High Energy Universe: Gamma Rays

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Gamma Ray Astronomy - *a discipline in its own right*

- gamma-ray astronomy - as one of the branches of Astroparticle Physics
- gamma-ray astronomy as an established truly Astronomical discipline

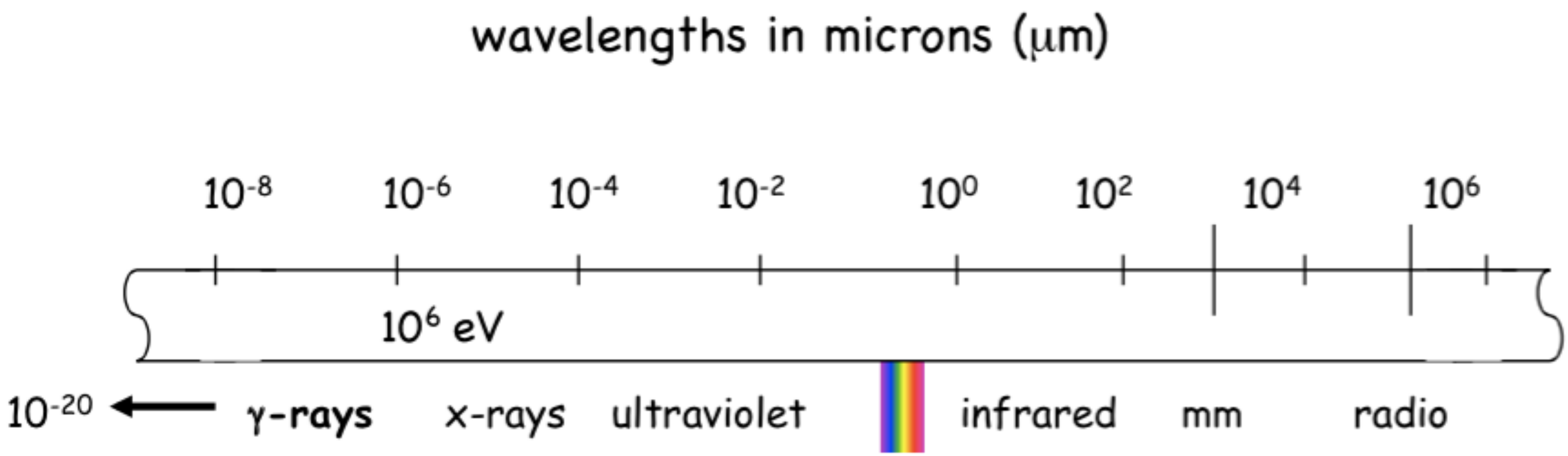
to a large extent, Gamma Ray Astronomy is a *discipline in its own right*:

interdisciplinary field of research at interface of Physics, Astrophysics and Cosmology strongly supported by both the (Astro) Particle and Astronomy&Astrophysics communities

HE & VHE gamma-rays - are *effectively detectable* (by space- and ground-based instruments) messengers of *crucial information* about "most energetic and violent phenomena in the Universe"

Why Gamma Ray?

'the last window' in the cosmic EM spectrum !



8+ decades - detected; potentially - 14 decades

LE	or	MeV :	0.1 -100 MeV	(0.1 -10 + 10 -100)
HE	or	GeV :	0.1 -100 GeV	(0.1 -10 + 10 -100)
VHE	or	TeV :	0.1 -100 TeV	(0.1 -10 + 10 -100)
UHE	or	PeV :	0.1 -100 PeV	(*only hadronic*)
EHE	or	EeV :	0.1 -100 EeV	(*unavoidable because of GZK*)

low bound - nuclear gamma-rays, upper bound - highest energy cosmic rays

the window is opened in MeV, GeV, and TeV bands:

LE,HE *domain of space-based astronomy*

VHE, ... *domain of ground-based astronomy*

potentially 'Ground-based γ-ray astronomy' can cover five decades (from 10 GeV to 1 PeV) , but presently it implies 'TeV γ-ray astronomy'

1MeV=10^6 eV, 1GeV=10^9 eV, 1TeV=10^{12} eV, 1PeV=10^{15} eV 1EeV=10^{18} eV

VHE gamma-ray astronomy - a success story

"over last 20 years the field has bee revolutionized…"

before – *"astronomy with several sources"*

(Astroparticle Physics rather than Astronomy)

now – a "*truly astronomical discipline*" with characteristic key words: energy spectra, images, lightcurves, surveys...

> 150 reported VHE emitters representing

>10 *Galactic & Extragalactic populations*

main reasons?

powerful detection technique:

Stereoscopic Arrays of Imaging Atmospheric Cherenkov Telescopes

abundance of effective TeV sources:

