Prospects for Studies of the local Universe with CTA

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on behalf of the CTA Consortium

with special input from

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Ginzburg Conference on Physics, Lebedev Physical Institute, Moscow,
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OUTLINE

What is CTA?

Performance capabilities

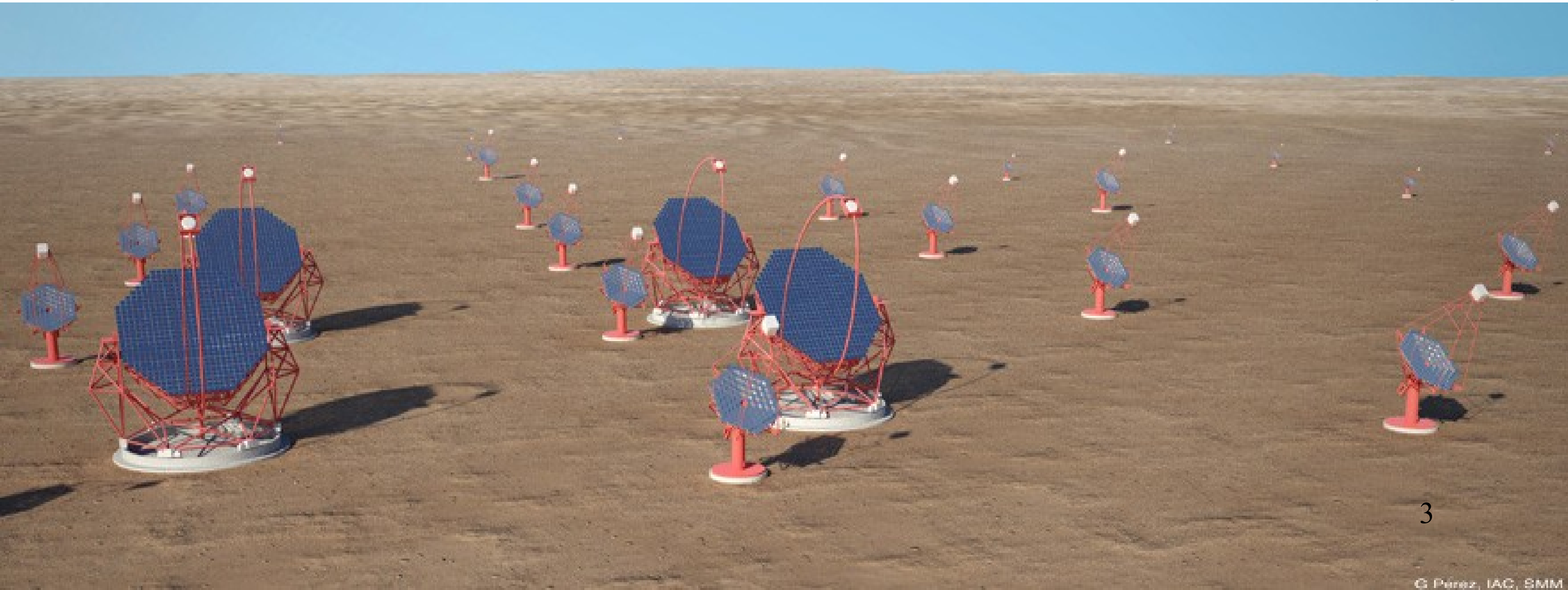
Physics goals

Summary

The Cherenkov Telescope Array (CTA): the future in VHE gamma-ray astronomy

The CTA project is an initiative to build the next generation ground-based very high energy gamma-ray instrument

http://www.cta-observatory.org



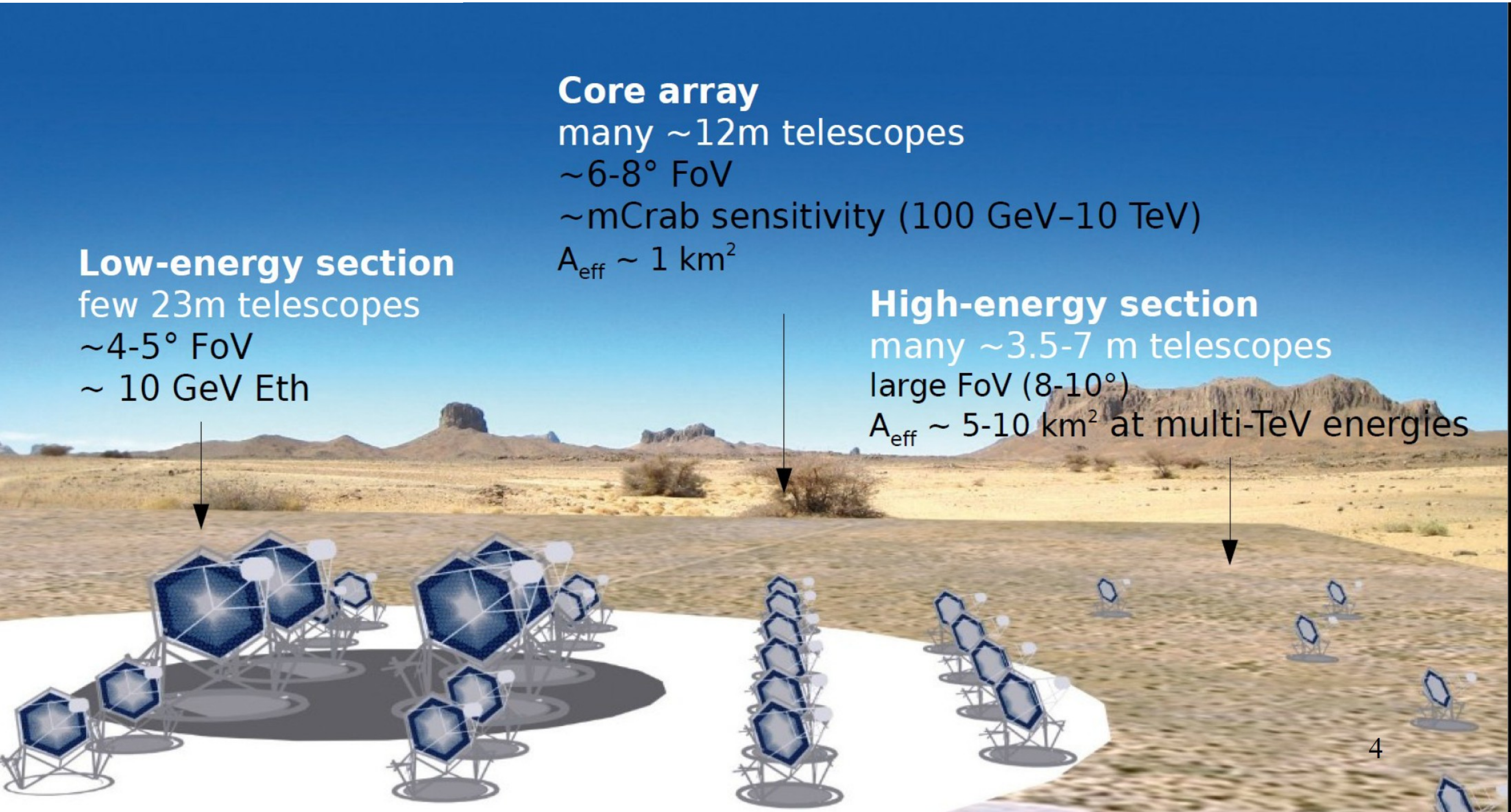
CTA and Lebedev Physical Institute

The Nobel Prize in Physics 1958
"for the discovery and the interpretation of the Cherenkov effect".

P.A. Cherenkov I.Y. Tamm I.M. Frank

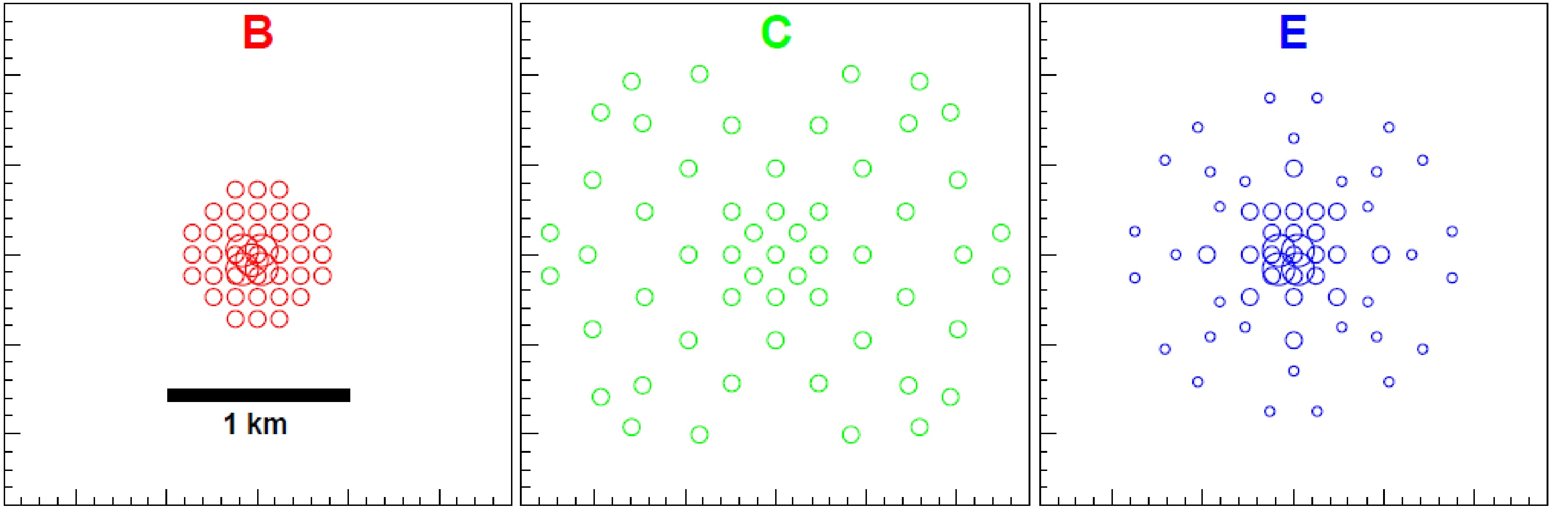
The Cherenkov Telescope Array: open observatory

„*Design concepts for CTA*", 2011, ExA, 32, 193



Possible CTA configuration

Selection of different possible sub-arrays (here three examples)



Densely packed array of 12 m and 24 m telescopes
→ focus on low E

Wide spread array of 12 m telescopes
→ focus on mid and high E

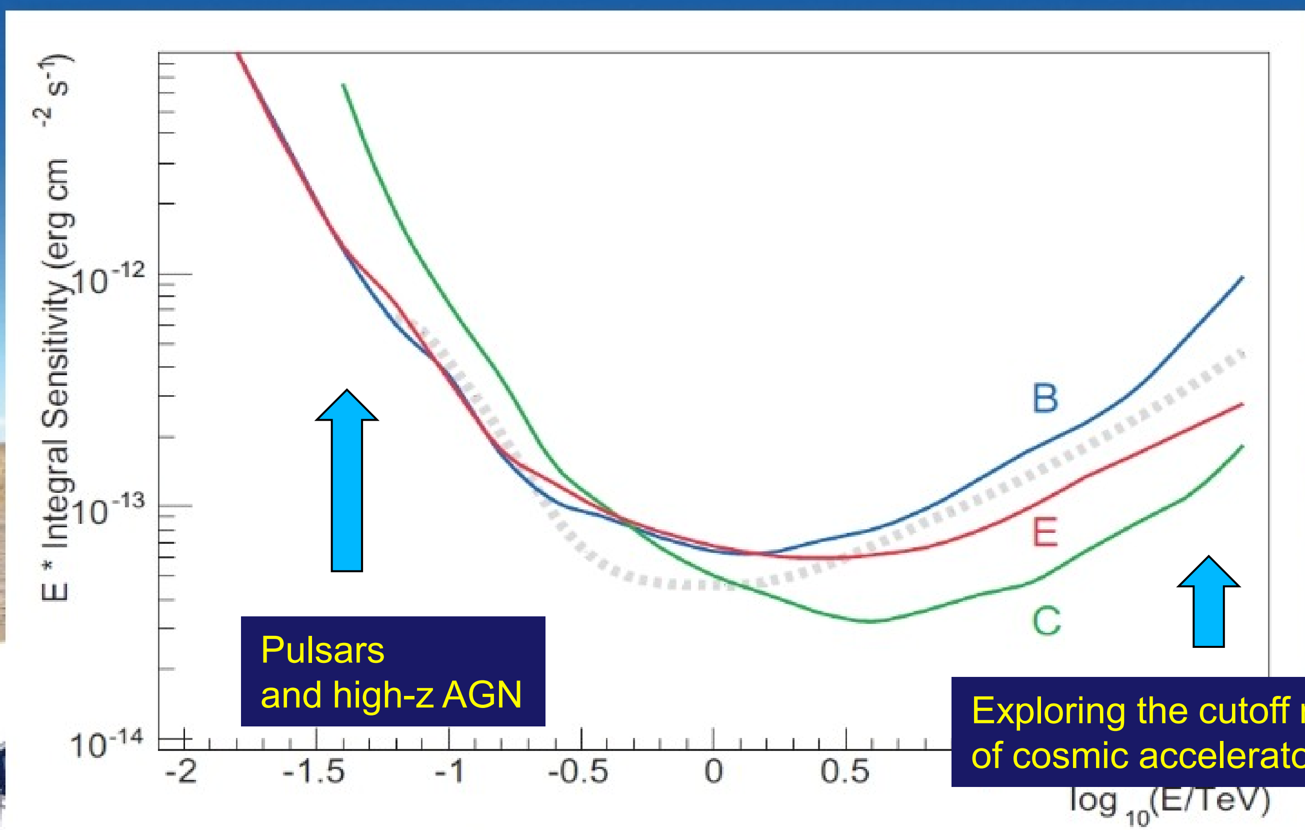
Mixed array of 7, 12 and 24 m telescopes
→ Balanced sensitivity over large E-range

