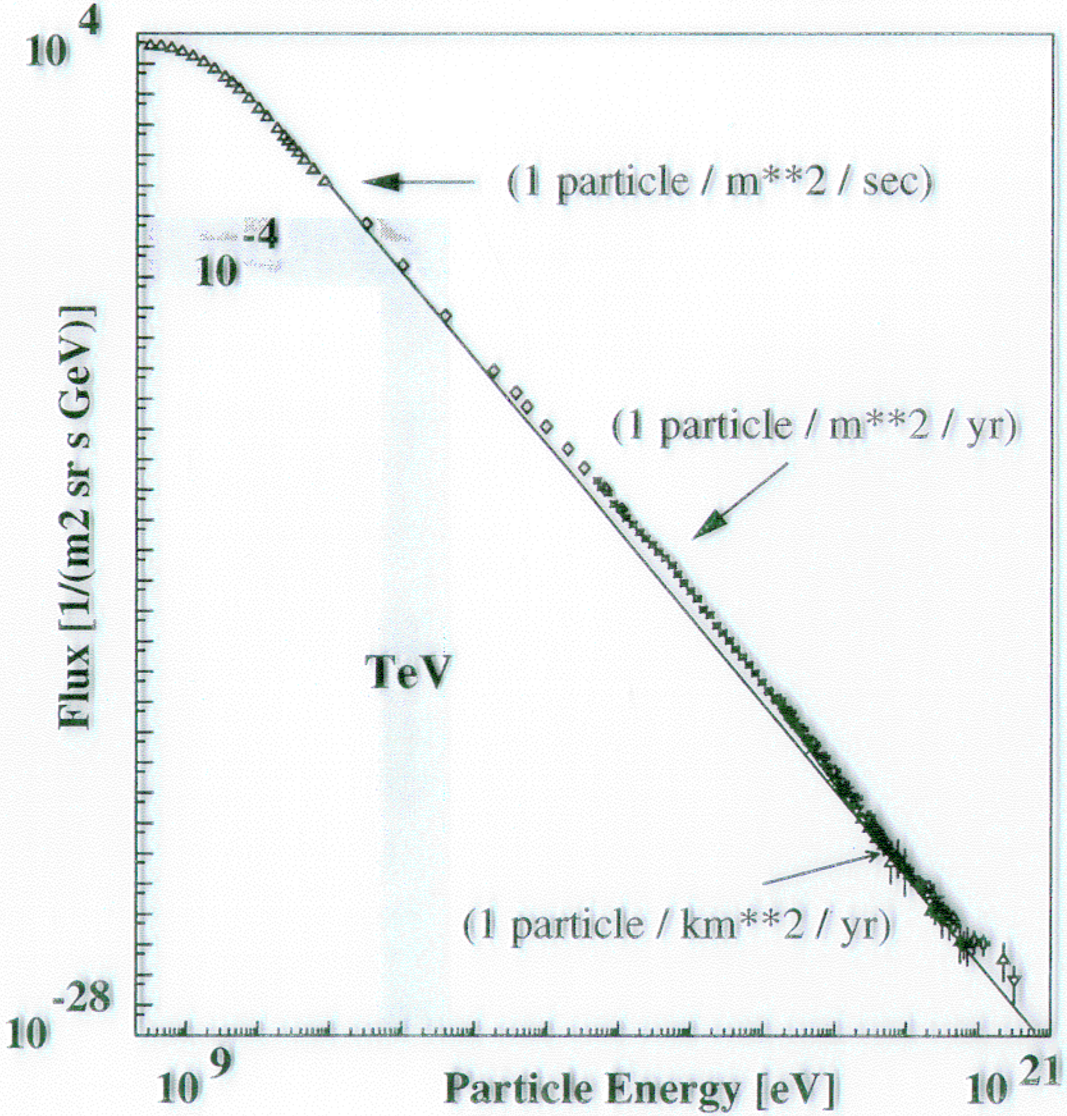
Night-sky background light



Cosmic-ray showers



Cosmic rays



Spectrum

- $dN/dE \sim E^{-2.7} \ldots E^{-3.0}$
- non-thermal

Energy density

- Cosmic rays ~ 1 eV/cm^3

- Gal. gas (thermal) ~ 1 eV/cm^3
- Gal. gas (kinetic) ~ 1 eV/cm^3
- Gal. magn. field ~ 0.3 eV/cm^3
- Magnetic fluctuations ~ 0.3 eV/cm^3
- Galactic star light ~ 0.5 eV/cm^3
- 3^o background ~ 0.4 eV/cm^3

Physics goals of H·E·S·S: TeV gamma-ray astrophysics

or, more detailed

A comprehensive study of non-thermal phenomena in the Universe, using TeV gamma-ray emission as a diagnostic tool, with emphasis on the precise spectral and spatial mapping

in this context, "TeV gamma rays" stands for the $10^{12\pm1}$ eV range

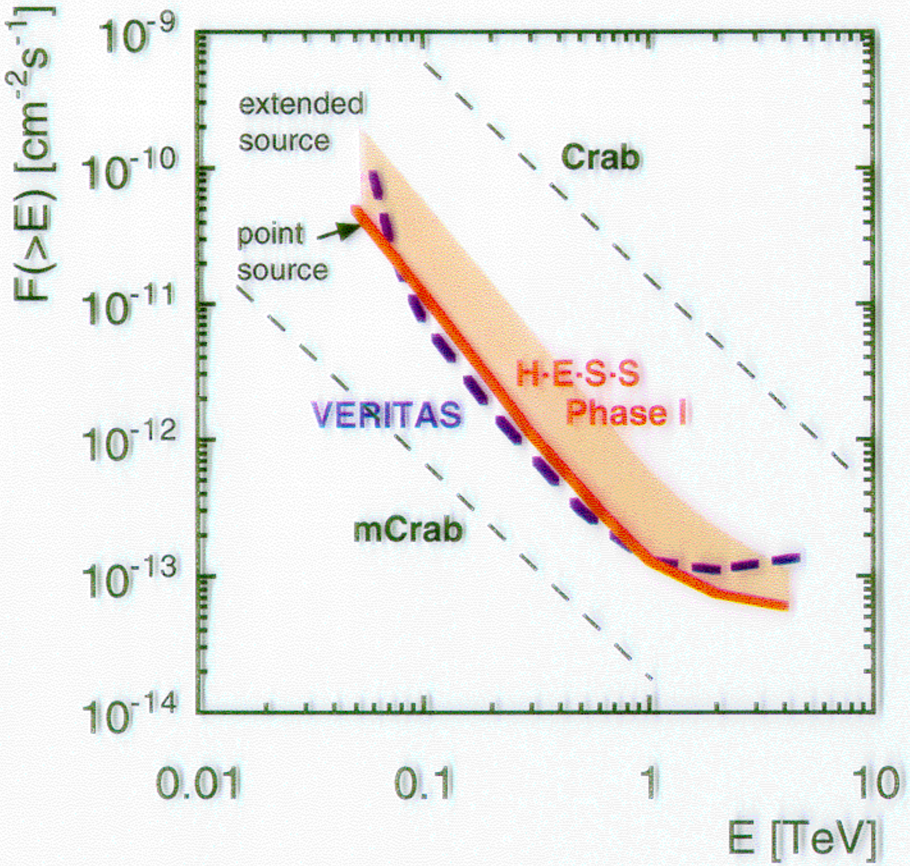
TeV gamma rays are always secondary products;
one is primarily interested in the parent population:

- **Galactic and extragalactic nonthermal electron populations**
- **The nucleonic component of the nonthermal universe**

in addition

- **Observational cosmology and astroparticle physics**
- **Surveys**

H·E·S·S Sensitivity



Flux sensitivity
5 σ , > 10 events, 50 h

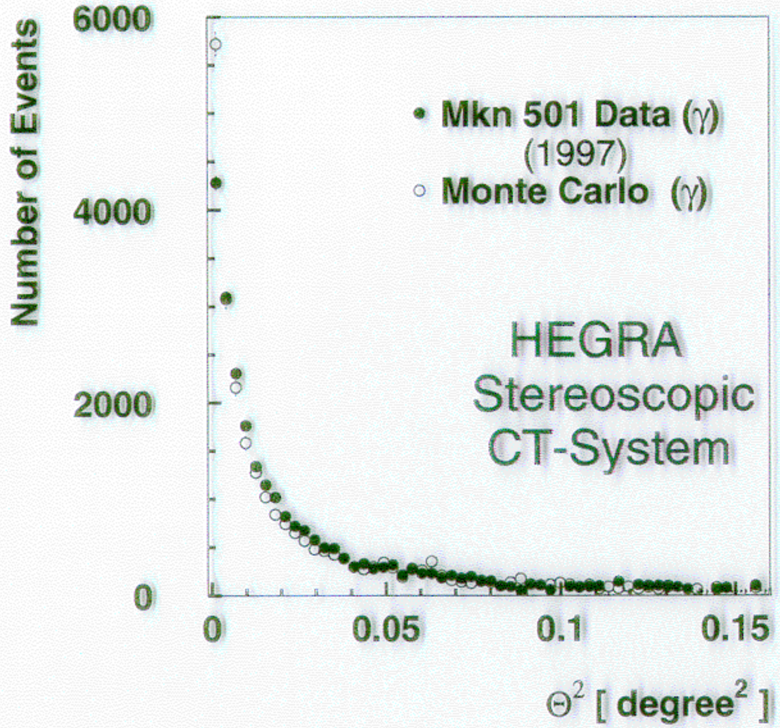
Preliminary

(MC uses not quite the
final parameters)

HESS Phase I:
4 Telescopes, ≈ 8.5 MDM + cont.

VERITAS
7 Telescopes. ≈ 16.6 M$

H·E·S·S angular resolution



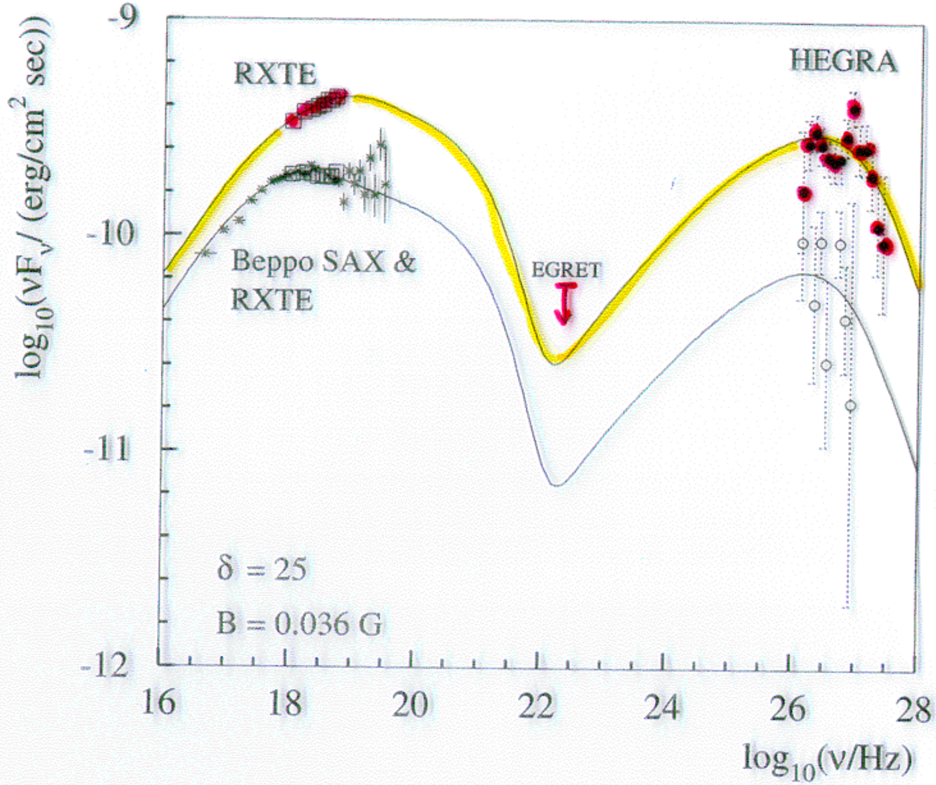
Hess at 100 GeV
like HEGRA at 1 TeV

Angular resolution: 0.1 degree per individual photon

Gamma rays from nonthermal electron populations

Gamma rays generated by synchr. radiation and IC process

Characteristic double-humped multiwavelength gamma-ray spectra allow to determine e-spectra, B



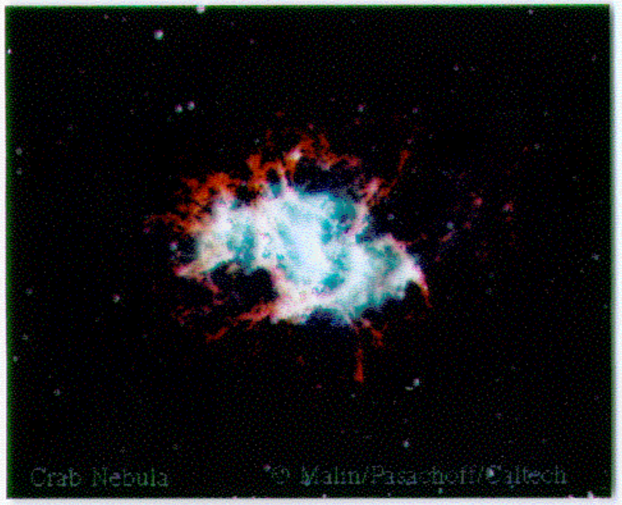
Galactic sources

• Pulsars and pulsar nebulae	MHD flow, acceleration
• x-ray binaries	Accretion, jet formation and particle acceleration

Extragalactic sources

• AGNs / XBLs	Accretion, jet formation and particle acceleration
• Giant radio lobes	Shock acceleration
• Quasars	Accretion, acceleration near compact objects