Particle Accelerators (TeVatrons) and Gamma-Ray Emitters

on all astronomical scales from compact objects (BHs/NSs) to Galaxies

the strength and uniqueness

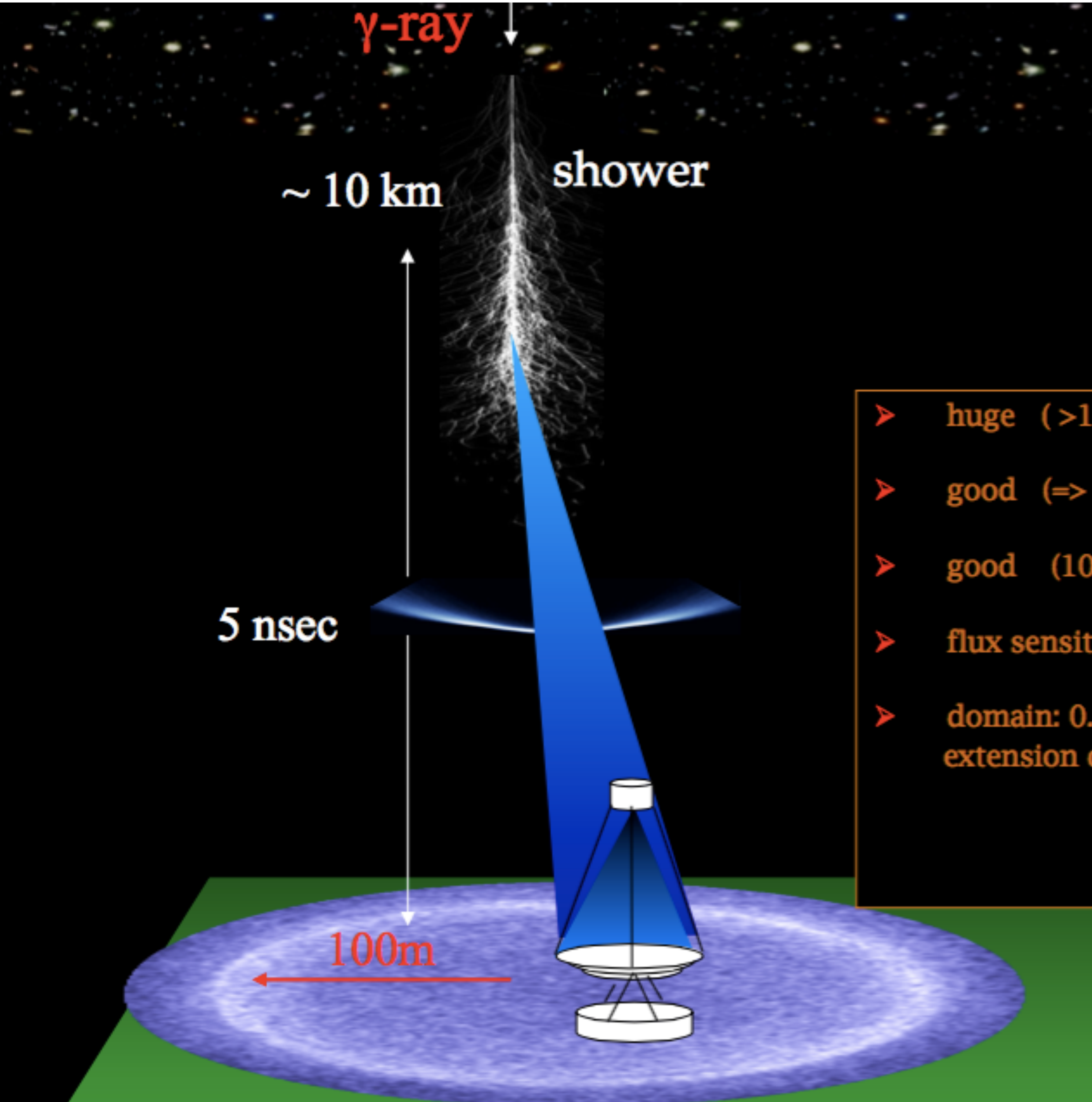
- ***crucial*** - for specific topics e.g. for the solution of
  Origin of Galactic an Extragalactic Cosmic Rays

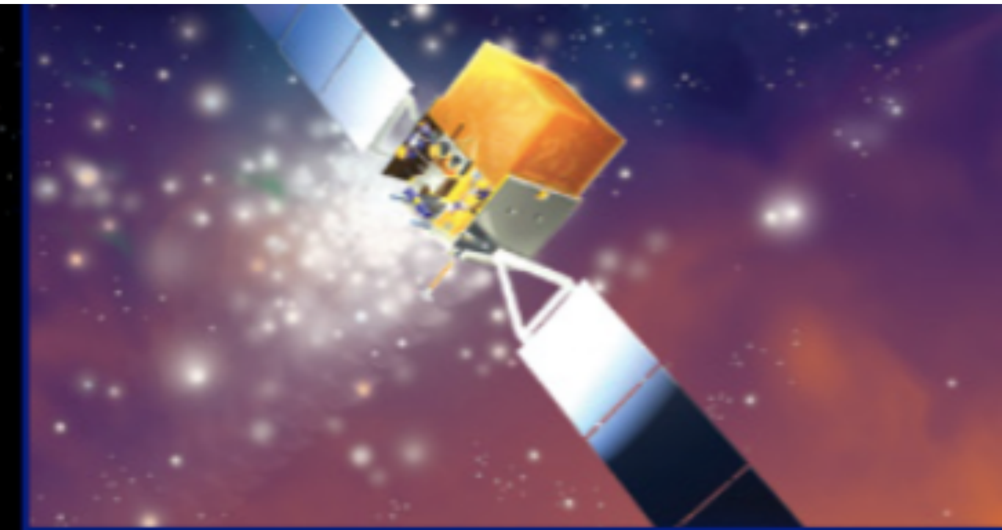
- ***unique*** - may provide key insight into a number of principal issues
  e.g. paradigm of *"Pulsar/Pulsar-Wind/Pulsar-Wind-Nebula"*,
  physics and astrophysics of Supermassive Black Holes

- ***contribution to fundamental physics*** - *violation of Lorentz invariance,* search for *Dark Matter*, or less exotic issues, like *Relativistic MHD* "experiments" (e.g. in PWNe and AGN)

- ***established detection technique*** - *IACT arrays* - for adequate *spectrometry, morphology, timing, surveys*, with a clear plan for next steps (in the foreseeable future - CTA)

Stereoscopic Imaging Atmospheric Cherenkov Telescope Arrays:
powerful tools for detection of Cosmic gamma-rays from GeV to PeV energies





- huge (>1km² or larger) detection area
- good (=> 1arcmin) angular resolution
- good (10-25 %) energy resolution
- flux sensitivity => 10^{-14} erg/cm² s
- domain: 0.1 - 100 TeV with a potential of extension down to 10GeV and up to 1PeV