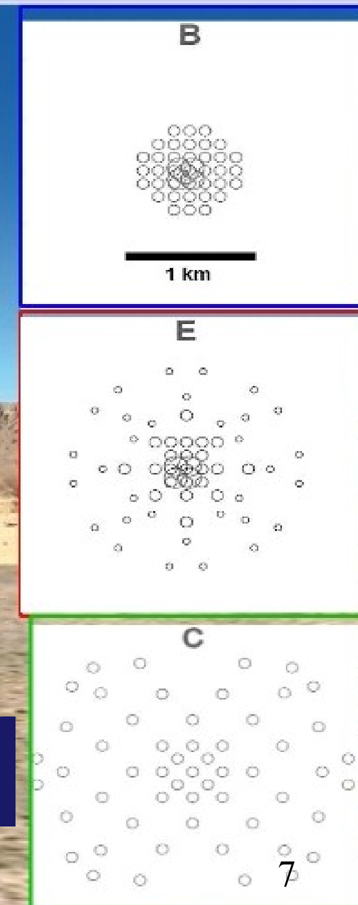
G. Hermann

The Cherenkov Telescope Array (CTA): Goals

"Design concepts for CTA", 2011, ExA, 32, 193

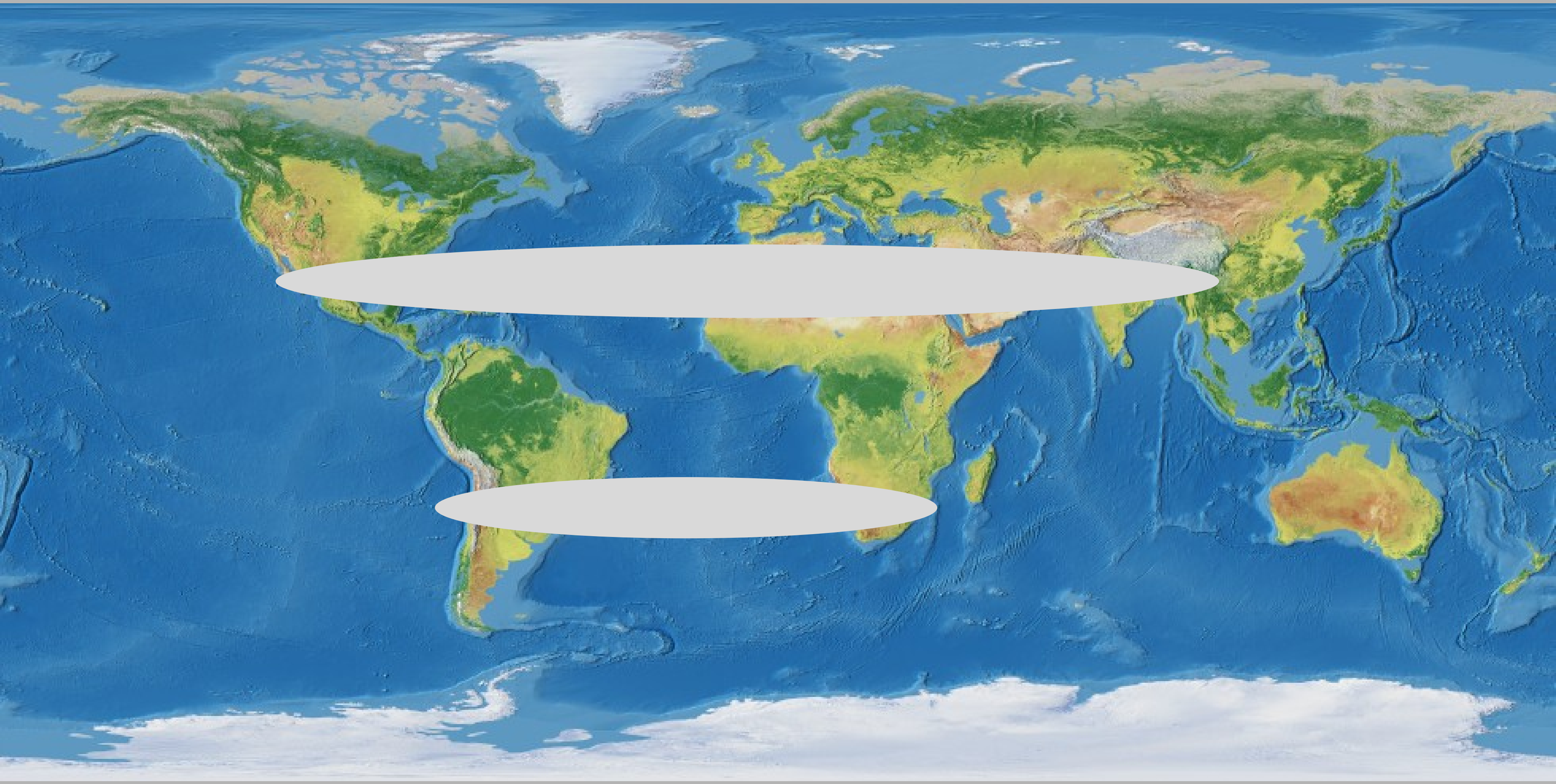
x10 sensitivity (100GeV-10 TeV)	~mCrab, 5σ, 50h @ TeV	~1000 sources. Population studies



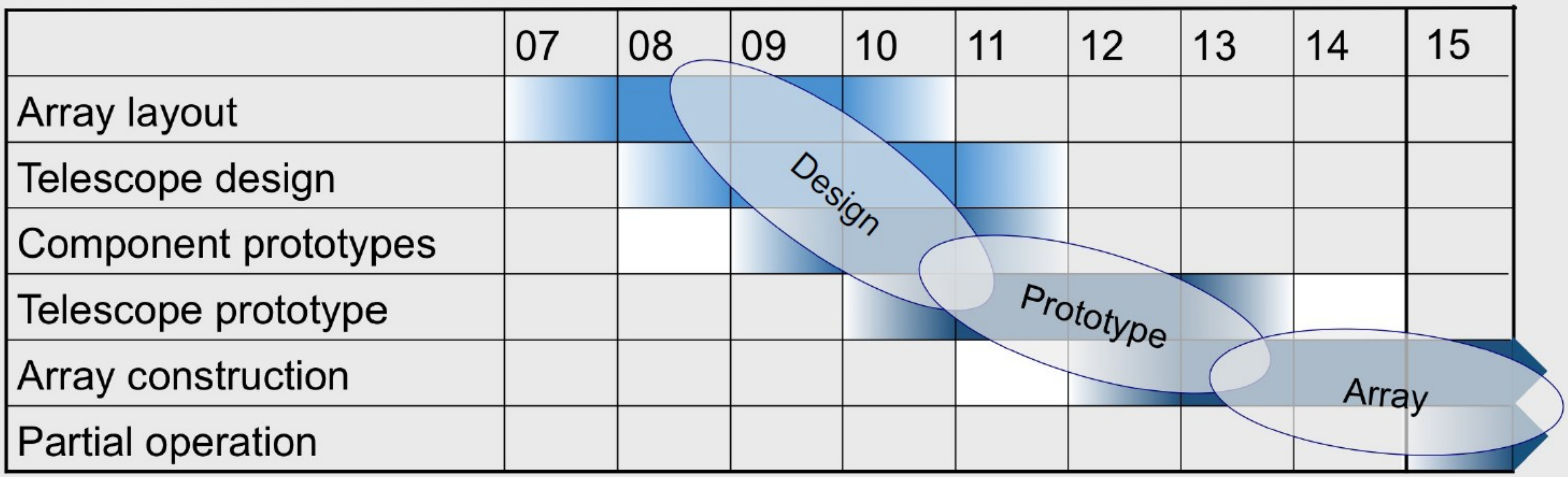


Photomontage from ASPERA

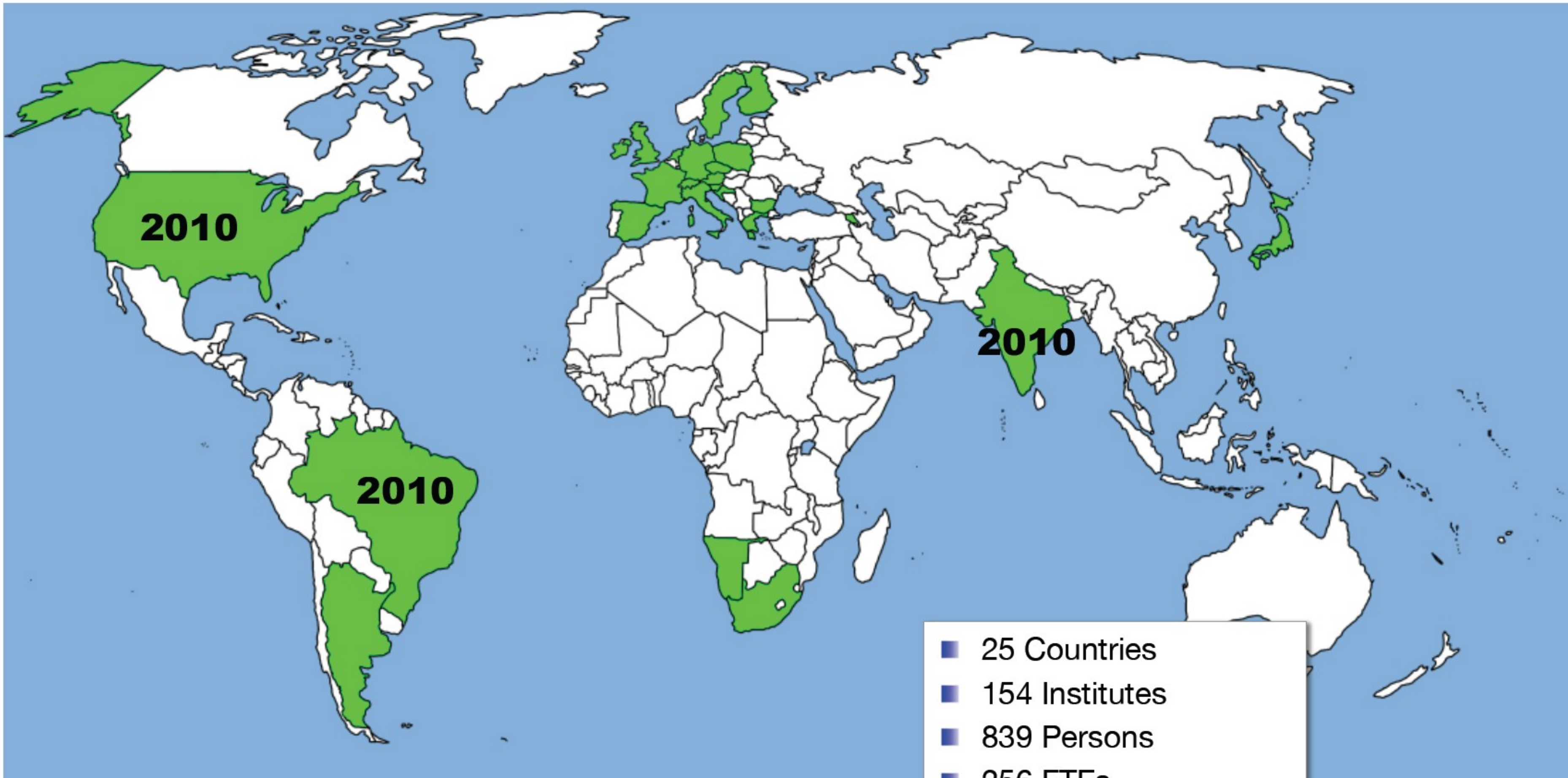
An open observatory with two sites for all-sky coverage – Northern Array & Southern Array - operated by one consortium



Tentative timeline towards the *CTA* observatory



The CTA world map



- 25 Countries
- 154 Institutes
- 839 Persons
- 256 FTEs

more want to join

Main characteristics of CTA

High sensitivity - 4 orders of magn. dynamic range in flux (max,min)

Wide spectral range - from 50 GeV to 100s of TeV

Angular resolution up to 0.02 deg, 10-20" source localization

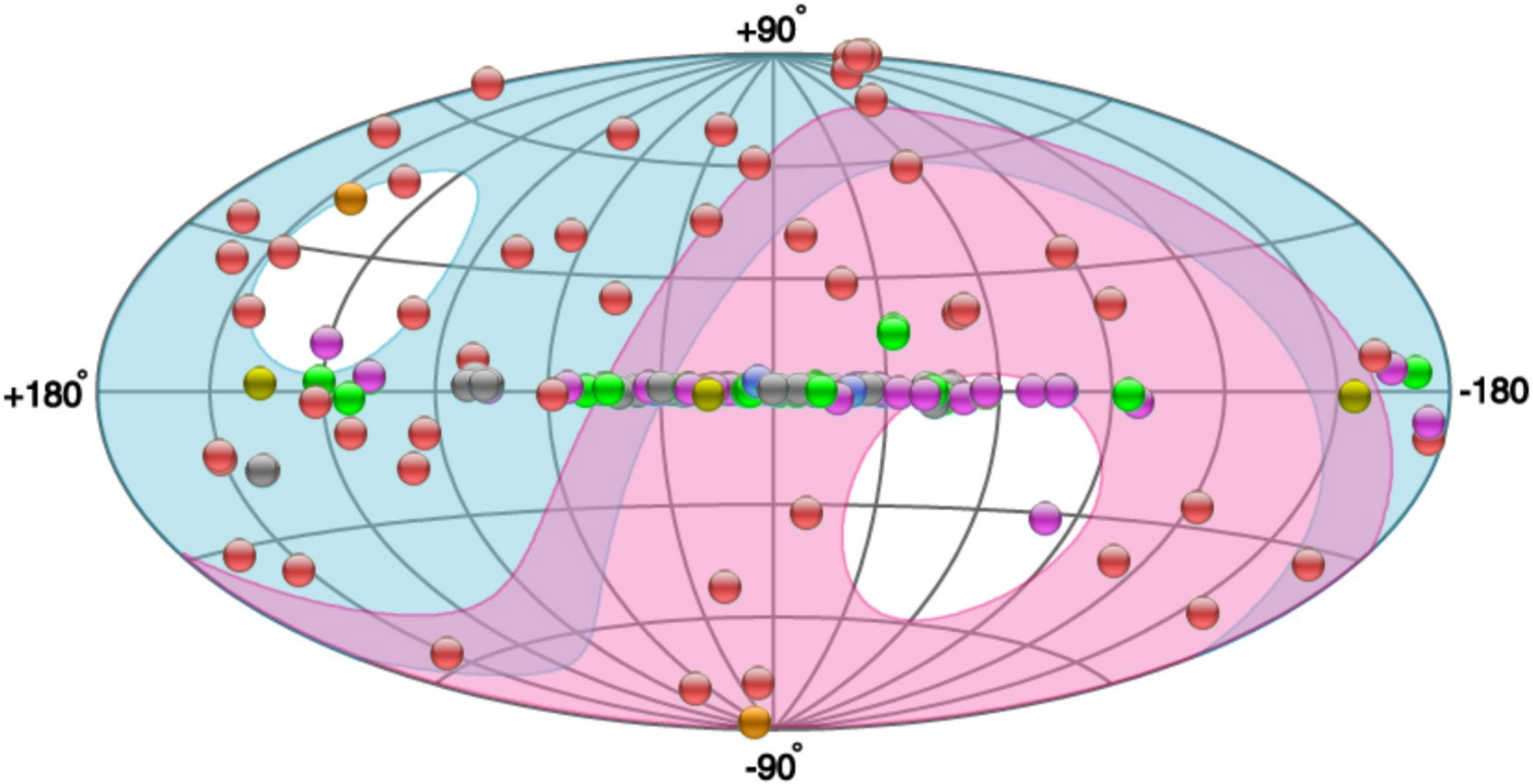
Large field of view – survey and serendipitous discoveries of AGN, GRB, other

Surveying capabilities – full-sky survey at O(1%) Crab in ~ 1 year

Monitoring capabilities – possible use of sub-arrays for monitoring e.g. AGN

In 1990 – one confirmed VHE source !

In 2011 – 75 Galactic sources, 47 extragalactic (from the TeVCat catalog, July 2011)

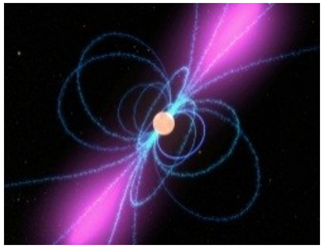


Expectations for CTA: ~1000 sources

CTA science impact

- **Cosmic rays: origin and they impact in the Universe**:
  - Particle accelerators: PSRs, PWN, SNRs and γ-ray binaries.
  - Effects on the environment: from massive SFR to starburst galaxies.
- **Nature of black hole particle accelerators**:
  - AGN, blazars and radio galaxies.
  - EBL, galaxy clusters, GRBs.
- **Dark matter search and physics beyond the standard model**:
  - Dark matter and their annihilation signatures
  - Lorentz invariance tests
  - New observational signatures that might change our understanding of the Universe.

