XIX Vulcano Workshop on Frontier Objects in Astrophysics and Particle Physics

On Major Motivations and Objectives of gamma-ray astronomy with Atmospheric Cherenkov Telescope Arrays

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Ground-Based Gamma-Ray Astronomy - *a success story*

over the last two decades the field has been revolutionized

before – *"astronomy" with several sources - Astroparticle Physics rather than Astronomy*

now – *a truly astronomical discipline with*

hundreds (> 300) of detected VHE/UHE gamma-ray sources representing at least 14 Galactic and Extragalactic source populations:

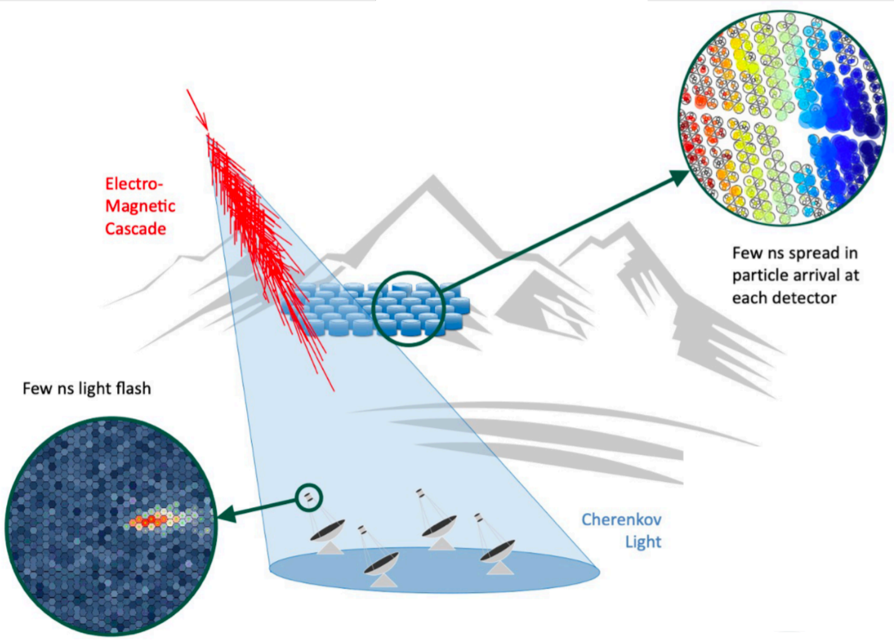
SNRs, GMCs, Massive Stellar Clusters, Novae, Pulsar Winds, PWN, Pulsar Halos, Binary Pulsars, Microquasars, Starburst Galaxies, Radiogalaxies, Blazars, GRB afterglows…

and

two effective detection techniques:

- *Stereoscopoic IACT Arrays*
- *Particle (EAS) Detectors*

Particle Detector Arrays



Imaging Cherenkov Telescope Arrays

major factors which make possible this success ?

several factors… but basically thanks to the lucky combination of two:

✓ *great potential of the detection technique*

✓ *effective acceleration of TeV/PeV particles on all astronomical scales coupled with favourable conditions for production of gamma-rays*

predictions for future - *solid and optimistic!*

- good understanding of the detection technique
- information based on the observations of TeV sources and adequate interpretation of data based on reliable phenomenology/theory
- ongoing CTA mega project

Can we conclude that the sucess can be repeated (i.e. the field is not yet "saturated")

- *In which areas do we expect breakthroughs with CTA and other IACT arrays ?*
- *do we expect further substantial improvement in the performance (beyond CTA)?*

Stereoscopic IACT arrays - high performance and great potential

- huge detection areas, potentially >> 1 km^2
  => huge photon statistics coupled with
- good (~10 to 20%) energy resolution and
- good angular resolution (down to 1-2 arcmin)
- relatively large FoV (5 to 10 degree)

=> spectrometry, morphology, timing, surveys

- sensitivity for point-like sources potentially below 10^{-13} erg/cm^2s
  (impressive by standards of modern astronomical instruments!)