IACT arrays - high performance and great potential

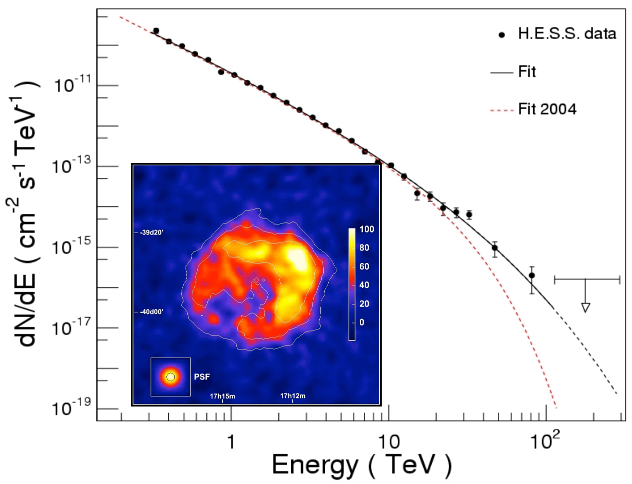
- huge detection areas, potentially >> 1 km^2
  => huge photon statistics coupled with
- good (~10 to 20%) energy resolution and
- good angular resolution (down to 1-2 arcmin)
- relatively large FoV (5 to 10 degree)

=> spectrometry, morphology, timing, surveys

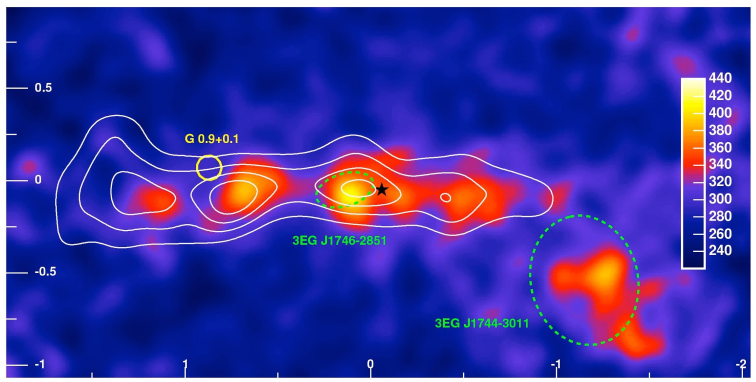
- sensitivity for point-like sources down to 10^{-14} erg/cm^2s
  (impressive by standards of modern astronomical instruments!)

- energy coverage from 10 GeV to 1 PeV (5 decades!)
  using the same technique ! (unique in astronomy)

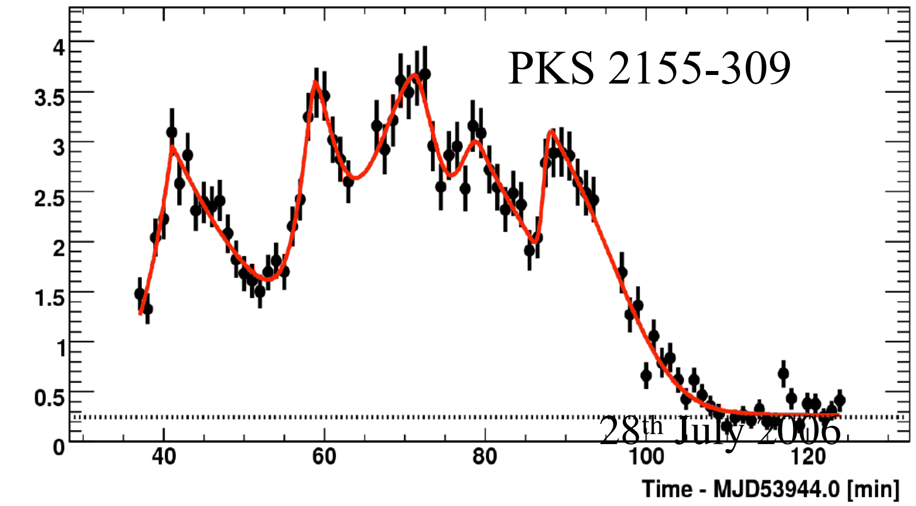
IACT Arrays : nice performance



TeV image and energy spectrum of a SNR



resolving GMCs in the CMZ
200pc region of Galactic Center



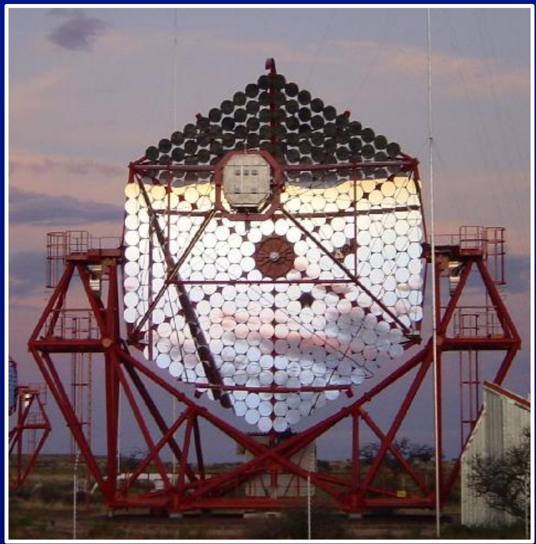
variability of TeV flux of a blazar on minute timescales