Nonthermal electron populations
Pulsars and pulsar nebulae

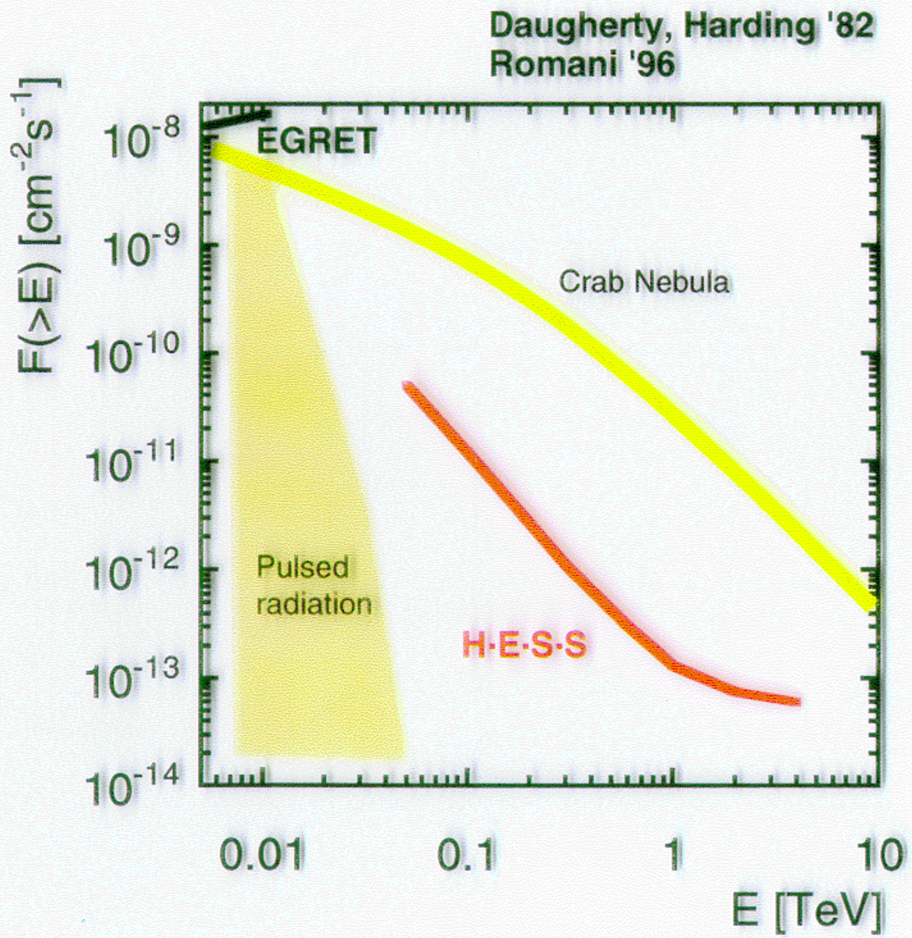


- Crab-like sources could be detected virtually anywhere in the Galaxy
- Flux determined by

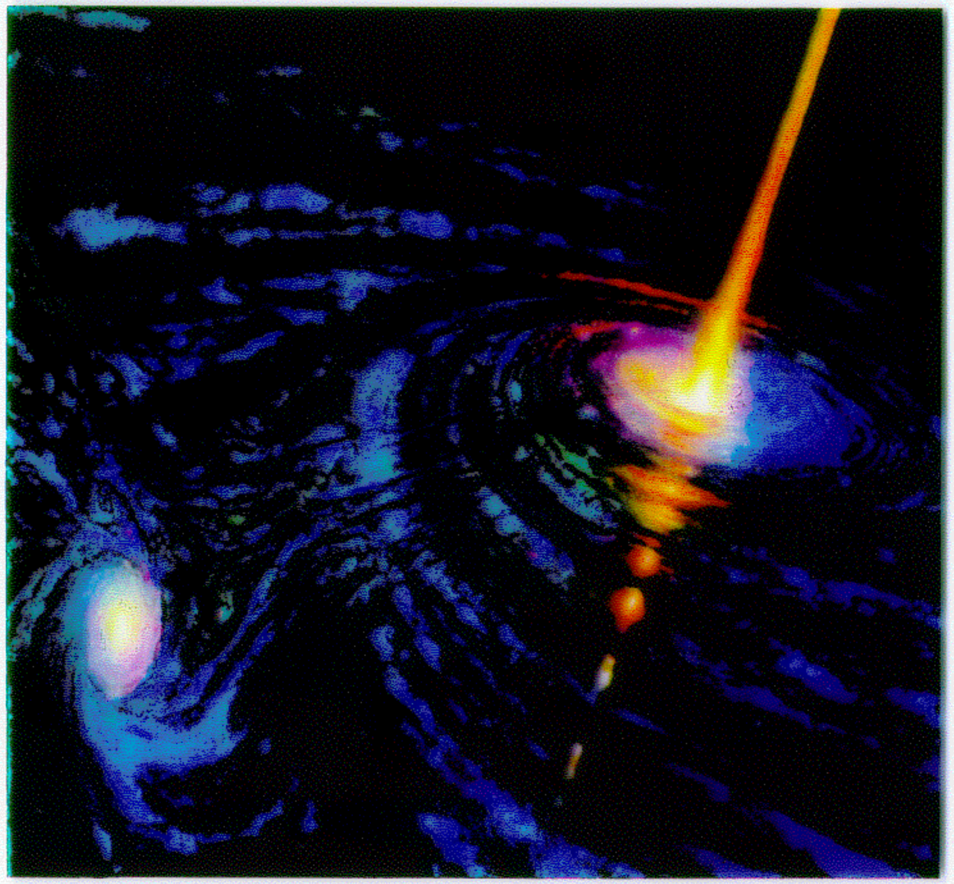
$$F \approx \frac{L_o}{d^2} \frac{W_r}{W_r + B^2/8\pi}$$

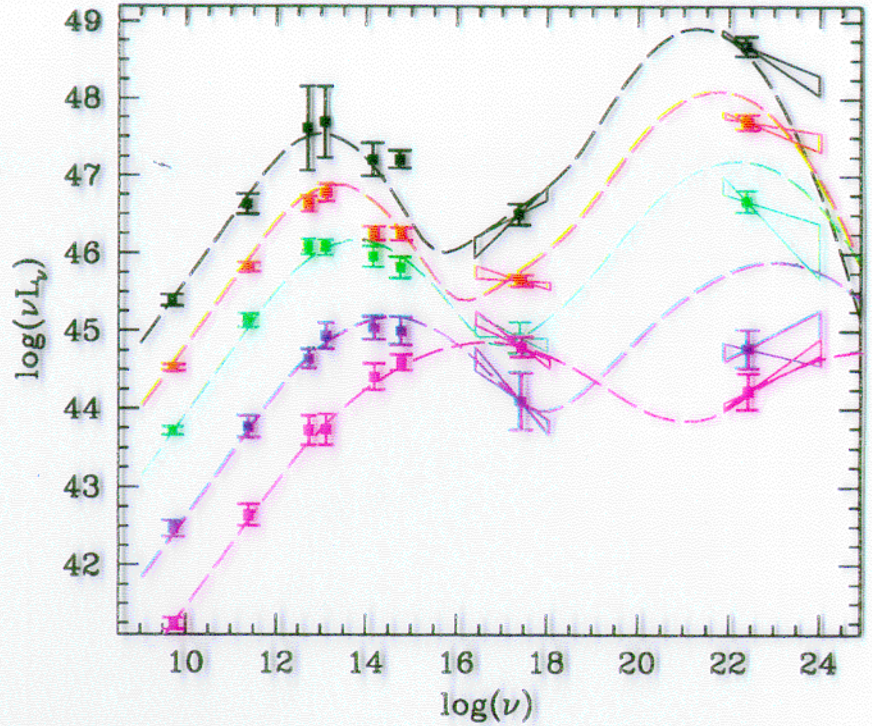
Objects with low L_o and low B can have high gamma flux

(Aharionian, Atoyan, Kifune '97)



Nonthermal electron populations
AGNs





Fossati at al., 98

Physics issues

- Unfied models for AGNs
- Jet composition and energetics
- Acceleration mechanism
- Location, size of emission region
- Origin of time variability
- Photon absorption

x-ray binaries as scaled-down AGN models?

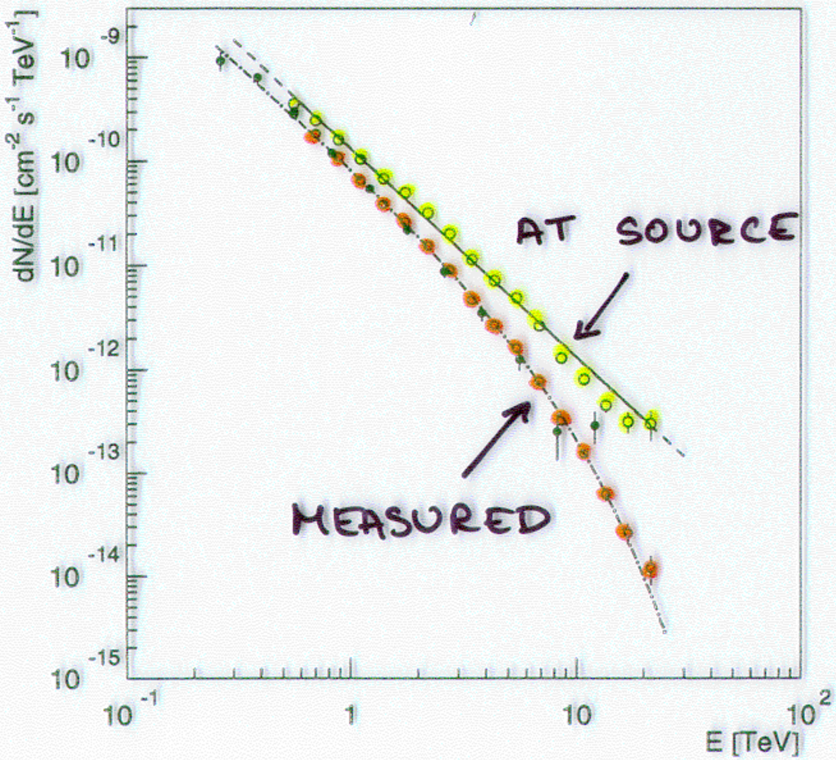
Extragalactic absorption of high-energy gamma-rays and the IR/O background radiation

Mechanism:

$\gamma_{VHE}\gamma_{IR/O} \rightarrow e^+e^-$

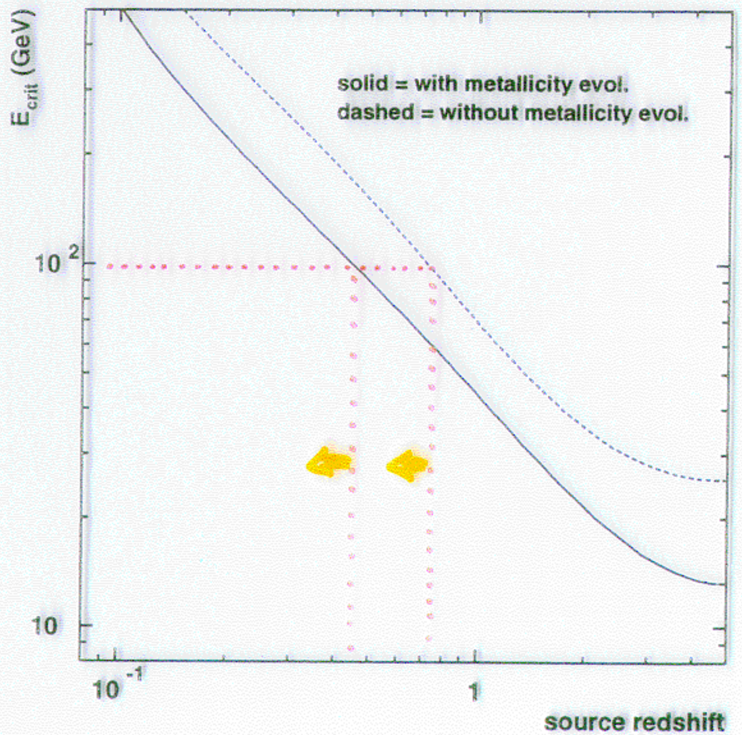
- Allows to measure extragalactic IR/O background density

Konopelko et al. '99

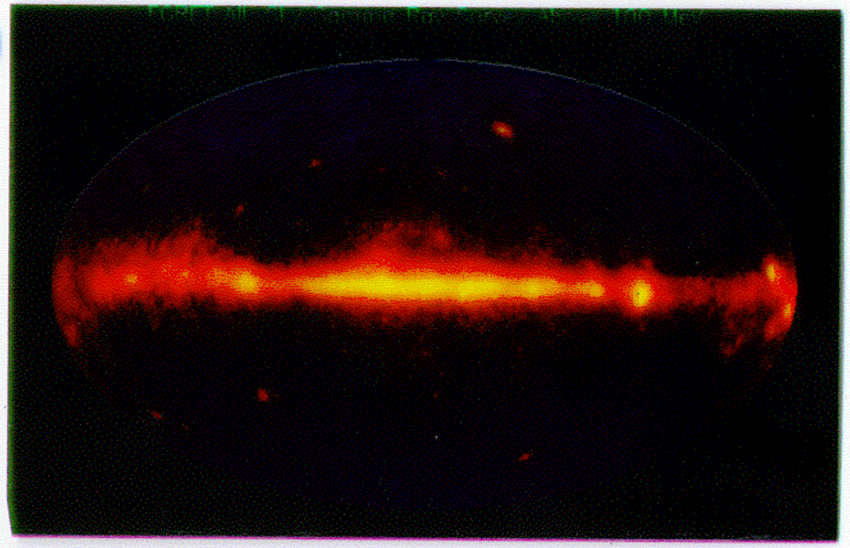


- Limits z range of observations to z < 0.5

Stecker '99



Cosmic rays - the nucleonic component



Dominant nonthermal component
Crucial for energetics & evolution

Gamma-rays are generated in p-interactions

Probe local CR density x local gas density

Spectra: $E^{-2.1}$ for interaction near source
$E^{-2.7}$ after propagation

Study of CRs in our Galaxy

• Supernova remnants (SNRs)	Sources of CR? Shock acceleration mechanisms
• Giant Molecular Clouds (GMCs)	Targets to measure local CR density
• GMCs near accelerator sites	Test characteristics of sources and propagation
• Diffuse radiation from Galactic Plane	CR density near Galactic Center
• Measurement of flux and composition	Identification based in Cherenkov images

Study of CRs in other galaxies

• Nearby normal galaxies	CR density in other galaxies - hard to detect
• Starburst galaxies	CR density in star formation regions
• Clusters of galaxies	History of cluster formation, accumulation of CRs
• HECR-induced cascades	Point to sources of HECR

Cosmic rays - the nucleonic component
Supernova remnants - sources of CRs ?

