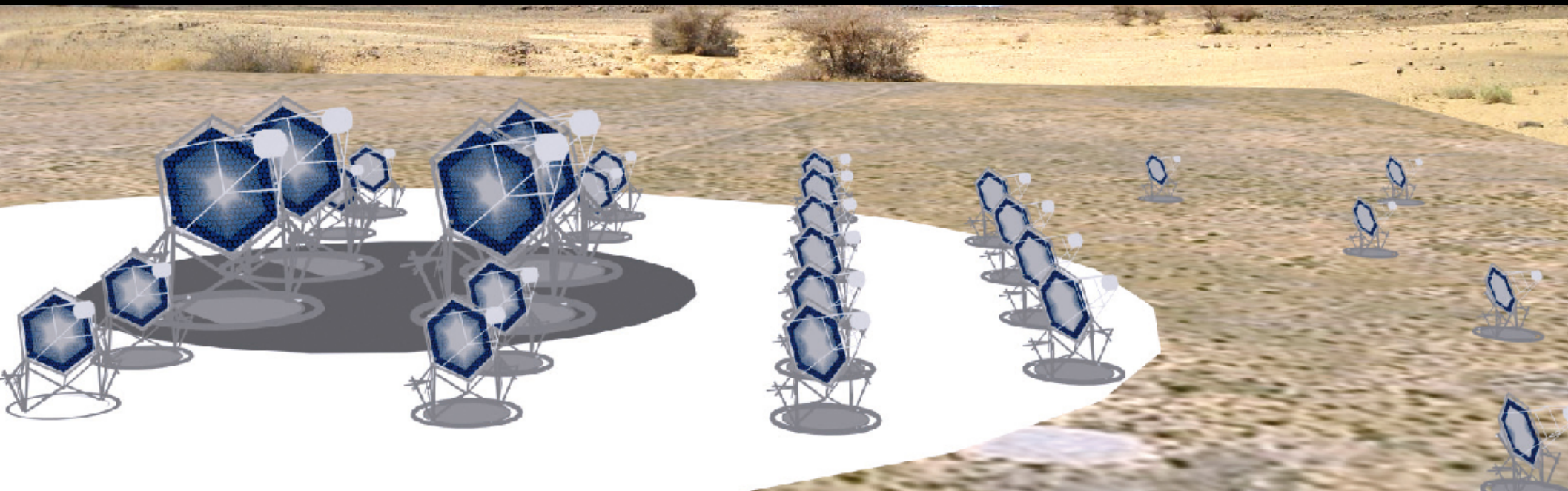
Cherenkov
Telescope
Array

l'Observatoire de Paris
LUTH
Laboratoire de l'Univers et de ses Théories

Science Prospects for CTA

A. Zech

SNOWPAC, March 2010