multi-functional tools: *spectrometry / temporal studies / morphology / surveys*

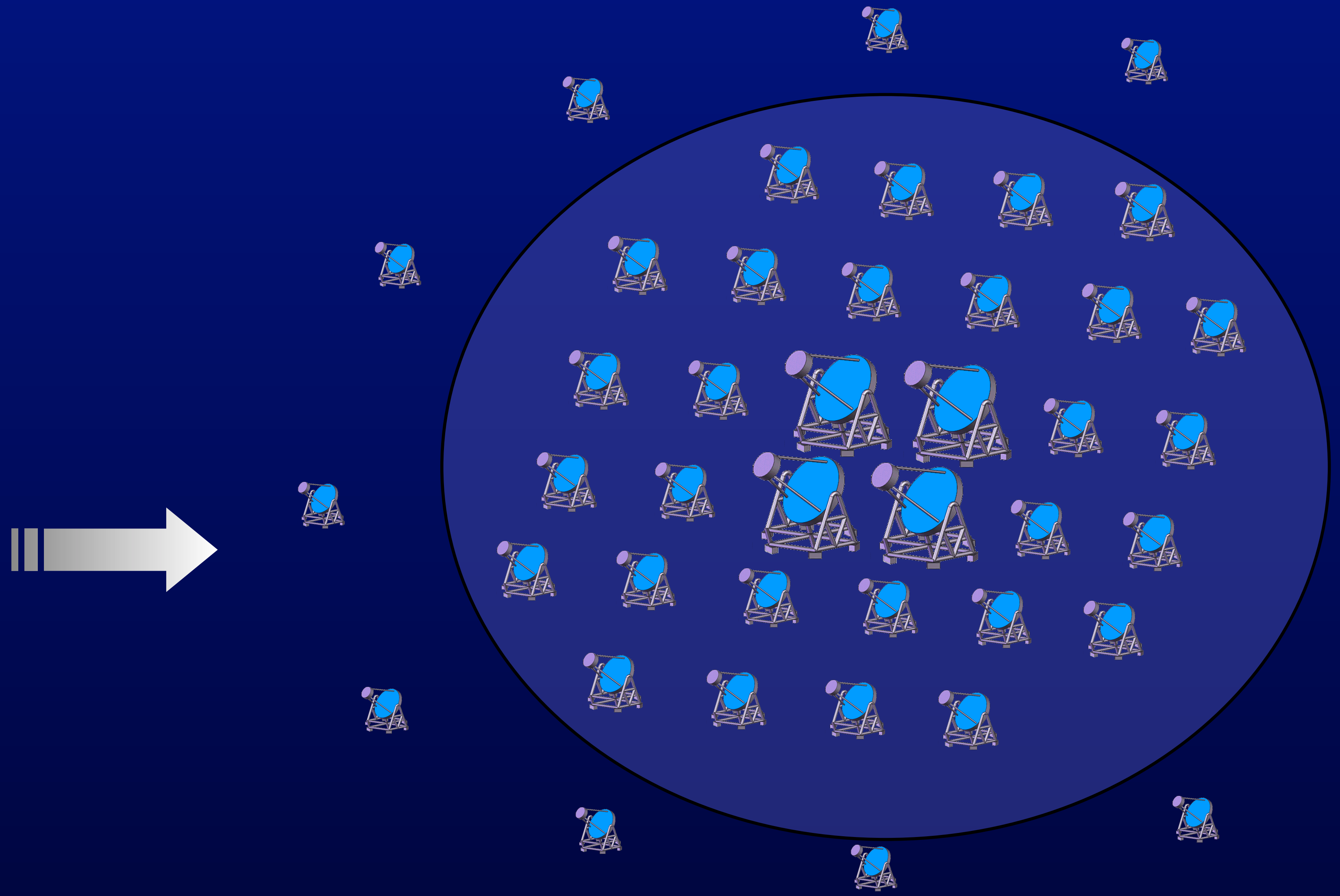
✓ extended sources: *from SNRs to Clusters of Galaxies*

✓ transient phenomena *μQSOs, AGN, GRBs, ...*

Galactic Astronomy | Extragalactic Astronomy | Observational Cosmology



from *HEGRA/HESS/MAGIC/VERITAS* to CTA…



- an order of magnitude better sensitivity
- broader energy coverage: 10^{10} to 10^{15} eV
- angular resolution down to 1-2 arcmin
- energy resolution 5 to 25 percent
- larger (up to 6-8 degree FoV)

major scientific goals of **CTA**:

full realization of the great potential of Stereoscopic Arrays of Imaging Atmospheric Cherenkov Telescopes as powerful multifunctional tools

(1) to explore most energetic/violent phenomena in Universe through studies of temporal, spectral and morphological properties of sources of HE&VHE gamma-rays in the energy range 30 GeV - 300 TeV;

(2) to explore fundamental laws of physics in extreme environments characterized by huge gravitational and magnetic fields, relativistic shocks, highly turbulent plasma;

(3) to address key issues of Astroparticle Physics (indirect search for Dark Matter, search for possible violation of the Lorentz invariance) and Cosmology (probes of intergalactic radiation and magnetic fields), sources with redshifts of non-cosmological origin, etc…

with two planned arrays in the Northern and Southern Hemispheres, CTA will cover the entire sky. Regarding the performance, CTA has two major objectives:

(i) significant improvement (compared to current arrays) of the flux *sensitivity, angular and energy resolutions; larger FoV*

(ii) extension of the energy domain in both directions: *down to 20-30 GeV and well beyond 100 TeV.*

large, medium and *small* size telescope sub-arrays - **LSTs, MSTs, SSTs,** will operate together as *open access observatory*. The telescope designs are essentially completed, and advanced prototyping is underway; while feasibility of the telescope construction is very high, controlling of large number telescopes and the handling of huge datasets are two major challenges. Installation of first telescopes - soon! Construction period - five years with plans for early operation of partial arrays