Pulsars physics goals with CTA



- Pulsed VHE emission from young pulsars

- Pulsed VHE emission from millisecond pulsars

- Unpulsed VHE emission from Globular Clusters

PWNe physics goals

- Maximum/minimum resolvable size

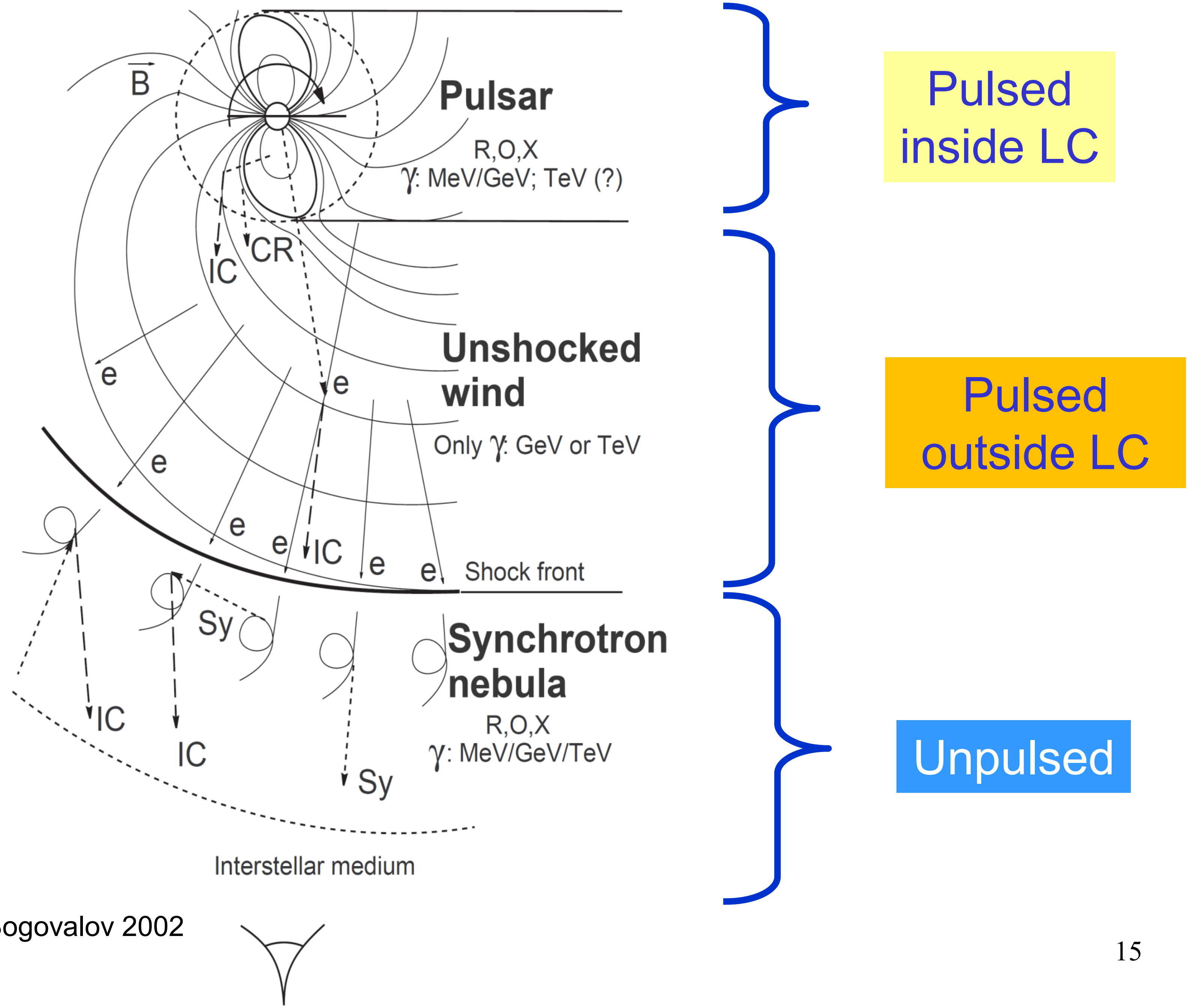
- Electron cooling effects

- Composite SNRs

- Population studies

- Energy & morphology modelling

Radiation from a **Pulsar-wind-nebula** complex

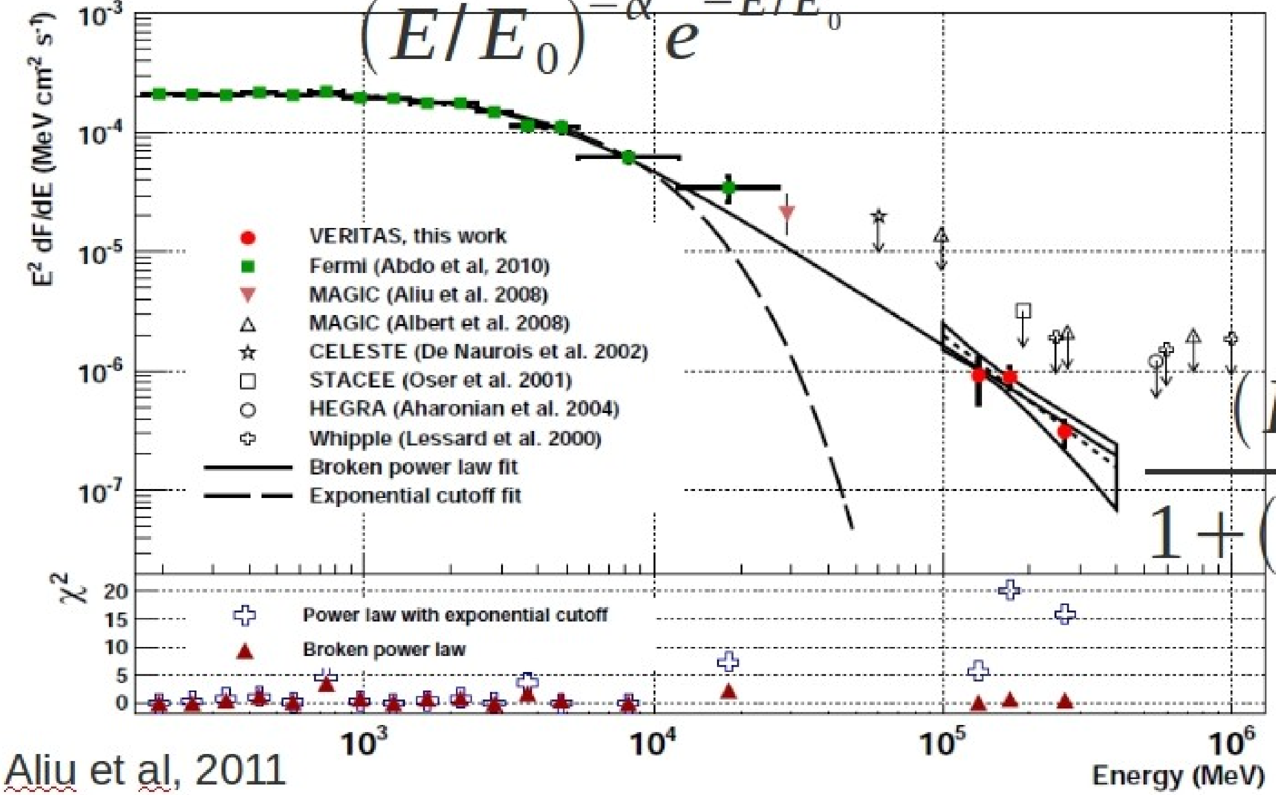


Aharonian, Bogovalov 2002

Pulsars at Very-High Energies: Crab (PSR J0534+2200)

- Fermi 1st γ-ray pulsar catalog (2010): Exponential cut-off
- VERITAS Crab pulsar (2011): broken-power law

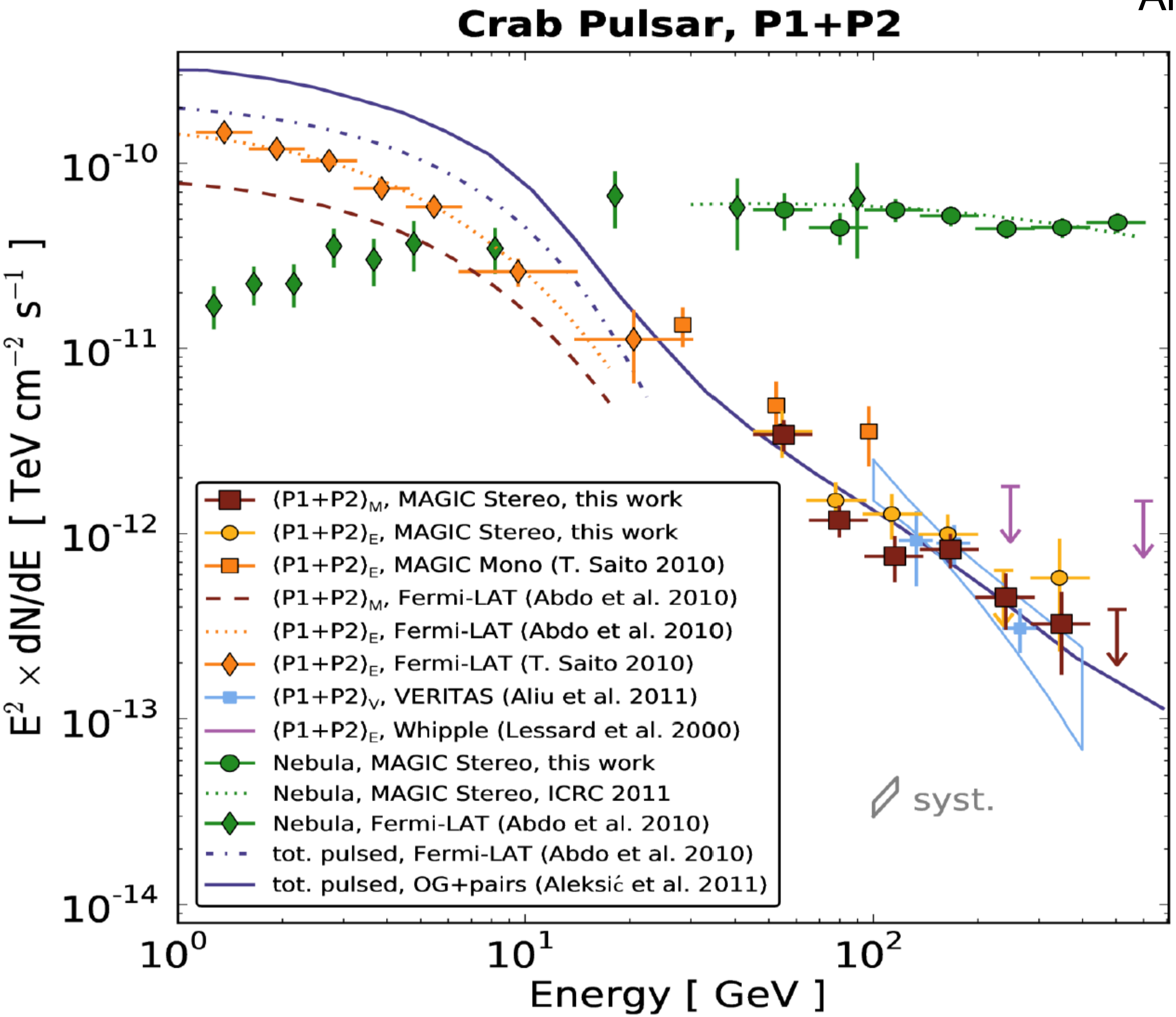
$$(E/E_0)^{-\alpha} e^{-E/E_0}$$



$$\frac{(E/E_0)^{-\alpha}}{1+(E/E_0)^{-\alpha+\beta}}$$

Aliu et al, 2011

Aleksic et al. 2012



Fermi LAT : ~ 15 Globular Clusters

47 Tucanae

Abdo et al. 2009; Webb & Knoedlseder 2010

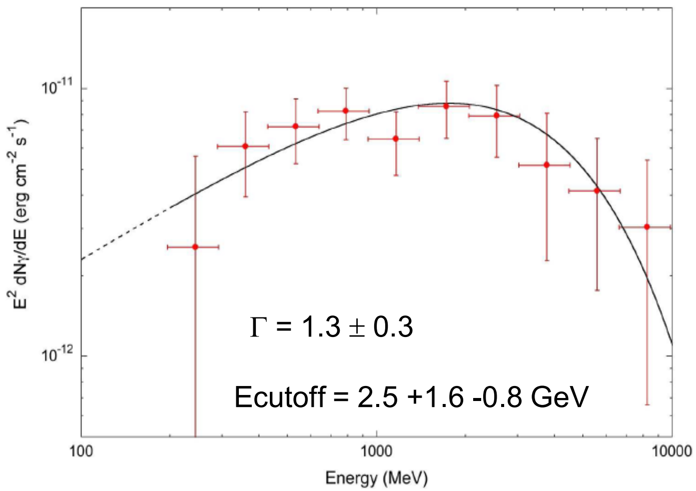


FIG. 2: Spectral energy distribution ($E^2 dN_\gamma/dE$) of the Fermi source seen toward 47 Tuc. The solid line shows the fit of an exponentially cut-off power law obtained for the energy ... dashed line indicates t... ...eV.

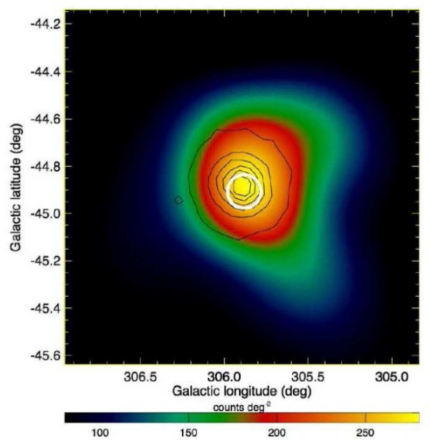


FIG. 1: Fermi LAT gamma-ray image (200 MeV to 10 GeV) of a 1.5° × 1.5° region centered on the position of 47 Tuc. The map was adaptively smoothed by imposing

Terzan 5

Kong et al. 2010

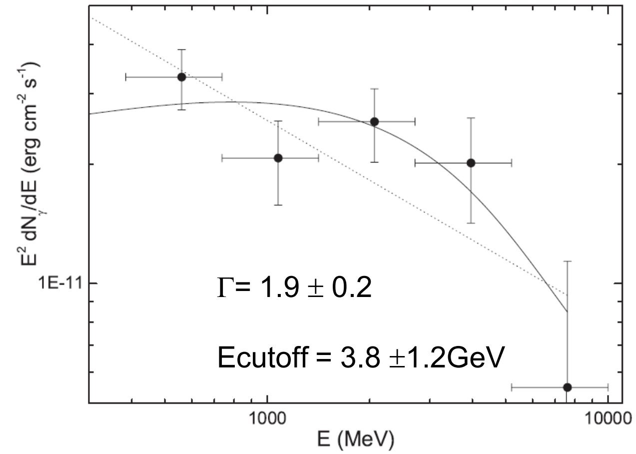
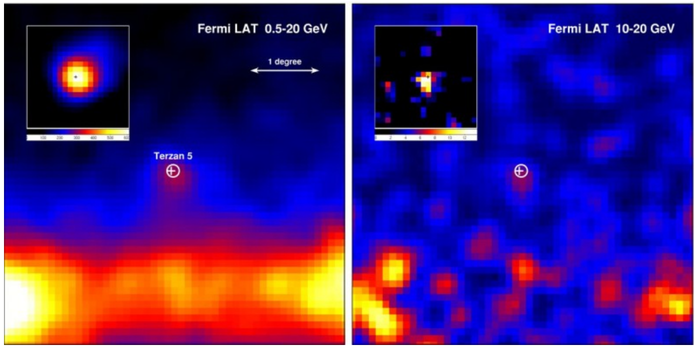
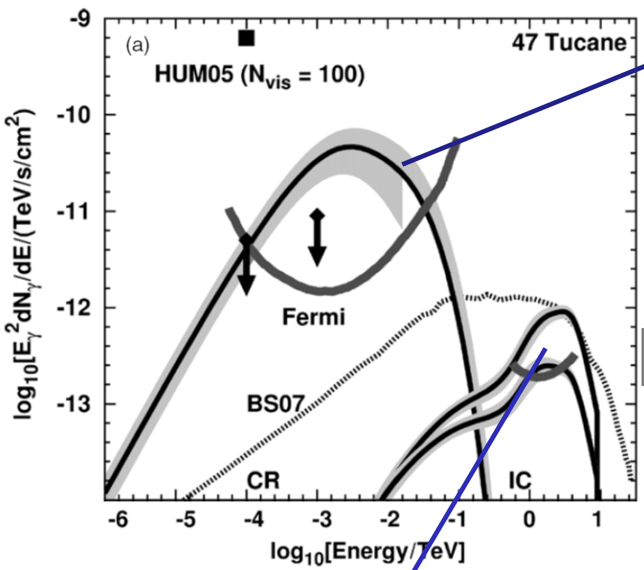


Figure 2. *Fermi*/LAT spectrum of Terzan 5. The solid line is the best-fit exponential cutoff power-law model obtained by *gtlike*. The dotted line is the best-fit simple power-law model. The error bars are statistical only.