- energy coverage from 30 (3) GeV to 30 (300) TeV 3 (5) decades
  using the same technique ! (unique in astronomy/physics)

Four Energy Regimes of IACTs

very low or **multi-GeV**: < 30 GeV (down to 3 GeV) ?

low or **sub-TeV**: 30 GeV - 300+ GeV *now*/*soon*

high or **TeV** : 300 GeV - 30+ TeV *now* !

very-high or **sub-PeV** > 30 TeV **(**100 TeV**)** *soon*

based on

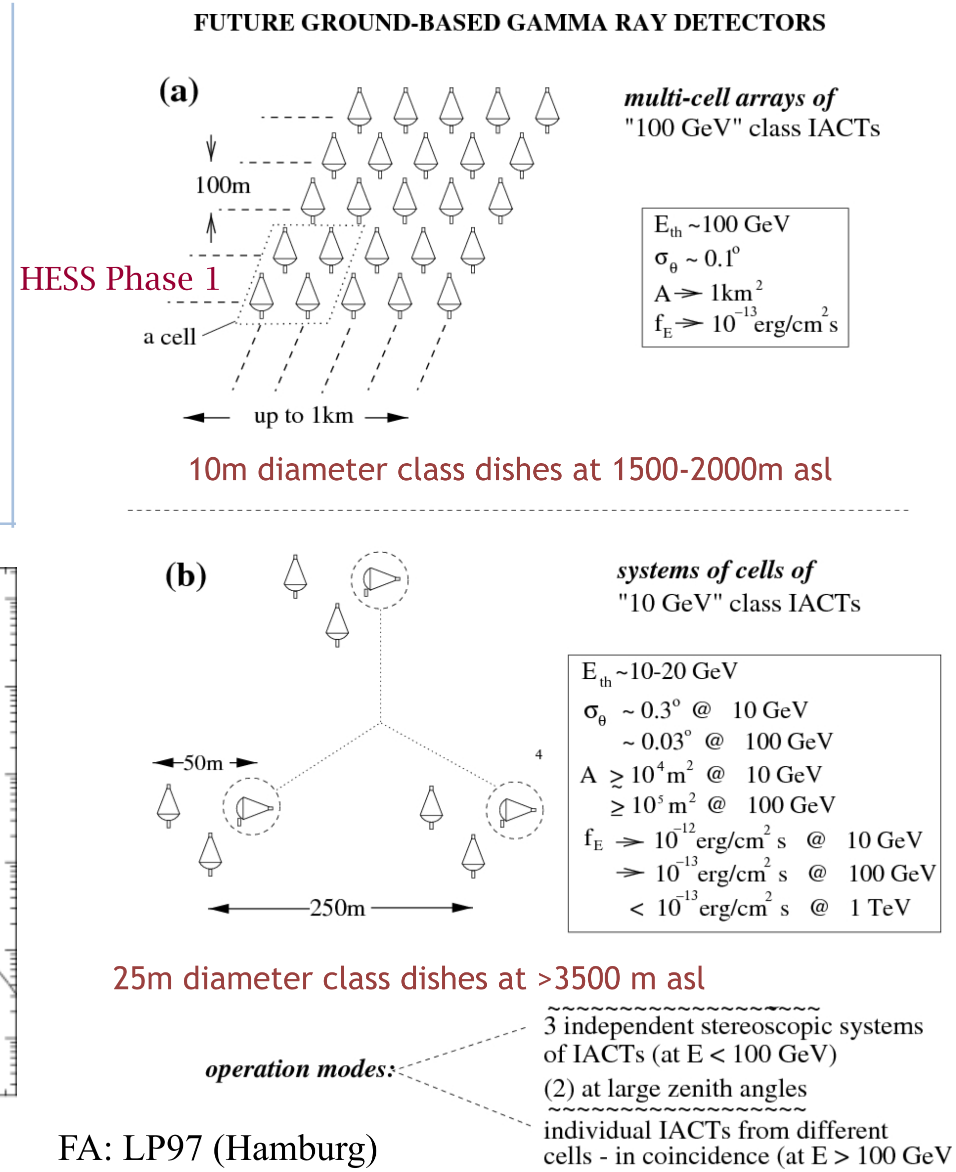
(i) detection specifics and (ii) principal scientific issues