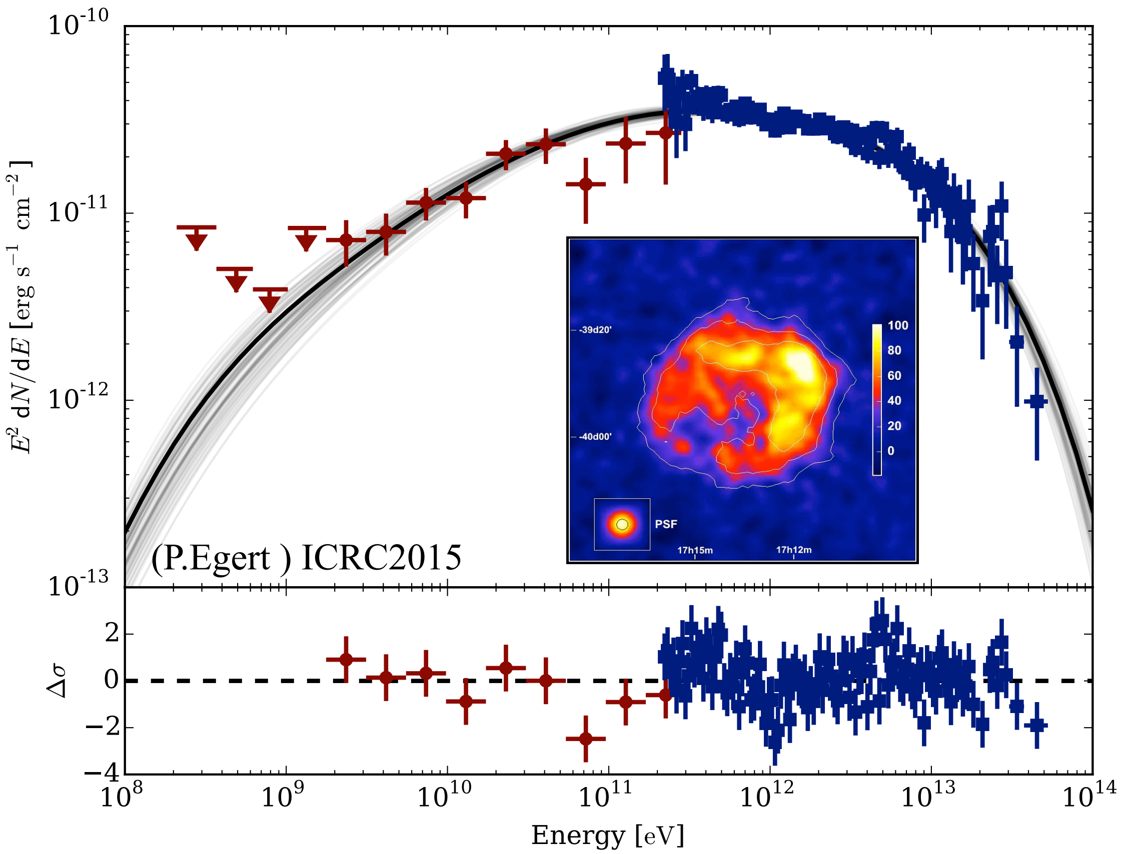
some highlights

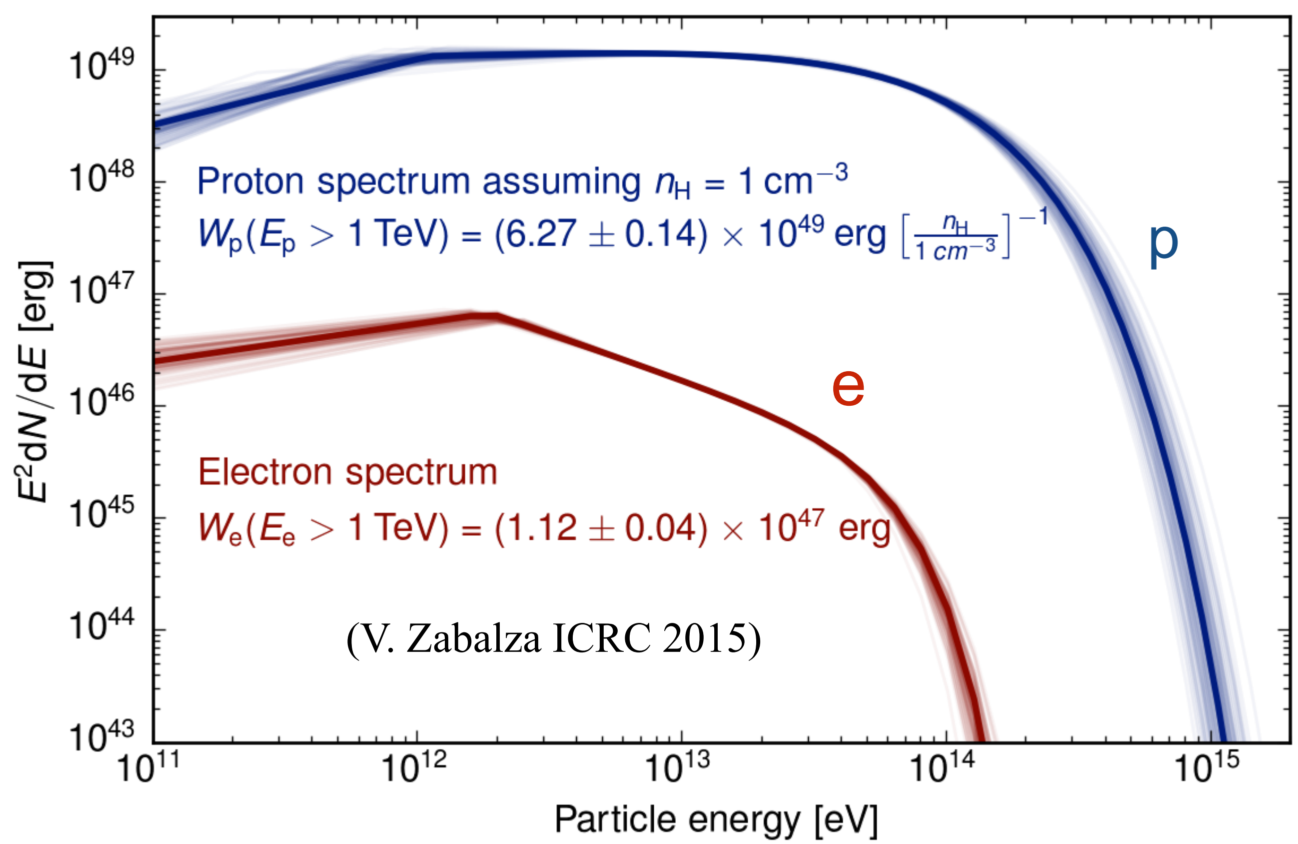
Probing the distributions of accelerated particles in SNRs

