The Cherenkov Telescope Array Project
– current status and science goals

Bronisław Rudak (CAMK)

for the CTA Consortium

10th Rencontres du Vietnam, ICISE, Quy Nhon
August 3-9, 2014

OUTLINE

What is CTA?

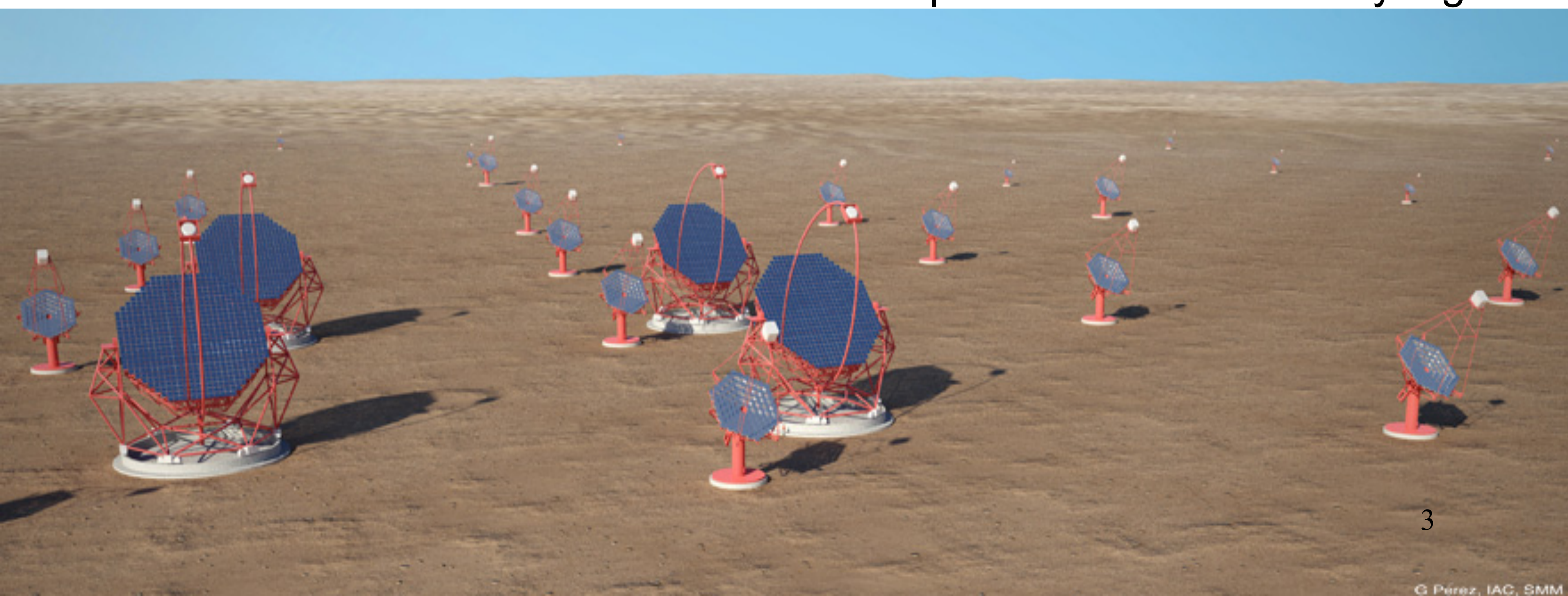
Status of the Project in 2014

Physics and astrophysics with CTA

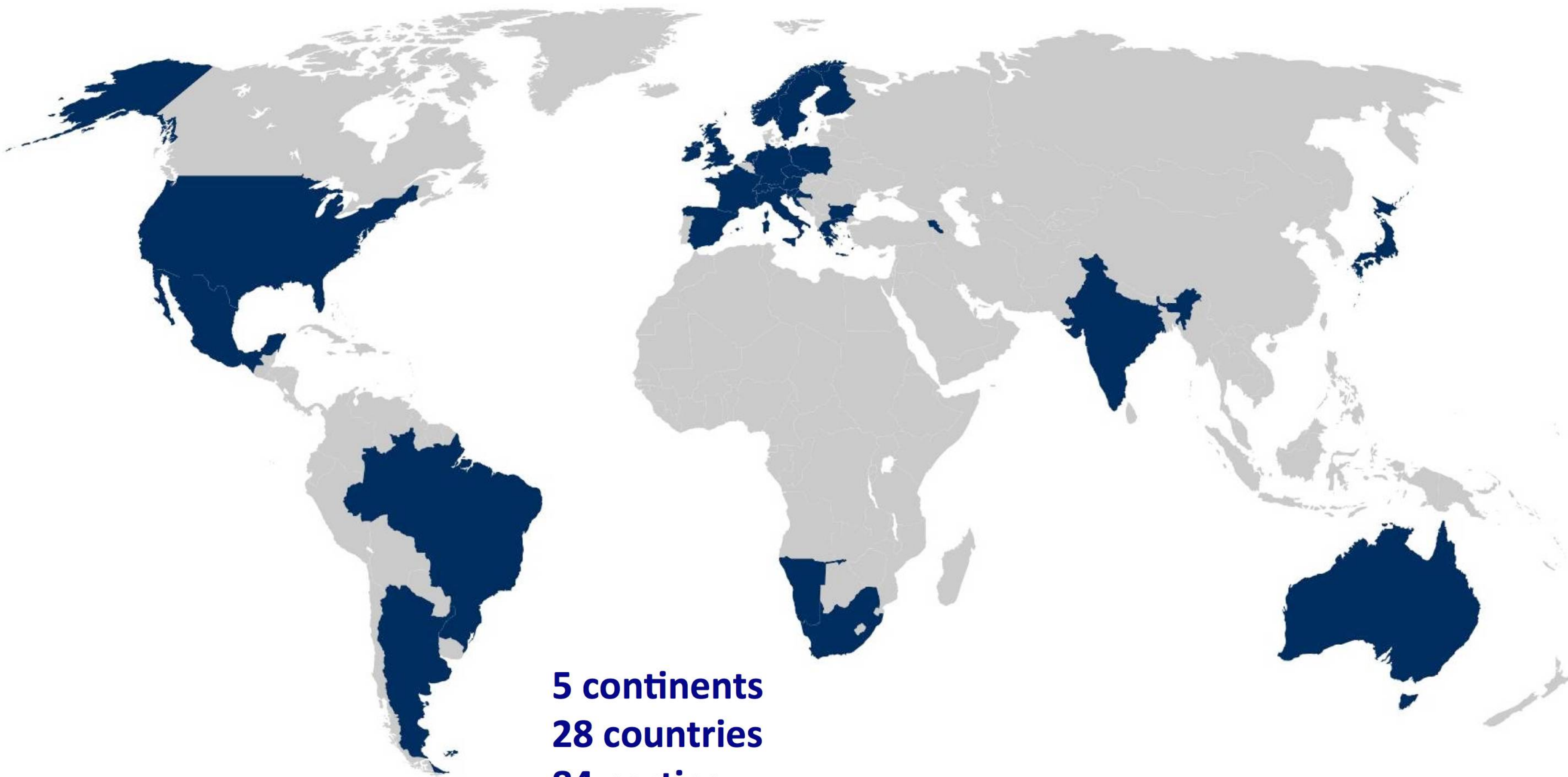
The Cherenkov Telescope Array (CTA): the future in VHE gamma-ray astronomy

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

http://www.cta-observatory.org

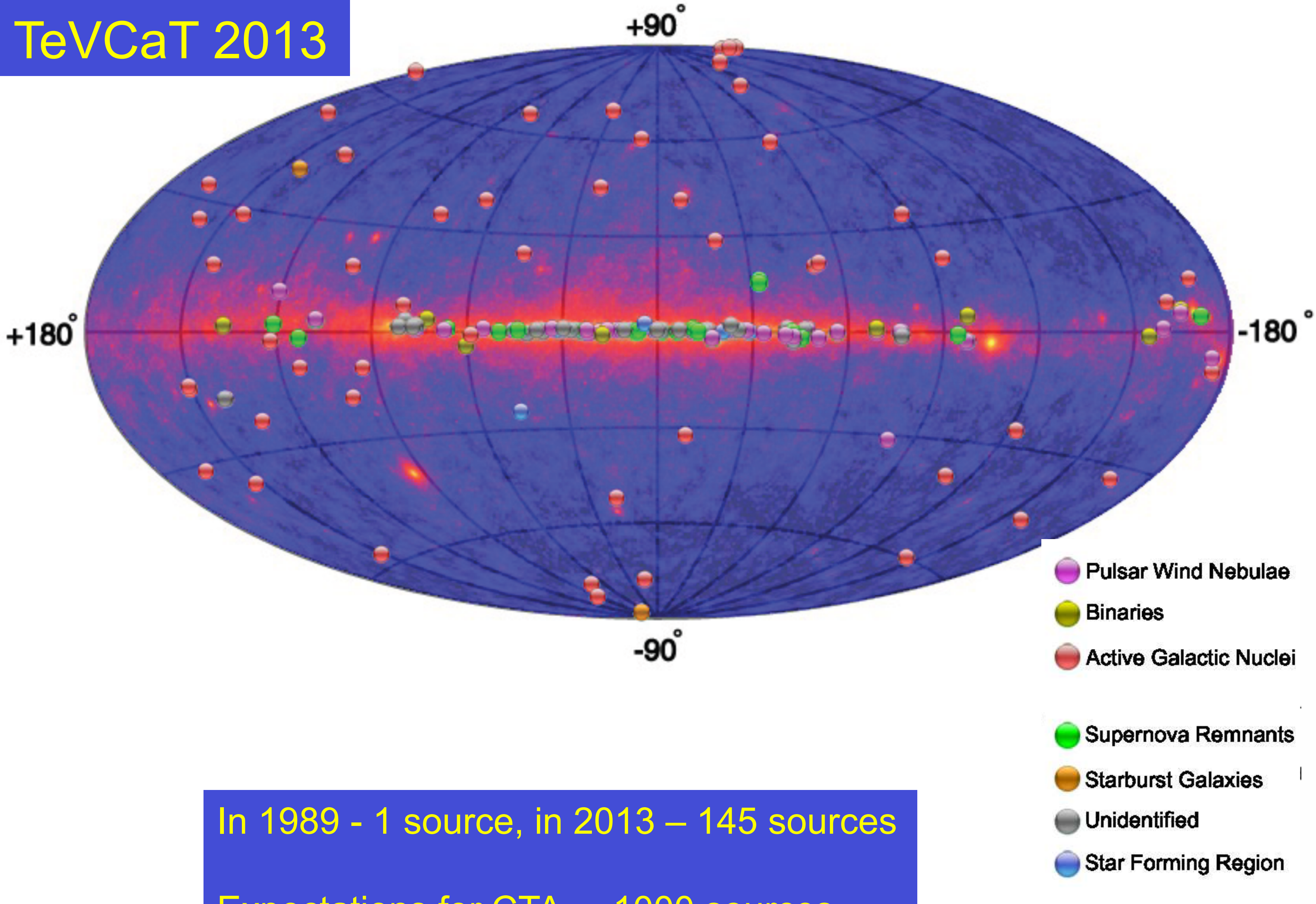


The CTA world map



5 continents
28 countries
84 parties
173 institutes
1178 members (378 FTE)