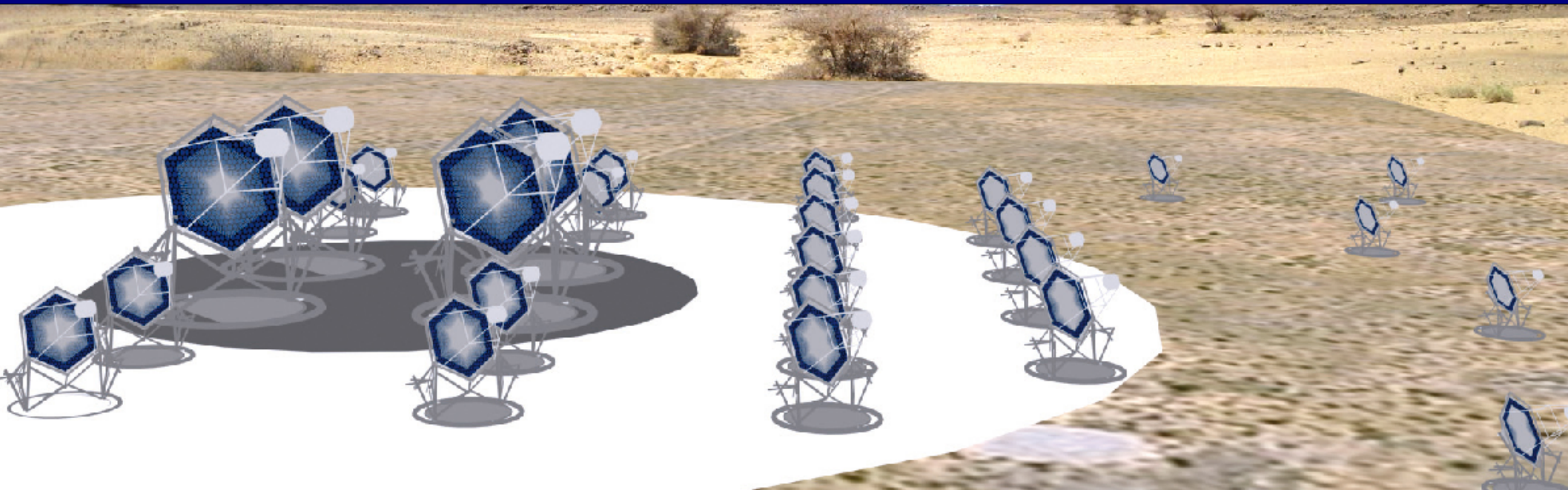
Outline

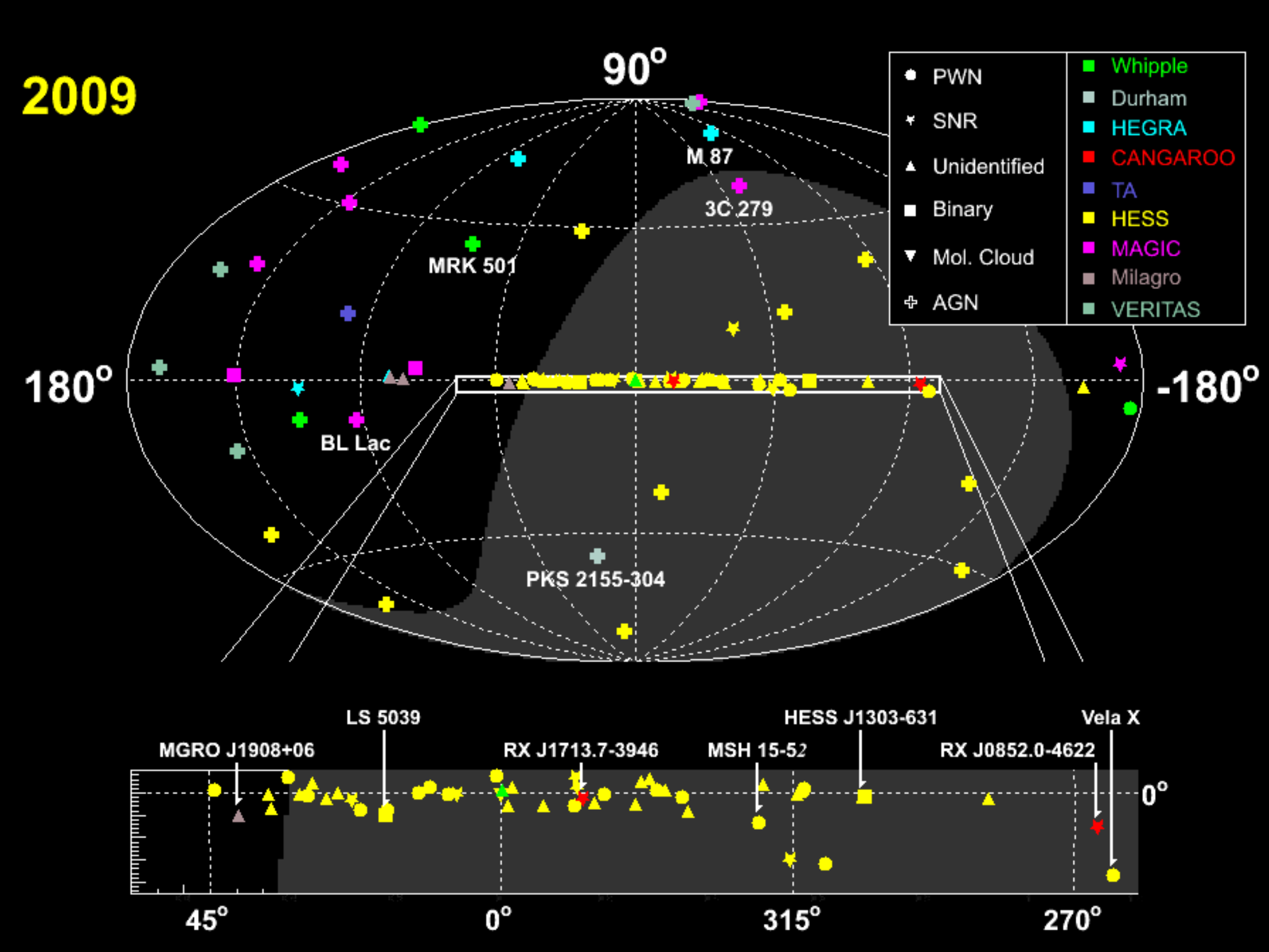
1) The Cherenkov Telescope Array
   a) Science Case
   b) The CTA project
   c) CTA Design Study