HESS measurements

derived spectra of e and p

RXJ 1713

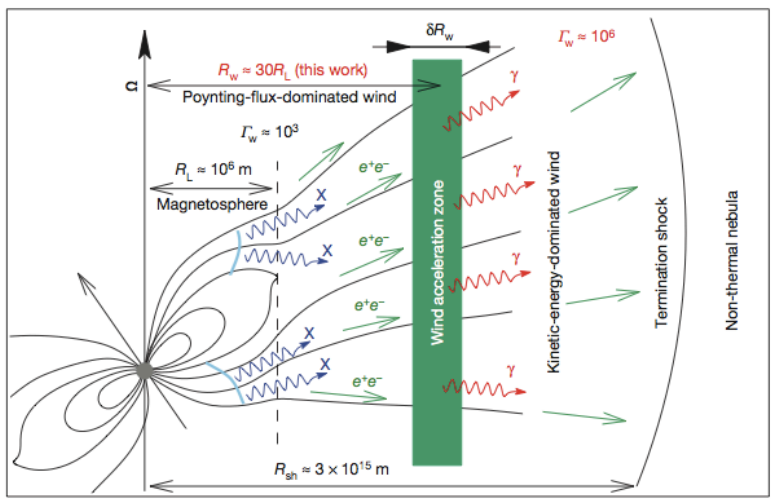


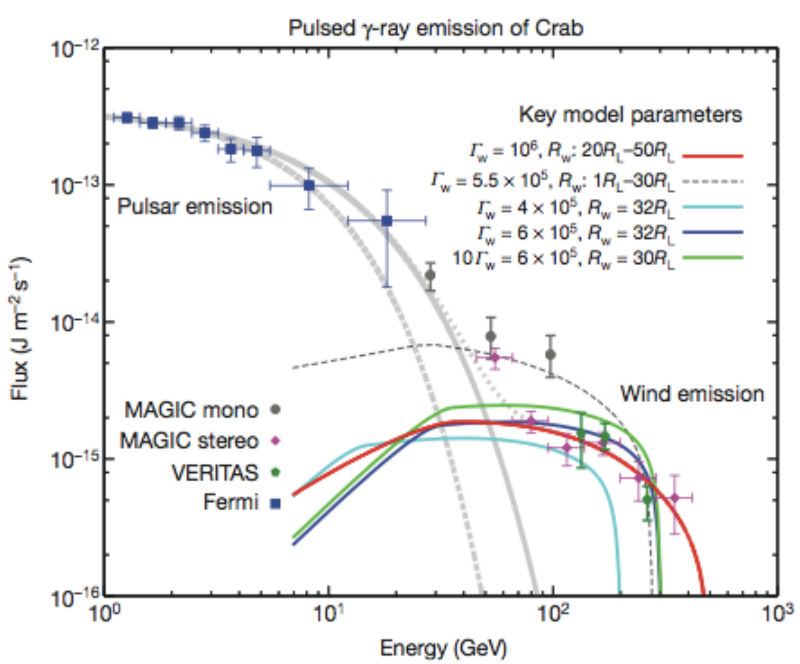


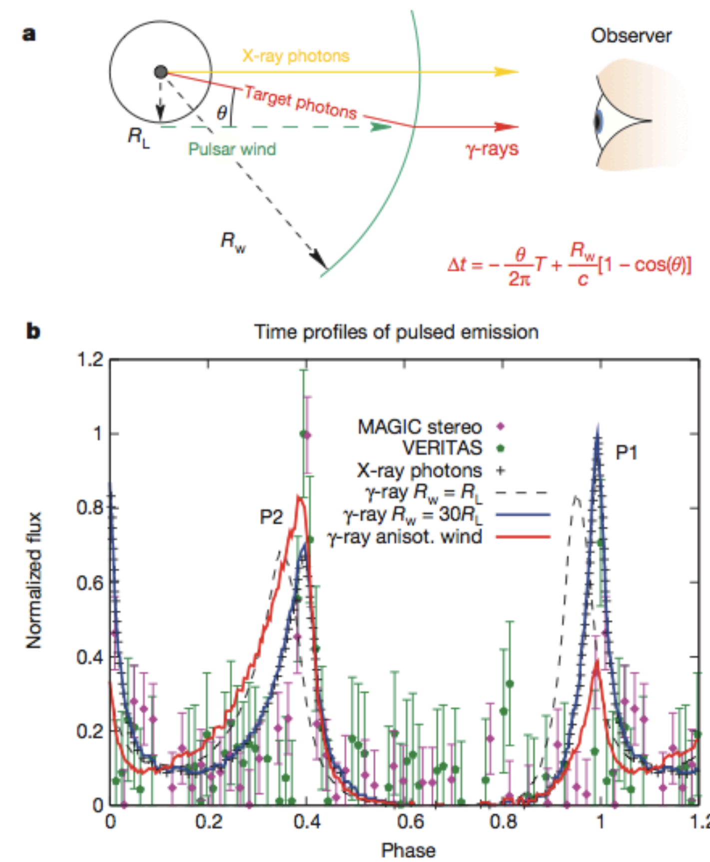
CTA can do much better; extension of measurements to >100 TeV
a few arcmin (sub-pc) structures
particles beyond the shell

probing the paradigm of Pulsar Magnetosphere-Wind-Nebula

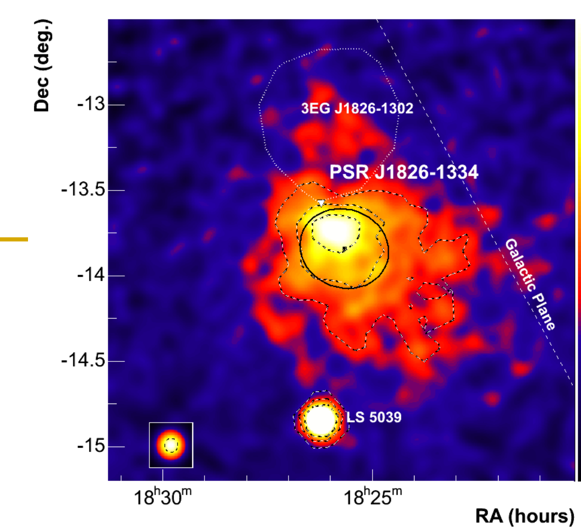
Pulsed VHE gamma-rays from the Crab – Comptonization of the cold ultrarelativistic pulsar wind?