Globular clusters are expected to be the VHE sources



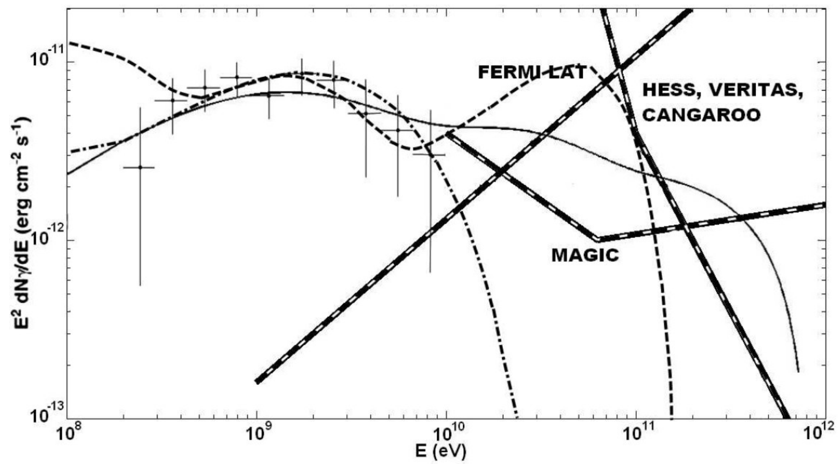
Pulsed CR

H.E.S.S. UL

Unpulsed ICS:
B=10 μG,
B=1μG.

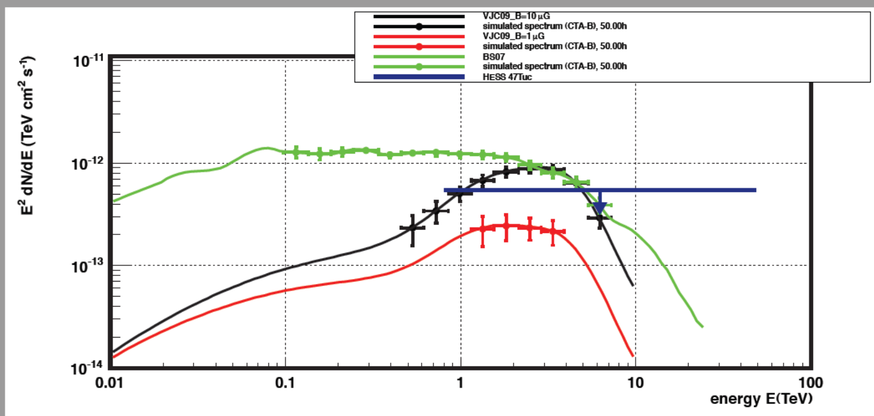
Venter et al. 2009

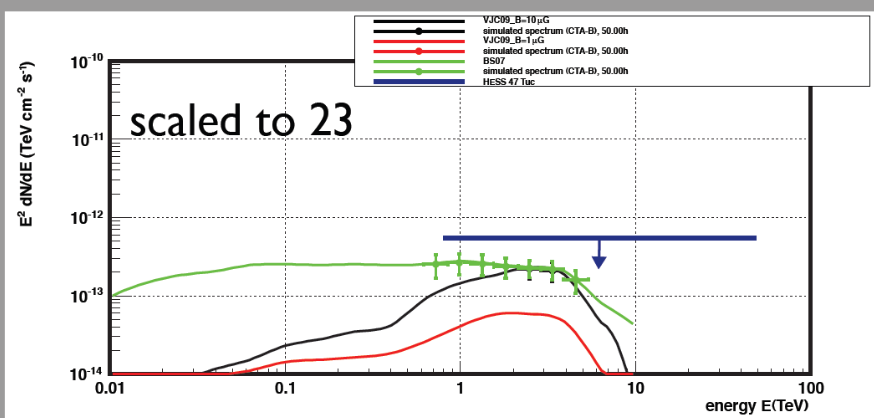
All-unpulsed ICS gamma-ray emission model for GC 47 Tuc.



Cheng et al. 2010

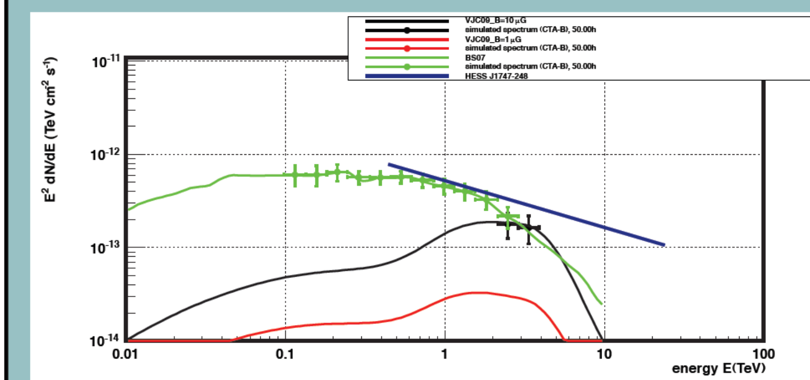
47 Tuc for 100 mpsr





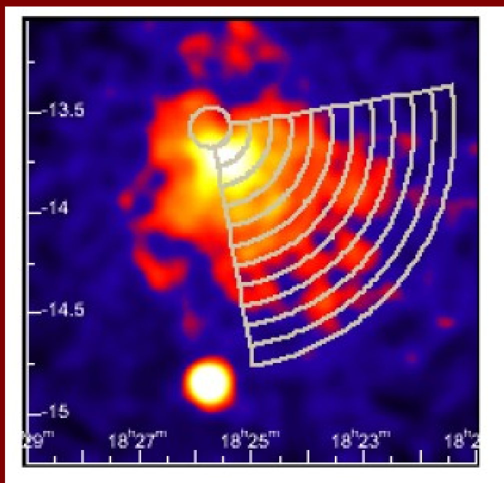
- Best candidates: Ter 5 and 47 Tuc
- Models from Venter et al 09 and Bednarek et al 07

Ter 5 for 100 mpsr



Cooling Effects in PWN

- HESS J1825-137 used as prototype (with configuration B and E)
- Simulation of surface brightness and spectral index distribution: wedges



We can also simulate the capability of CTA to distinguish different spectral indices for the same surface brightness distribution. In 20 hours of observation it is possible to distinguish among scenarios of synchrotron cooling or adiabatic cooling (constant spectral index).

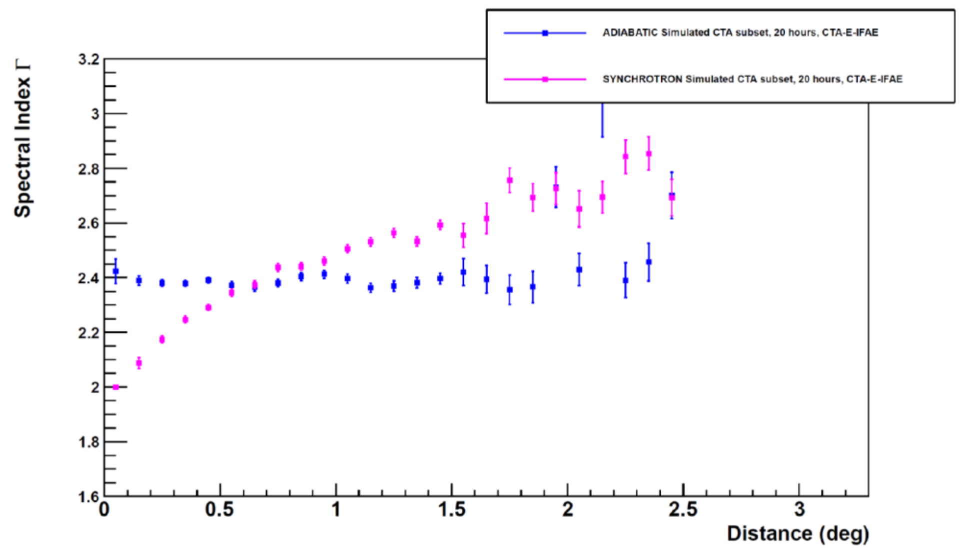
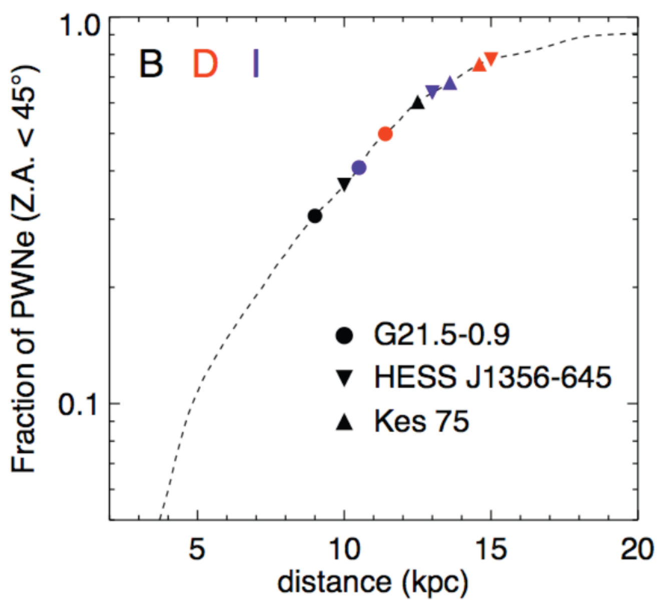
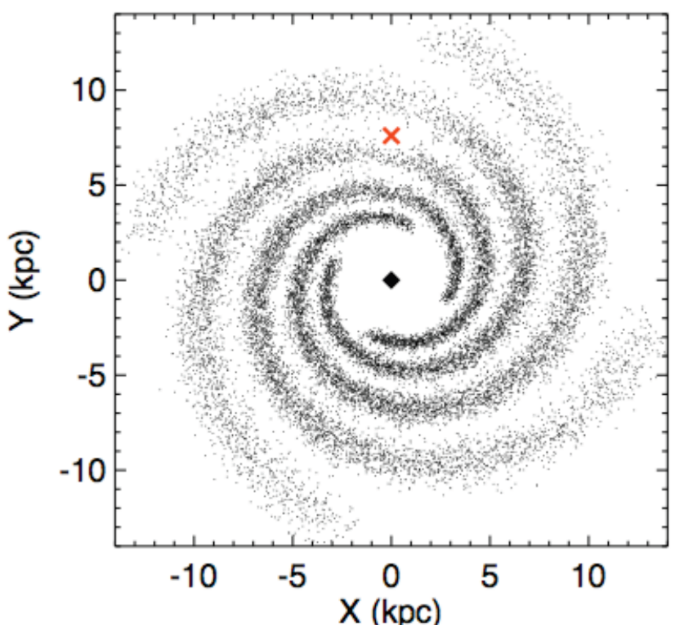


Figure 11: 20 hours of observations using configuration E. The two simulated cases, synchrotron or adiabatic cooling show a clear distinguishable spectral index distribution

Population Studies of PWN

- G21.5-0.5, HESS J1356-654 & Kes 75 are used as prototype
- Horizon of detectability: maximum distance to obtain σ=5
- Using a model of the Galactic source distribution -> fraction of PWNe detectable f_{pwn}=(0.4-0.8)
- If they shine for 40 kyrs: N_{pwn}~800 f_{pwn} (τ_{pwn}/40 kyr)(ν_{psr}/2)~(300-600)





Gamma-ray signatures of CR acceleration, propagation and confinement

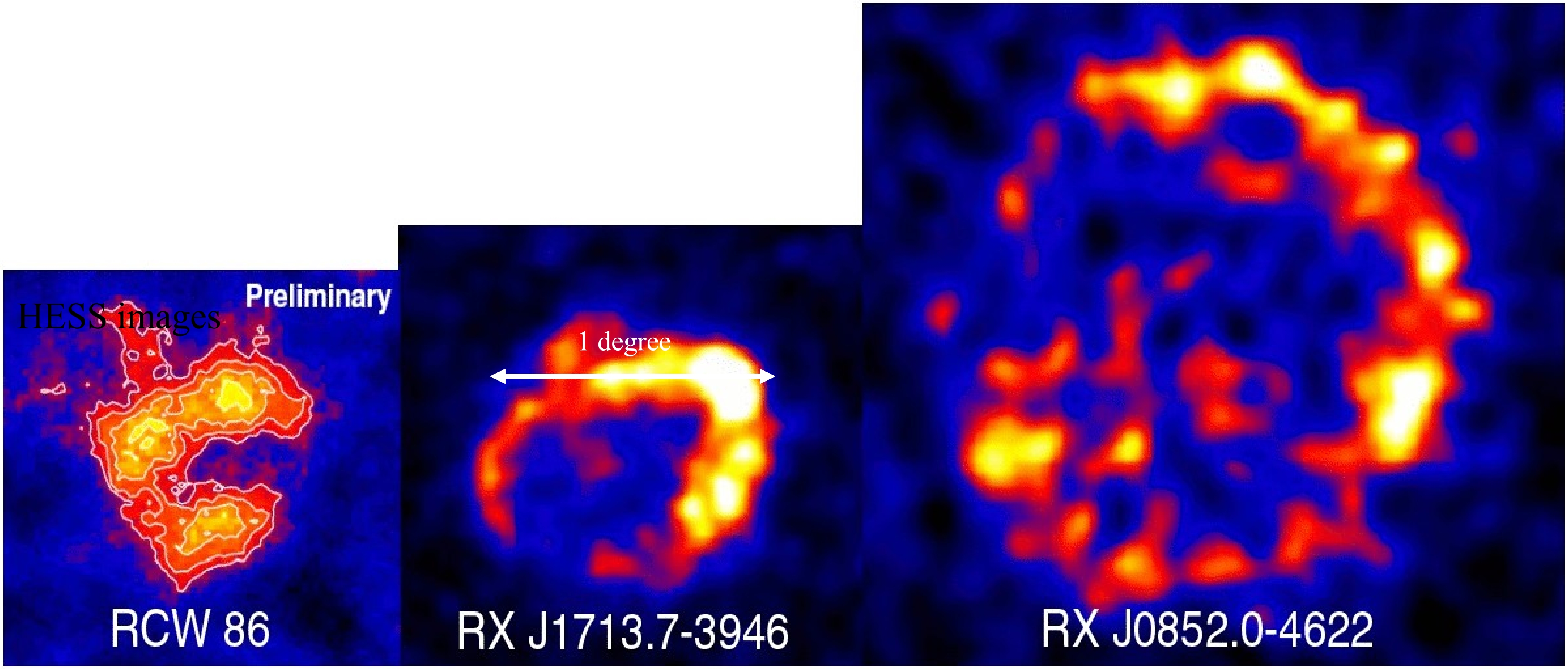
SNRs and Molecular Clouds:

- better quality spectral studies (cut-offs, breaks, etc)

- population studies

Supernova remnants: shells and acceleration properties

Several shell-type supernova remnants have been already resolved as TeV gamma-ray shells: direct proof of shock acceleration of particles to hundreds of TeV energies at supernova remnant shocks