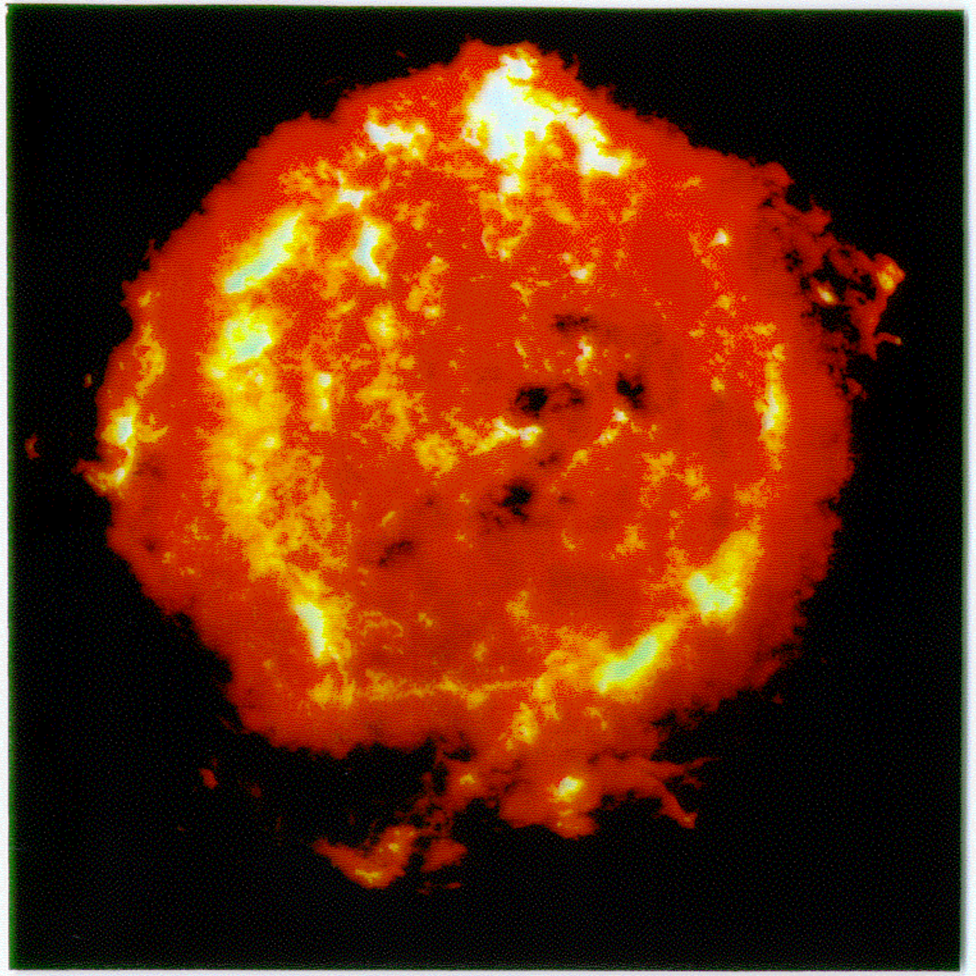
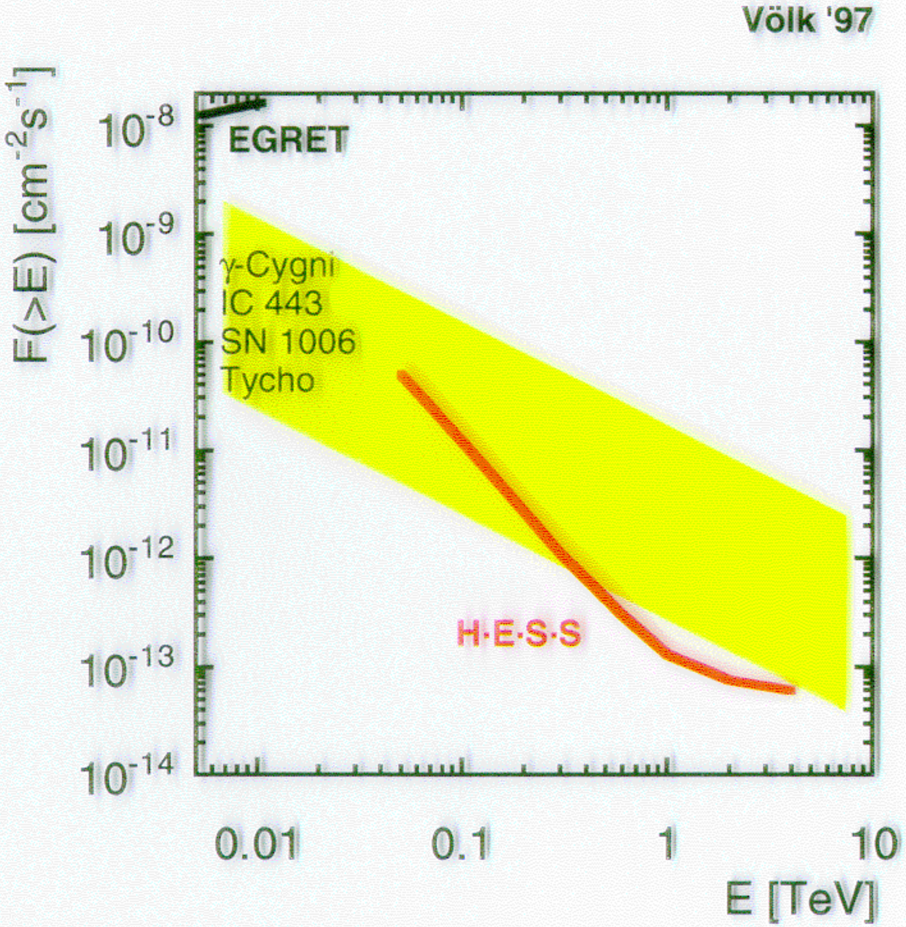


Figure 3: Explosion cloud (remnant) of the Supernova Cassiopeia A. It occurred in the year 1680 A.D. in our Milky Way at a distance of 10.000 light years. The remnant is about 15 light years across. The photograph is made from radiation at radio wavelengths, produced by energetic particles which were accelerated in this source.

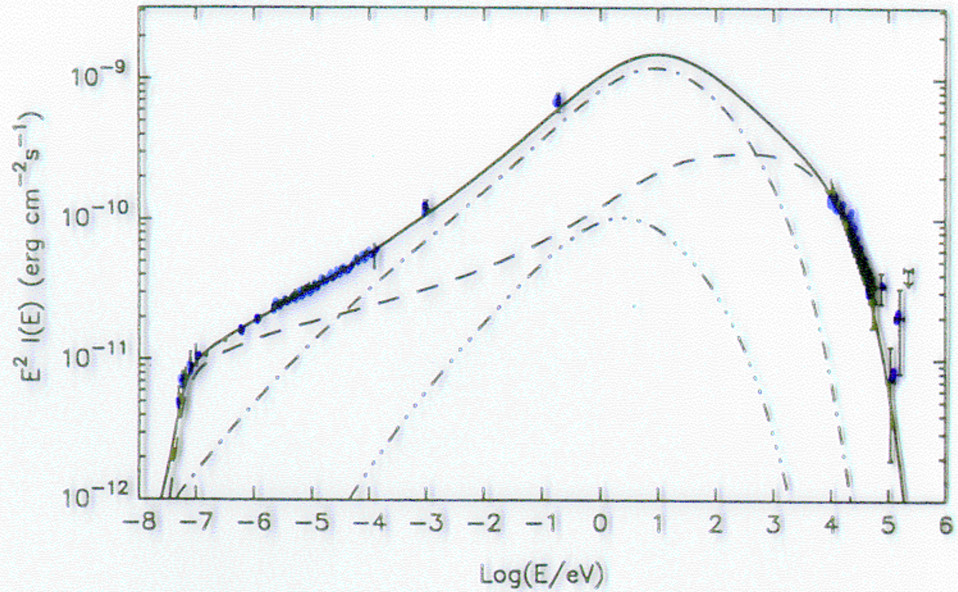


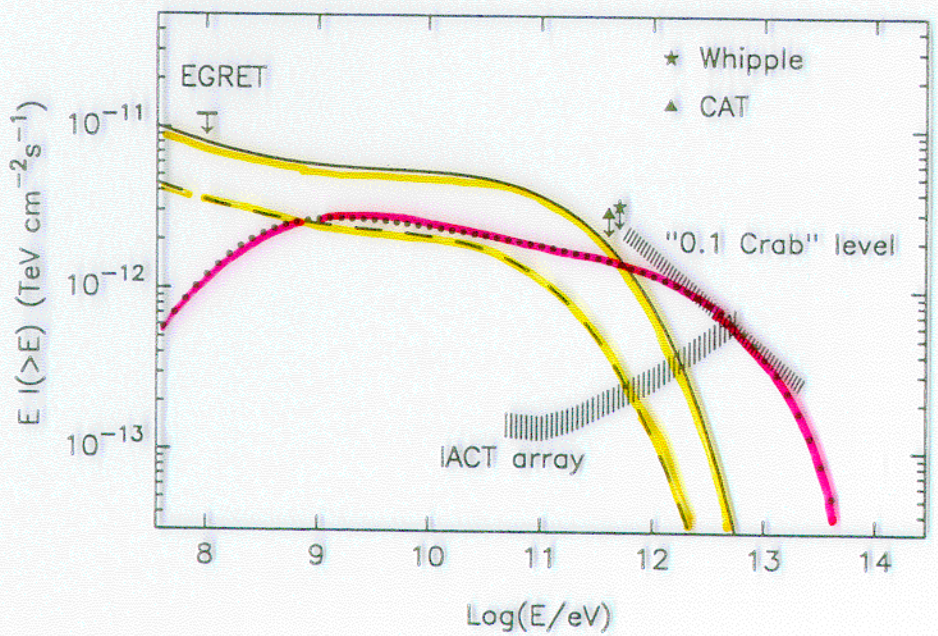
Separating the nucleonic and IC components

Most sources accelerate both electrons and protons

⇒ Gamma rays both from π^0 decay and IC processes

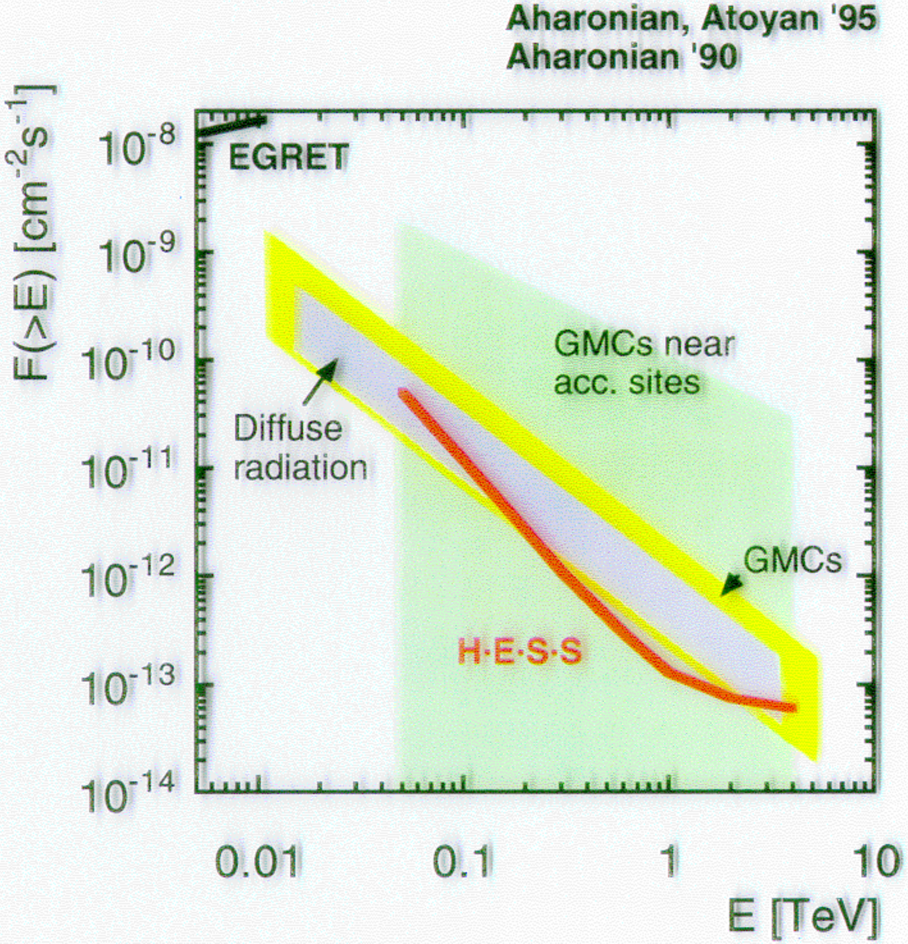
Estimate IC contribution using synchrotron spectra; IC gammas will usually be softer due to electron cooling





Atoyan, Aharonian, Tuffs, Völk '99

Cosmic rays - the nucleonic component
GMCs, gas in galactic plane as passive CR targets



- **GMCs illuminated by uniform CRs**

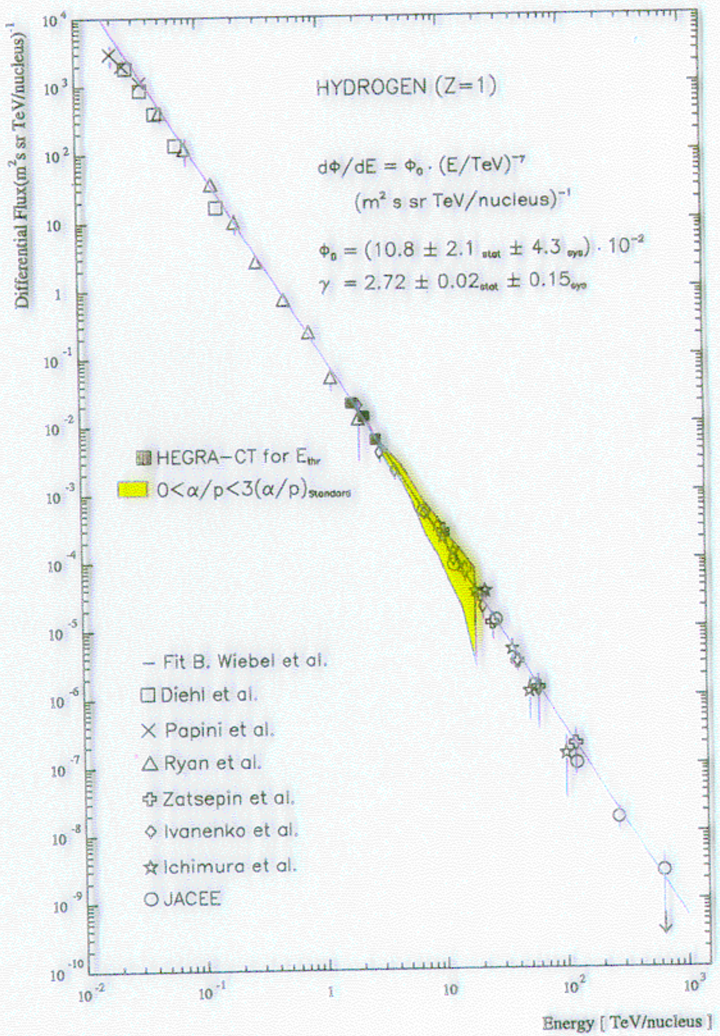
$$F\,(>E) \approx 2 \times 10^{-13}\, E^{-1.7}\, k\, \frac{M_5}{d^2_{kpc}} \quad (\,cm^{-2}\, s^{-1})$$

- **GMCs illuminated by nearby sources**
- **Diffuse radiation,**
  in particular from Gal. Center