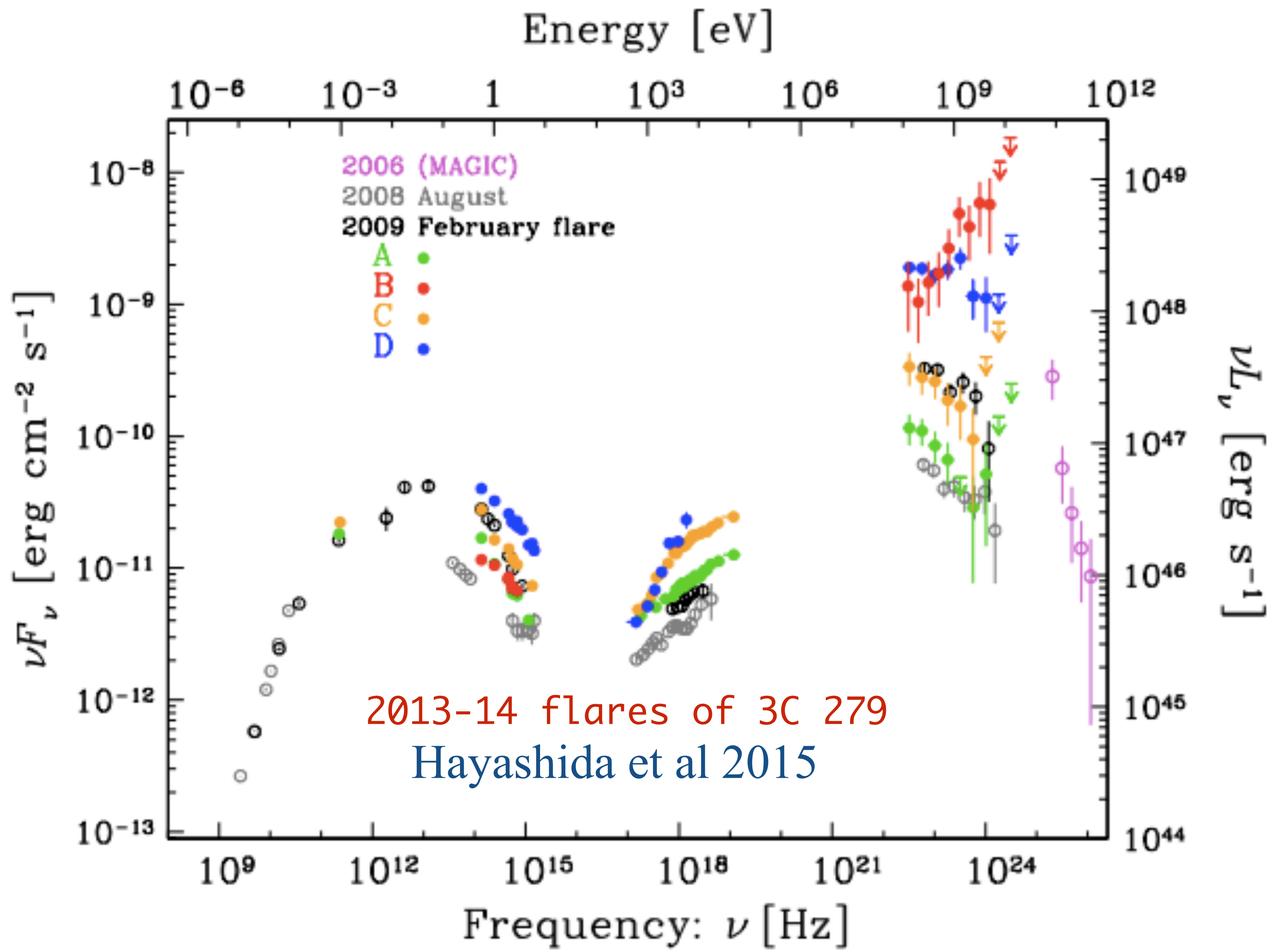




$\Gamma \sim 10^6$; R ~ 30 L



highlights: *probing the variability and energetics of AGN*



Fermi LAT: variability t~ 7 10^3 sec vs t_{bh} ~ (3-8) 10^3 sec !

What CTA *can* do

these days, proposing any ground-based gamma-ray instrument one should take into account that CTA is going to be a very powerful multifunctional instrument for effective morphological, spectrometric and temporal studies, operating over 4+ energy decades, at energies as low as 30 GeV and as large as 300 TeV

because of its superior sensitivity and despite the (relatively) small FoV, CTA telescopes can provide effective population studies based on surveys of specific regions of the sky (like the Galactic Disk) and unbiased probes of non-variable source populations, (e.g. SNRs, PWNe, X-ray binaries , Starburst Galaxies, Radio Galaxies, Clusters of Galaxies, etc.)

almost everything!

What CTA *cannot* (effectively) do

- search for solitary VHE events
- continuous unbiased monitoring of episodic/transient events
- study of very large diffuse structures

(more effectively) *can be done* by
large FoV high-altitude particle detector arrays

my opinion regarding
the role and uniqueness of large FoV particle detector arrays

they *cannot* and therefore should not try compete with CTA on most of topics indicated before, but they can be *complementary* and *unique* for search for solitary gamma-ray events/phenomena and for monitoring of transient flares of AGN, microquasars, etc.

for these two objectives *the disadvantages* of particle arrays compared to IACT arrays (poor angular resolution, limited flux sensitivity, poor energy resolution) are *less essential* than the big advantage - the large FoV.

if so, the highest priority should be given to the *lowest possible energy threshold* - for different reasons, in particular

- to provide adequate photon fluxes given the limited (compared to CTA) collection areas (realistically, <0.1 km^2)

- variable can be only compact objects - most of them (e.g. powerful AGN and the binary systems) are typically not transparent for TeV photons at energies above 100 GeV