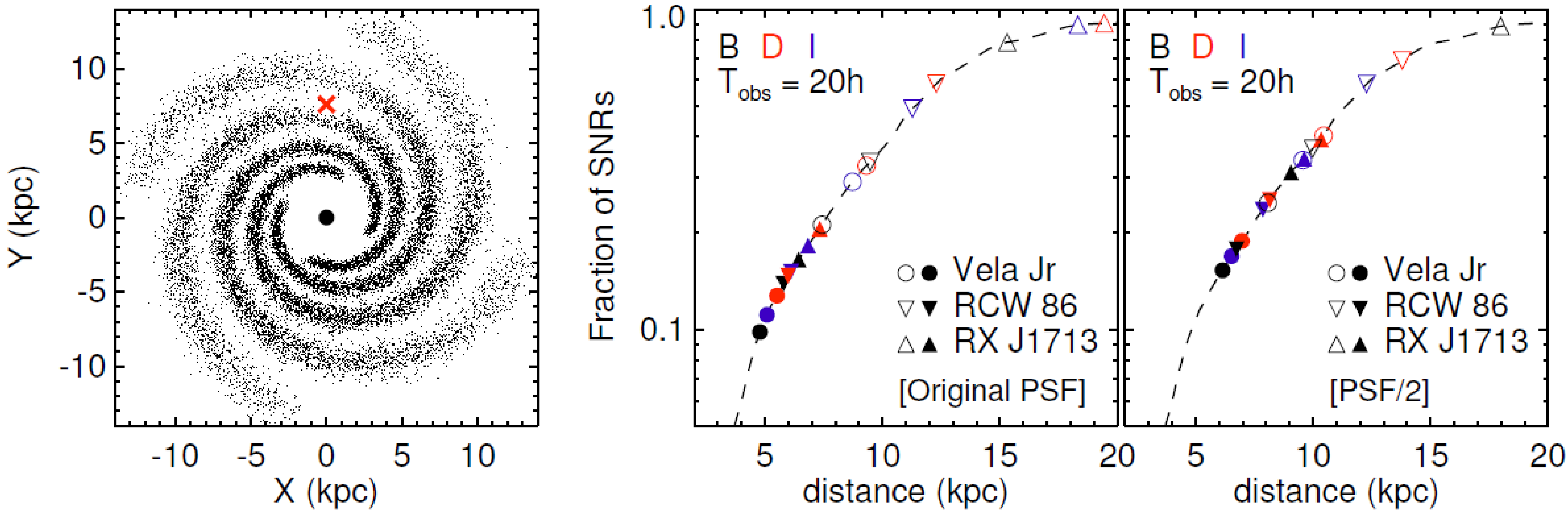
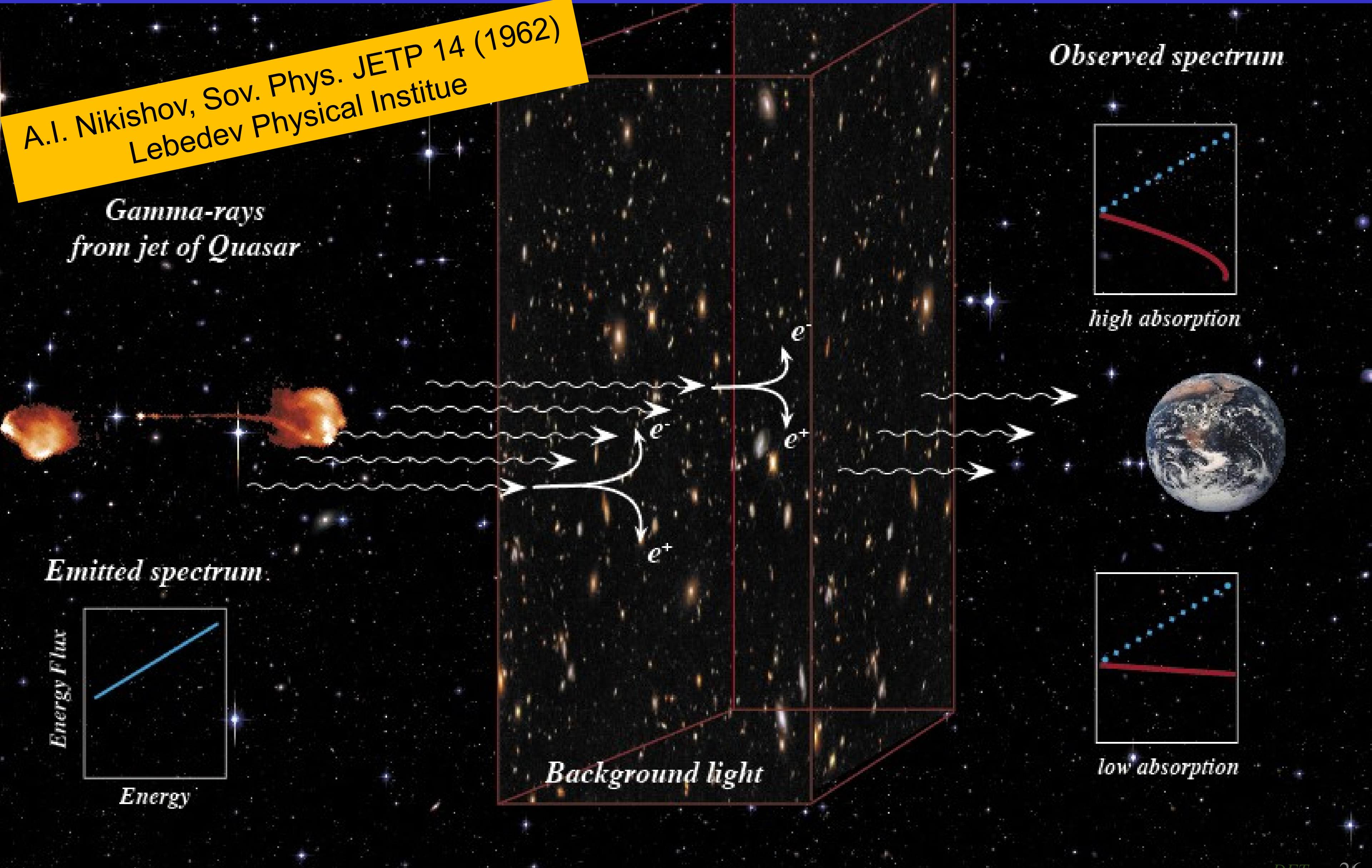
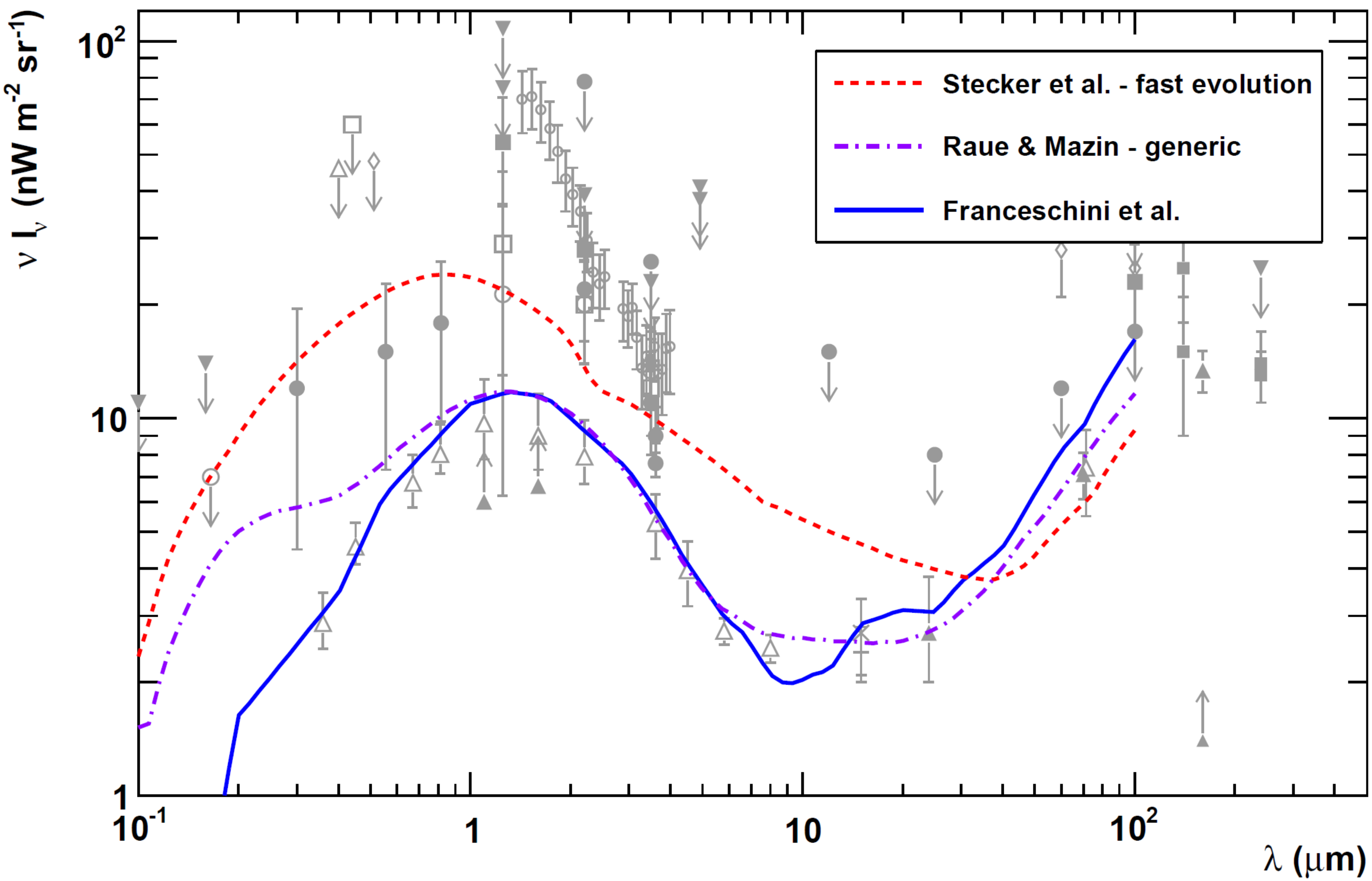


Figure 3: Left: simulated distribution of Galactic core-collapse SNRs. The Sun and the Galactic center are depicted by the red cross and the black dot, respectively. Middle: Fraction of SNRs visible with zenith angle $< 45°$, for a ground-based instrument located at the same latitude as the H.E.S.S. experiment, as a function of distance from Earth (dashed line). Configurations B (in black), D (in red) and I (in blue), for an observing time of 20 h, and for three known VHE-emitting SNRs: Vela Junior (circles), RCW 86 (downward triangles) and RX J1713.7-3946 (upward triangles). Open symbols refer to the horizon of detectability, filled symbols to the horizons of resolvability. Right: same as middle, except that the original CTA PSF from the configuration files has been improved by a factor of 2.

Studies of Extragalactic Background Light with CTA

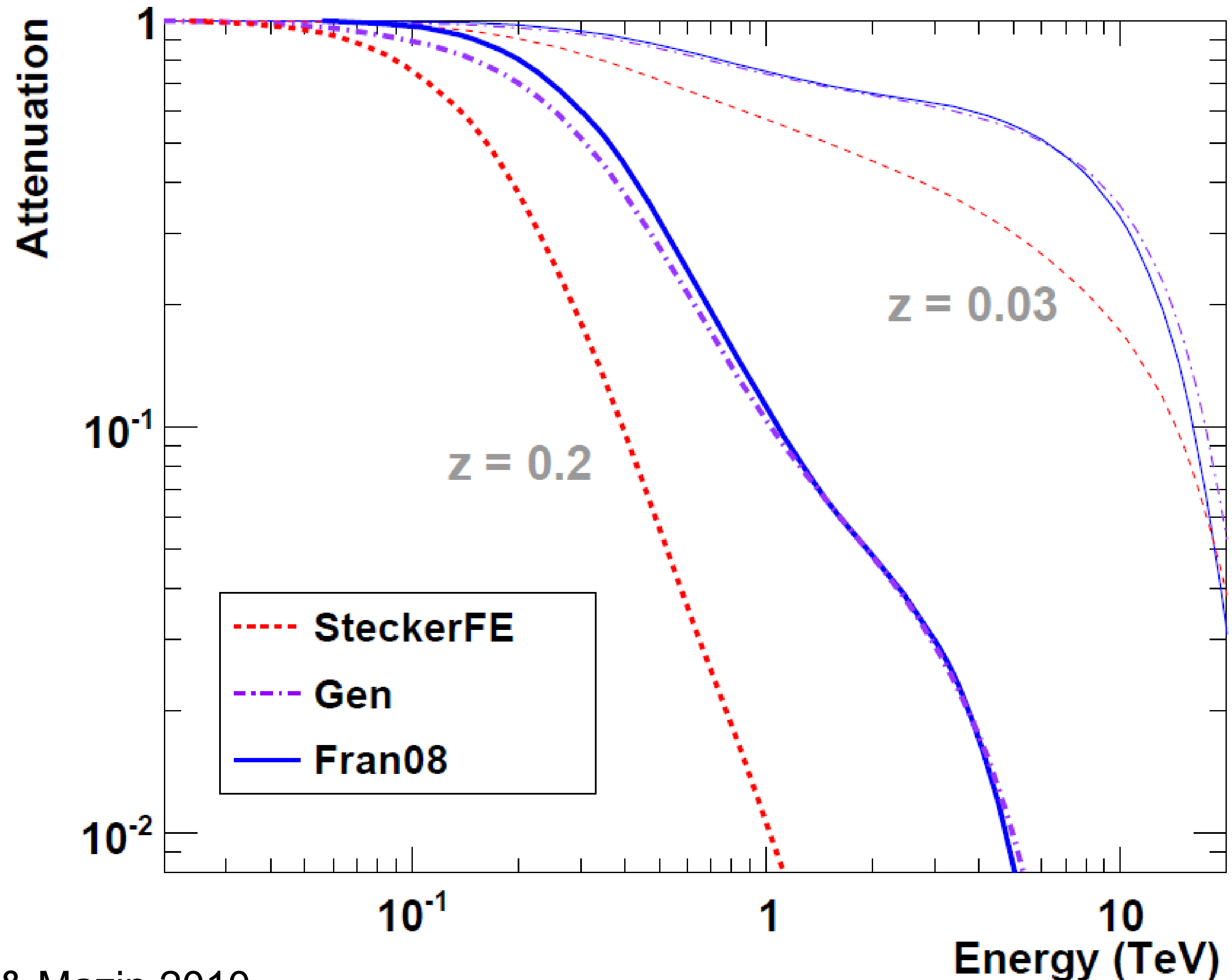
A.I. Nikishov, Sov. Phys. JETP 14 (1962)
Lebedev Physical Institue





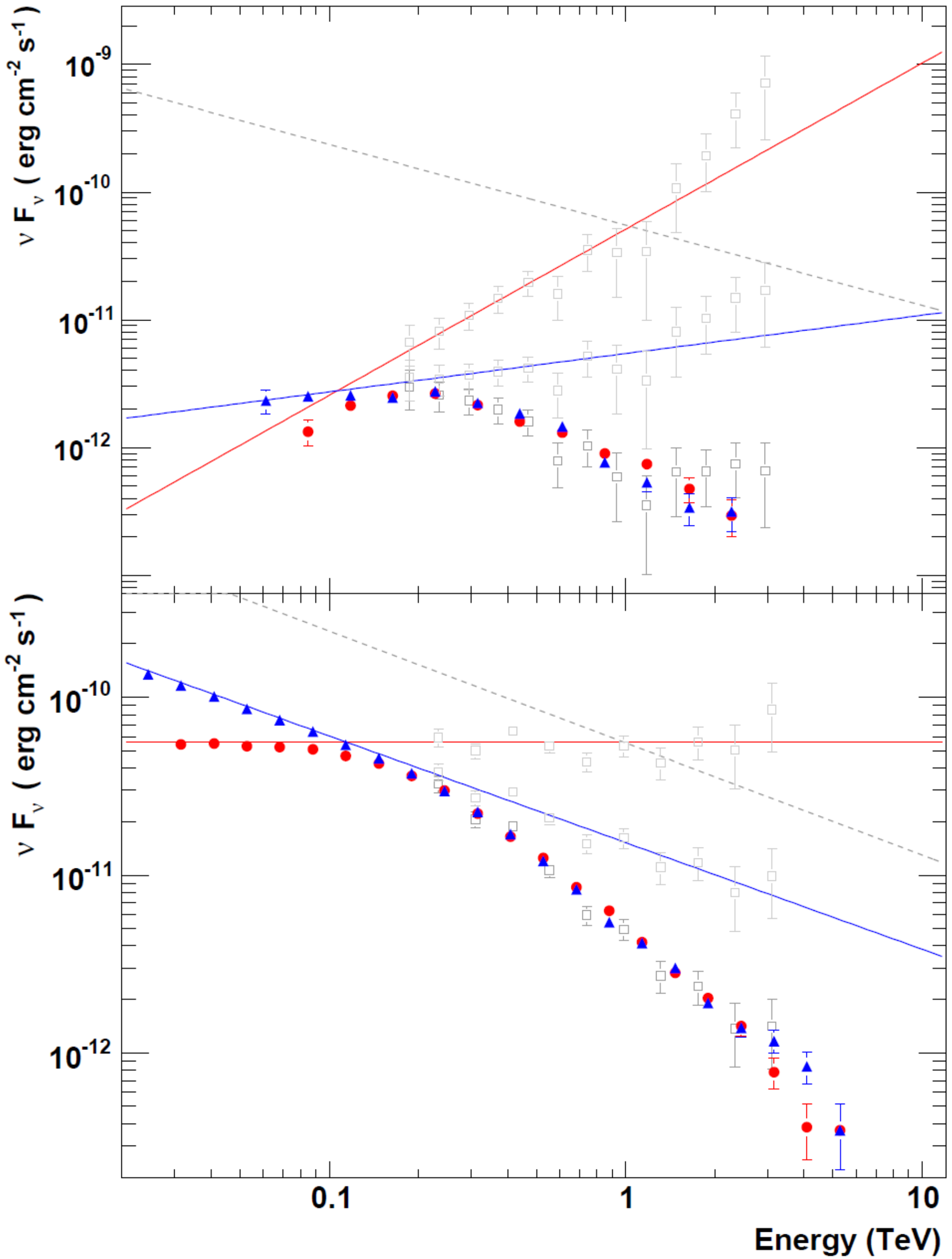
Raue & Mazin 2010

CTA will allow for the observation of the unabsorbed part of the spectrum, together with the signature of attenuation at higher energies