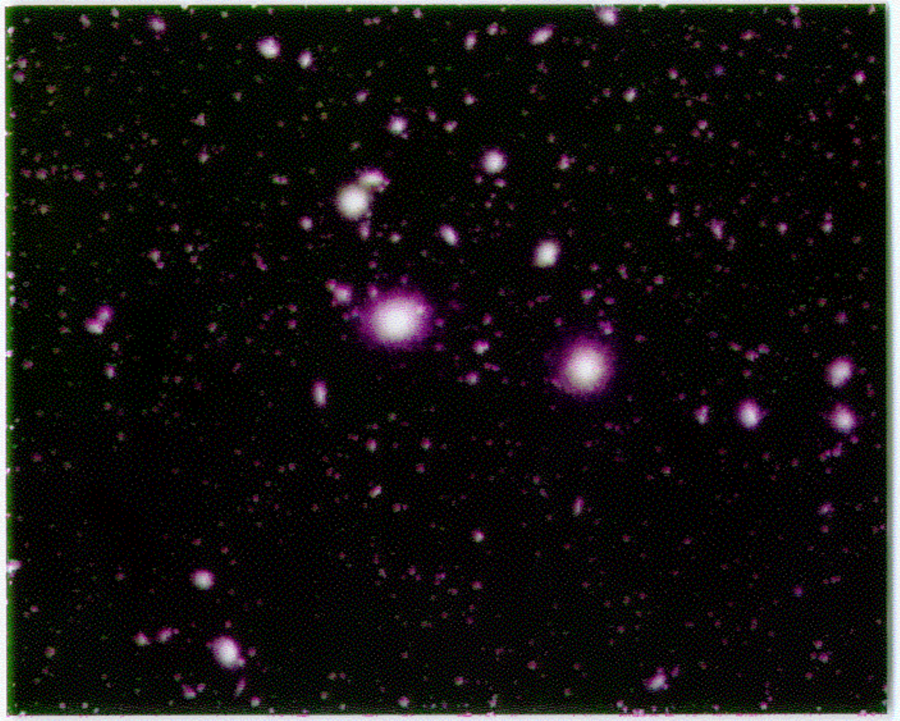
Cosmic rays - the nucleonic component
Direct composition measurements

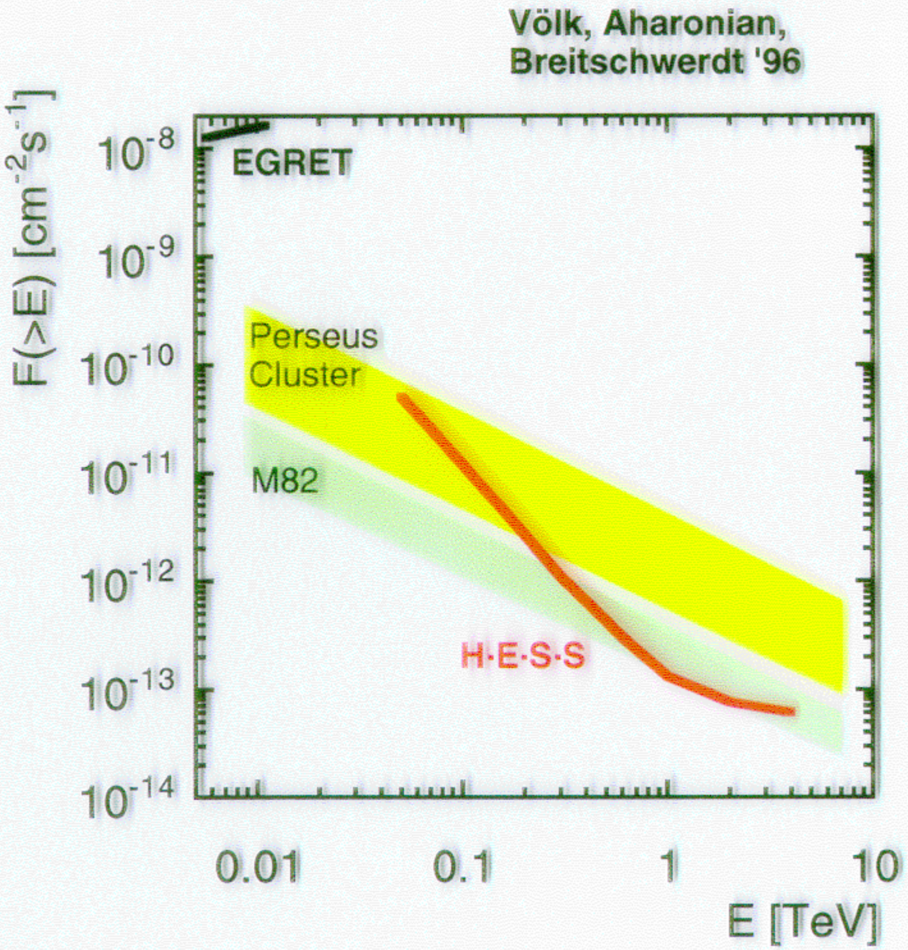
Cherenkov image parameters (width, length, fluctuations) are sensitive to particle type

- See HEGRA results on TeV p-spectra: cover region between space expts and ground-based expts
- Composition analysis in progress
- Much improved separation with HESS due to larger light yield and better definition of images



Cosmic rays - the nucleonic component
Starburst galaxies, clusters of galaxies





CR production rate enhanced due to high SN rate, strong winds

Observational cosmology and astroparticle physics

Observational cosmology

- **Diffuse extragalactic IR/O background radiation** — Photon-photon absorption modifies energy spectra of distant sources ($z > 0.01$); background level relates to age of galaxies
- **Formation of pair halos around AGNs** — Provides absolute distance scale and measurement of local IR/O background density

Astroparticle physics

- **Search for topological defects** — Sources of HECR, HE gamma-rays. Diffuse gamma-ray background at 10-100 GeV from cascades. Marginal flux, problems with diffuse electron background; lack of clear signature
- **Dark matter searches** — WIMP annihilation lines from GC; sensitivity sufficient to constrain models for mass range up to 300 GeV. Good energy resolution helps!
- **Quantum gravity ... and other (very) exotic phenomena**

The importance of a positive result in this area $\rightarrow \infty$

The probability of finding anything $\rightarrow$ 0

Nice to complement a solid physics program...

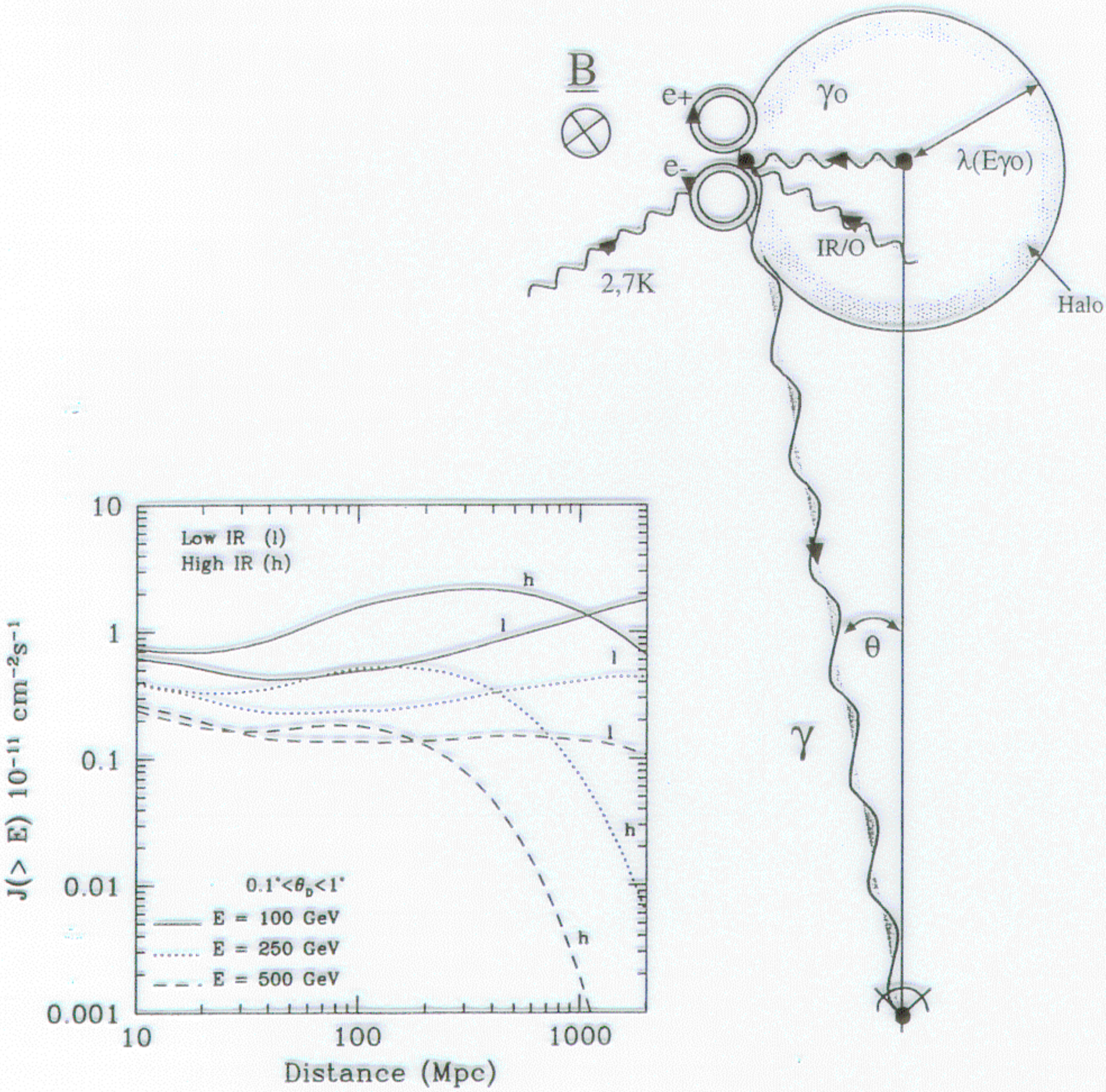


Figure 7: Physics of Pair Halos. In the right part the interaction processes of a "primary" gamma photons (γ_0), with high energy E_{γ_0}, with photons of the Infrared/Optical (IR/O) and the universal 2.7 K diffuse extragalactic background radiation (DEBRA) fields are shown. The (e^+, e^-) pairs from pair production on the IR/O background are isotropized in the magnetic field B. Their subsequent inverse Compton scattering on 2.7 K photons produces lower energy γ-rays. The angular size θ of the resulting pair halo is given by the mean free path $\lambda(E_{\gamma_0})$ and the absolute source distance. The left part of the figure shows the expected halo radiation fluxes integrated within $\theta = 1°$ above 100 GeV, 250 GeV , and 500 GeV as a function of the source distance for 2 different levels of the IR/O background: 'Low' ($n(\epsilon) = 10^{-3}\epsilon^{-3}\,\mathrm{ph/cm^3eV}$), and 'High' ($n(\epsilon) = 10^{-3}\epsilon^{-2}\,\mathrm{ph/cm^3eV}$). The assumed VHE luminosity of the central source above 10 TeV is $L_0 = 10^{46}(d/1\mathrm{Gpc})^2$ erg/s [39].

GRBs

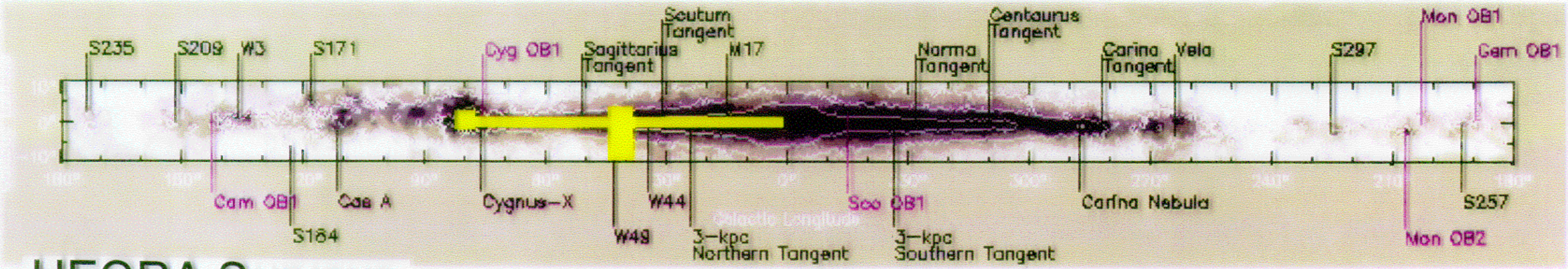
A handful of GRBs will go off each year, within view of the telescopes.

Slew speed of mounts 100 degr./min
Acceleration time 2 s

Could point to GRB within 1 - 4 min. after alert

Will not try to compete with MAGIC and (worse) MILAGRO

Surveys as an important part of the H·E·S·S programm



HEGRA Surveys

Pointed observations rely on preconceived source models, but

- Models are changing, see e.g. recent emphasis on young SNR
- Predictions are frequently unreliable, e.g. due to poorly known source parameters or oversimplified geometry
- Extrapolation from other wavelength ranges is non-trivial (e.g. EGRET AGNs)

H·E·S·S is a very good survey instrument

- Large (5 degr.) field of view of cameras
- Good imaging (due to large f/d) and uniform pixel size throughout fov
- Unambiguous reconstruction of the direction of single gammas to 0.1 degr. or better
- < 15% energy reconstruction without assumptions concerning source position

About 1 year to survey $\Delta\Omega = \pi$ at < 0.1 Crab sensitivity; significantly improved in Phase II

Choice of the energy threshold

In favor of a low threshold

Energy cutoffs

- in the acceleration mechanism
- in the propagation over extragalactic distances

  number of potential sources larger for lower thresholds

Statistics

integral flux decreases like 1/E or steeper

on the other hand

Key issue: Search for proton acceleration sites

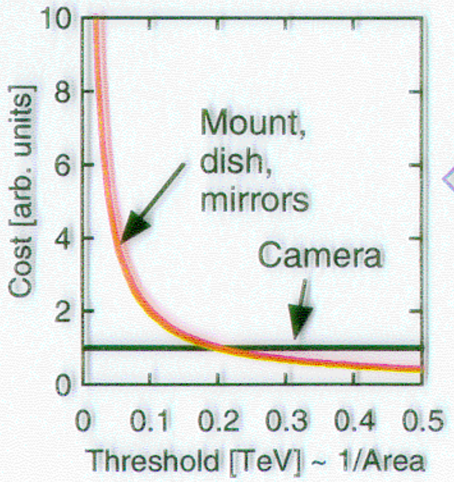
physics S/N and signature best at high energies