2) Prospects of AGN science with CTA

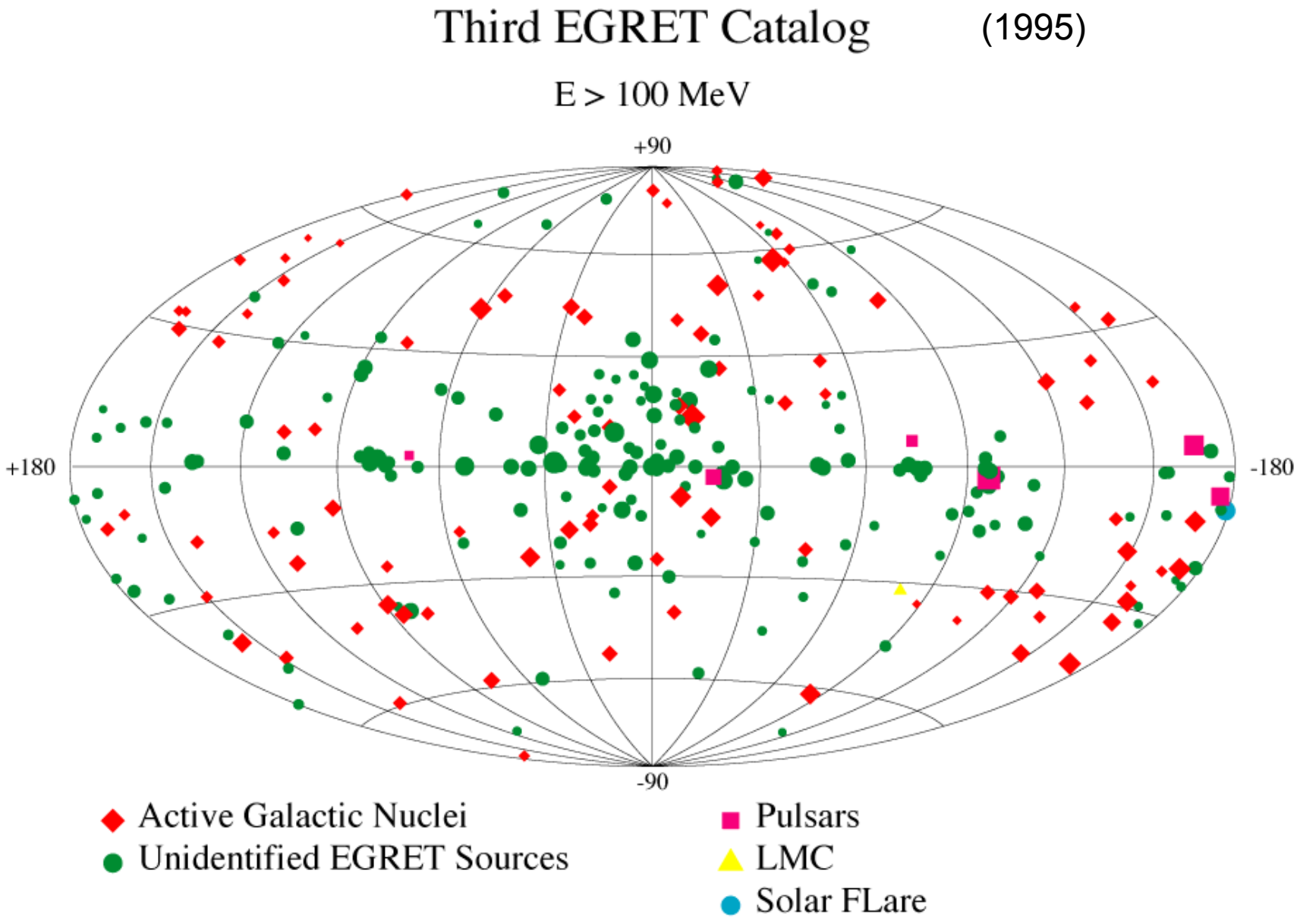
1) The Cherenkov Telescope Array

a) Science Case




2009
90°
180°
-180°
PWN
SNR
Unidentified
Binary
Mol. Cloud
AGN
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
VERITAS
M 87
3C 279
MRK 501
BL Lac
PKS 2155-304