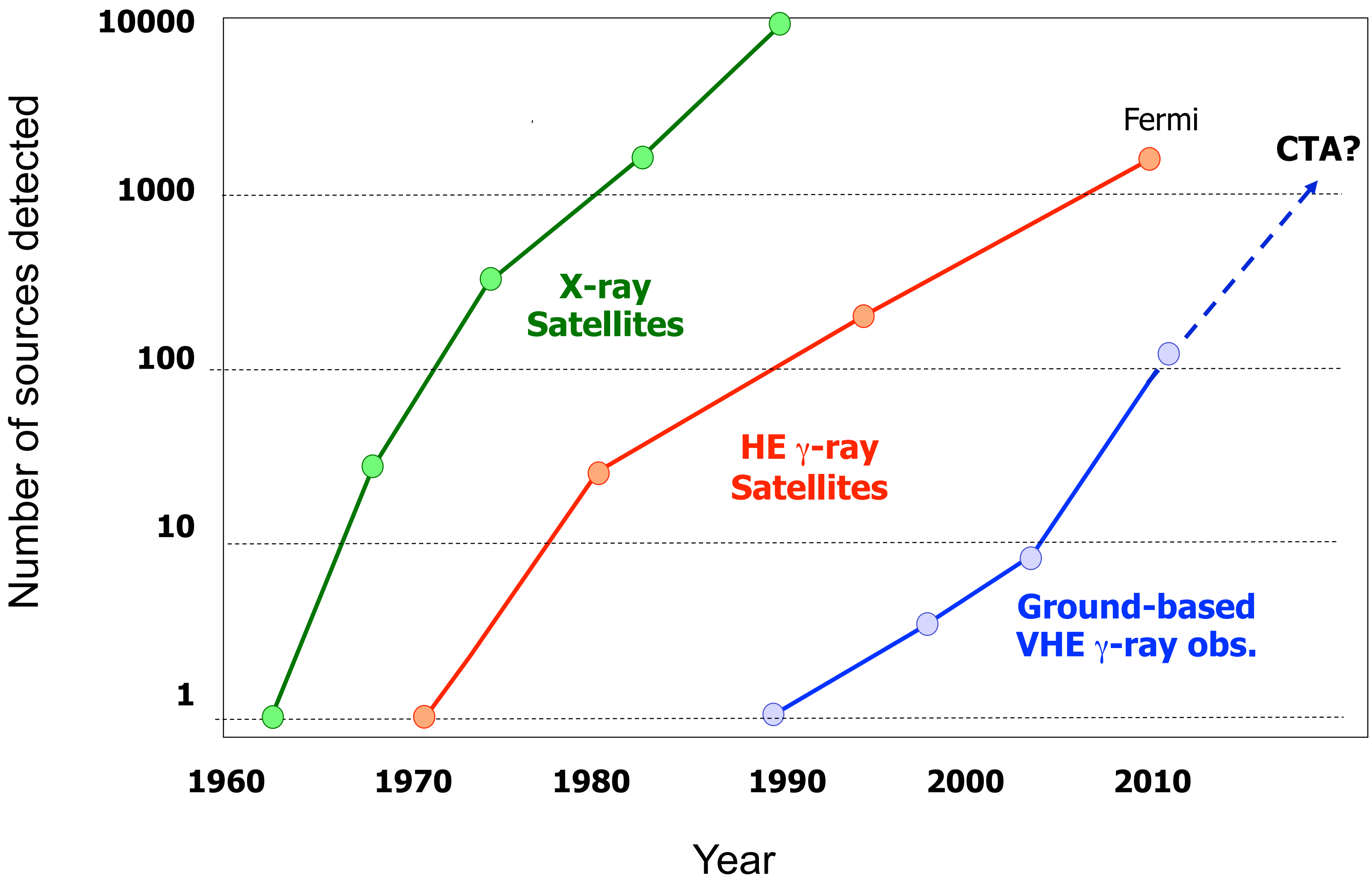
TeVCaT 2013



In 1989 - 1 source, in 2013 – 145 sources

Expectations for CTA ~ 1000 sources

Kifune plot



10000
1000
100
10
1
Number of sources detected
Fermi
CTA?
X-ray
Satellites
HE γ-ray
Satellites
Ground-based
VHE γ-ray obs.
1960
1970
1980
1990
2000
2010
Year

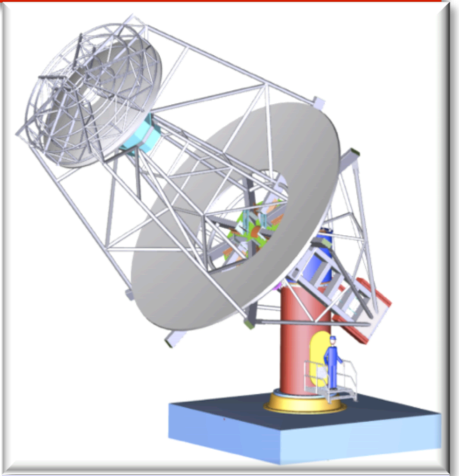
Courtesy of Maria Concetta Maccarone
INAF IASF/Palermo

Telescopes, Mirrors (and Camera Sensors)

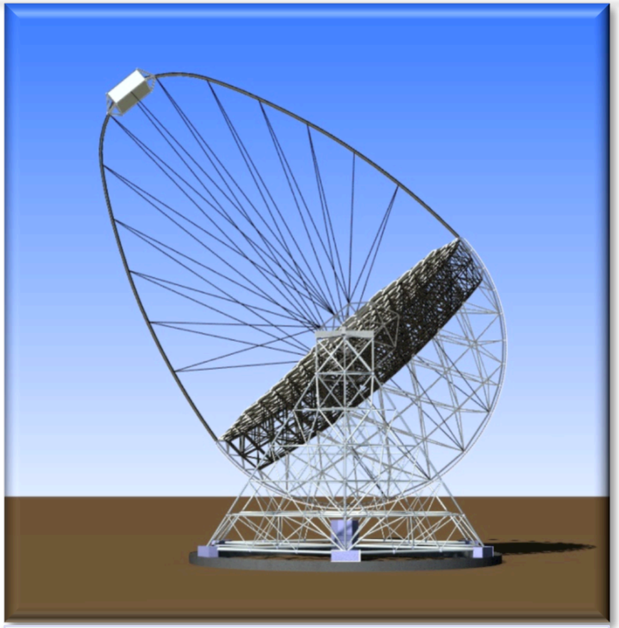
The prototyped technological '*zoo*':

- 6 telescope structures
- 3 optical configurations
- 7 cameras
- several different front-end and read-out electronics
- …

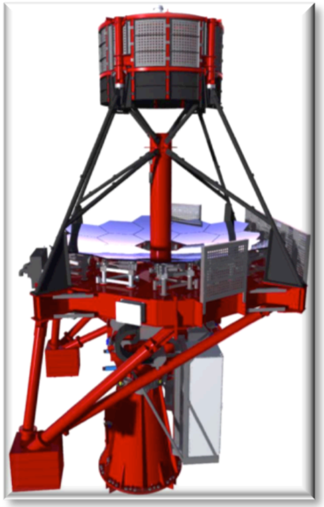
MST, 12m ø (PMTs)



SC-MST, 9m Ø (SiPMs)



LST, 24m Ø (PMTs)

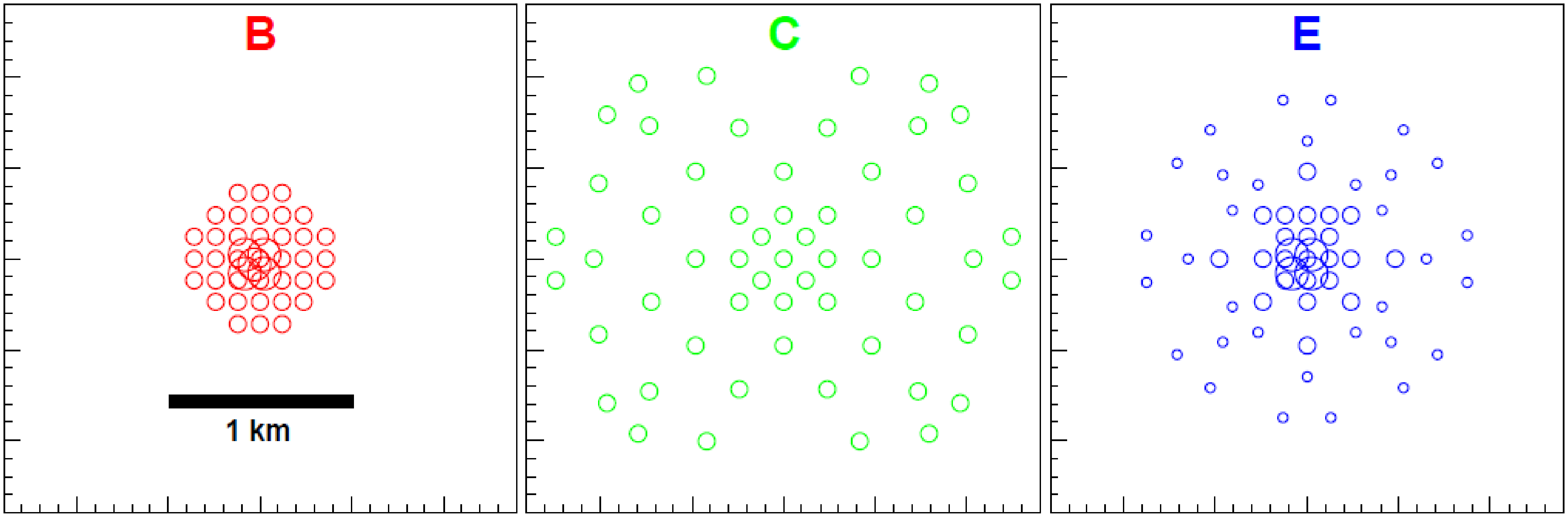


SST-2M ASTRI, 4m Ø (SiPMs)

SST-2M GATE, 4m Ø (MAPMTs/SiPMs)

SST-1M, 4m Ø (SiPMs)

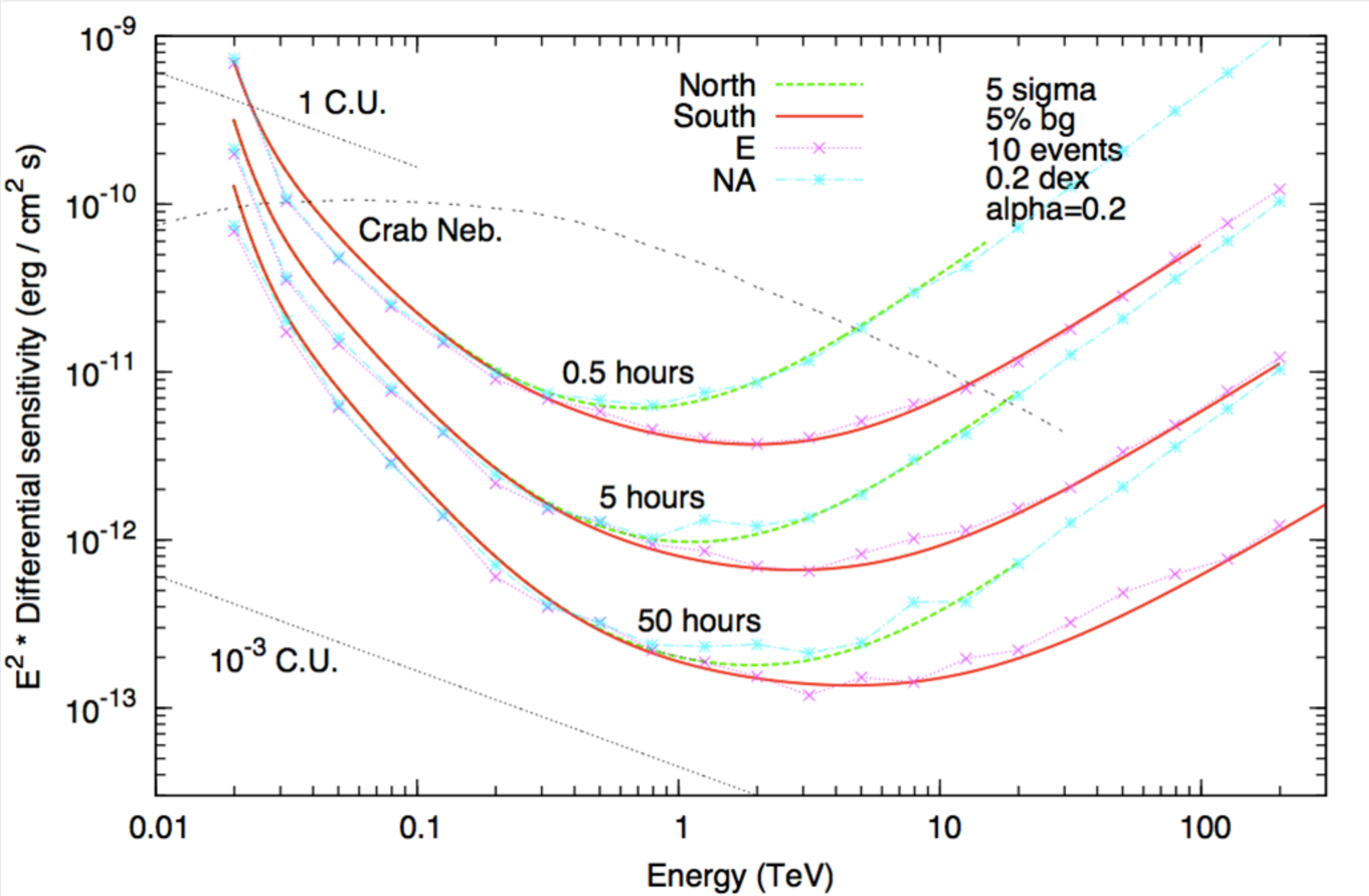
Three different arrays used in the preliminary Monte Carlo Prod-1 simulations