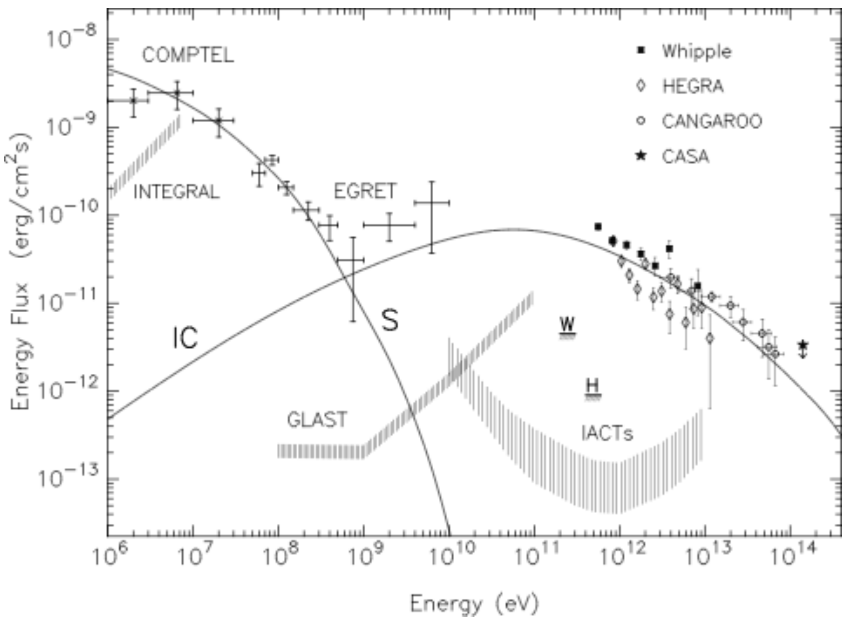
each energy interval requires a specific configuration of IACTs but each configuration covers at least one decade

First proposals for “Future IACT arrays”

The results of the Whipple 10 m single dish and he HEGRA 5x3m diameter Stereoscopic System prompted us to think in mid 1990s about the next generation IACT arrays, and in which direction should we move on

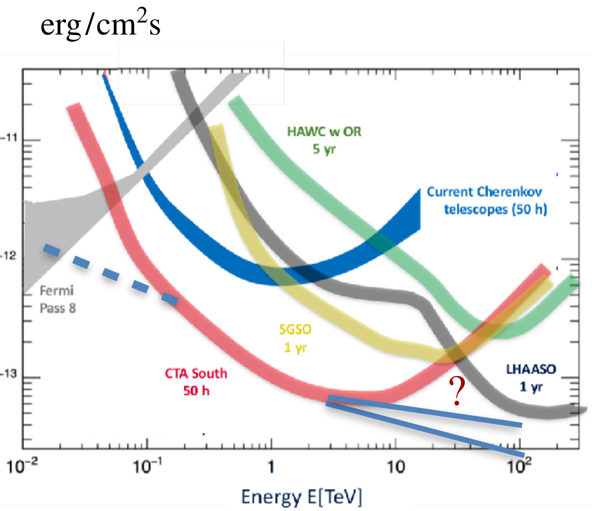
H.E.S.S./Magic/VERITASS proved the concept in 2000s and motivated appearance of CTA project

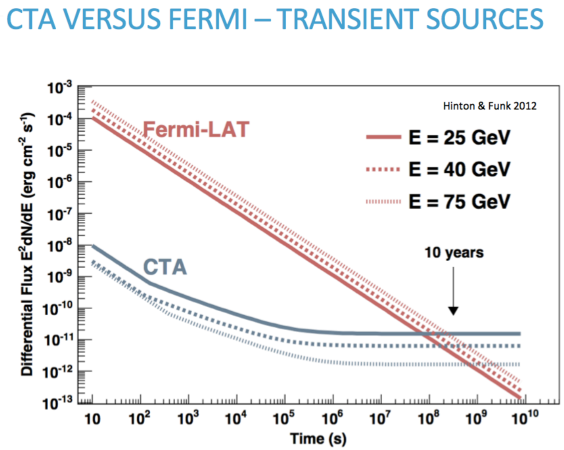




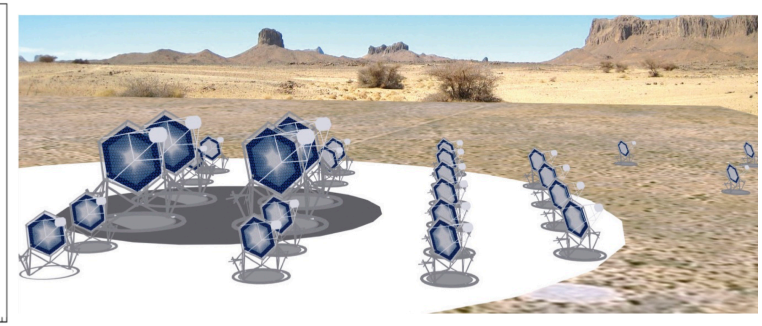
FA: LP97 (Hamburg)

and the *“TenTen”* (FA&G.Rowell) concept of 10 km² small IACT array for study of PeVatrons





CTA South



Flux sensitivity improvement by CTA by a factor of ~5 (at 100 GeV) to ~50 (at 10 TeV)

=> dramatic reduction of required observation time

=> effective surveys, discovery of many new sources, deep study of bright sources with great details in

morphology
important for identification of extended sources, for study of (energy-dependent) spatial distributions protons/electrons

energy spectra
important for understanding the acceleration, propagation and radiation processes

lightcurves
important for understyanding evolution of compact sources,

Further performance improvements? *Do we desparately need this?*

Is it feasible and cost effective?