MGRO J1908+06
LS 5039
RX J1713.7-3946
MSH 15-52
HESS J1303-631
RX J0852.0-4622
Vela X
0°
45°
0°
315°
270°

gamma-ray astronomie in 1995



gamma-ray astronomy in 2010

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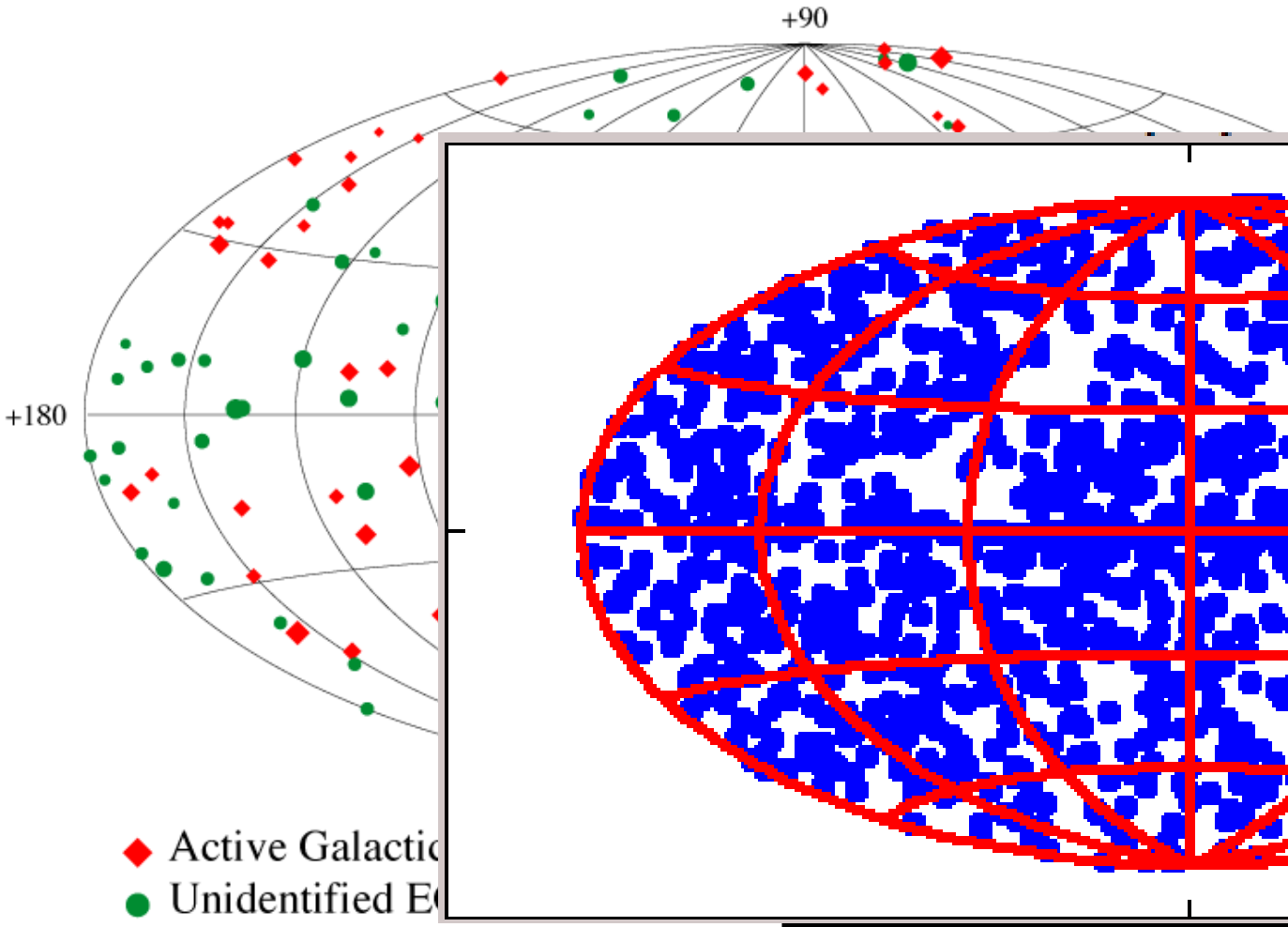
Third EGRET Catalog (1995)