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

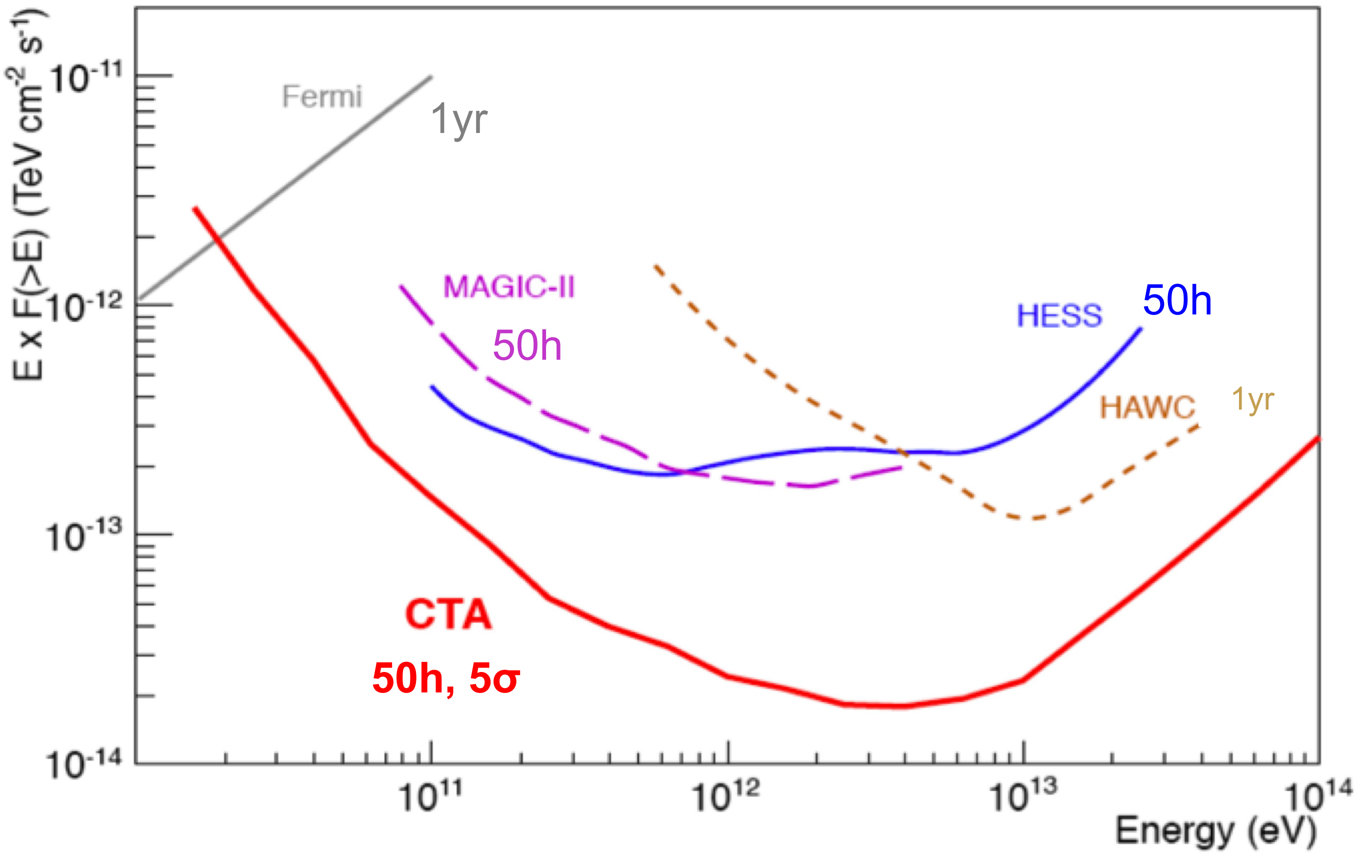
Wide spread array of 12 m telescopes
→ focus on mid and high E

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



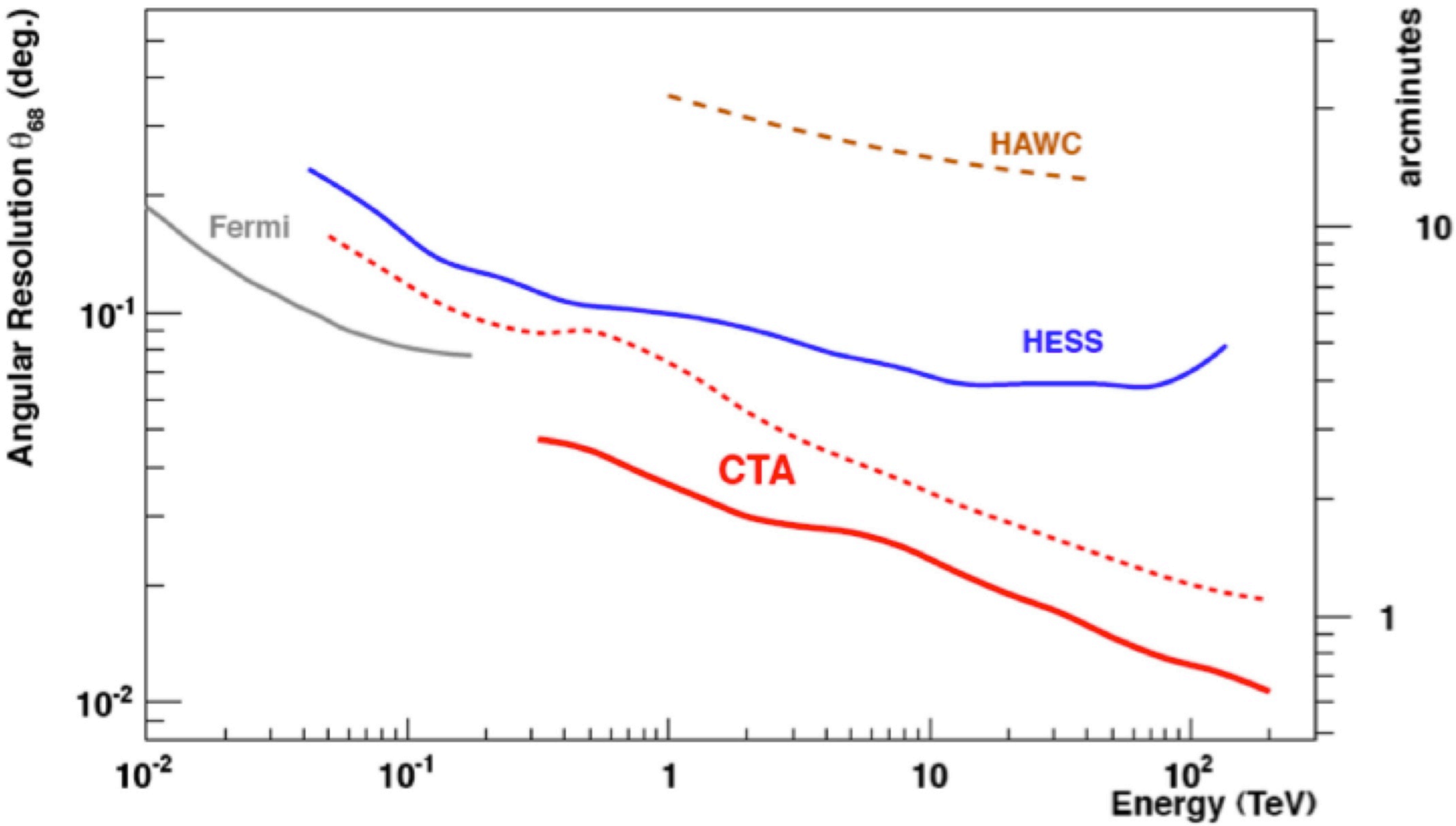
North
South
E
NA
5 sigma
5% bg
10 events
0.2 dex
alpha=0.2
1 C.U.
Crab Neb.
0.5 hours
5 hours
50 hours
10^{-3} C.U.
E^2 * Differential sensitivity (erg / cm^2 s)
Energy (TeV)

Point source sensitivity



Pulsars
and high-z AGN

Exploring the cutoff regime
of cosmic accelerators



Angular Resolution θ68 (deg.)
arcminutes
HAWC
Fermi
HESS
CTA
10
1
10-1
10-2
10-2
10-1
1
10
102
Energy (TeV)

Site locations for the CTA Observatory

South (10 km^2 for 4 LST, 25 MST, 24 SC-MST, ~70 SST)

Chile – Cerro Armazones (ESO)	2500 m (asl)
Namibia – Aar	1650 m

North (1 km^2 for 4 LST, 15 MST)

USA – Meteor Crater (Arizona)	1680 m
USA – Yavapai (Arizona)	1670 m
Mexico – San Pedro Martir (Baja California)	2434 m
Spain – Teide (Tenerife)	2290 m

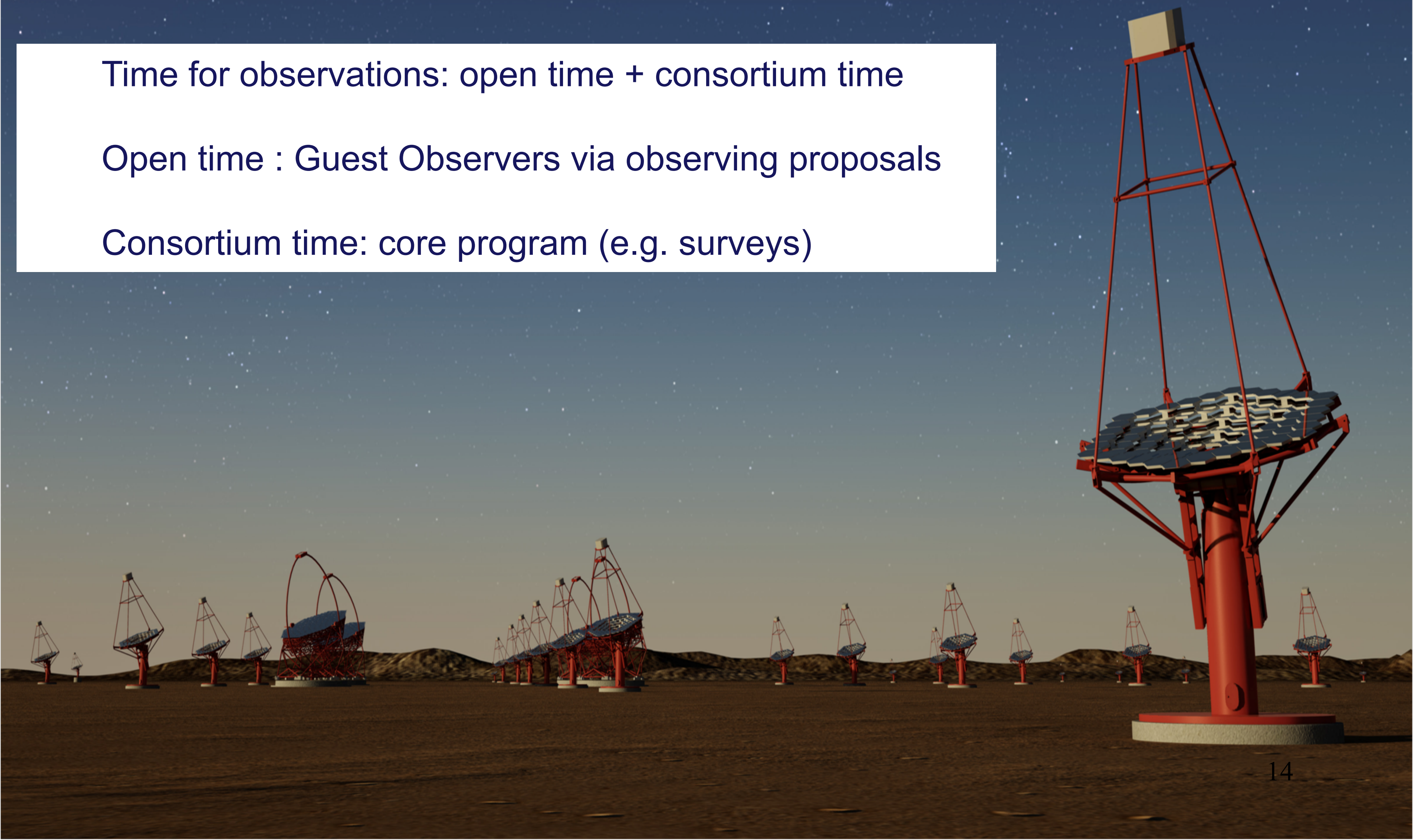
Cerro Armazones – one of the two selected sites in the South

The CTA Observatory – the first open TeV observatory

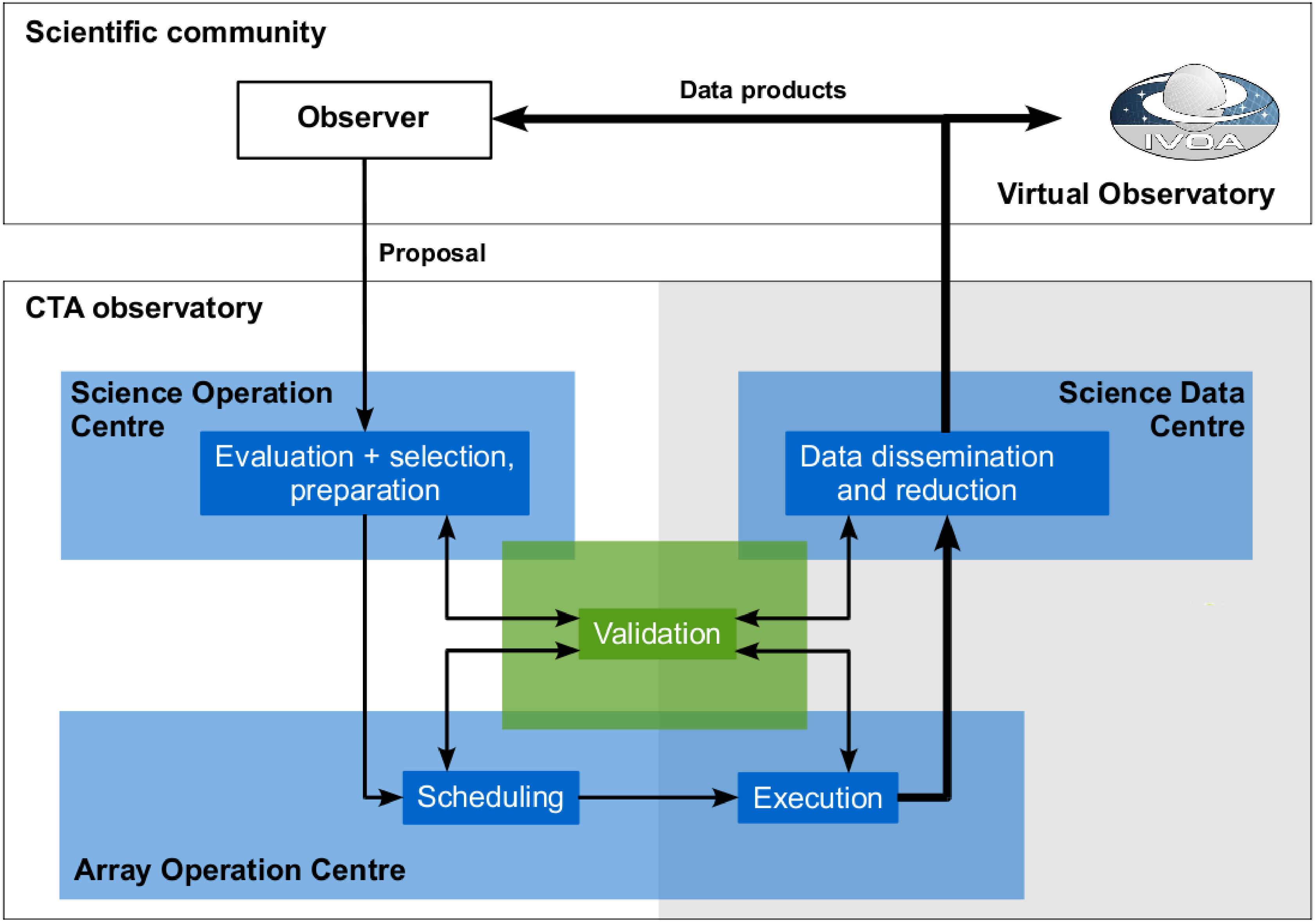
Time for observations: open time + consortium time