- for sources at cosmological distances ($z>2$-3) the IGM is not transparent for gamma-rays at > 100 GeV

very-high altitude very large IACT arrays
as multi-GeV Timing Explores (concept "5@5")

or an aggressive attempt to enter the
satellite-based detector's domain

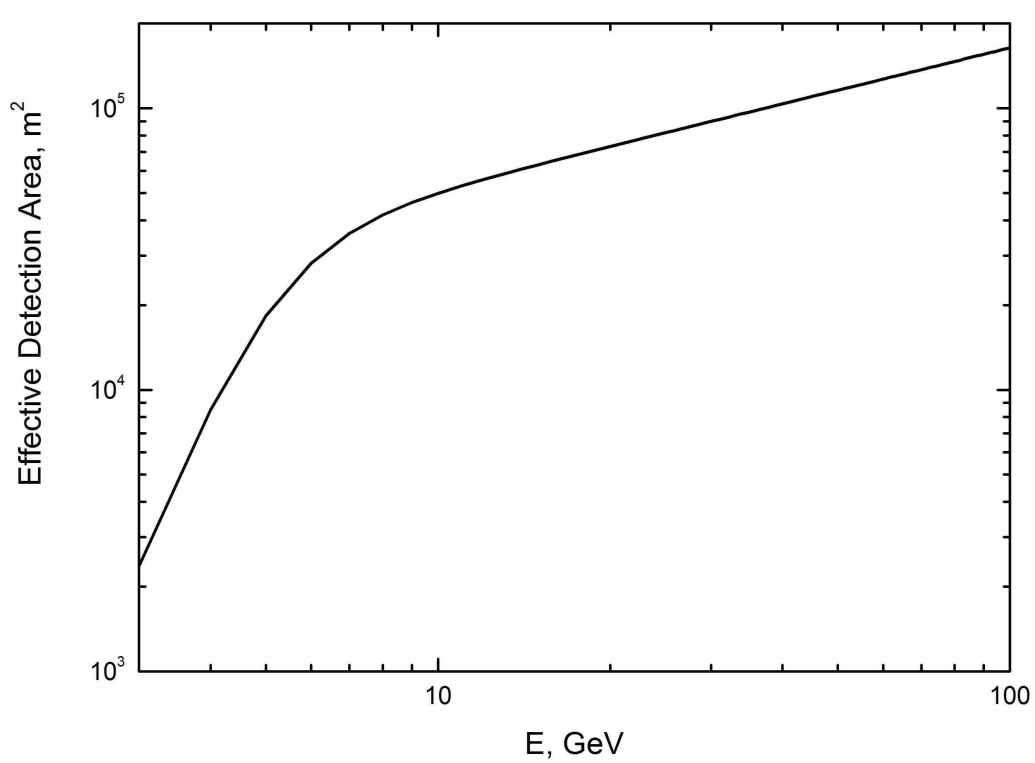
energy threshold of LSTs around 20-30 GeV is rather conservative:
it can be, in principle, reduced down to 5 GeV or even less

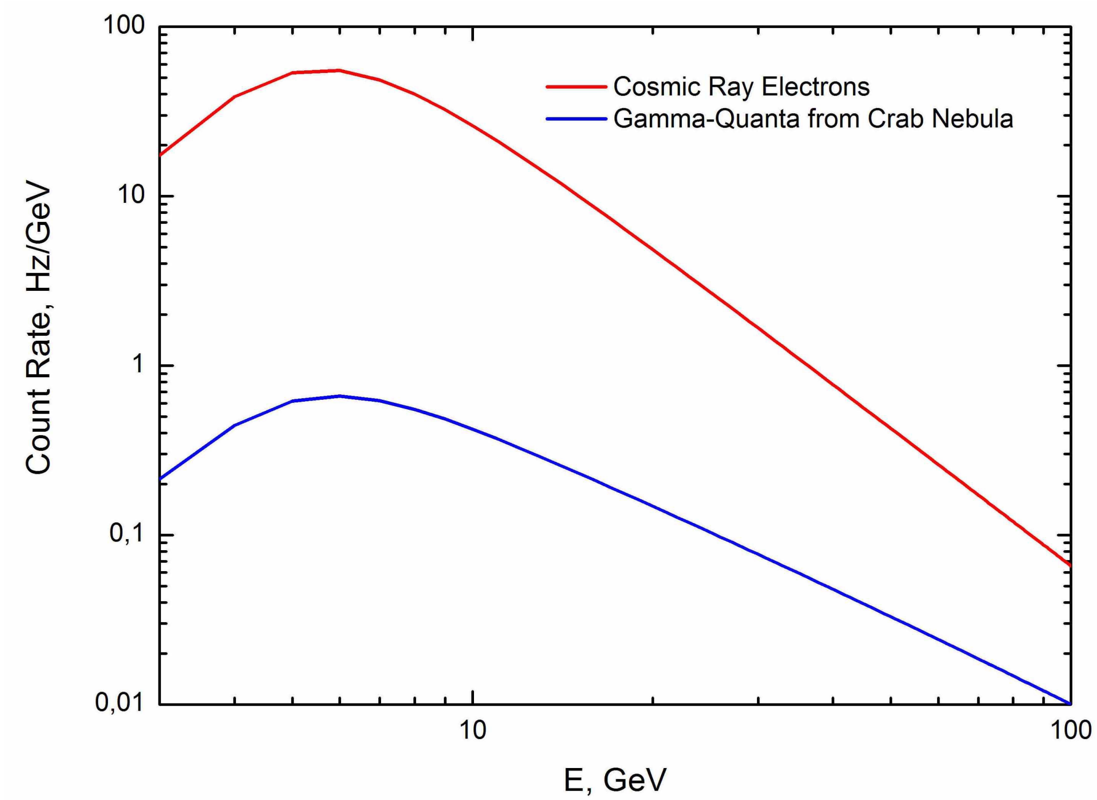
is it so important/critical issue? YES! (for specific sources/topics)

our Russian colleagues are working in that direction - ALEGRO project:
two steps: ~4 km a.s.l. in Caucasus/Russia, 5km+ - ALMA site

in my view - huge potential for study of physics of variable sources
like Microquasars, AGN, GRBs …

ALEGRO





although significantly poorer performance (angular&energy resolutions, p/gamma separation power, etc.) - high fluxes at GeV energies and very large collection ares can provide unique probes of temporal characteristics of variable/transient phenomena

Summary:

future of ground-based gamma-ray astronomy - *very bright* !

- solid predictions (based on the current data and theory)
- exciting expectations which can dramatically change our present understanding of the nonthermal Universe
- solid plans for realization of CTA
- large FoV&low Energy-Threshold particle arrays: complementary to CTA with huge discovery potential