Performance of IACTs suffers at very low energy

shower fluctuations, earth magnetic field

Cost of IACTs increases rapidly as E_{thr} decreases

tradeoff: # of telescopes (= area, precision) vs threshold



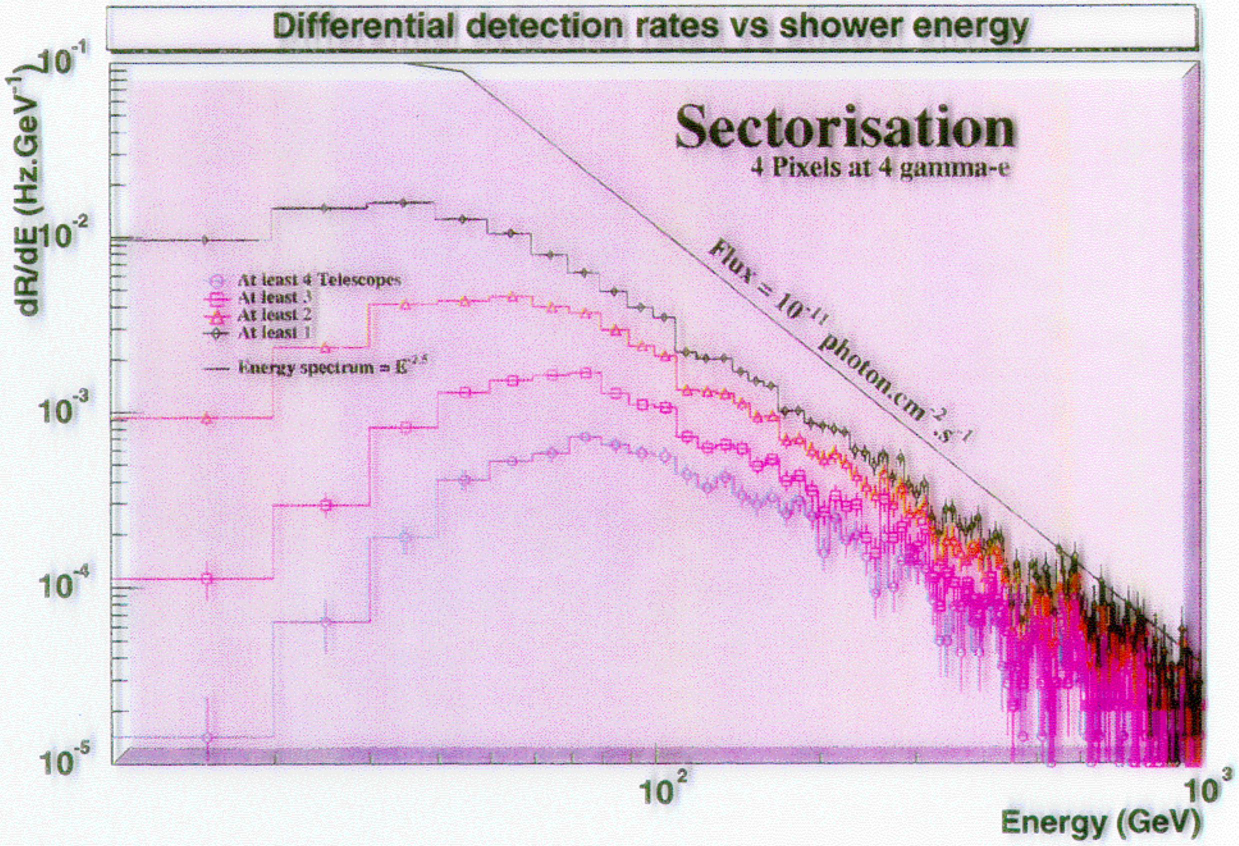
Complementarity

H·E·S·S should complement future space missions such as GLAST (range up to 10...100 GeV)

H·E·S·S energy threshold

H·E·S·S provides

- full spectroscopy and angular resolution above 100 GeV
- detection capability above ≈ 40 GeV



Basic H·E·S·S design parameters

Number of telescopes	Phase I: 4 Phase II: up to 16
Dish:	
Effective mirror area	≈ 110 m^2 (fully equipped) ≈ 70 m^2 (initially ?)
Focal length	15 m
f/d	1.2
Camera:	
Pixel size	0.16^o
Field of view	4.3^o (initially), ≈ 700 pixels 5.0^o (fully equipped), ≈ 900 pixels
Photodetectors	8 stage PMT, bialkali cathode (Phase I)

The number of telescopes (Phase I)

2, 3, 4 ... Telescopes ?

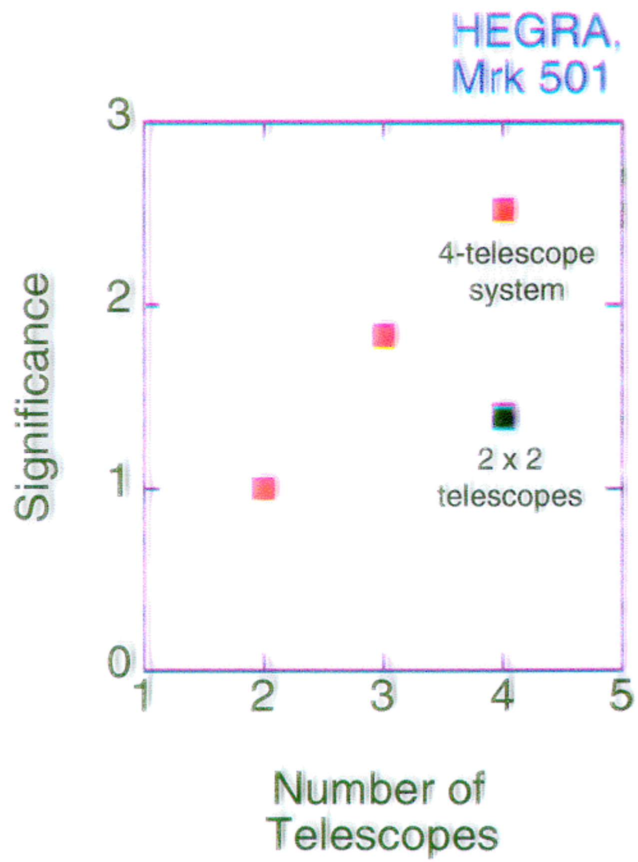
Reconstruction and study of systematics

- Minimum of 2 telescopes for stereoscopy
- Minimum of 3 telescopes to overconstrain geometry
- Minimum of 4 telescopes for two independent measurements

Sensitivity

- Big step in background rejection between 2 and 3 telescopes
- Number of valuable 3-telescope events is doubled for 4-telescope system, as compared to 3-telescope system

For illustration:
HEGRA system with 2, 3, 4 telescopes
(others turned off in software)



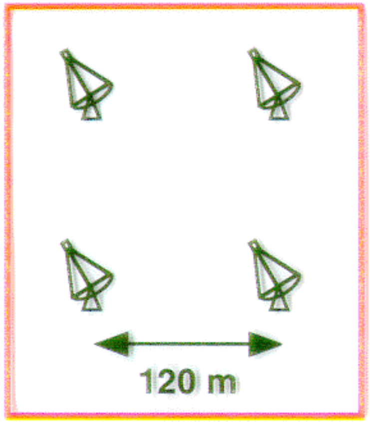
Multi-target mode

- 4 telescopes allow to monitor two targets in stereo mode

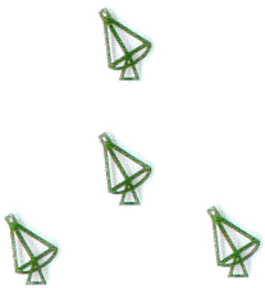
⇒ **Aim for 4 telescopes**

Arrangement of telescopes (Phase I only)

Arrangement:



or



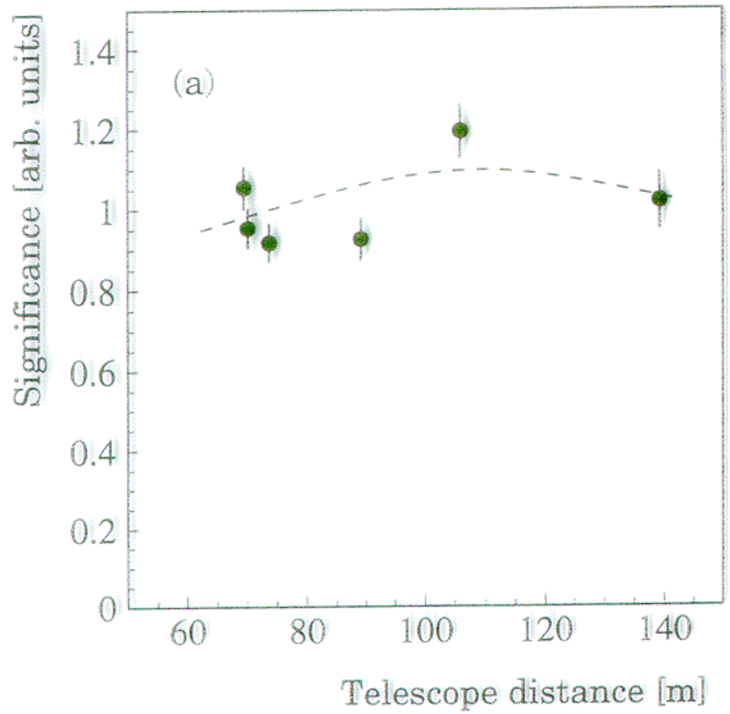
quite similar
in performance

Spacing:

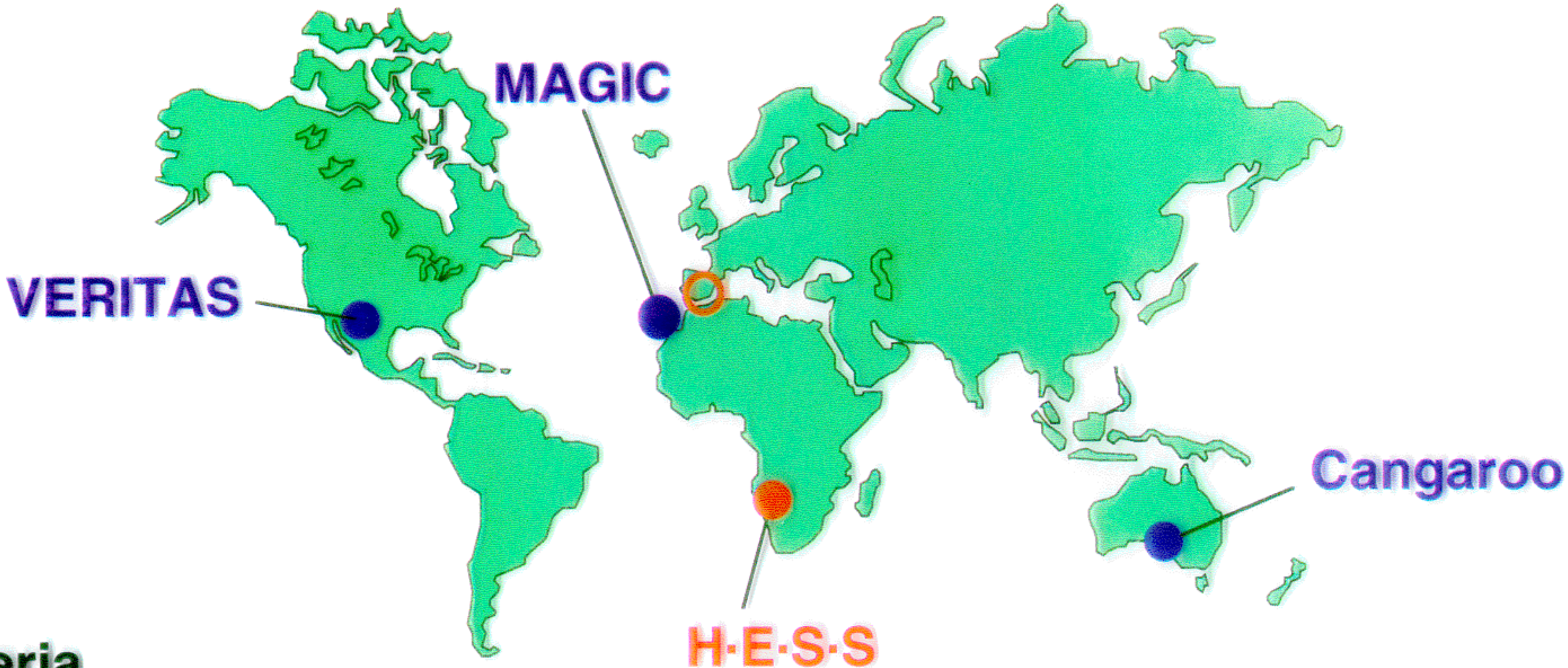
relatively large spacing as compromise between lowest threshold and high-energy detection

HEGRA-Results: **spacing relatively uncritical**

Mrk 501 $S/\sqrt{B}$
vs spacing of
telescope pairs



Configuration choices: the site for H·E·S·S



Criteria
- Sky coverage (Milky Way)
- Documented optical quality
- Mild climate
- Available area and access
- Infrastructure availability/cost

Optimal sky coverage by next-generation telescopes !