Open time : Guest Observers via observing proposals

Consortium time: core program (e.g. surveys)



CTA science data flow



Timeline towards the CTA Observatory

2008 – 2010	Design Phase (array layouts, telescope design)
2011 – 2014	Preparatory Phase (telescope & component prototypes)
In 2014	Site selection, Creation of legal entity (for site negotiations, production phase, etc.)
	Preparation for a Critical Design Review in 2015
2016 – …	Array Construction Phase, Site development
In 2018	Partial operation

Main characteristics of CTA

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

Wide spectral range - from 20 GeV to 100s of TeV

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

High time-resolution (superior to Fermi-LAT) – flares, GRB, other short time-scale events

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

CTA selected by ESFRI as one of the projects eligible for implementation support under Horizon2020

COUNCIL OF
THE EUROPEAN UNION

EN

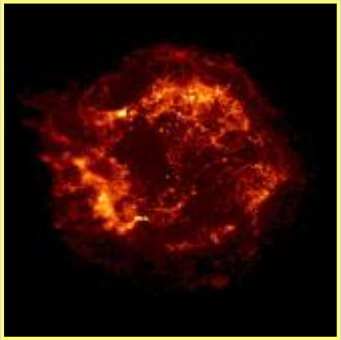
Conclusions on the implementation of the roadmap for the European Strategy Forum on Research Infrastructures

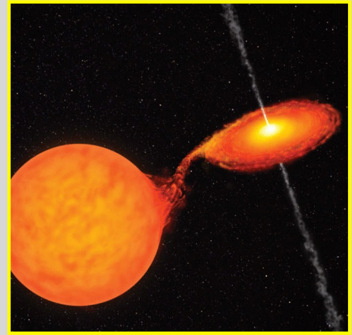
COMPETITIVENESS Council meeting
Brussels, 26 May 2014

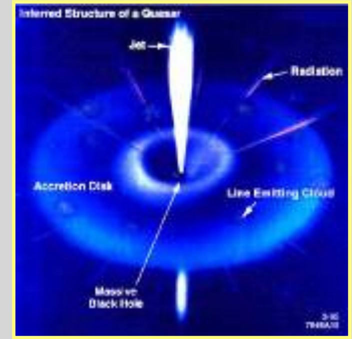
Implementation Support

- ECCSEL: European Carbon dioxide Capture and Storage Laboratory Infrastructure
- EISCAT-3D: The next generation incoherent scatter radar system
- EMSO: European Multidisciplinary Seafloor & Water column Observatory
- BBMRI: Biobanking and Biomolecular Resources Research Infrastructure
- ELI: Extreme Light Infrastructure
- CTA: Cherenkov Telescope Array
- SKA: Square Kilometre Array
- CLARIN: Common Language Resources and Technology Infrastructure
- DARIAH: Digital Research Infrastructure for the Arts and Humanities

CTA science:
astrophysics, cosmology, fundamental physics

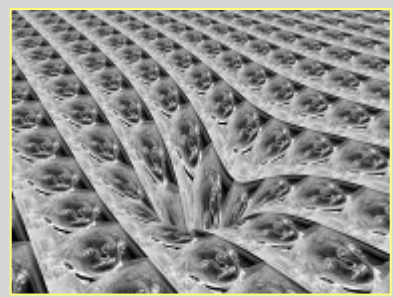


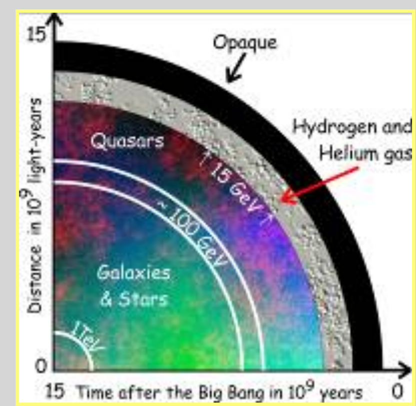




Origin of Cosmic Rays
- Particle accelerators: SNR, PWN, pulsars, micro-QSOs
- Related: massive SFR and starburst galaxies

Black hole particle accelerators
- Blazars, radio-galaxies, AGN, GRB
- EBL, galaxy clusters, cosmic magnetism





Fundamental Physics
- Search for annihilation signatures of WIMPs
- Search for Axion-like Particles
- Testing Lorentz Invariance Violation

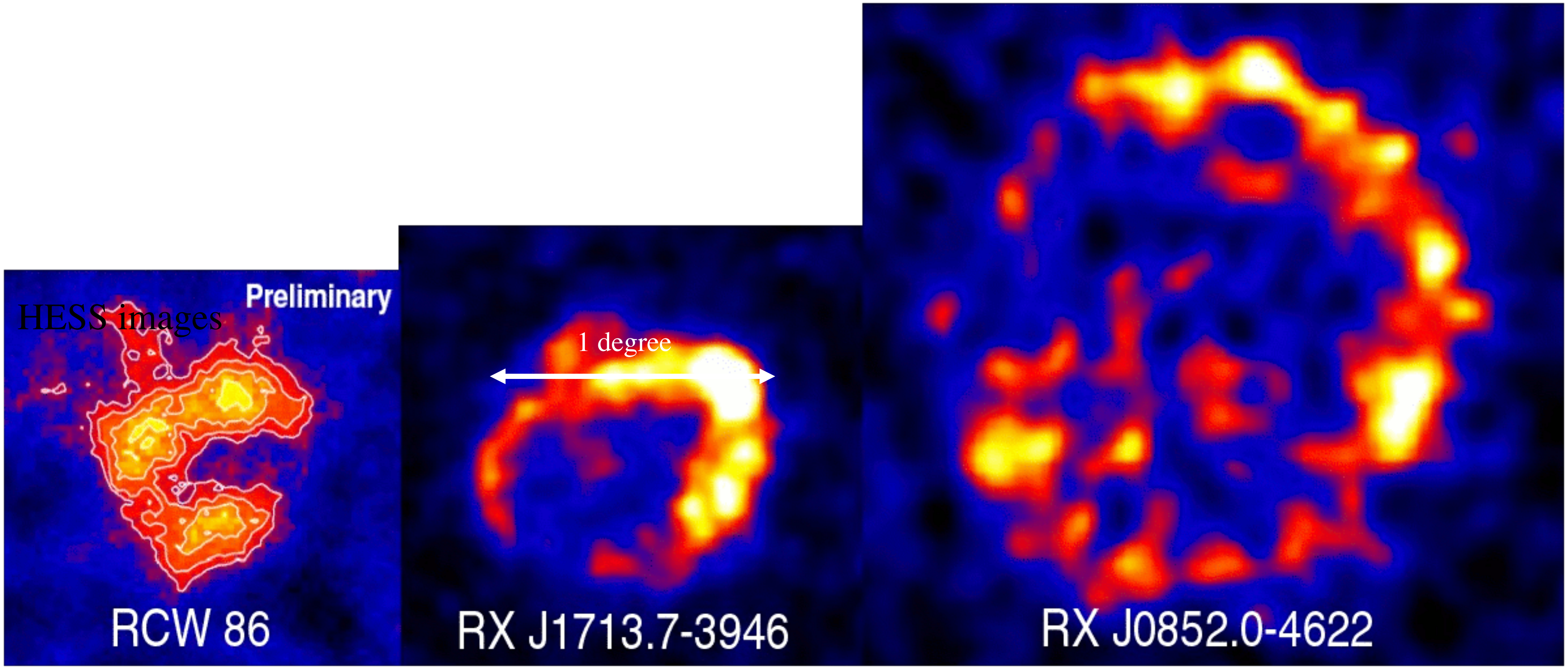
Gamma-ray signatures of CR acceleration, propagation and confinement

SNRs and Molecular Clouds:

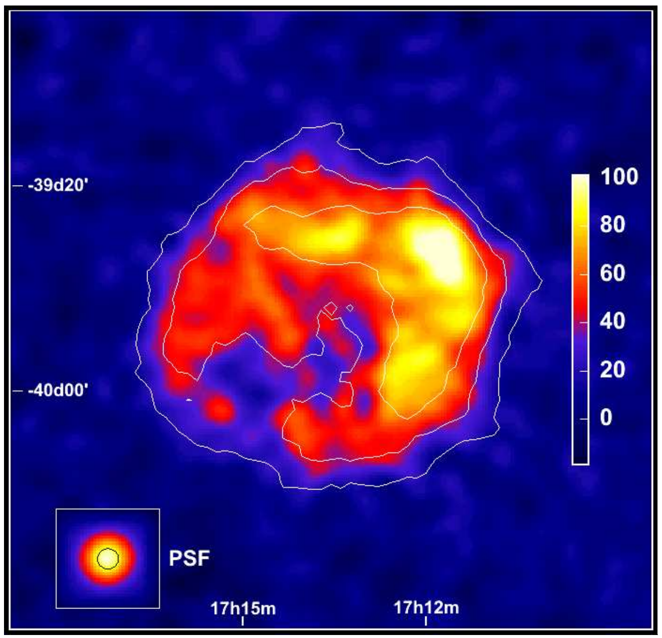
- better quality spectral studies (cut-offs, breaks, etc)

- population studies

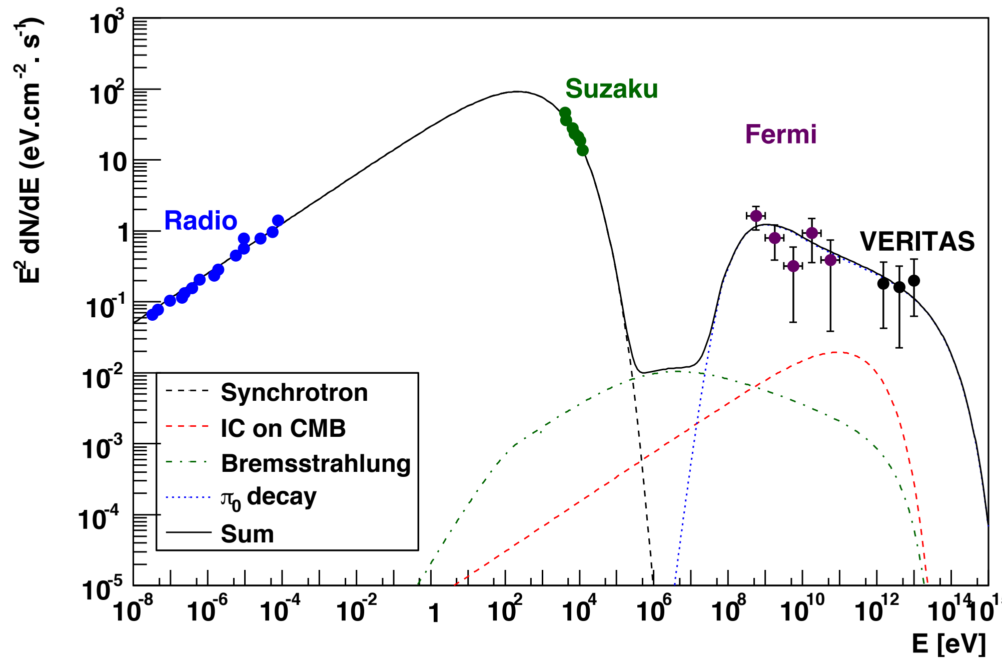
Several shell-type supernova remnants have been already resolved as TeV gamma-ray shells: in support for shock acceleration of particles to hundreds of TeV energies at supernova remnant shocks



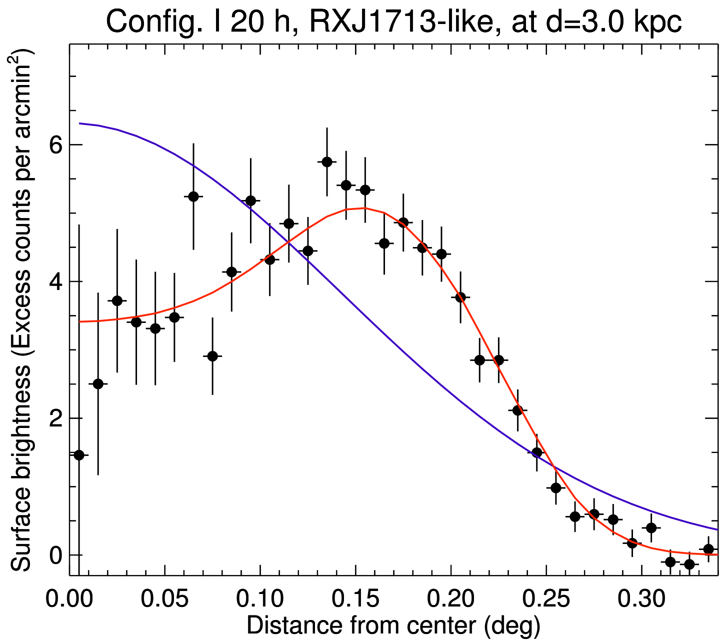
RXJ 1713.7-3946
The first SNR resolved at TeV
(H.E.S.S.)