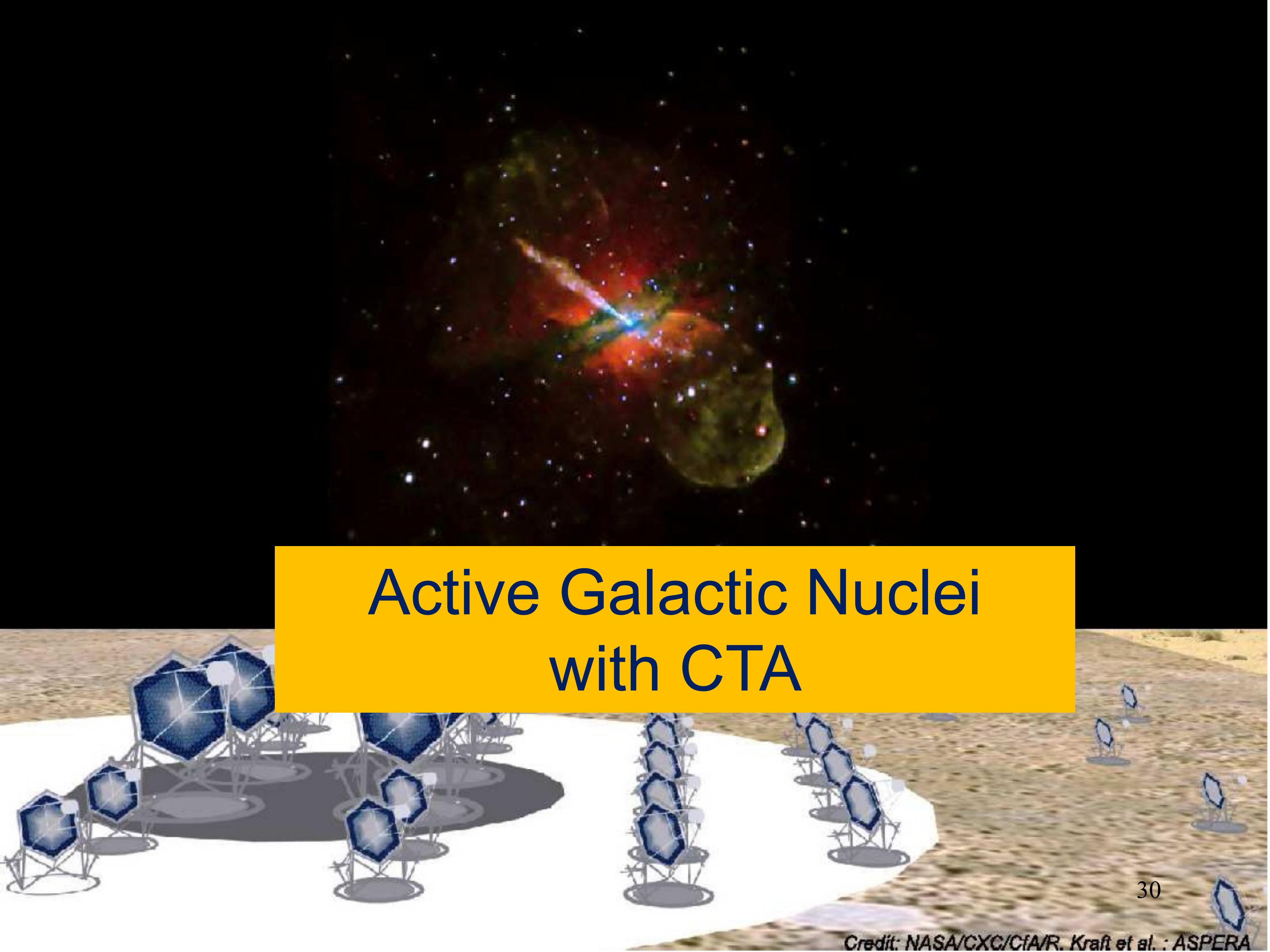
Raue & Mazin 2010

Simulated VHE spectra of blazars for two EBL models



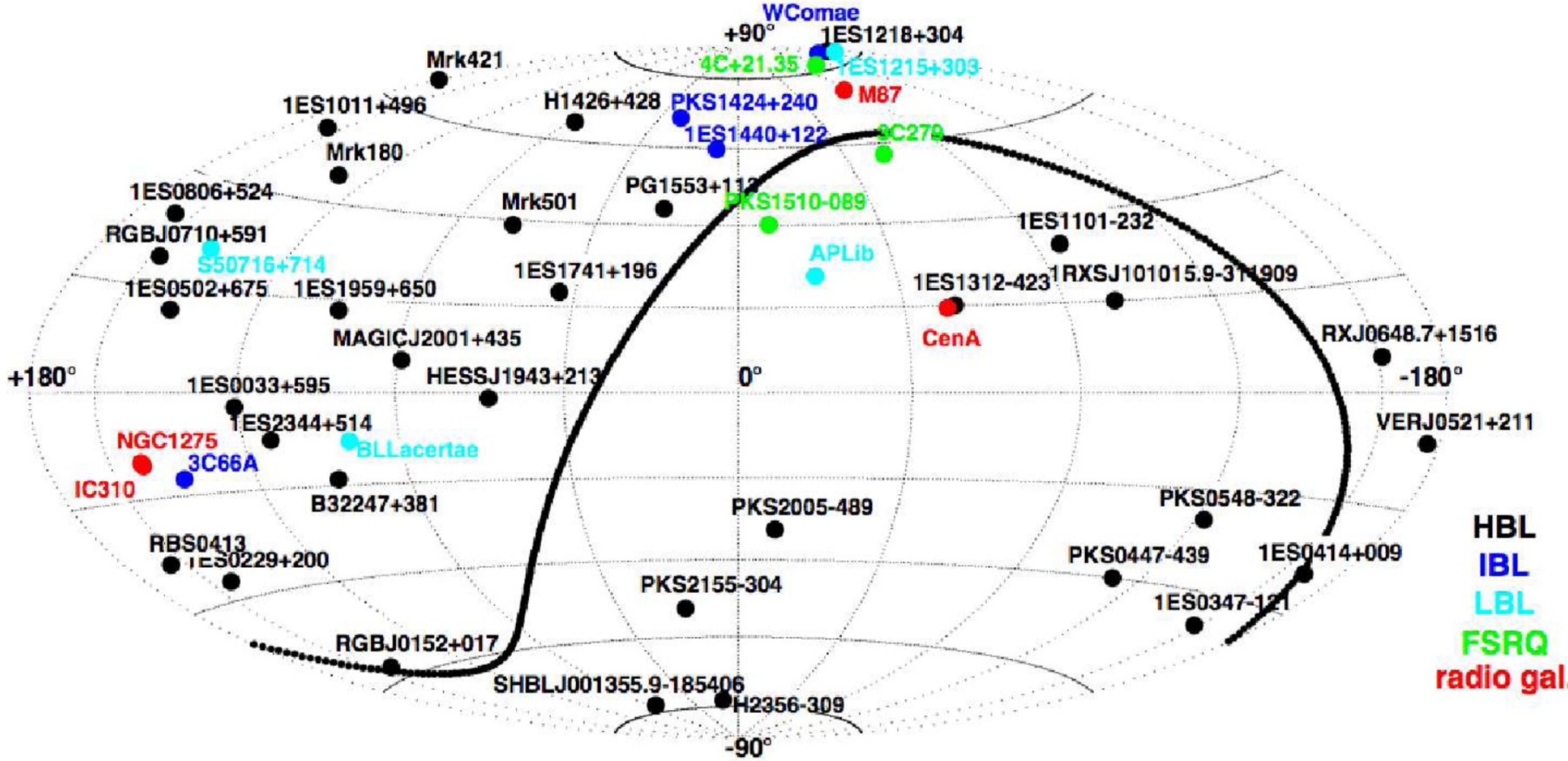
Raue & Mazin 2010

Active Galactic Nuclei with CTA



AGN detected at VHE (status of November 2011) according to the TeVCAT catalog

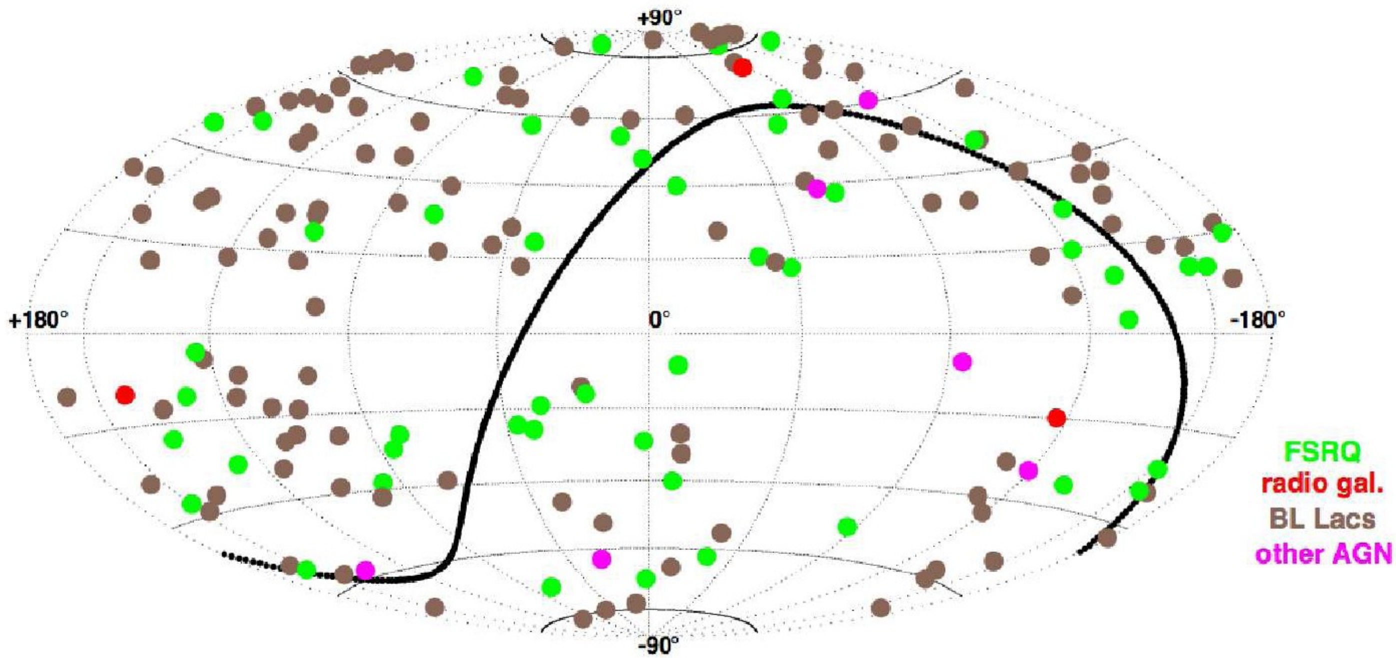
Zech et al. 2012

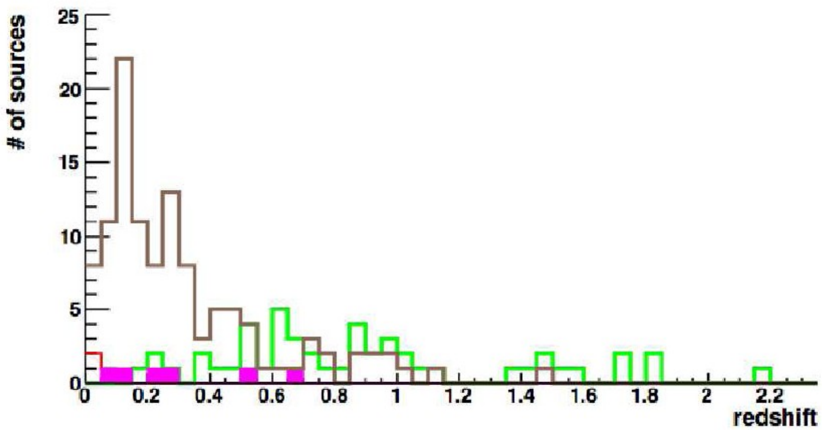


48 objects
(40% of currently detected VHE sources)

Predicted AGN detections with CTA based on extrapolations of Fermi-LAT spectra for a maximum observation time of 50 hr per source