- *angular resolution* - $\phi \approx 2\,\mathrm{arcmin}$ - most likely is a realistic limit; it is sufficient to probe galactic sources (SNRs, PWNe, …) on the scales of $1 \leq 1(d/1\,\mathrm{kpc})\,\mathrm{pc}$ well as nearby (< 10 Mpc) extragalactic sources (e.g. Cen A, M87, as Virgo Cluster, M 82, NGC 253) on 1 to 10 kpc scales

- *energy resolution* - 10-15 % is a robust limit; e.g. it is sufficient to measure energy spectra with super-exponential cutoff even for sources of < 0.1 Crab strength, seach for TeV gamma-ray line structures (DM, Cold ultrarelativisticv Pulsar Winds), …

we can hardly improve substantially the angular and energy resolutions, but we can significantly enhance the potential of spectrometry and morphology by improving the sensitivity (background-dominated regime) and increasing the detection's collection area (statistics-dominated regime) sensitivity - it is always desirable to improve the sensitivity if it is feasible and cost-effective

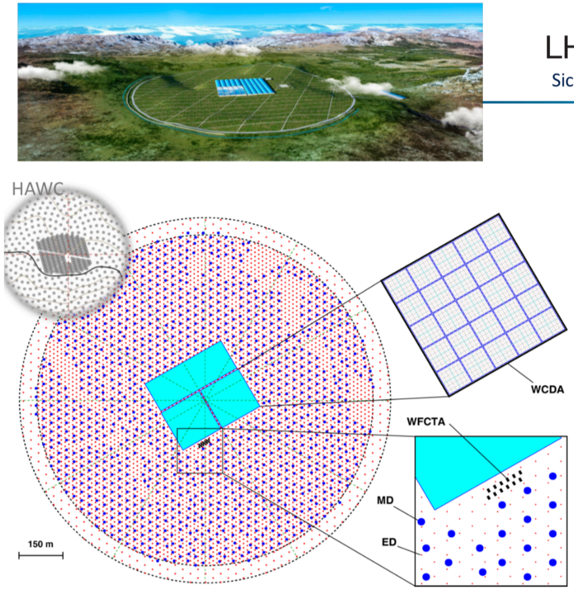
0.3 - 30 TeV - in the case of CTA, the sensitivity is determined by the background, therefore a promising (potential) resource is to improve the γ/p separation power, κ, e.g., down to $\kappa = 10^{-3}$ (currently it is 10^{-2}). Is it feasible? No deep and focused investigations have been conducted so far (to my knowledge) to clarify this issue. . The LHAASO remarkable achievent in this context tells us that one should explore the reason why the canonical ("Hillas") number is close to $\kappa \sim 10^{-2}$: does it have a "physics background" (the probability of production of a highly leading π^0 -meson at hadronic interactions) or an "instrumental background" (e.g. is limited by the quality of Cherenkov light images)?

> 10 TeV - to improve the sensitivity, an array consisting of more than 100 small IACTs distributed over $\geq 10\,\mathrm{km}^2$ (distance between telescope 300 to 500 m). This seems feasible (not fully crazy) if one can produce small telescopes for an affordable price. An alternative, less costly approch - observations at large zenith angles.

Such UHE IACT arrays with sensitivity comparable to LHAASO's sensitivity at 100 TeV, could hugely contribute to understanding the nature of PeVatrons - one of the most exciting discoveries of recent years. The much better angular resolution is instrumental for this objective.

< 300 GeV - can we make less sharp the worsening of the sensitivity (in erg/cm2 s) toward 10 TeV?