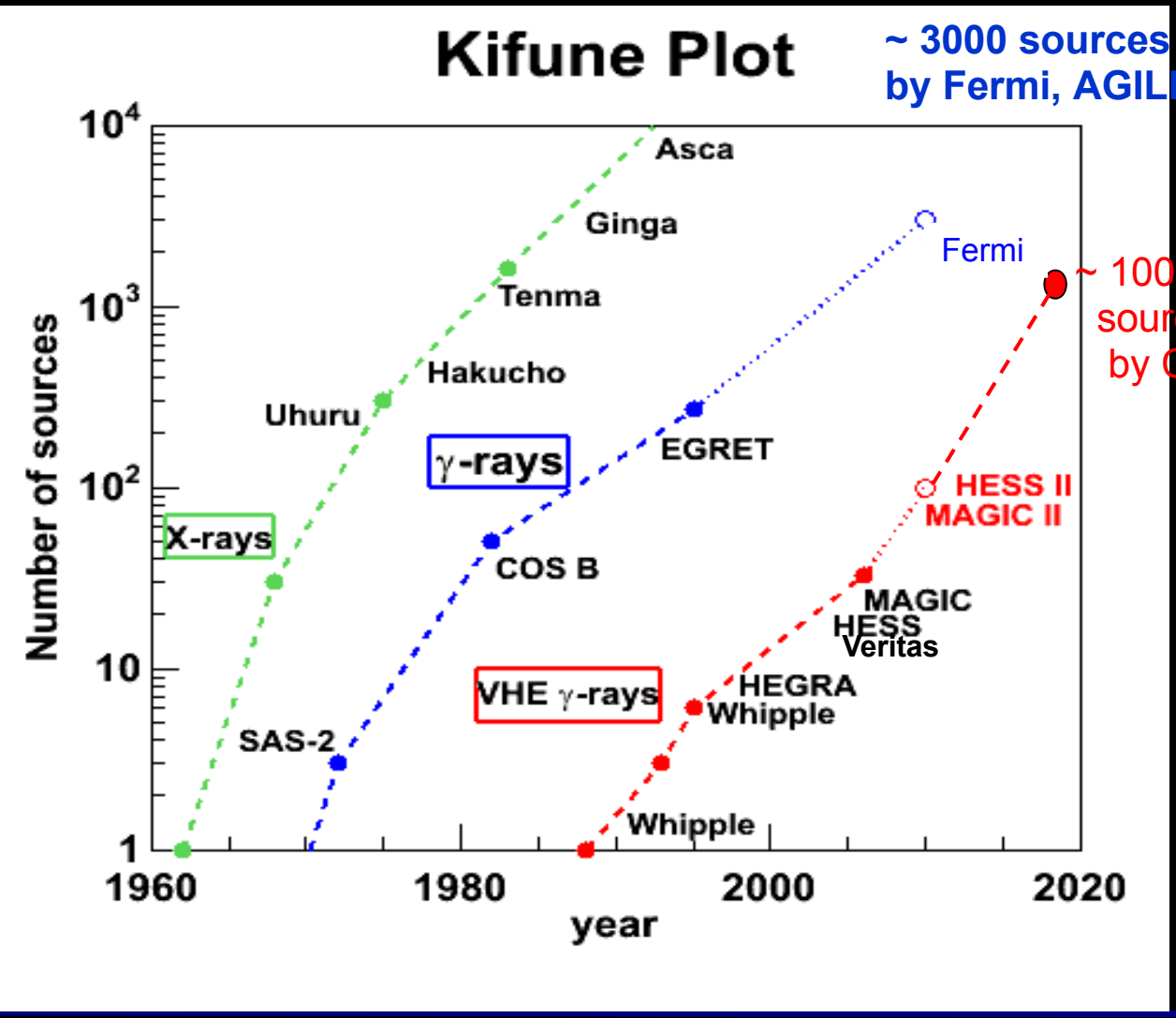
E > 100 MeV



Fermi 1 yr point source catalog (2010)

time for a VHE **Observatory** !

The next generation of IACT arrays needs to function like a true observatory.



-> observation time for the whole astrophysics and -particle community