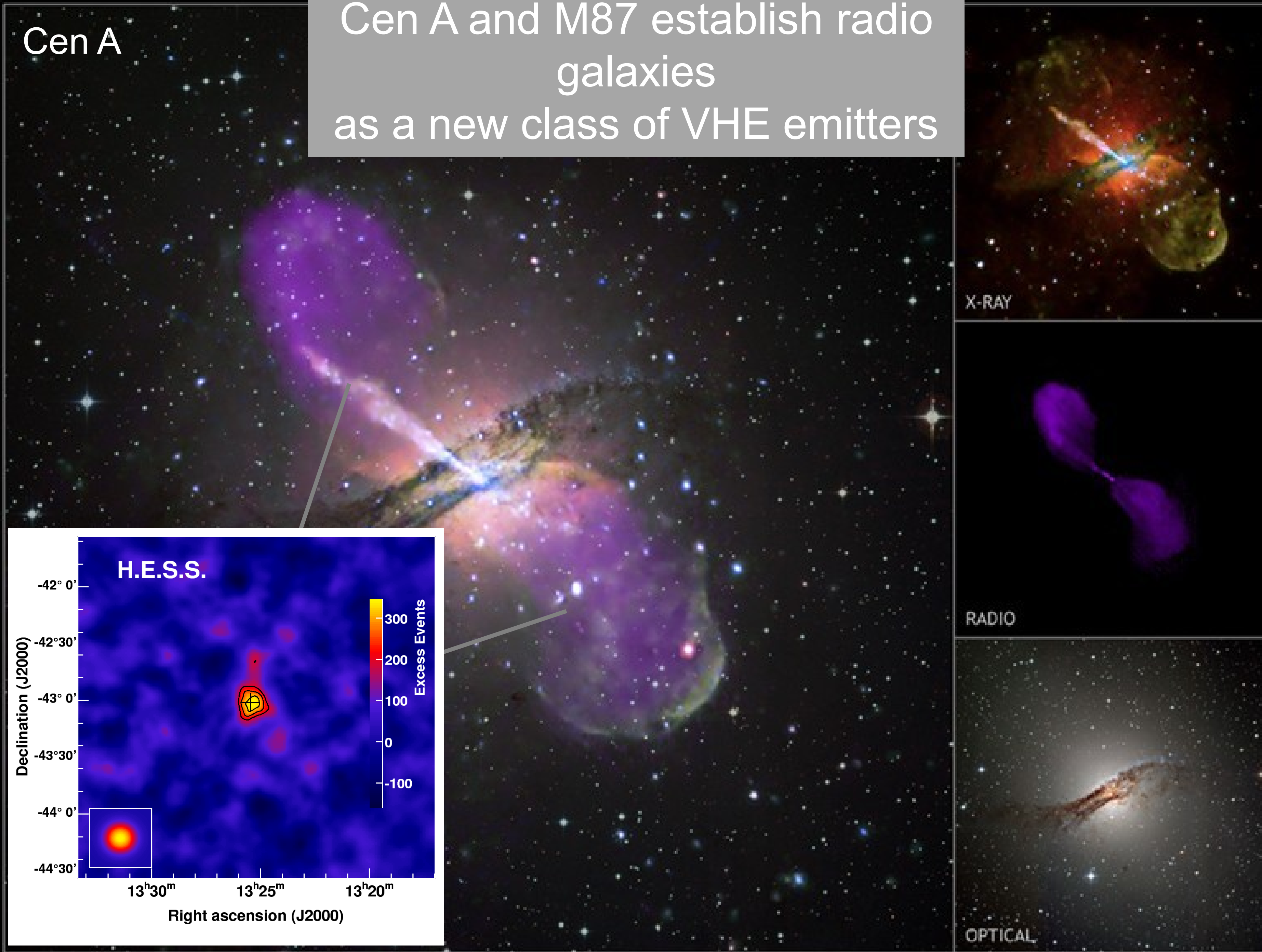
Zech et al. 2012



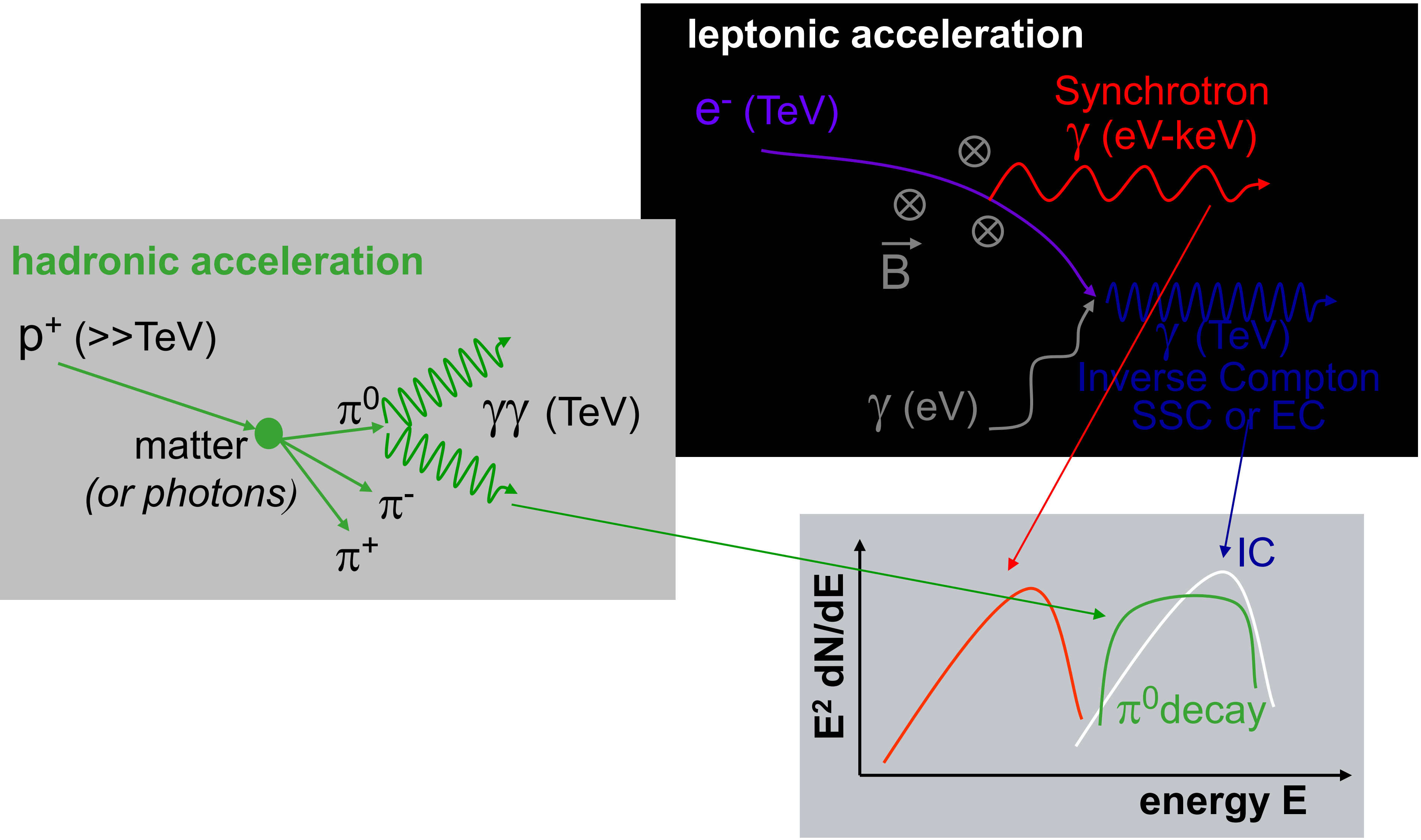


~170

Cen A and M87 establish radio galaxies as a new class of VHE emitters

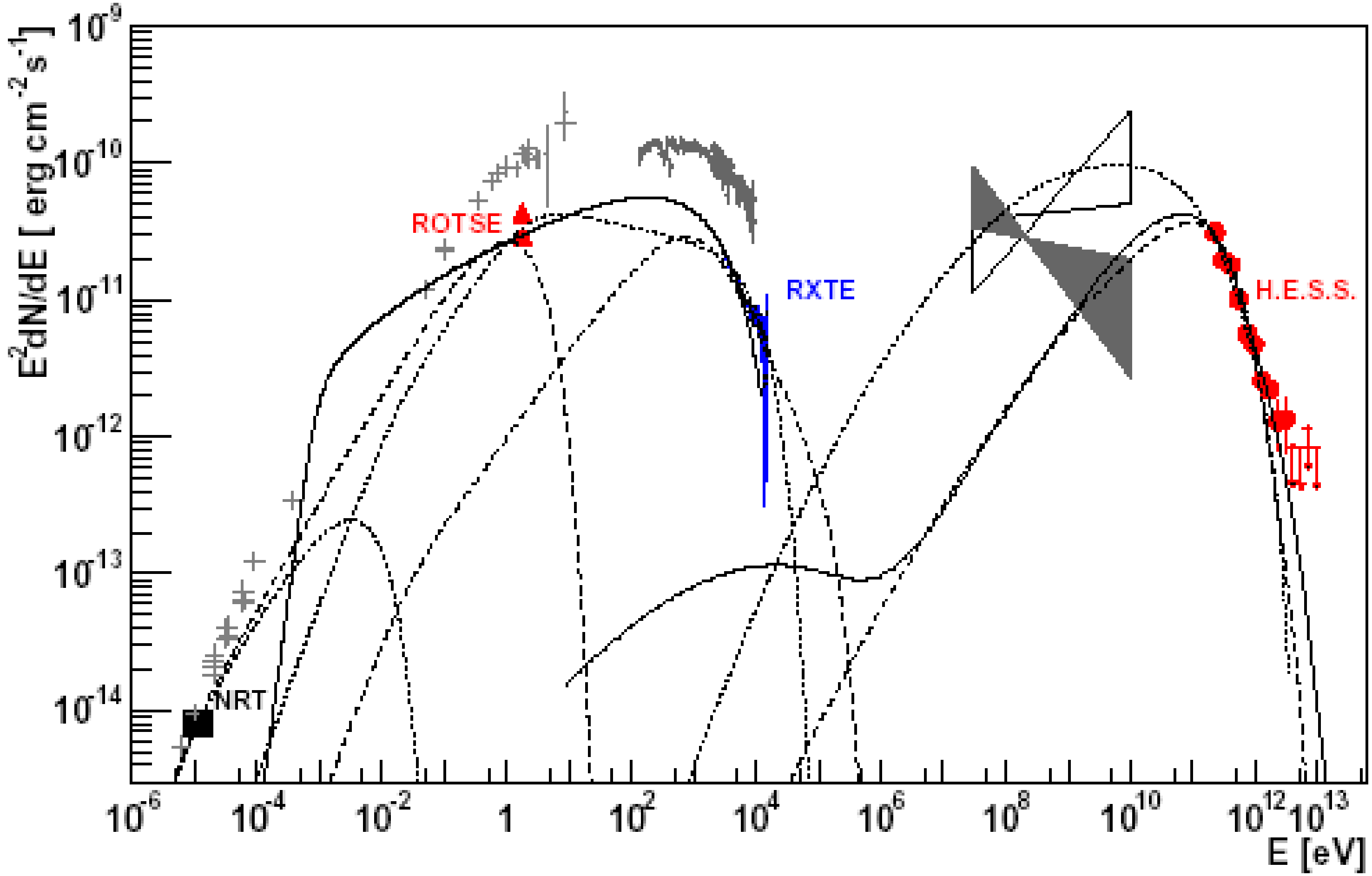


Basic scenarios for SED modeling

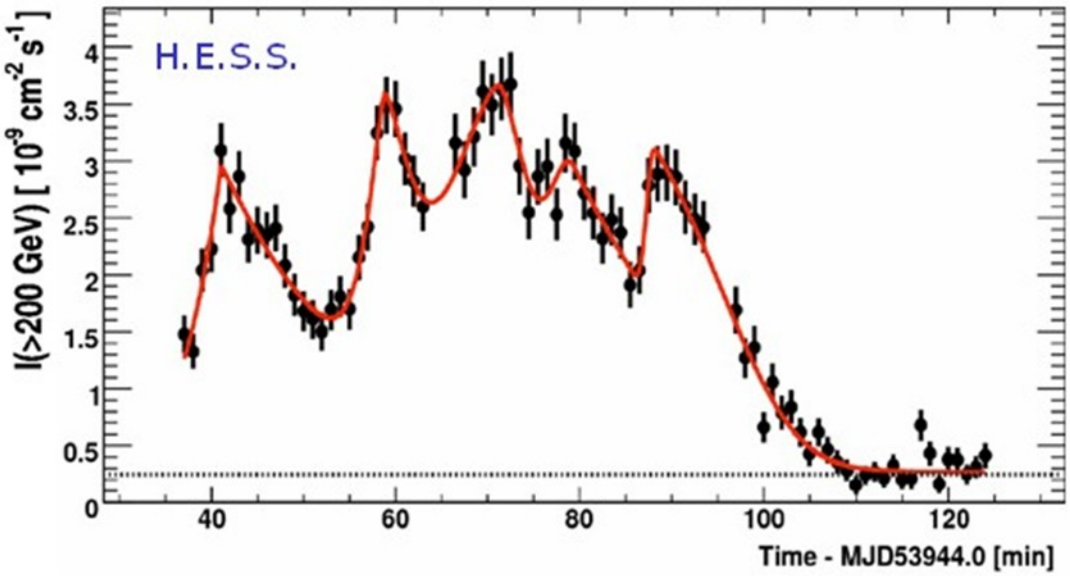


(adapted from De Lotto, 2009)

PKS 2155-304
in quiescent state

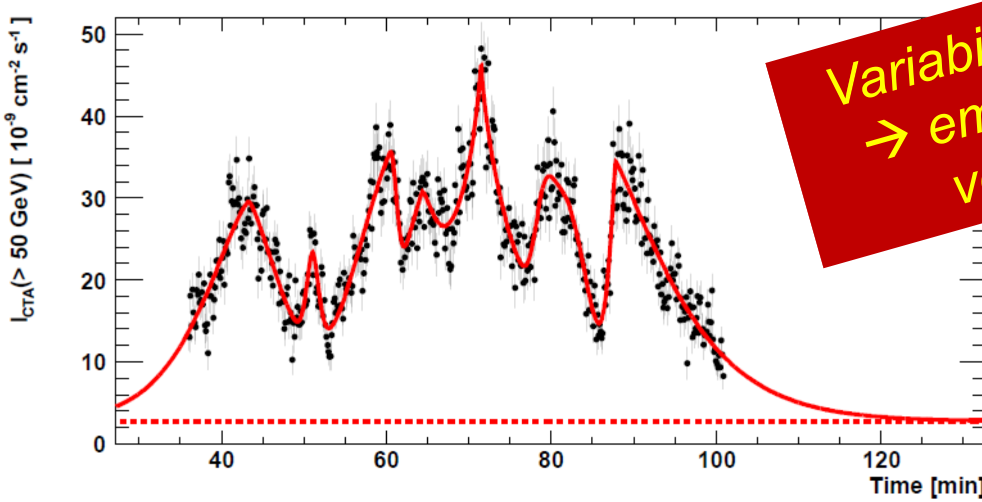


Various hadronic and leptonic models can often fit present available spectra of HBL



A flare from **PKS 2155-304** as detected with the HESS telescopes (July 28, 2006). The data are binned in one minute intervals.

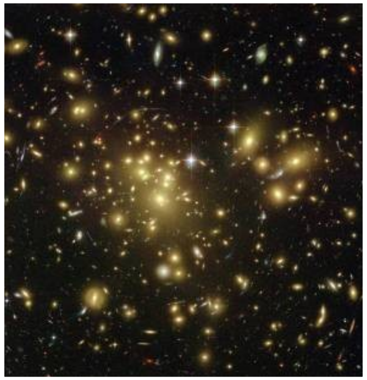
(Aharonian et al. 2007)



Variability down to minute time scale
→ emitting zone smaller than R_g or
very high bulk Lorentz factor

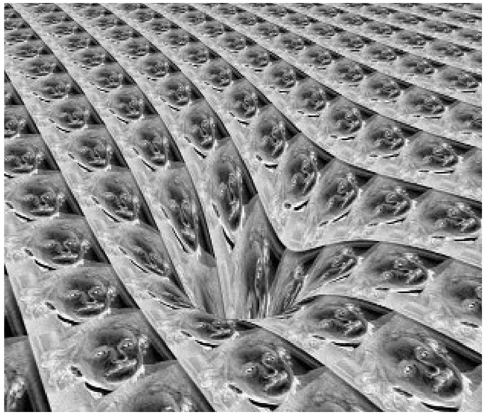
Figure 16: Simulated integral flux of PKS 2155-304 above 50 GeV as CTA would monitor it. This simulation relies on an extension of the red noise behavior to high frequencies, generating the short time scale structures (second and fourth peaks). The data are binned in 7.5 seconds intervals.