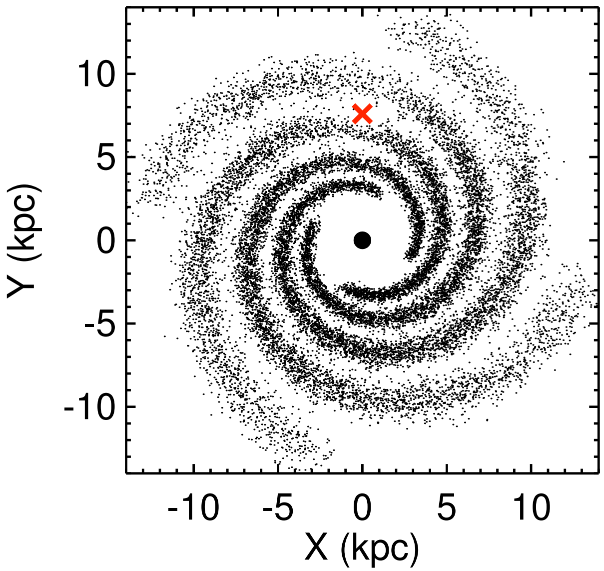


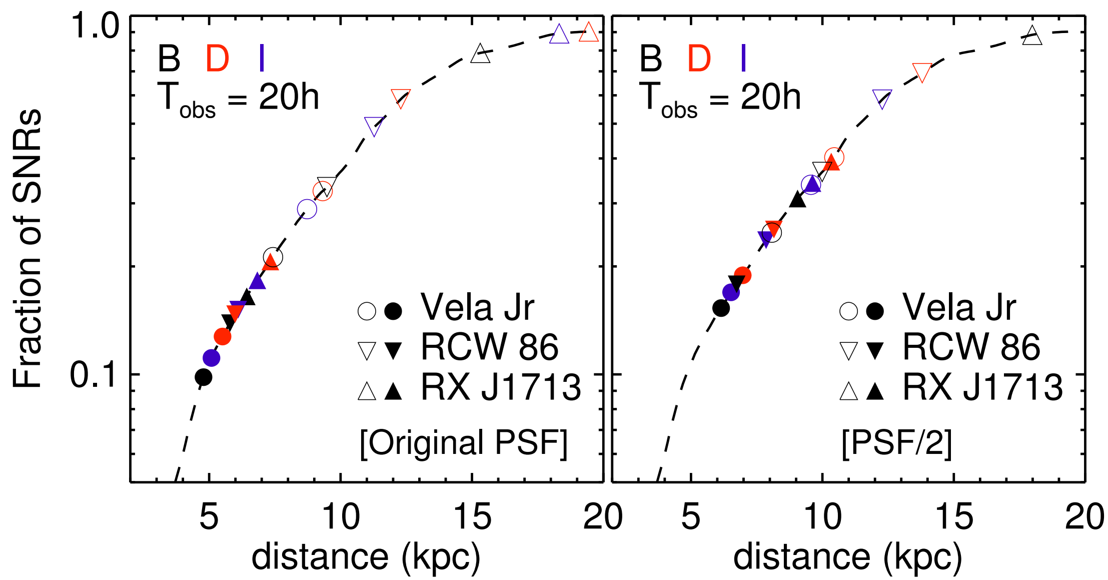
Tycho's SNR



Acero et al. 2013

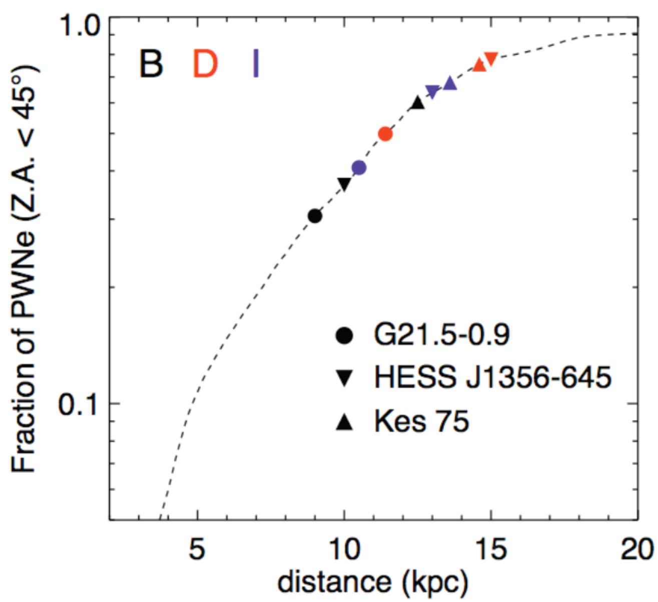


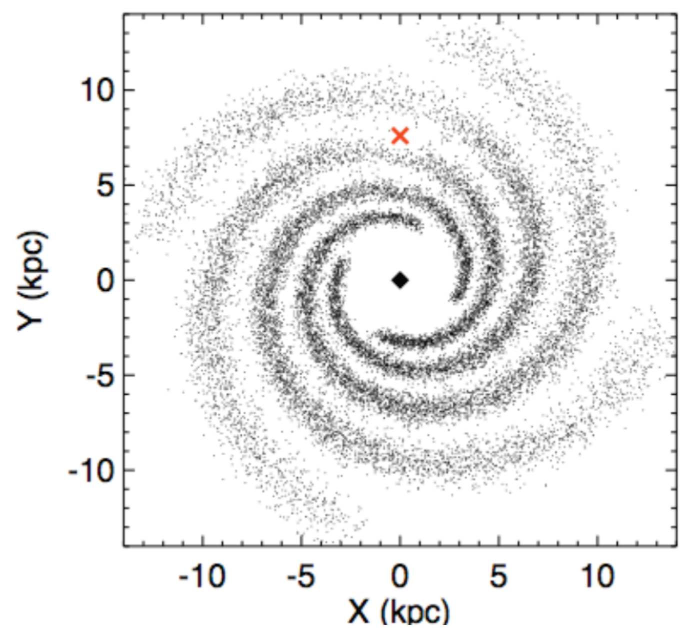




Population Studies of PWN

- 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)