H·E·S·S sky coverage

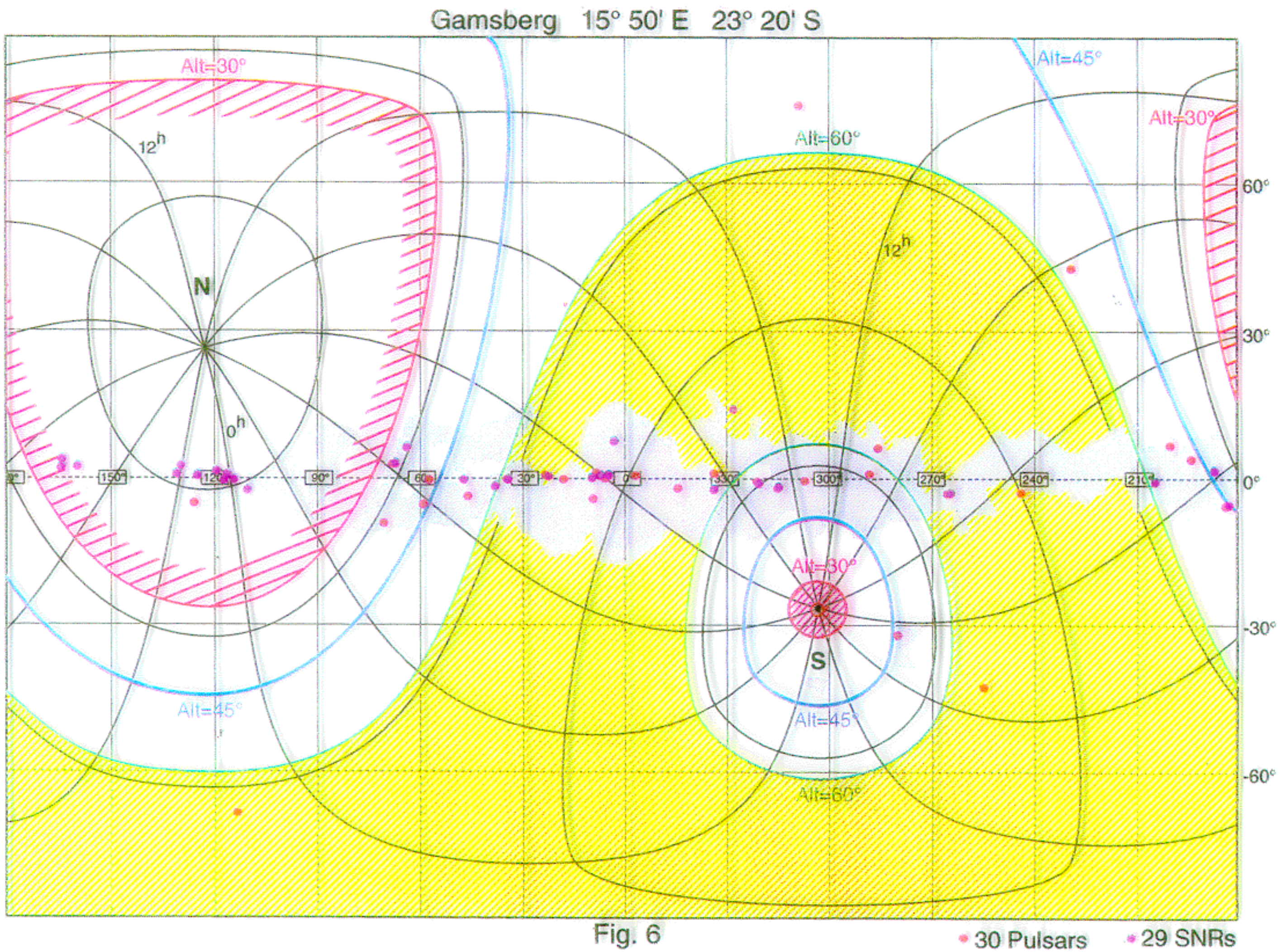
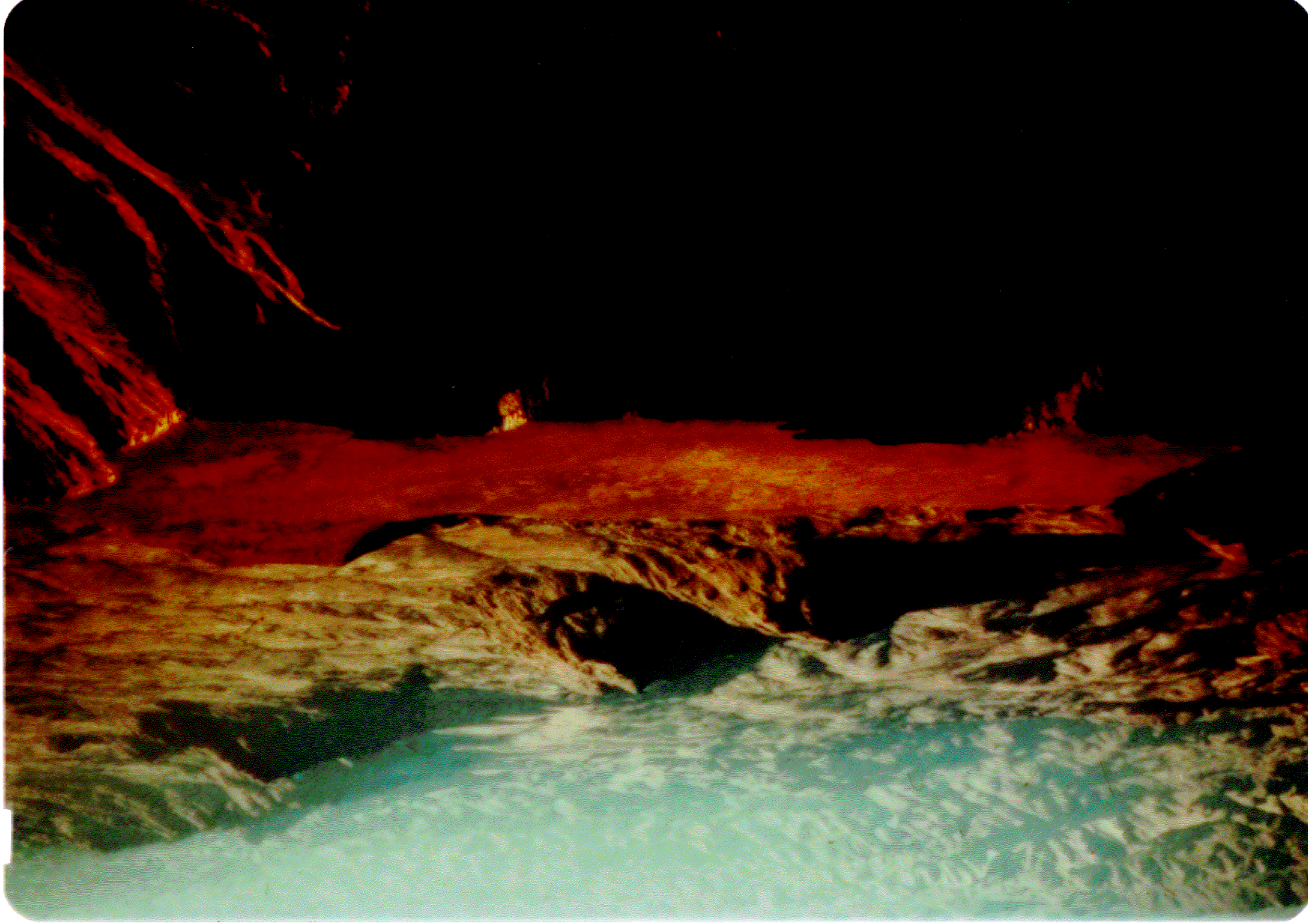


Fig. 6

ANGOLA
ZAMBIA
ZIMB.
BOTSWANA
SOUTH AFRICA
SOUTH ATLANTIC OCEAN
H.E.S.S. Site
Windhoek
Namibia
International boundary
District boundary
National capital
District capital
Railroad
Road
Track



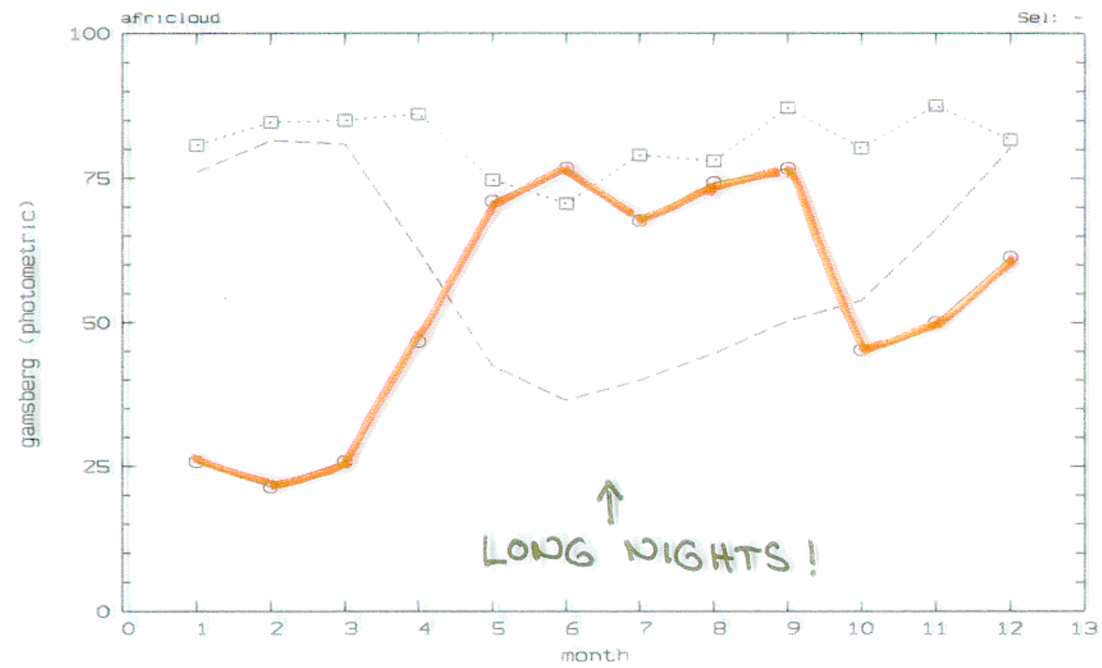
Optical quality of the Namibian site

Optical quality of the Gamsberg site monitored continuously in

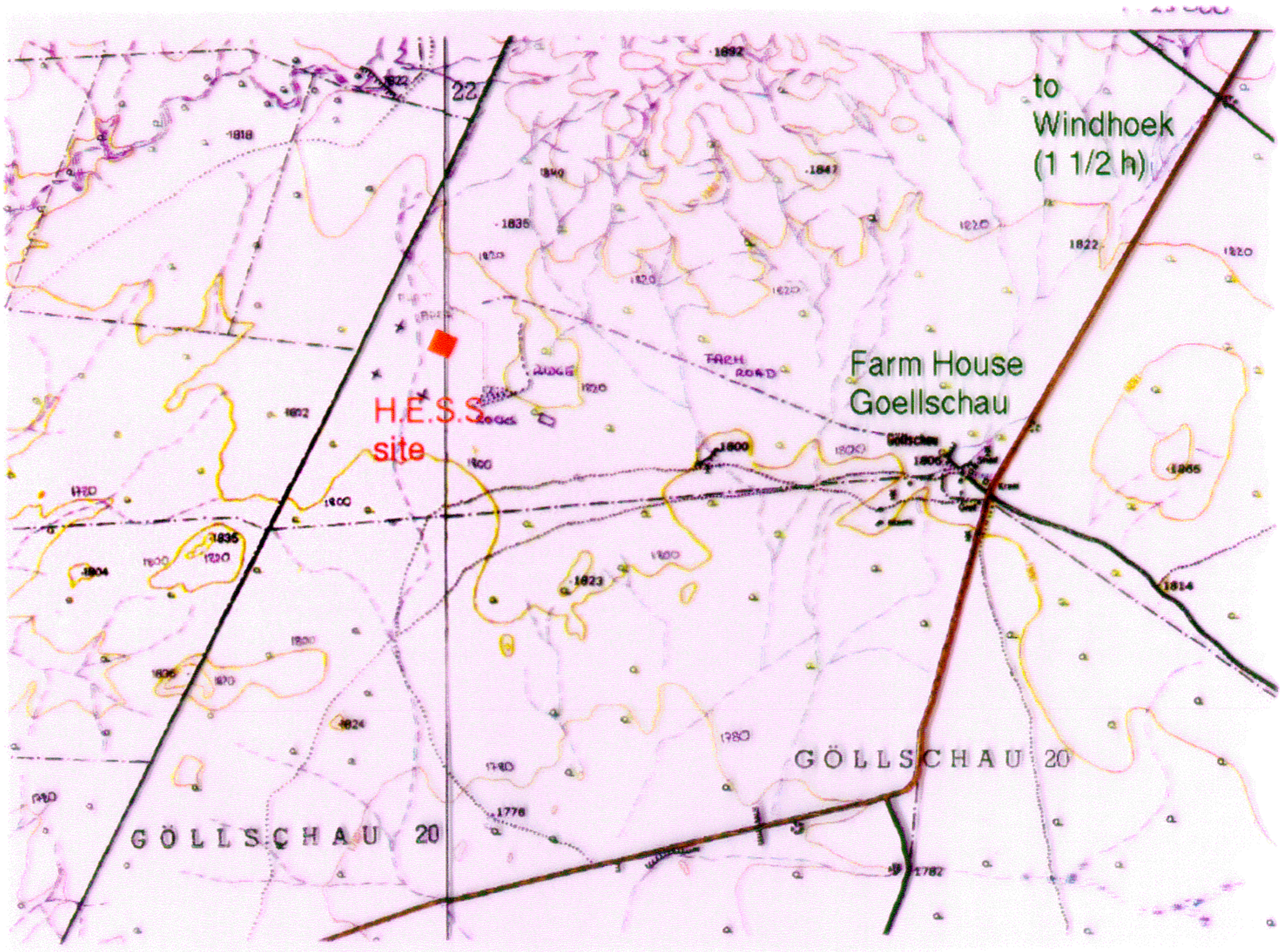
1970 to 1975 (MPIA)
1994 /1995 (ESO)

Equivalent to La Silla

Khomas highland (1800 m) is equivalent to Gamsberg plateau, except for seeing



ESO


to
Windhoek
(1 1/2 h)
Farm House
Goellschau
H.E.S.S
site
FARM
ROAD
GÖLLSCHAU 20
GÖLLSCHAU 20

Site infrastructure

Planned and provided by MPG central administration, very similar to a typical farm infrastructure, includes

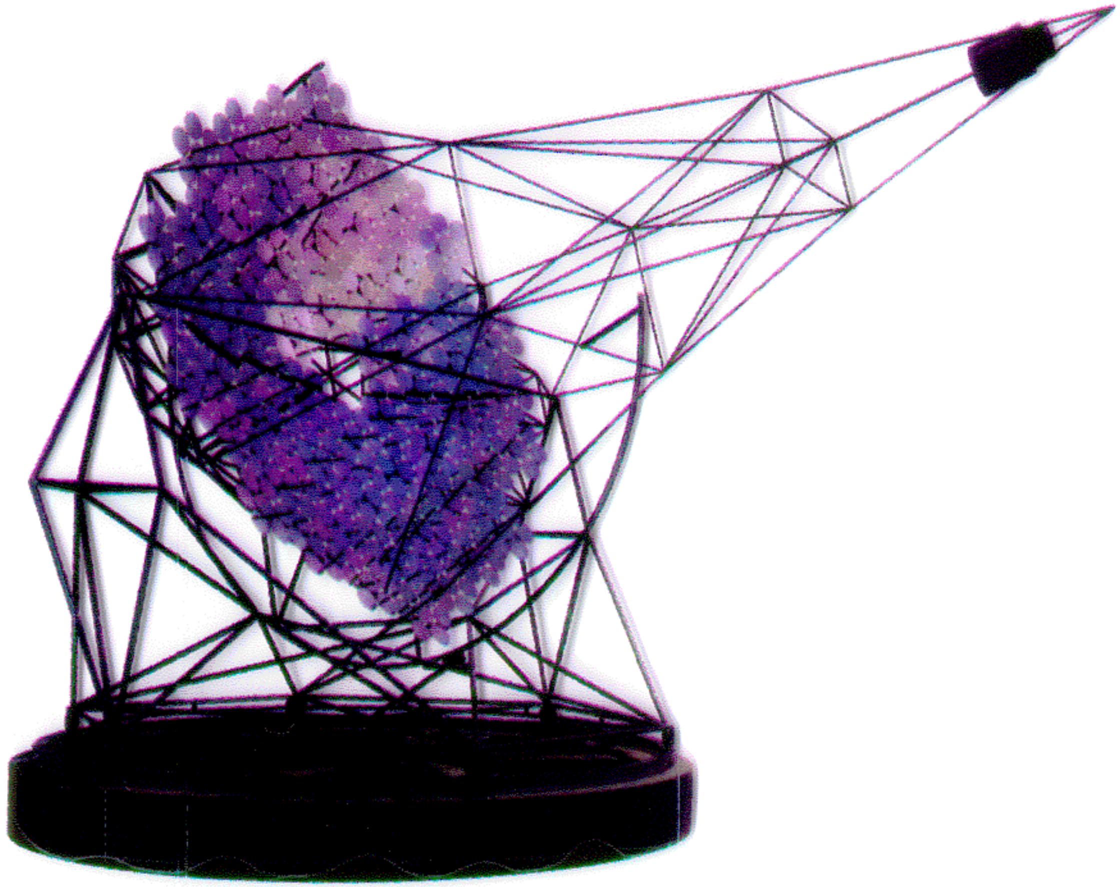
- Control building near telescopes
- Residential building
- Power generators
- Water and power distribution
- Fence
- Some road improvements
- Telescope foundations

Initial cost estimate ≈ 1.2 MDM including furniture, basic workshop equipment. In addition

- Communications link via Windhoek to Europe (64 kb/s, later 1 Mb/s)