(1) one should explore the possibility of improving the γ/p ratio
(2) reduce the energy threshold and thus shift A(E) toward low energies



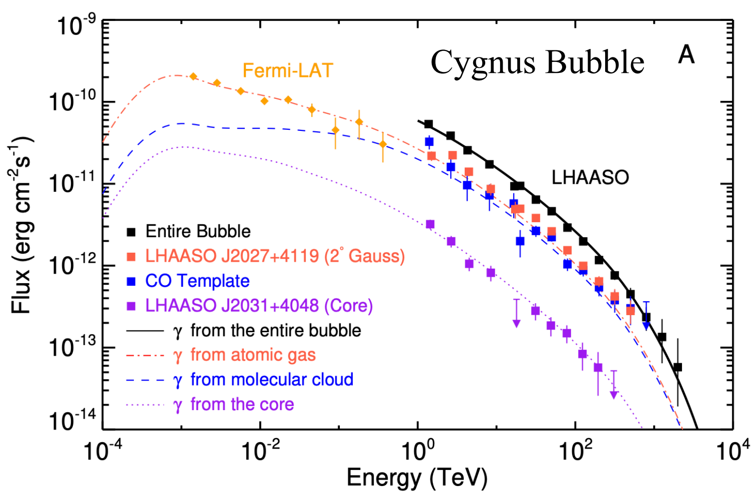
LHAASO
Sichuan, China, 4410 m asl

5195 Scintillators
- 1 m^2 each
- 15 m spacing

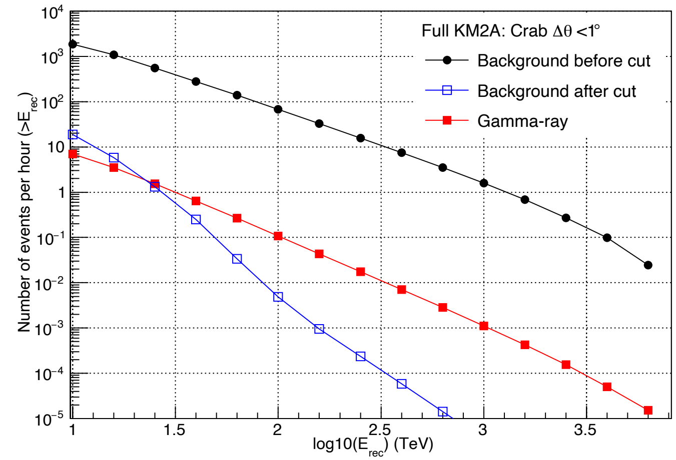
1171 Muon Detectors
- 36 m^2 each
- 30 m spacing

3000 Water Cherenkov Cells
- 25 m^2 each

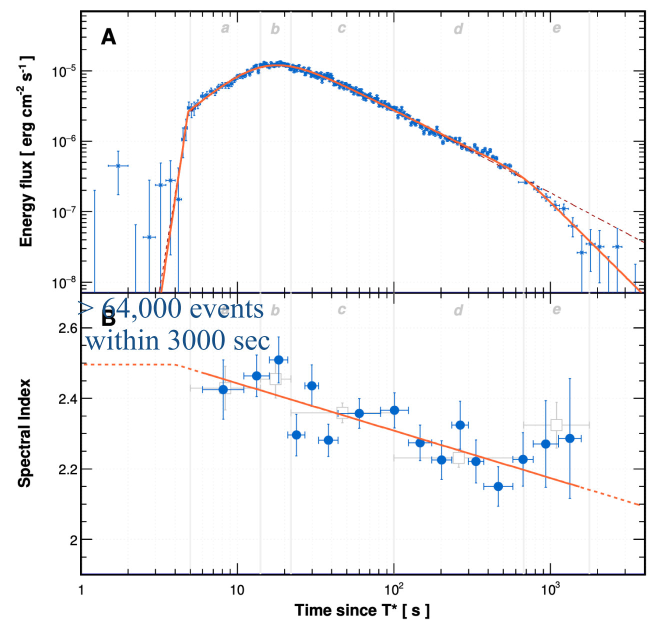
12 Wide Field Cherenkov Telescopes



CR-induced background rejection power



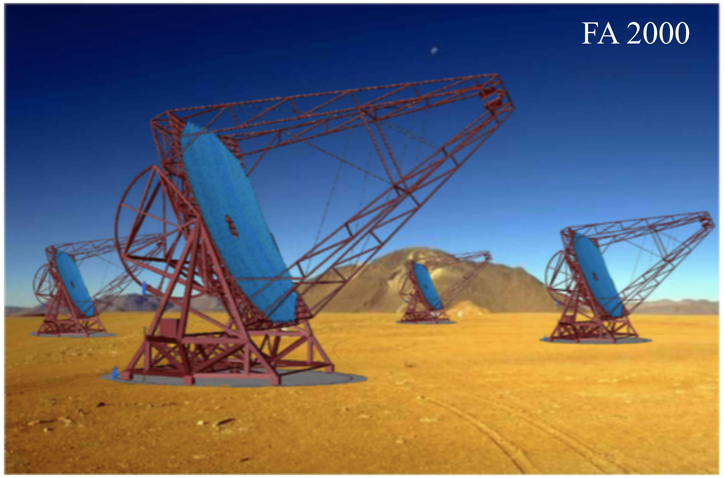
GRB221009A afterglow (WCDA)