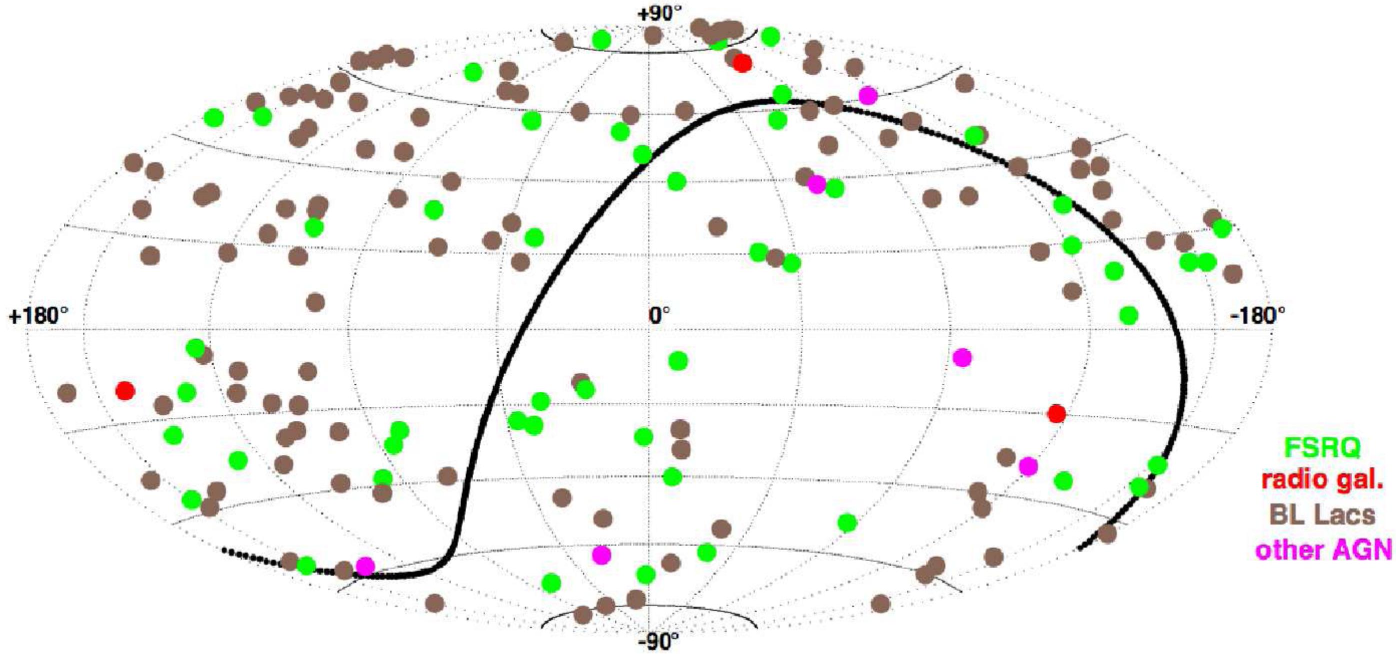


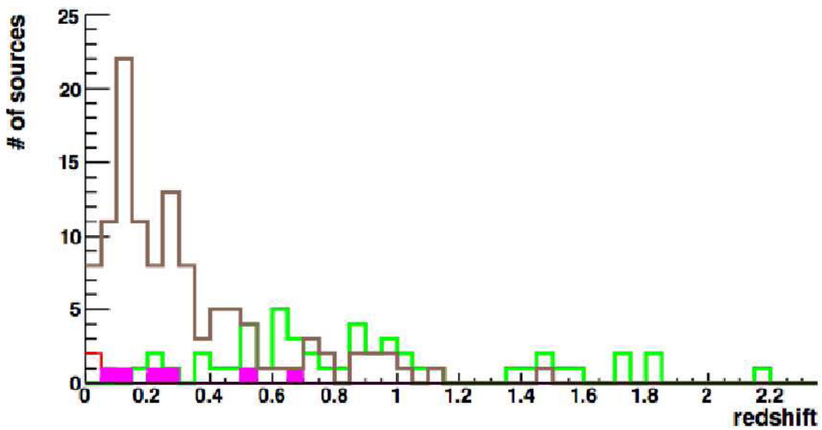
Active Galactic Nuclei with CTA

Credit: NASA/CXC/CfA/R. Kraft et al. : ASPERA

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

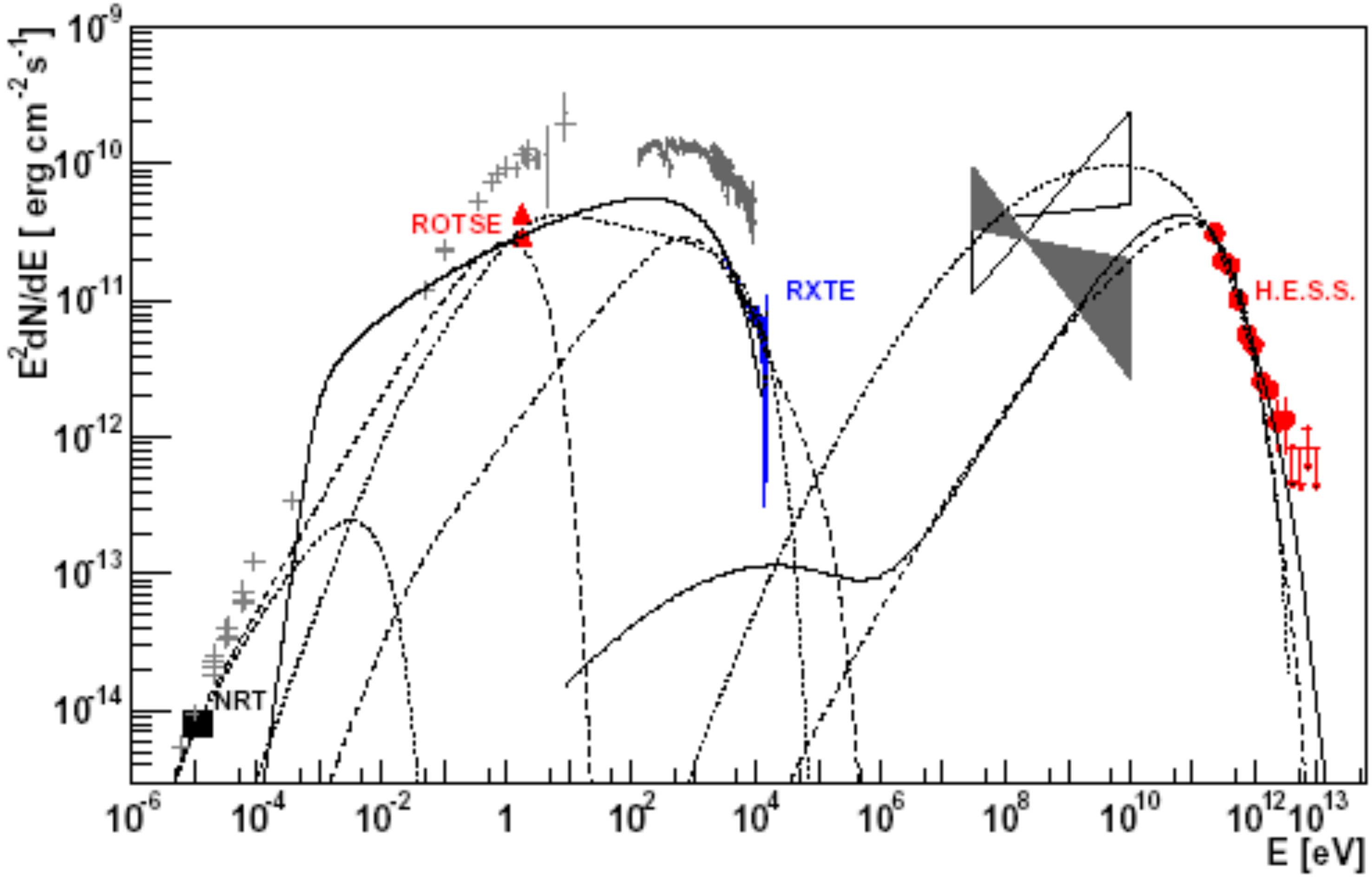
Zech et al. 2012





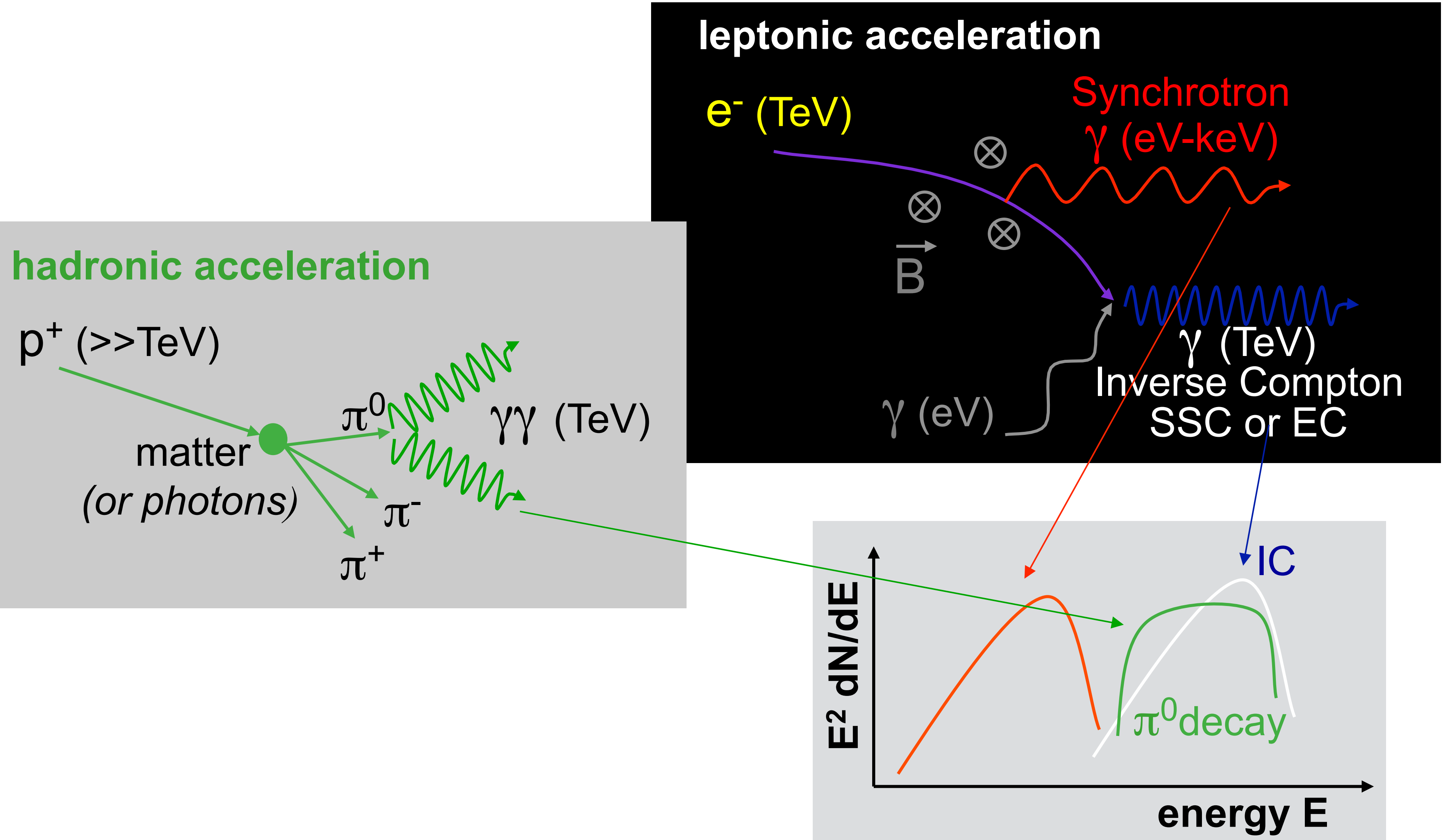
~170

PKS 2155-304
in quiescent state



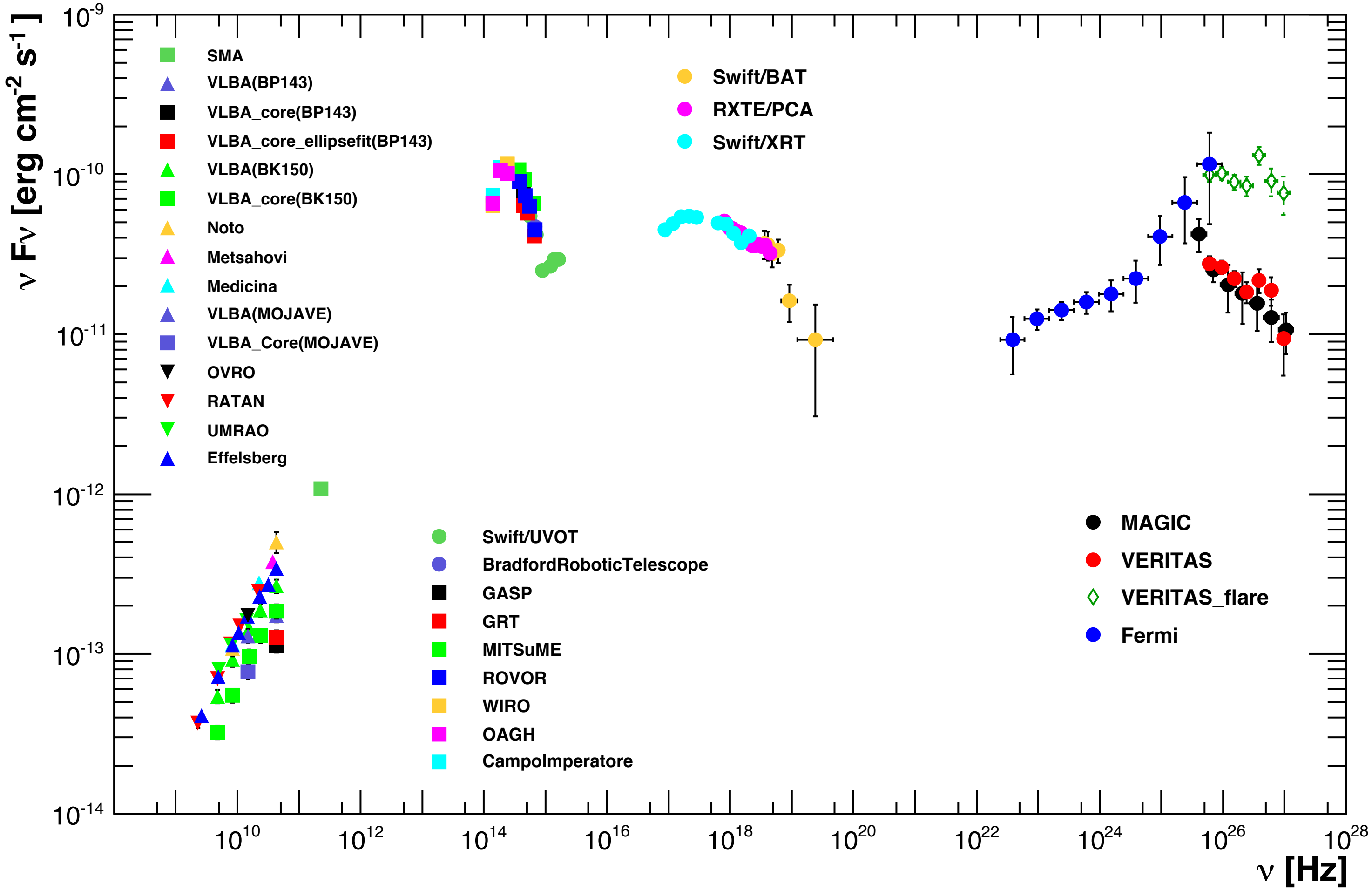
Various hadronic and leptonic models can often fit present available spectra of HBL

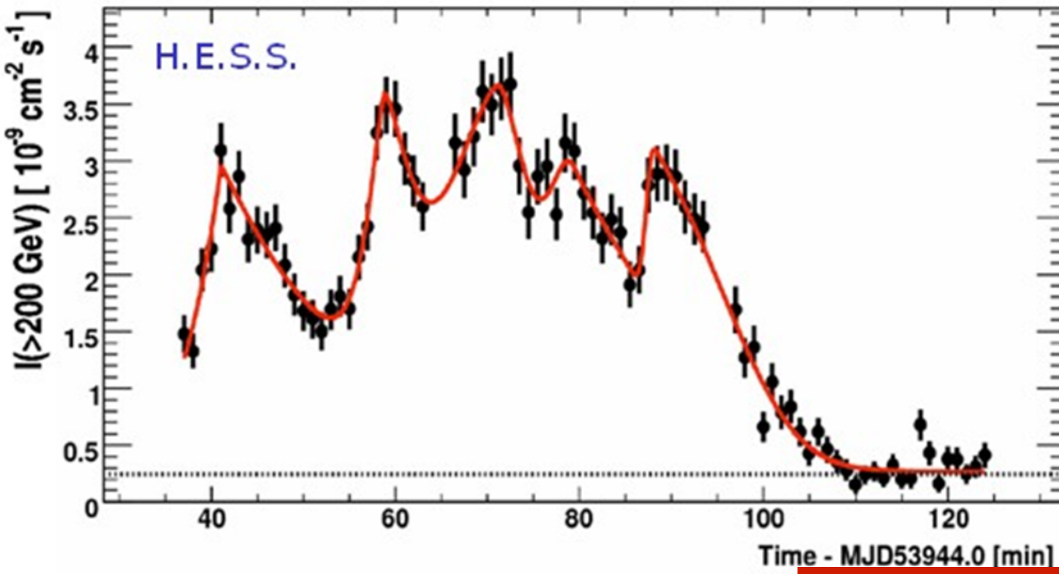
Basic scenarios for SED modeling



(adapted from De Lotto, 2009)

Markarian 501 in 2009 (3-day outburst)