Technical choices: Mount and dish

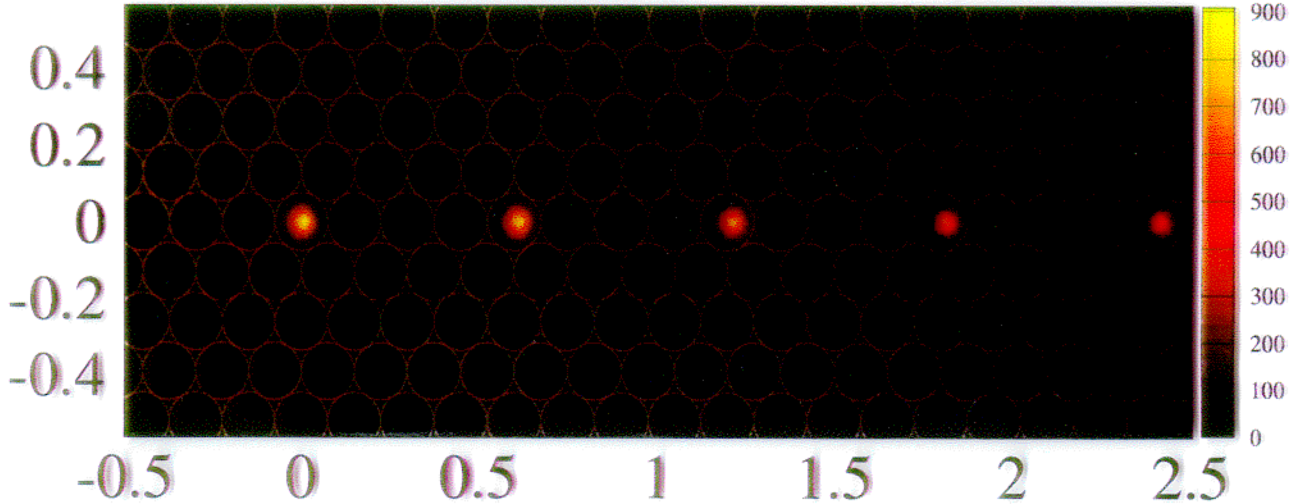
- **f=15 m Davies-Cotton**
  f/d ≈ 1.2
  good off-axis imaging for
  extended sources, surveys
- **Stability 0.14 mrad rms**
  Spot size < 0.4 mrad rms
  (Pixel size 2.6 mrad)
- **Steel construction**
  (Cost)
- **Rail drive systems**
  drive systems at large
  radius -> lower moments



Optical quality of mirrors

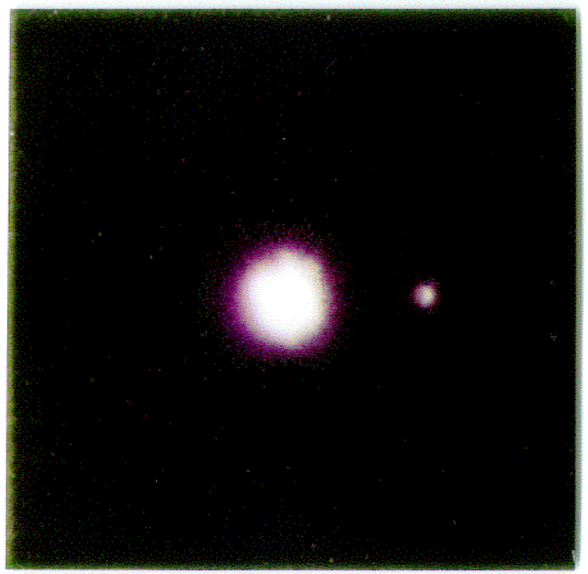
Simulated images of point sources

in comparison to pixel size



Alignment algorithm

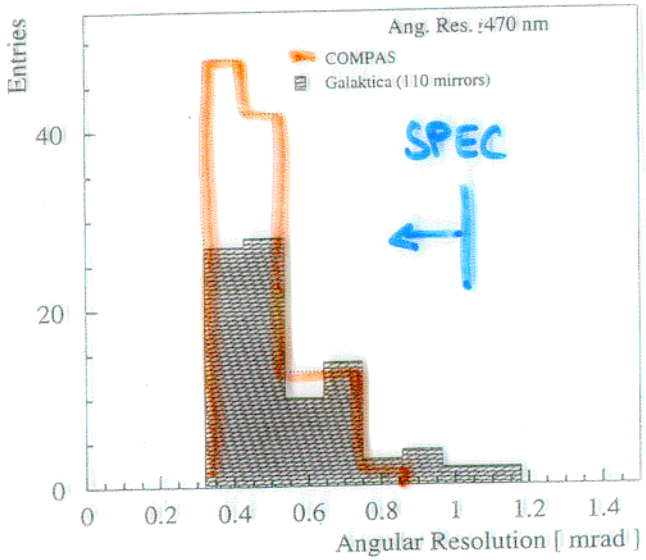
using images of
stars, observed
with a CCD camera



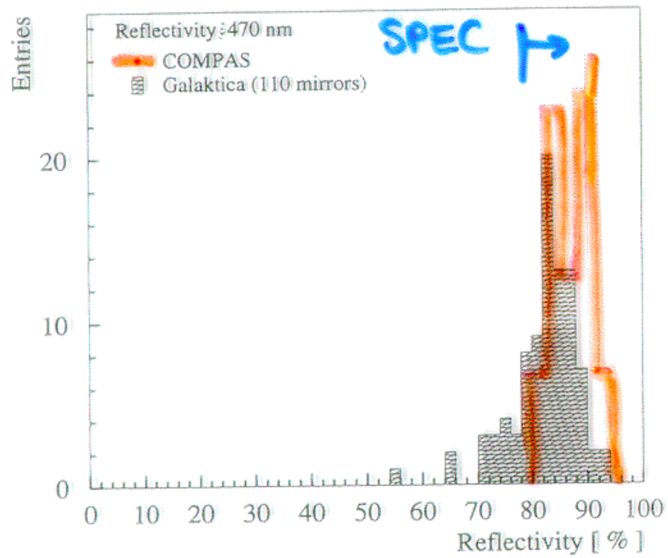
Technical choices: Mirrors

- Initially planned to use micromachined aluminum mirrors
  but
  - prototype series disappointing
  - no cost advantage compared to glass
- Use HEGRA/CAT type quartz coated aluminized glass mirrors made by COMPAS and GALAKTICA
- 60 cm ø round mirrors,
  > 80% reflectivity 300-600 nm
  < 1 mrad (80% ø) spot
- Motors for mirror adjustment
  (safety)
- 6 mirrors installed on site in Namibia

Spot size



Reflectivity



Technical choices: Photodetector and camera

Conventional PMTs for Stage I telescopes

- 30 mm, 8 dynode PMTs, bialkali photocathodes, gain $2x10^5$
- Samples from major manufacturers were characterized

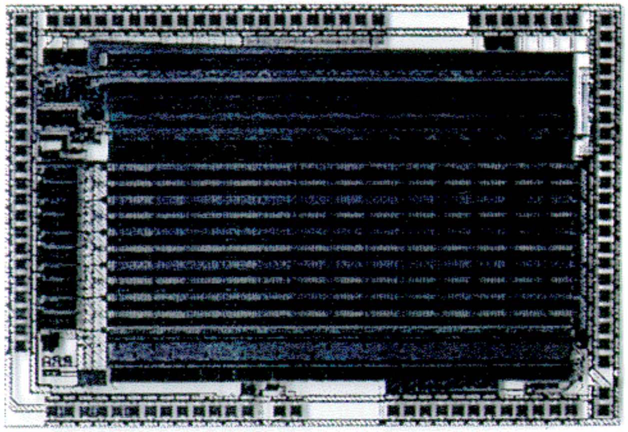
Electronics and trigger in the camera

- Increased reliability (but access more difficult)
- Avoids critical high-bandwidth cables
- Reduced packaging, connectors, interfaces, cost

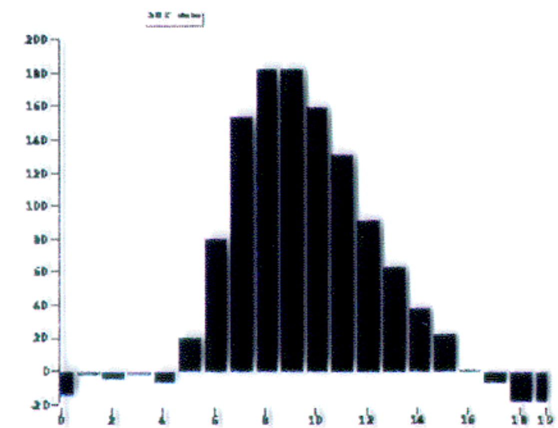
Two concepts in advanced prototyping

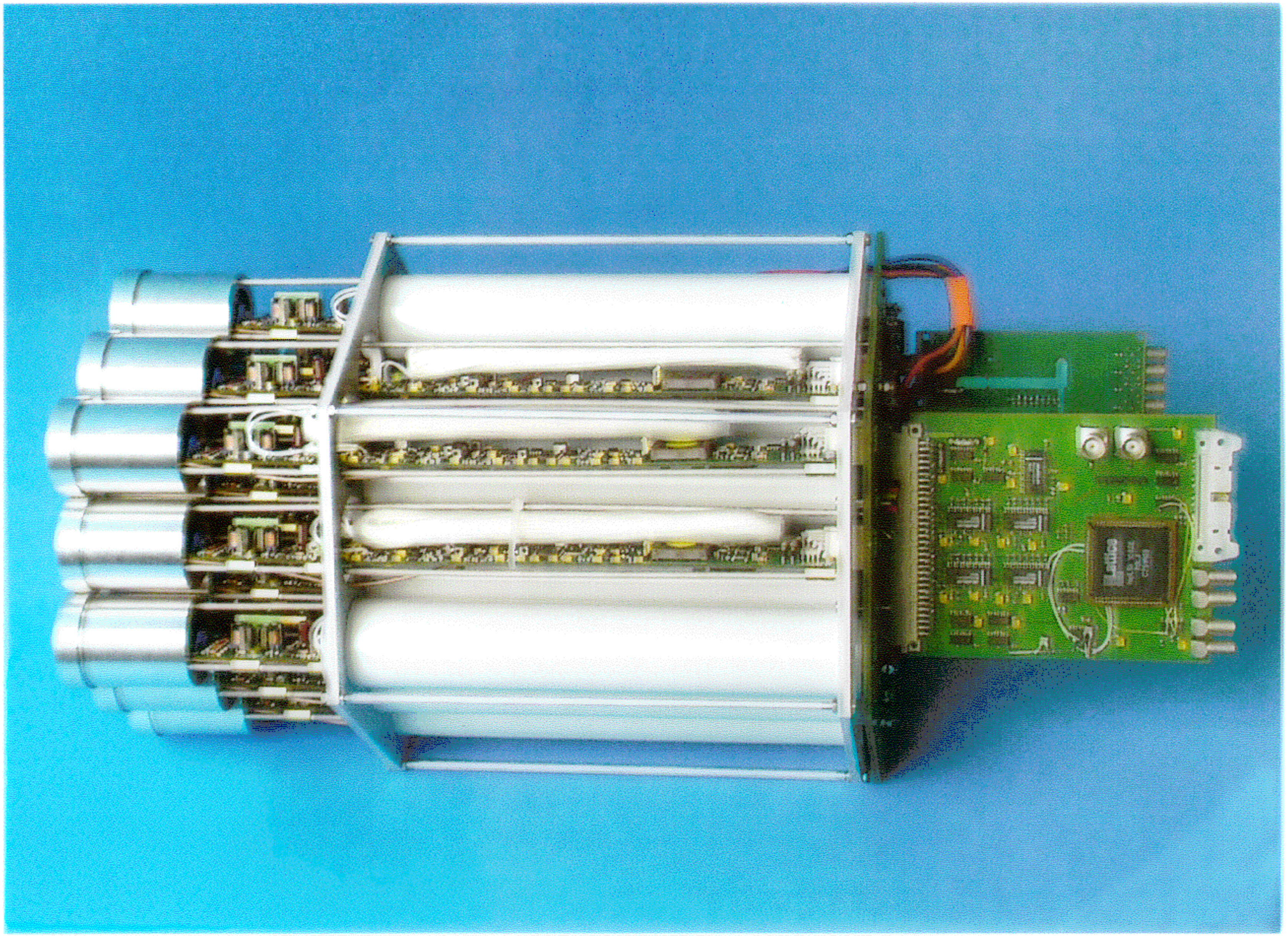
- ARS 1 GHz analog pipeline for signal delay, packaged in 16-PMT units, with digitization in camera
- Smart pixel: PMT, cable delay, processing, trigger electronics in indiv. pixels, plugging into large backplane, with analog bus

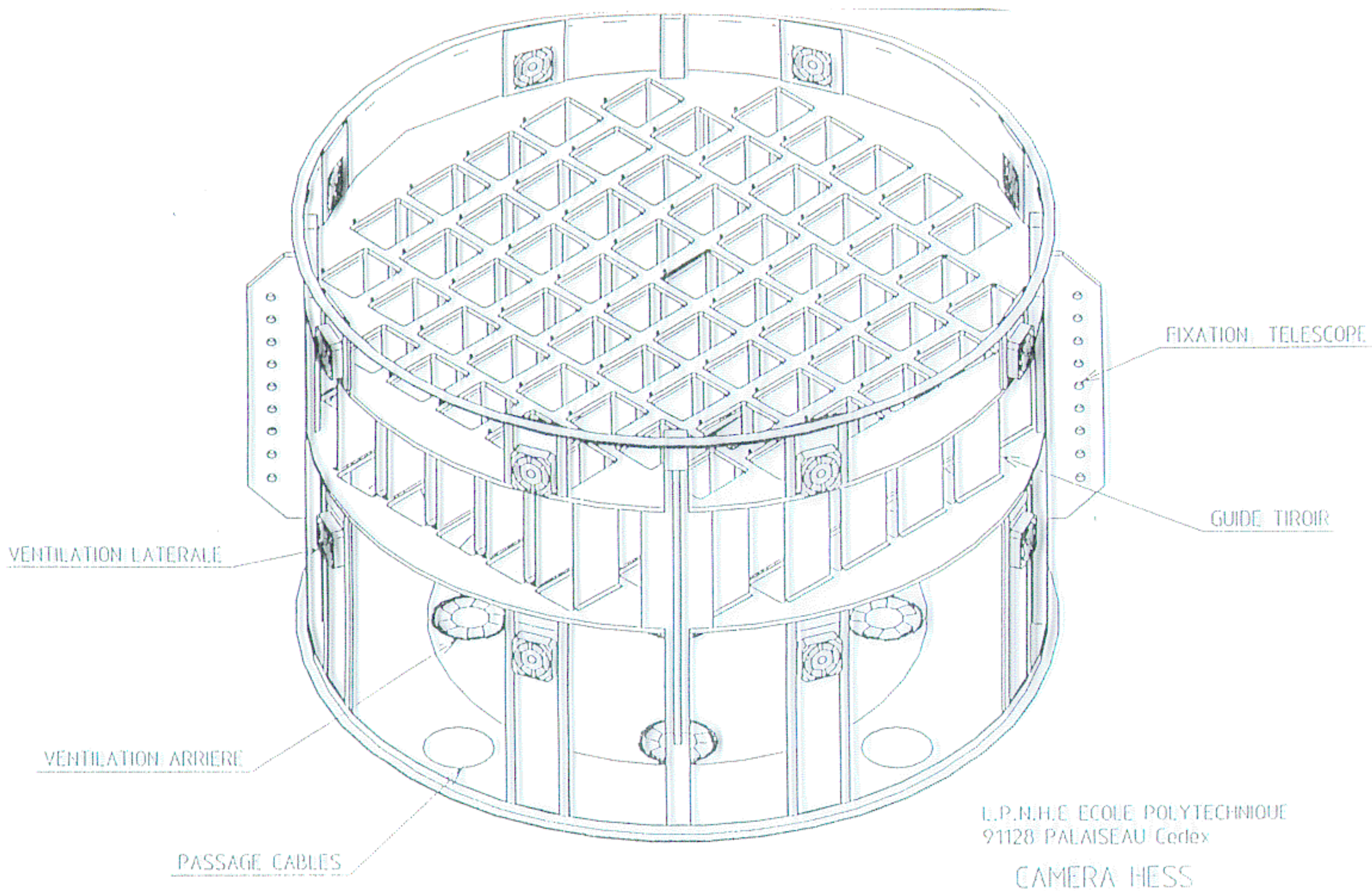
both provide 13 to 14 bit dynamic range (dual gain), 15-20 ns integration time, resolve single p.e.