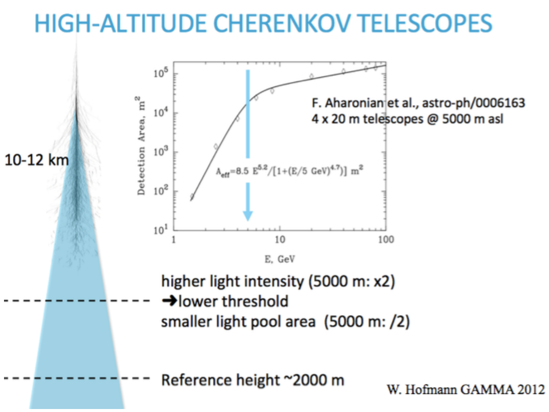
> 64,000 events
within 3000 sec

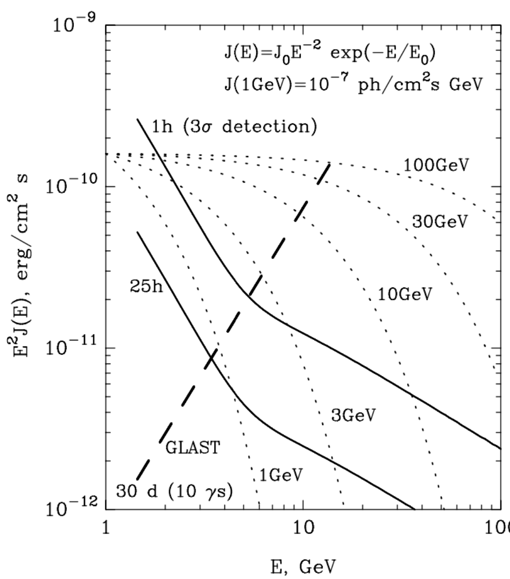
GeV Cherenkov Detectors?