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

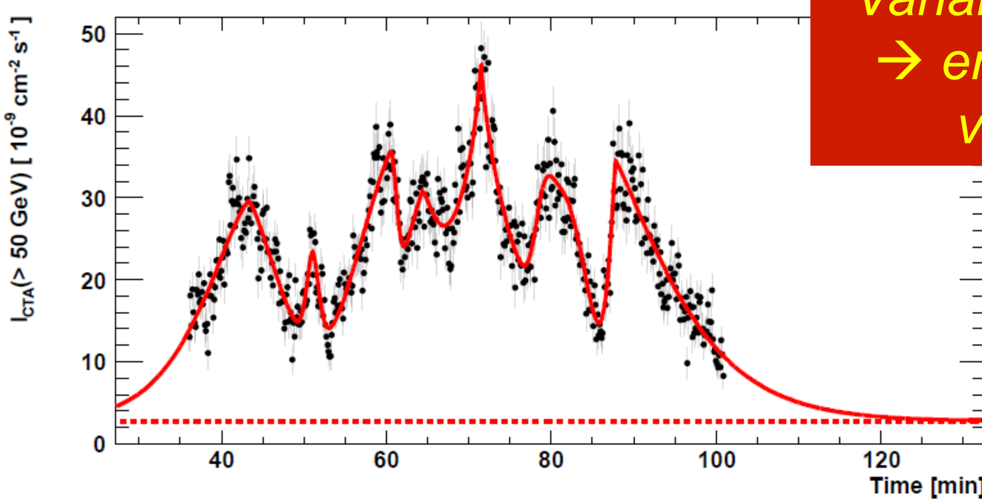
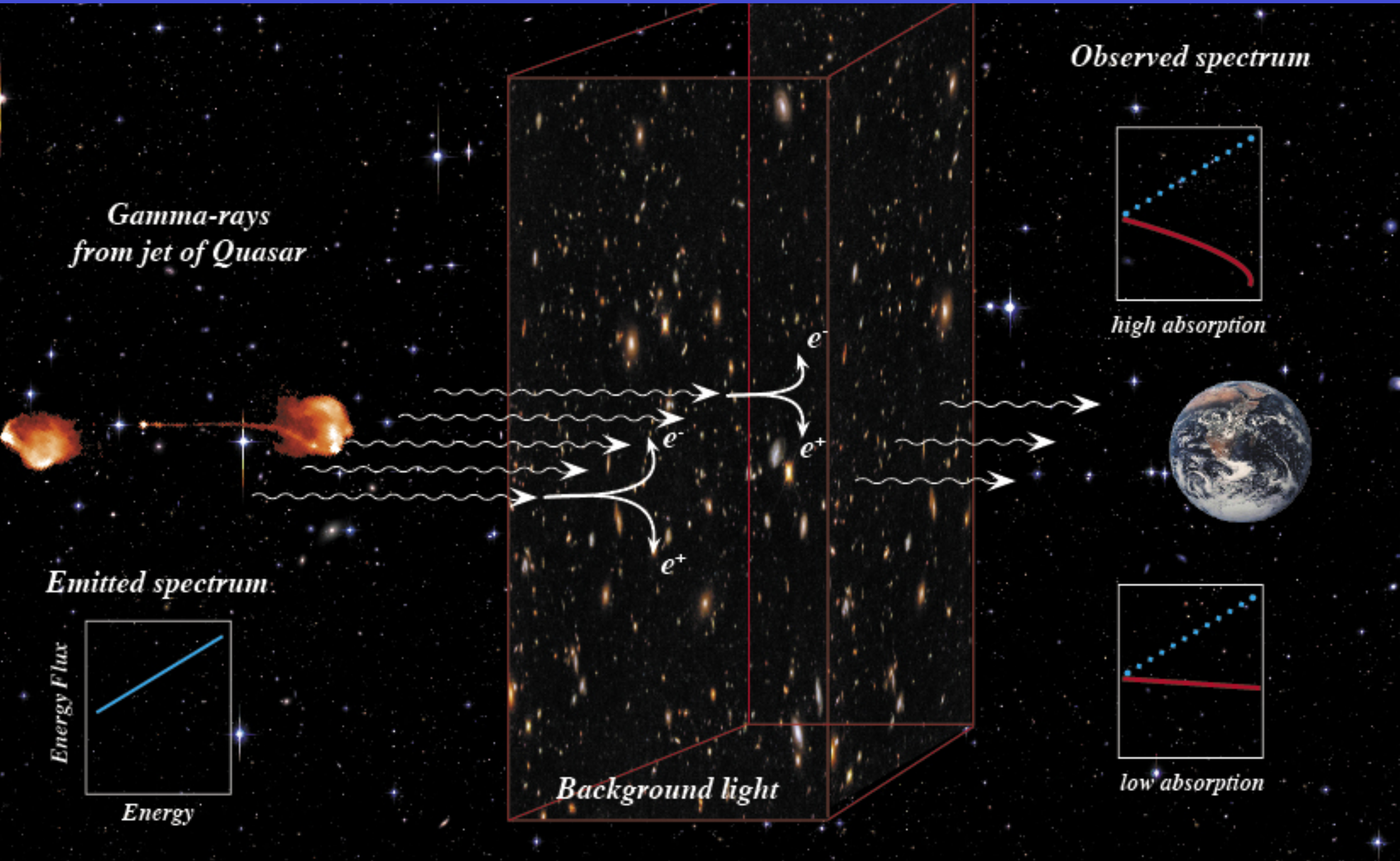


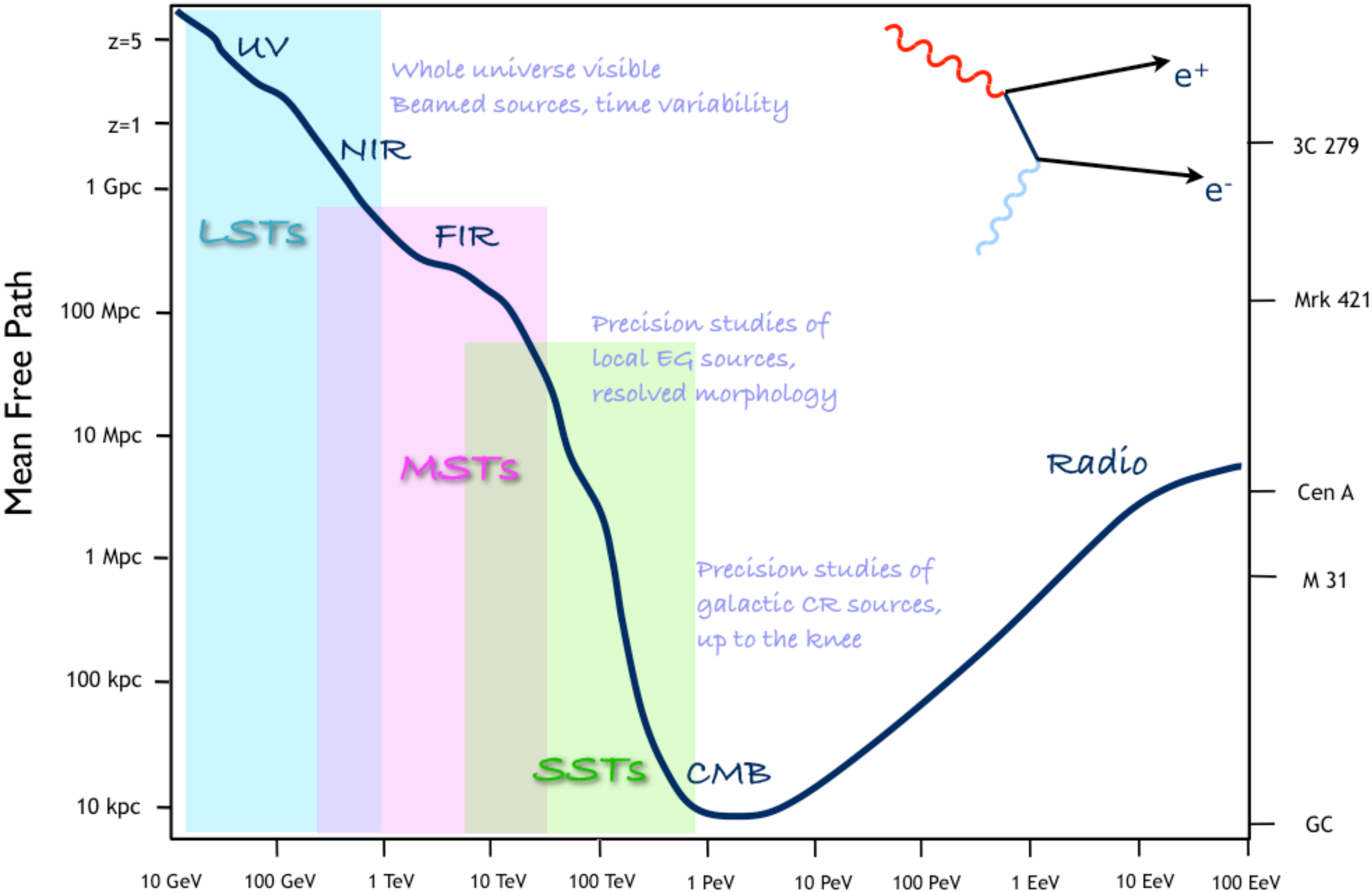
Figure 16: Simulated integral flux of PKS 2155-304 above 50 GeV as CTA would monitor it. This simulation relies on an extension of the red noise behavior to high frequencies, generating the short time scale structures (second and fourth peaks). The data are binned in 7.5 seconds intervals.

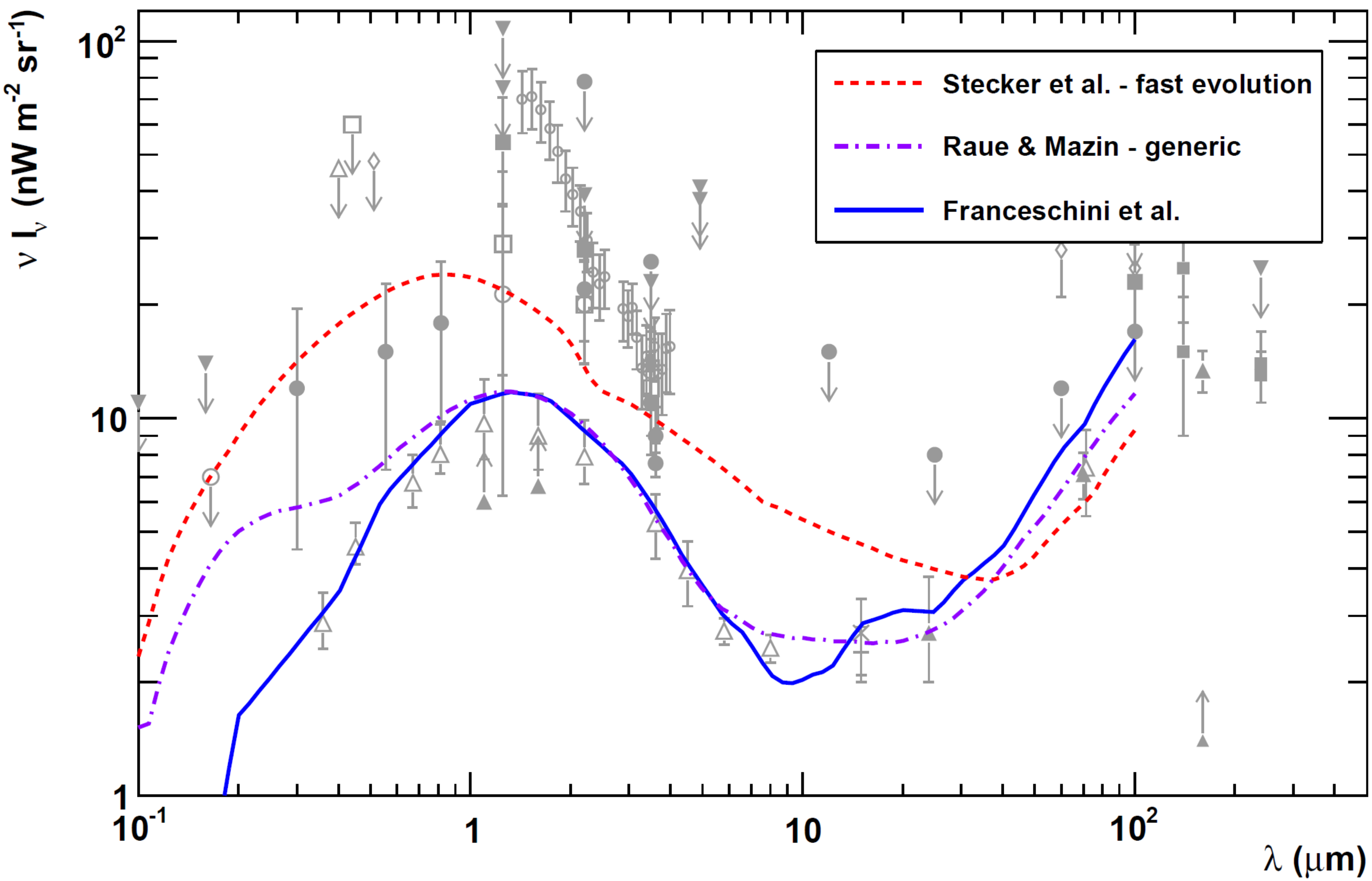
Studies of Extragalactic Background Light with CTA