4 channels,
128 samples,
1 Ghz sampling rate

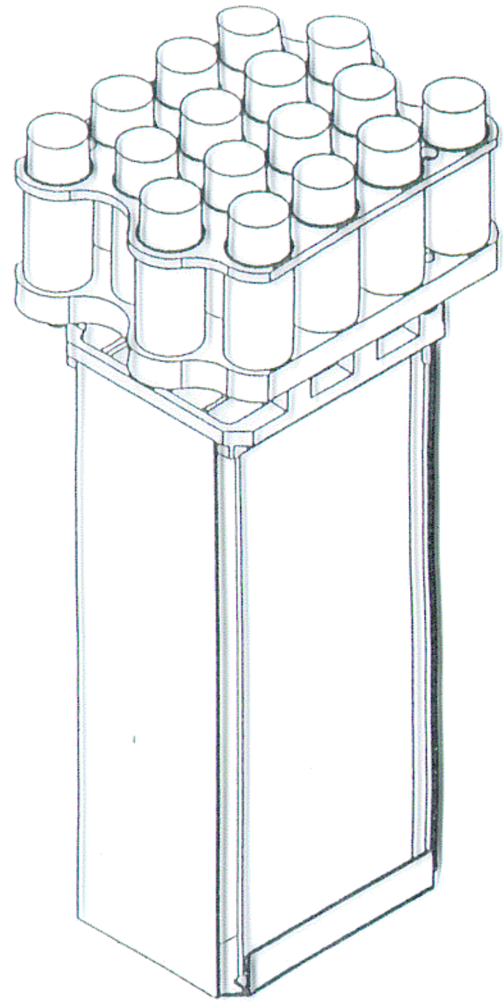






L.P.N.H.E ECOLE POLYTECHNIQUE
91128 PALAISEAU Cedex

CAMERA HESS
STRUCTURE

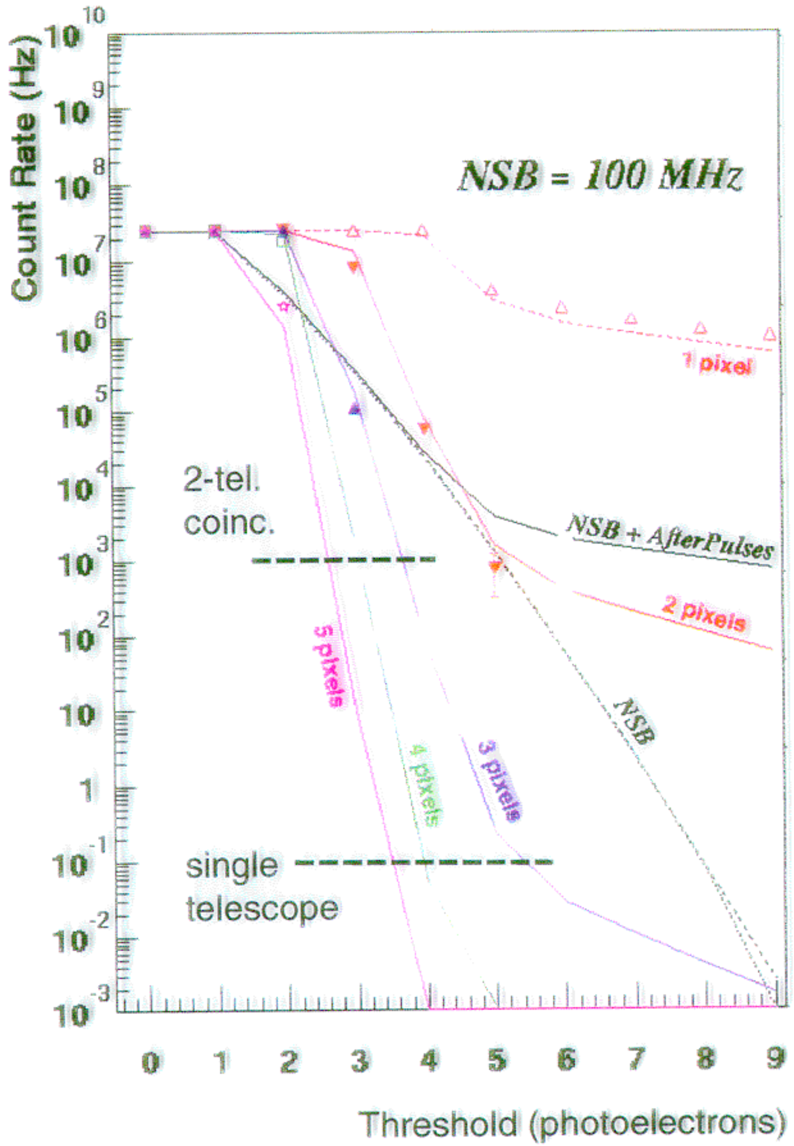


L.P.N.H.E ECOLE POLYTECHNIQUE
91128 PALAISEAU Cedex

TIROIR

The telescope trigger

Telescope trigger:
Local coincidence
of 3 to 5 pixels



Noise trigger rates

HESS

(*H*igh *E*nergy *S*tereoscopic *S*ystem)

An Array of Imaging Atmospheric Cherenkov Telescopes
for Stereoscopic Observation of Air Showers
from Cosmic Gamma Rays in the 100 GeV energy range

F. Aharonian, A. Heusler, W. Hofmann, I. Jung, R. Kankanyan, J. Kettler, A. Kohnle, A. Konopelko, H. Krawczynski, M. Panter, G. Pühlhofer, R.J. Tuffs, H. Völk, C.A. Wiedner, Max-Planck-Institut für Kernphysik, Heidelberg, Germany

T. Lohse, Humboldt Universität Berlin, Germany

R. Schlickeiser, M. Pohl, Ruhr-Universität Bochum, Germany

G. Heinzelmann, M. Andronache, N. Götting, D. Horns, Universität Hamburg, Germany

S. Wagner, K. Otterbein, Landessternwarte Heidelberg, Germany

W. Stamm, Universität Kiel, Germany

B. Degrange, L.M. Chounet, P. Fleury, O. Ferreira, P. Manigot, LPNHE Ecole Polytechnique, Palaiseau, France

M. Punch, P. Espigat, LPC College de France, Paris, France

M. Rivoal, P. Nayman, C. Renault, J.-P. Tavernet, F. Toussnel, P. Vincent, LPNHE Universites Paris VI - VII, France

P. Goret, CEA Saclay, France

G. Auriemma, S. Mari, F. Sartogo, C. Satriano, Universitá della Basilicata, Potenza, and INFN sezione di Roma, Rome, Italy

F. Giovannelli, IAS-CNR, Rome, Italy

L.O'C. Drury, Dublin Institute for Advanced Studies, Dublin, Ireland

L. Rob, Nuclear Center, Charles University, Prag, Czech Republic

A.G. Akhperjanian, V. Sahakian, Yerevan Physics Institute, Yerevan, Armenia

R. Steenkamp, University of Namibia, Windhoek, Namibia

B.C. Raubenheimer, O.C. de Jager, B.V. Visser, University of Potchefstroom, Republic of South Africa

H·E·S·S Status

Funding

- Major part of funding secured, but still some open isses
- Critical: support of German universities

Site

- Exchange of Notes concerning the installation and operation submitted to Nambian Government, affirmative statement by Namibian President
- Agreement with UNAM signed; final version of lease in preparation by MPG
- Work on infrastructure should start in January 2000

Hardware

- Mount and dish: design finalized, bids due early November
- Mirrors: first batches in production, mirrors for 1st telescope in HD
- PMTs: after extensive tests, procurement underway
- Electronics: advanced prototyping

Schedule

- Install first telescope in summer and fall 2000
- First light @ first telescope: early 2001
- Four telescopes complete: in 2002

The Future: H·E·S·S Phase II

Expansion to up to 16 large telescopes

- **Improved sensitivity**
  for deep observations (x 2 ... x 4)
- **2D-survey capability**
- **Multi-source mode** (4 ... 8 sources)
- **Variable base line**
  for obs. at large zenith angles
  (100 m, 250 m, 350 m, 450 m)
- **Effective area matches flux**

A possible layout
of the Phase II array

possibly:
small HEGRA-size
support telescopes

Stronger European component than in Phase I

New technologies?

Allgemeine Zeitung

Heute mit Buchvorstellungen auf Seite 16

N$ 2,00 (inkl. MwSt.)
ISSN 1560-9421

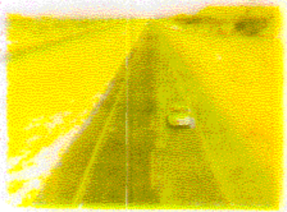
Älteste Tageszeitung Namibias

83. Jahrgang, Nr. 1
Freitag, 23. Juli 19

Redaktion: Postfach 2127, Windhoek, Telefon: 225822, Fax: 220225 - Anzeigenabteilung: Fax: 245200, Vertrieb: Postfach 2127, Windhoek - E-Mail: aznews@iafrica.com.na

Heute

Neuordnung



Die Verkehrsbestimmungen sollen überarbeitet werden. Ein entsprechender Gesetzentwurf hat bereits allgemeine Zustimmung gefunden. • Seite2

Umdenken

Namibias Löwen bekommen Schützenhilfe von Schülern. Die Tiere sollen ab sofort nur noch von Fotografen „geschossen" werden. • Seite 4

Steinbock

Auf den Pfaden der Ostindienfahrer findet sich heute unser Steinbock wieder. Folgen Sie ihm auf Seite • Seite 8

Kapitulation

Der Schweizer Stephane Chapuisat zieht Kons...

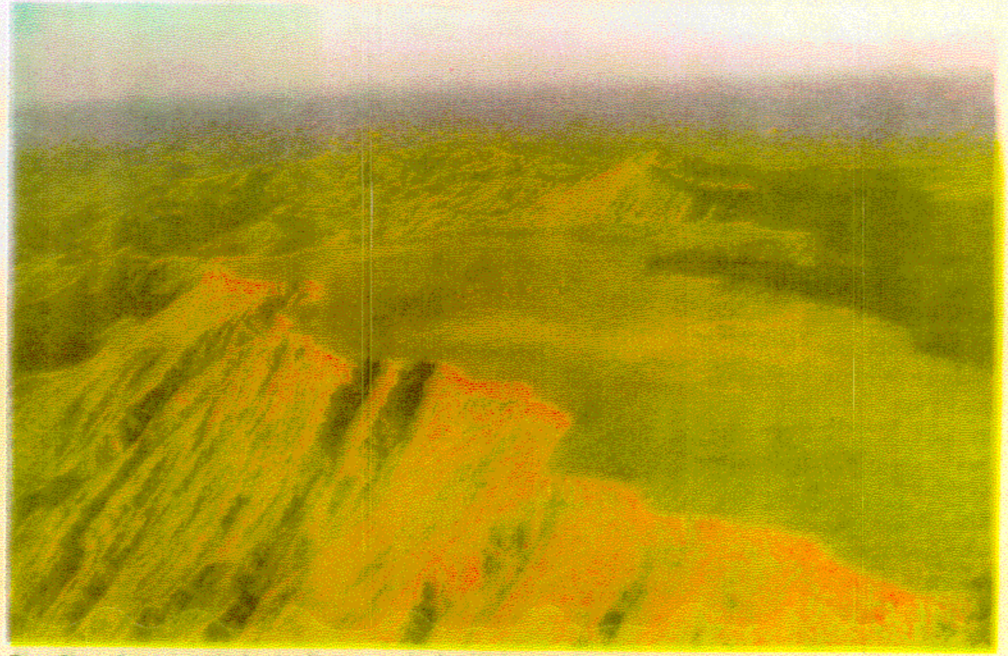
Richtstrahler ins All

Max Planck und 15 Hochschulen betreiben Forschung

Windhoek - Zuerst vier und danach 16 Radioteleskope werden spätestens im Jahr 2001 am Gamsberg Gammastrahlen aus dem Weltall einsammeln. Den Grundlagenvertrag zu diesem Millionenprojekt der Weltallforschung haben der Rektor Peter Katjavivi von der Universität von Namibia und der deutsche Botschafter in Windhoek, Harald Nestroy, diese Woche unterzeichnet. N$ 75 Millionen sind veranschlagt.

von Eberhard Hofmann

Bereits in den siebziger Jahren hatte das Max-Planck-Institut von Heidelberg in Deutschland am Gamsberg-Plateau Interesse gezeigt. Die trockene klare Luft und die Abwesenheit künstlicher Beleuchtung in der Nacht haben den Gamsberg seit jeher zu einem günstigen Standort für eine Sternwarte auf der südlichen Halbkugel gemacht. Die Errichtung eines solchen Objekts war zuerst aus politischen Gründen nicht möglich, wurde nach der Unabhängigkeit wiederbelebt und sogar im deutsch-namibischen Kulturprotokoll von 1995 aufgenommen. Aber nun ist der Schwerpunkt von einer Sternwarte auf ein Großprojekt der Astrophysik verlagert worden...



Der Gamsberg ist wieder im Brennpunkt der Weltraumforschung, aber die geplante Forschungs-

NBL im Disput

Windhoek (ms) - Die Gewerkschaft für Angestellte der Lebensmittelindustrie ((NAFAU), hat einen Disput mit den Namibia Brauereien (NBL) erklärt.

Dies folgt nachdem die beiden Parteien keine Einigung in den seit Tagen andauernden Gehaltsverhandlungen erzielen konnten. Die Gewerkschaft verlangt für ihre Mitglieder eine Lohnerhöhung von 17 Prozent und eine gehaltsabhängige Wohnungszulage von 25 Prozent. Diese Forderung, die einer allgemeingültigen Anhebung von 42 Prozent gleichkommt, wurde von der Brauerei abgelehnt, die ihrerseit eine Lohnerhöhung von 9 Prozent angeboten hat.

Die NAFAU zählt knapp 300 der rund 850 Brauerei-Angestellten zu ihren Mitgliedern und wurde erst im April diesen Jahres offiziell als Interessenvertretung des Personals anerkannt. Die Verhandlungspartner werden sich nun auf eine Person einigen müs-