Dark Matter and Fundamental Physics

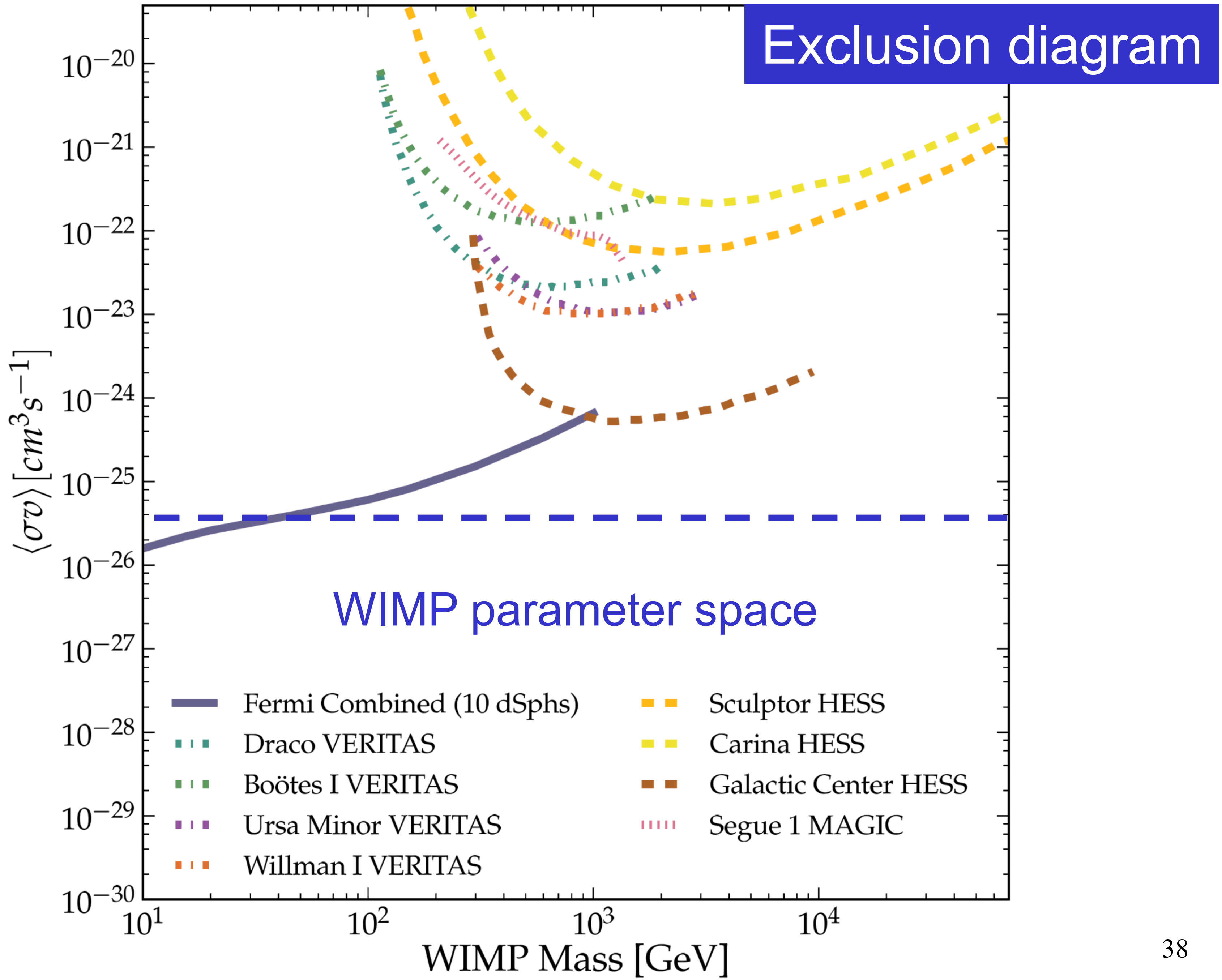


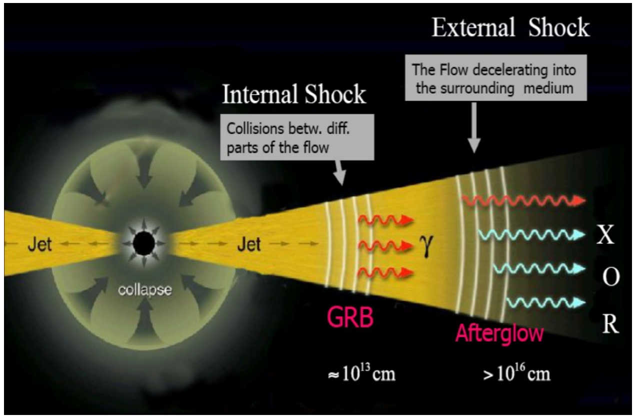
CTA prospects to search for CDM particles signatures:

- in dwarf satellite galaxies of the Galaxy
- around the Galactic Center
- in clusters of galaxies



CTA prospects to constrain high energy violations of Lorentz Invariance relative to current limits (Fermi).


Exclusion diagram
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
$\langle \sigma v \rangle [cm^3 s^{-1}]$
WIMP parameter space
Fermi Combined (10 dSphs)
Draco VERITAS
Boötes I VERITAS
Ursa Minor VERITAS
Willman I VERITAS
Sculptor HESS
Carina HESS
Galactic Center HESS
Segue 1 MAGIC
10^1
10^2
10^3
10^4
WIMP Mass [GeV]



Prompt GRB light curves and AGN light curves are used to determine the [lower limit of] Quantum Gravity scale by detection of the [lack of] delay between the arrival times of photons at different energies

The Lorentz invariance violating (LIV) part in the dependence of the photon momentum on its energy

$$c^2 p^2 = E^2 \left[1 \pm \xi_1 (E/E_{\rm Pl}) \pm \xi_2 (E/E_{\rm Pl})^2 \pm \ldots\right],$$

$$\Delta t \simeq \left(\frac{\Delta E}{\xi_\alpha E_{\rm Pl}}\right)^\alpha \frac{L}{c}$$

Fermi LAT and GBM light curves of GRB 090510

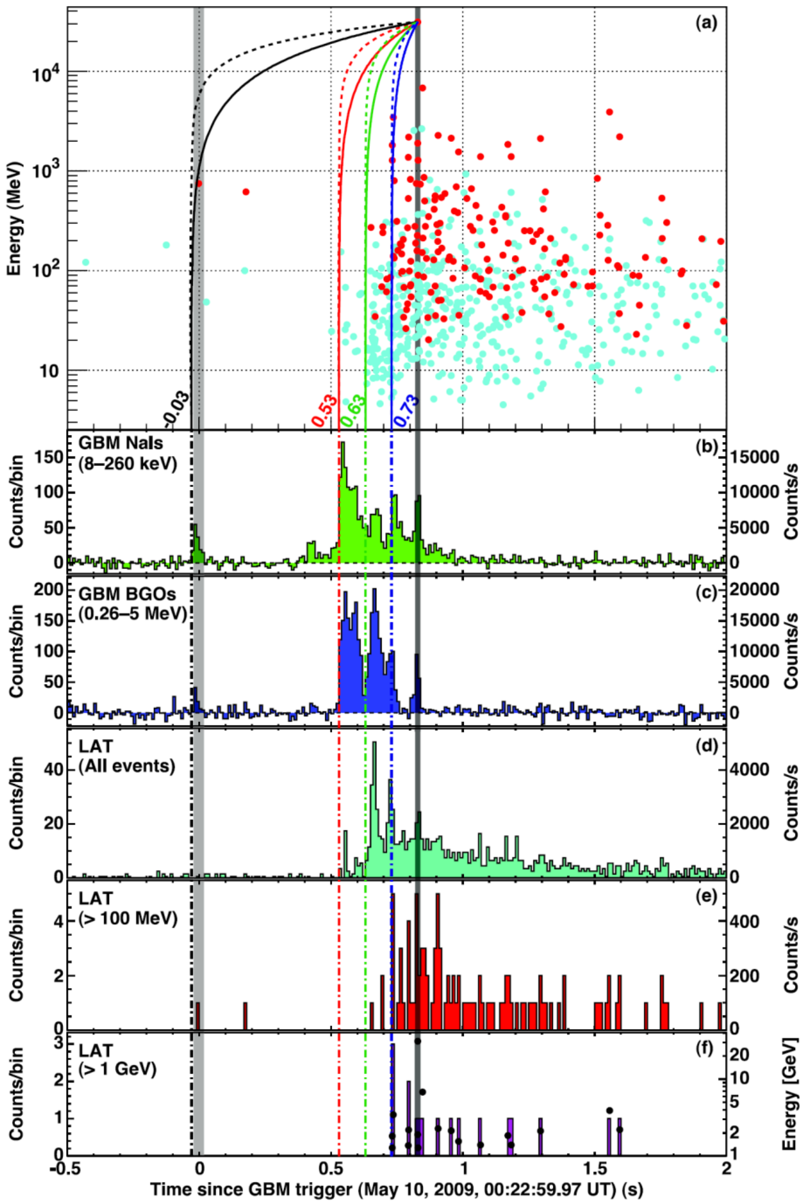
(Abdo et al. 2009)

Current lower limit on the QG energy scale due to possible linear dependence of the speed of light on photon energy:

$$E_{QG,1} = \xi_1 E_{Planck}$$

$$\xi_1 > 1.2$$

To test quadratic or higher order dependencies the sensitivity of CTA will be needed



Optical intensity interferometer

Dravins et al. 2012

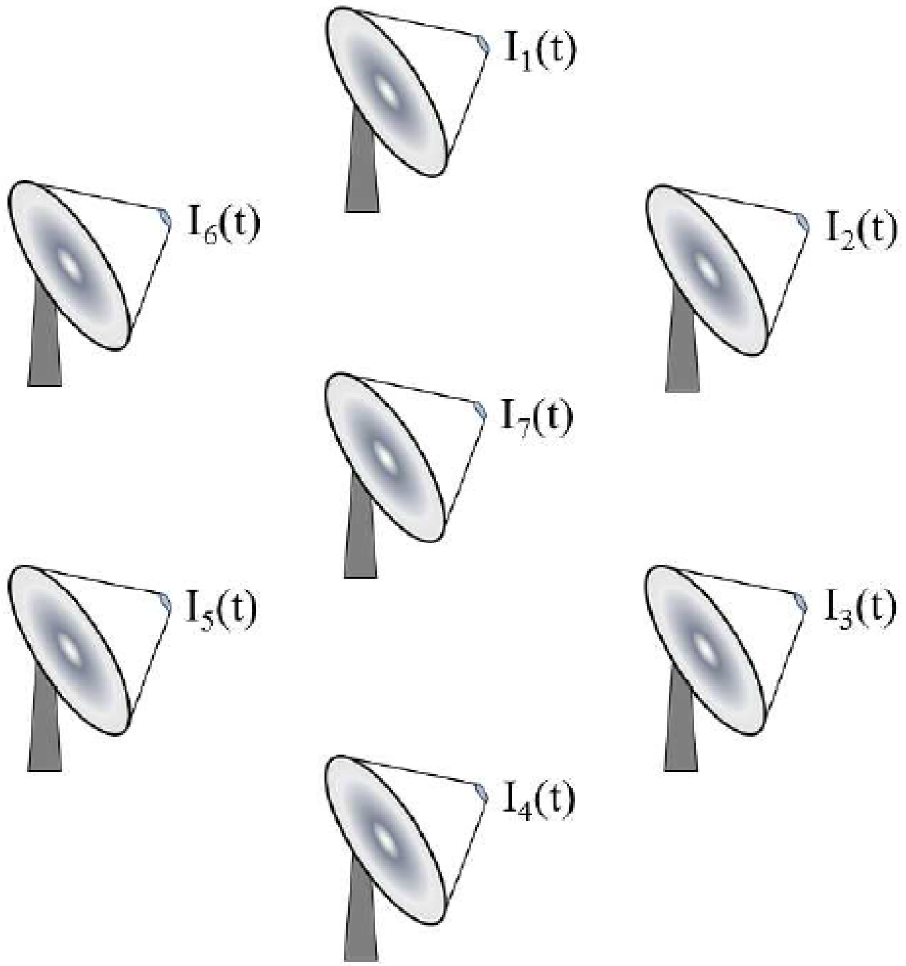
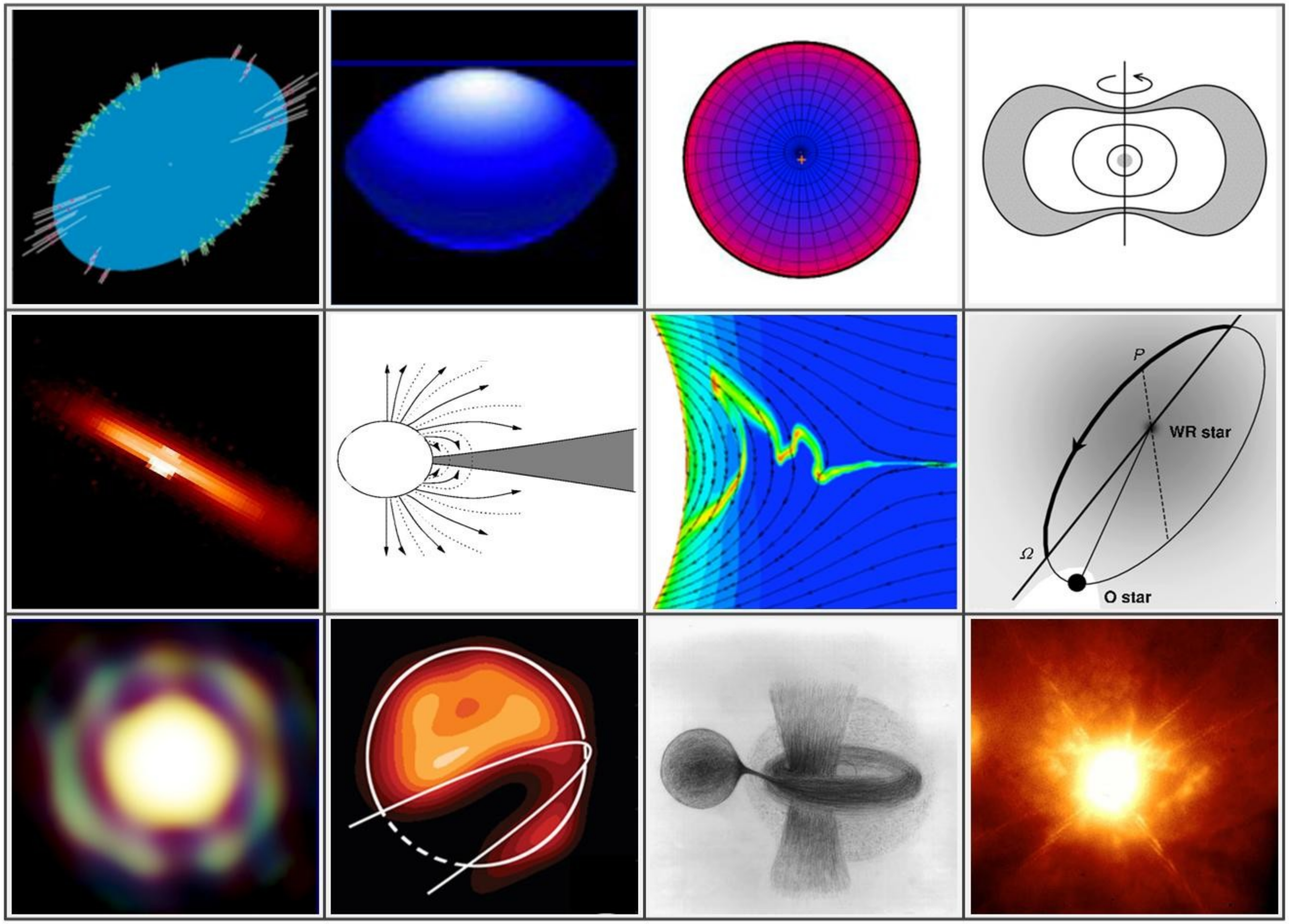


Figure 1: Principle of a multi-element stellar intensity interferometer. Several telescopes observe the same source, simultaneously recording its rapidly fluctuating optical light intensity $I_n(t)$. Cross correlations of the intensity fluctuations are measured between different pairs of telescopes: $\langle I_1(t)I_2(t)\rangle$, $\langle I_1(t)I_3(t)\rangle$, $\langle I_1(t)I_4(t)\rangle$, $\langle I_2(t)I_3(t)\rangle$, $\langle I_2(t)I_4(t)\rangle$, etc. These yield a measure of the second-order spatial coherence of light, from which an image of the source can be deduced, with an angular resolution corresponding to the optical diffraction over the projected baseline distance between each pair of telescopes.

Dravins et al. 2012

Mapping of stellar surface structures, may be realised with CTA, using a technique known as intensity interferometry.



Objects that could be studied using CTA as an intensity interferometer. Top row: Stellar shapes and surfaces affected by rapid rotation; Middle row: Disks and winds of hot gas around active stars; Bottom row: Stellar surroundings such as shells, obscuring clouds, and jets.

Summary

CTA will supersede all presently operating IACT arrays
in terms of performance characteristics

Core science topics are defined and substantial progress is expected
in studies of Galactic and extragalactic VHE-related phenomena

Discovery potentials of CTA are huge so be prepared
for discoveries of *known* unknowns and *unknown* unknowns

Спасибо за ваше внимание