Slide from Johannes Knapp

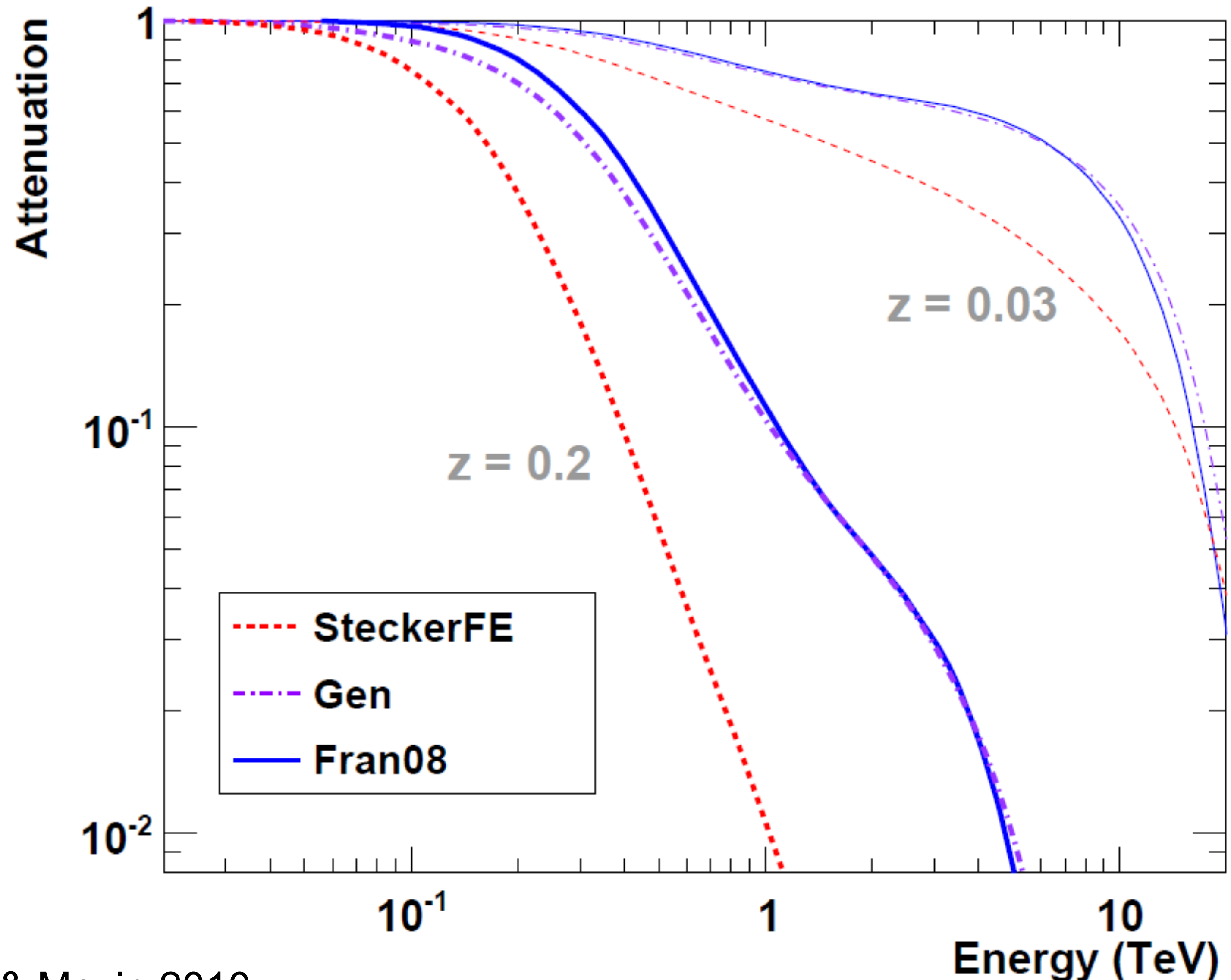
The Gamma-Ray Horizon $\gamma_{VHE} + \gamma_{..} \rightarrow e^+e^-$





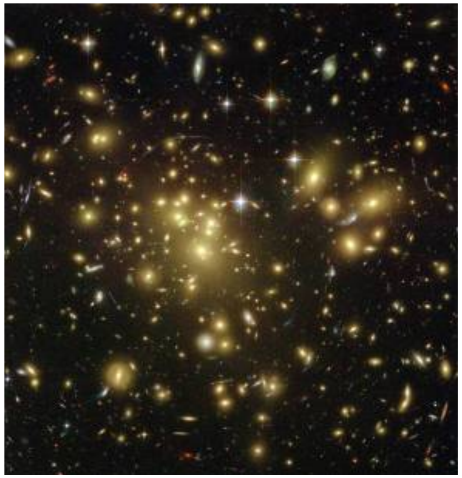
Raue & Mazin 2010

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



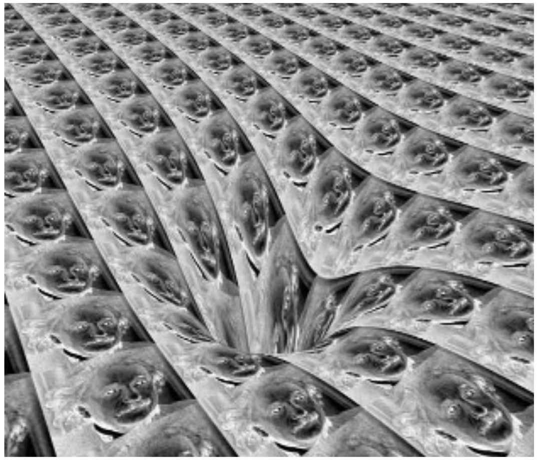
Raue & Mazin 2010

Dark Matter and Fundamental Physics



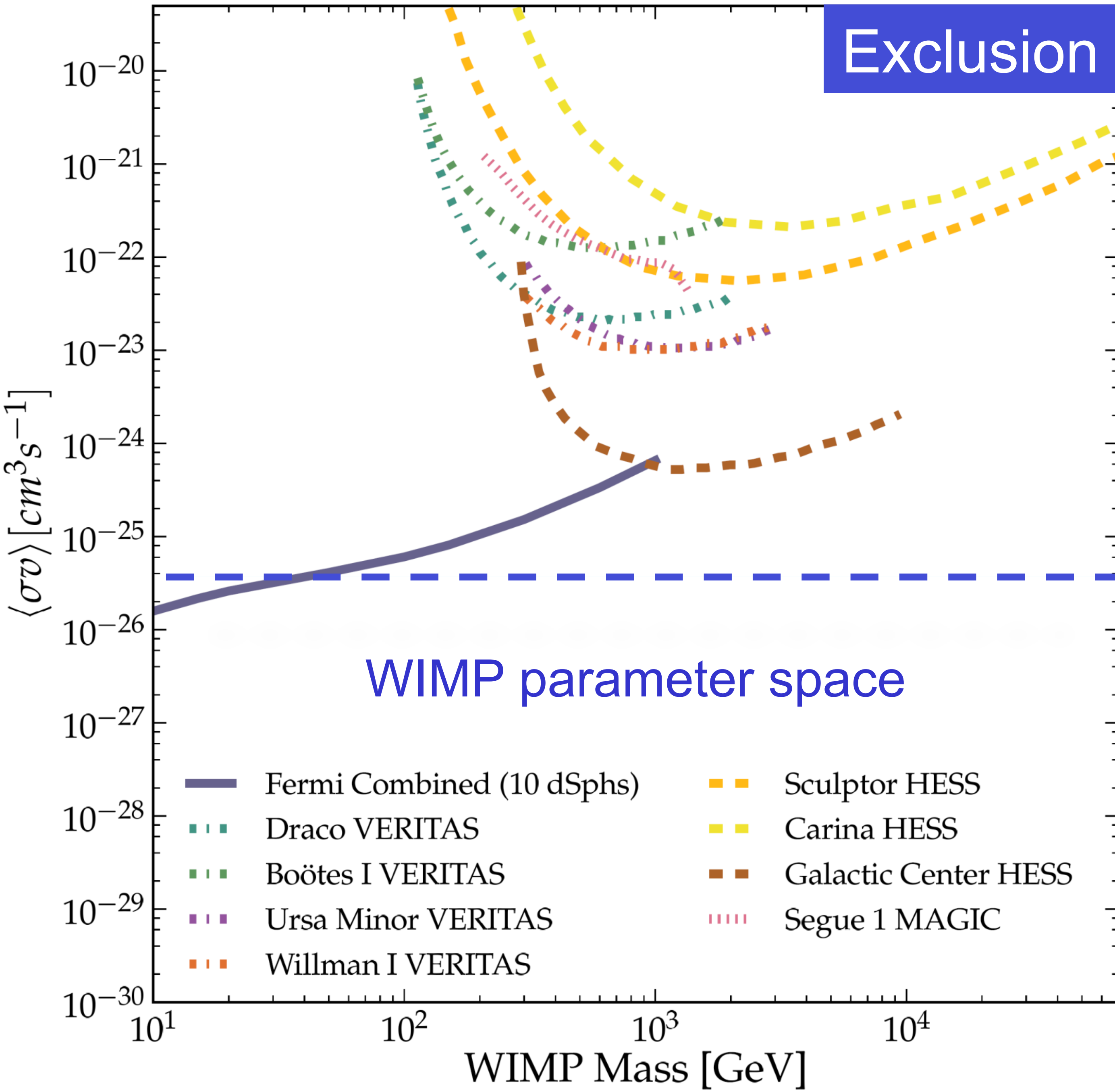
CTA prospects to search for CDM particles signatures:

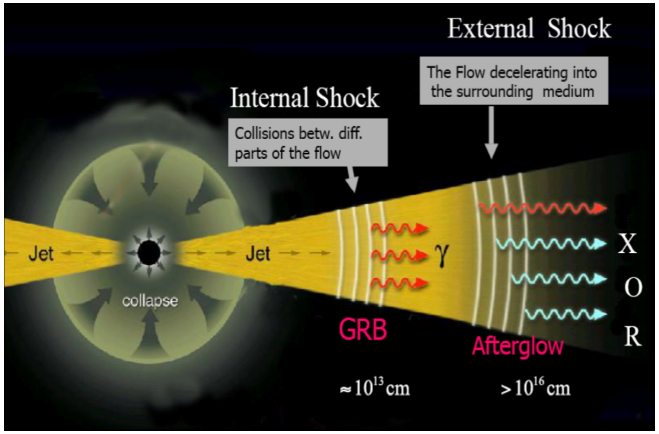
- in dwarf satellite galaxies of the Galaxy
- around the Galactic Center
- in clusters of galaxies



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

Exclusion diagram





Prompt GRB light curves and AGN light curves are used to determine the lower limit of Quantum Gravity scale by detection of the 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

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

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

Fermi LAT and GBM light curves of GRB 090510

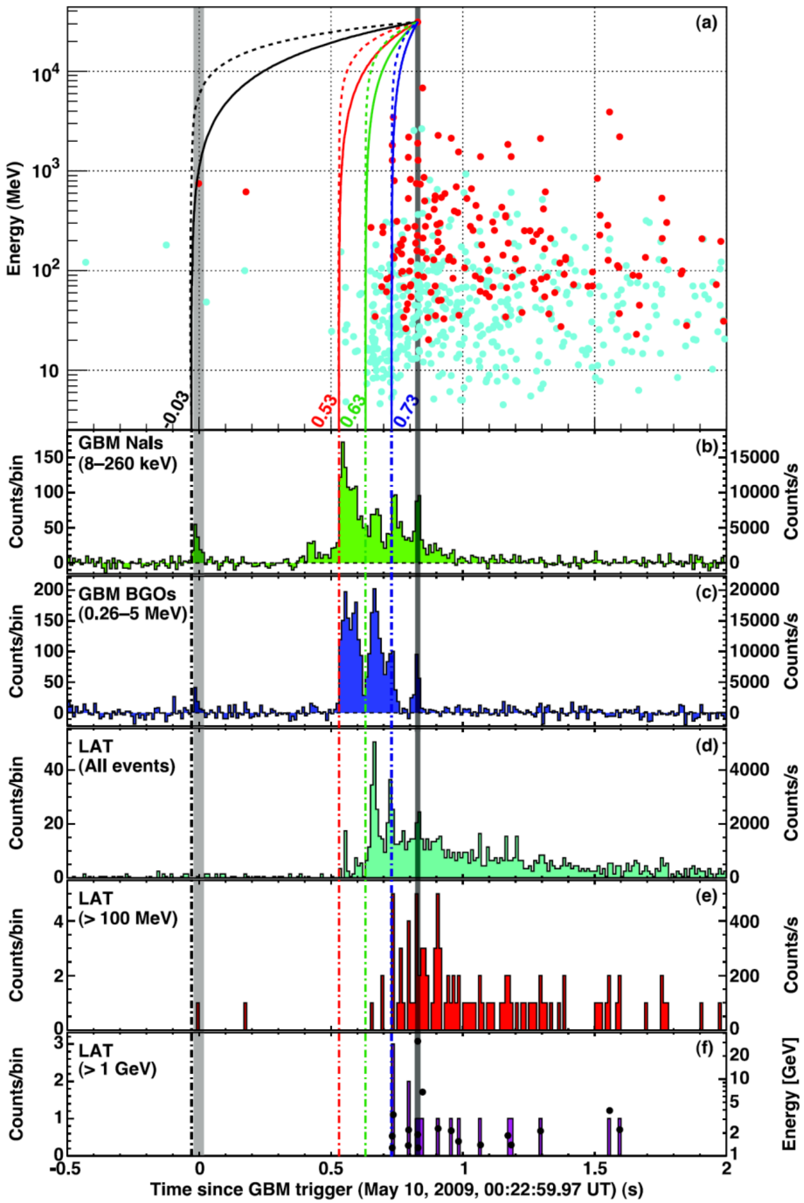
Current lower limit on the QG energy scale
due to possible linear dependence of the speed of light on photon energy:

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

$$\xi_1 > 1.2$$

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

(Abdo et al. 2009)



CTA – Summary

- The1st ever open IACT observatory

- Entire sky coverage

- Performance capabilities superior to major present-day IACTs

- Huge discovery potential for astrophysics, physics and cosmology

- Strong support from EC and national funding agencies

Acknowledgements

We gratefully acknowledge support from the agencies and organizations listed under Funding Agencies at this website: http://www.cta-observatory.org/.