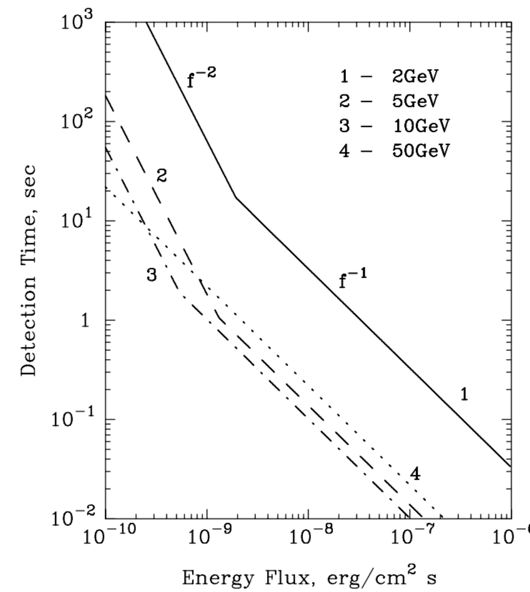
5@5 – a Gamma Ray Timing Explorer



70m diameter Cherenkov telescope



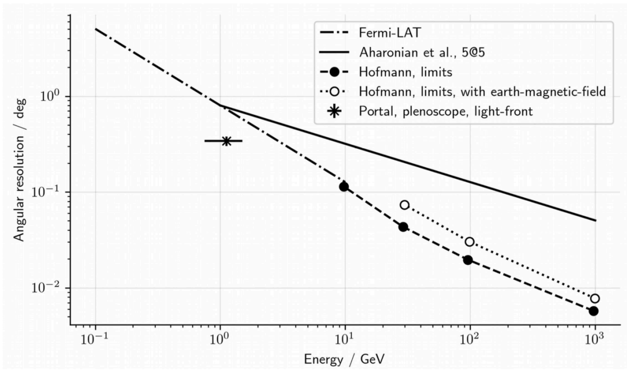


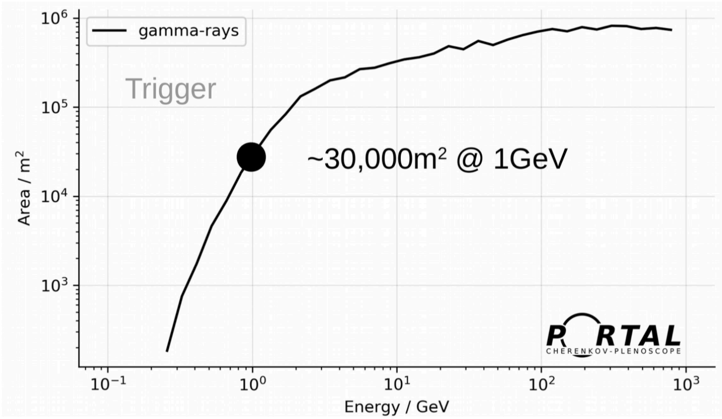


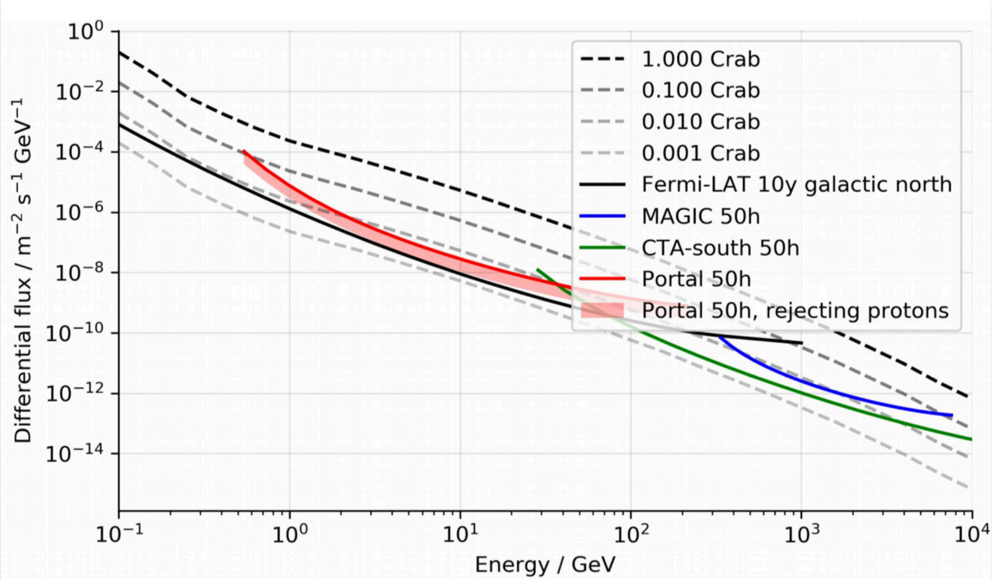
FA et al. 2000

Pulsars, Crab Flares, Microquasars, AGN flares, GRBs, FRBs, …

New studies of the performance - great if true!







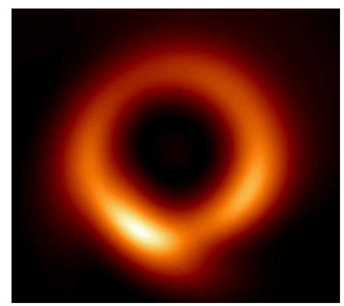
S. Mueller 2020

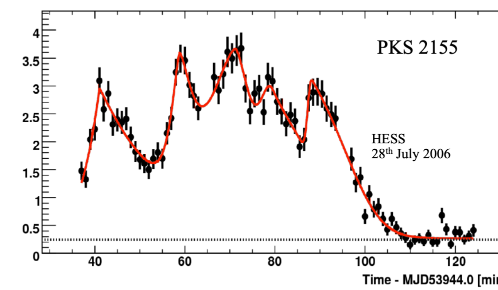
- *Energy threshold*

The reduction of the threshold (by using huge dishes and/or installing the telescopes at very high altitudes) can help to enter the GeV domain (in principle, down to a few GeV) and in this way, improve the detection area and, correspondingly, the photon statistics) by 4-5 orders of magnitude. In the case of success, one may have incredibly powerful instrument of the Time Domain Astronomy to study the highly variable or solitary phenomena like GRBs, FRBs, and AGN flares and, very likely, to discover new sources/phenomena in this exciting field.

an example:

Study of variable gamma-ray emission from Active Galactic Nuclei on minute timescales: unique probes of the environments close to Event Horizon of Supermassive Black Hole

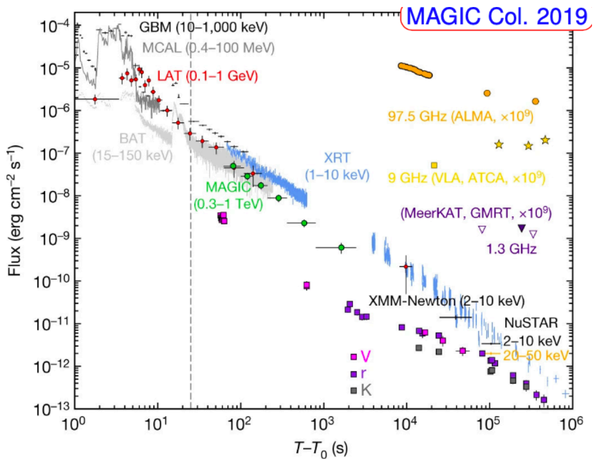


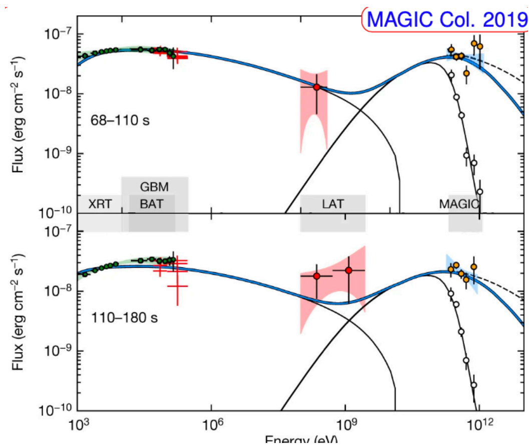


Gamma-ray detection rate for an event like the flare of PKS2155 in 29 July 2006, by GeV timing explore could exceed rate = $10^4\ s^{-1}$ corresponding to the linear scale of 10^{-5} of gravitation radius of the Supermassive Black Hole in PKS2155

CTA's sensitivity around 20 GeV should be awarded by very impressive results!

multi-GeV, sub-TeV, TeV and multi-TeV IACTs (most) powerful explorers of transient and periodic phenomena on time scales from seconds to days/months

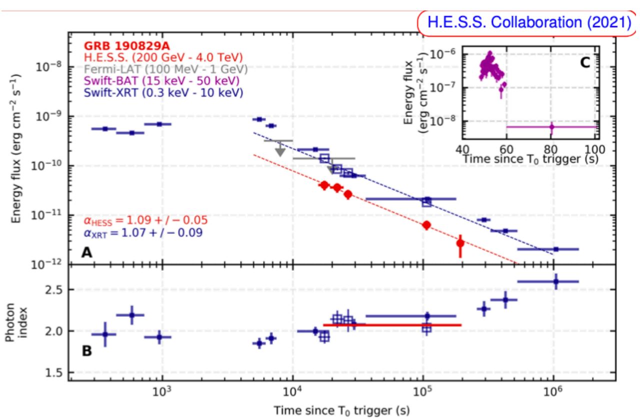


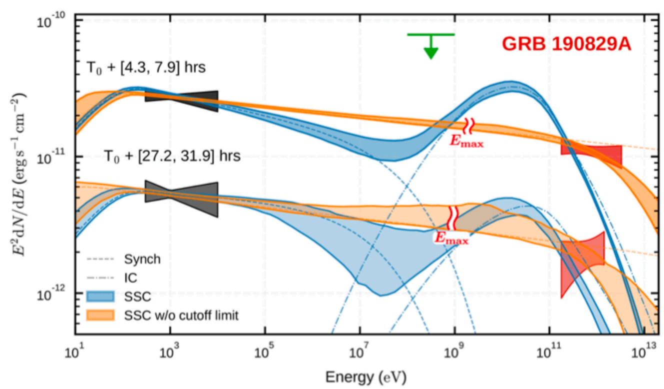


IACTs versus (super) LAT

disatvantage: field of view but this is not critical for GRB afterglows

advantage: $\geq 10^4$ (10^6) m^2 vs 1 (10) m^2





Important! network of IACTs distributed over at least three timezones:

North: (upgraded) VERITAS - CTA North/ASTRI - LACT

SOUTH: CTA South - (upgraded) H.E.S.S. - an array in Australia?