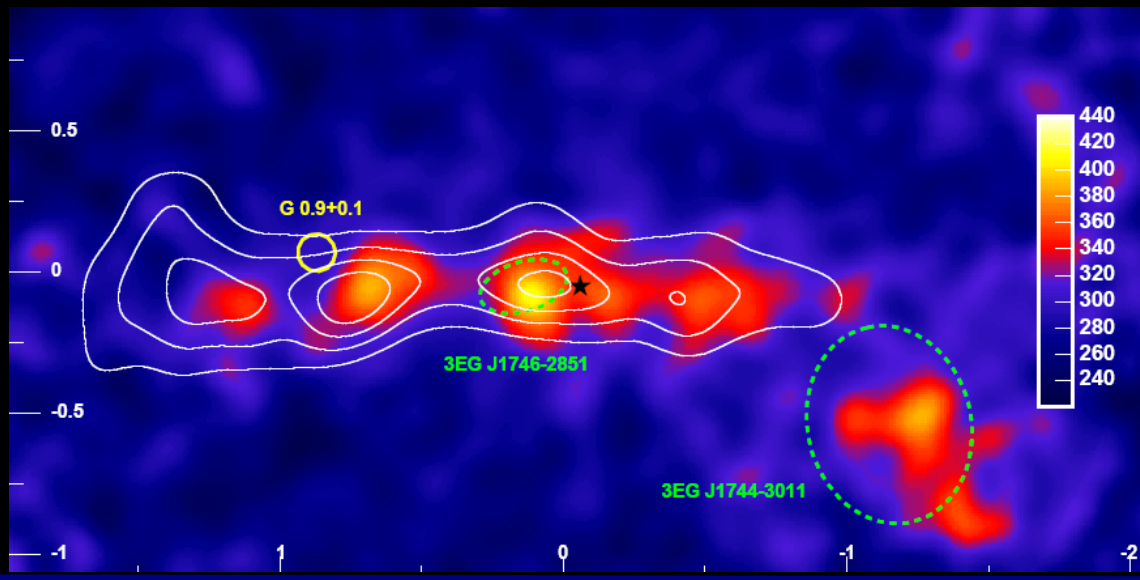
-> observation program driven by proposals

-> open access to data at different levels & to analysis tools

The Big Questions

What is the origin and nature of cosmic rays and how do they interact with their environment ?

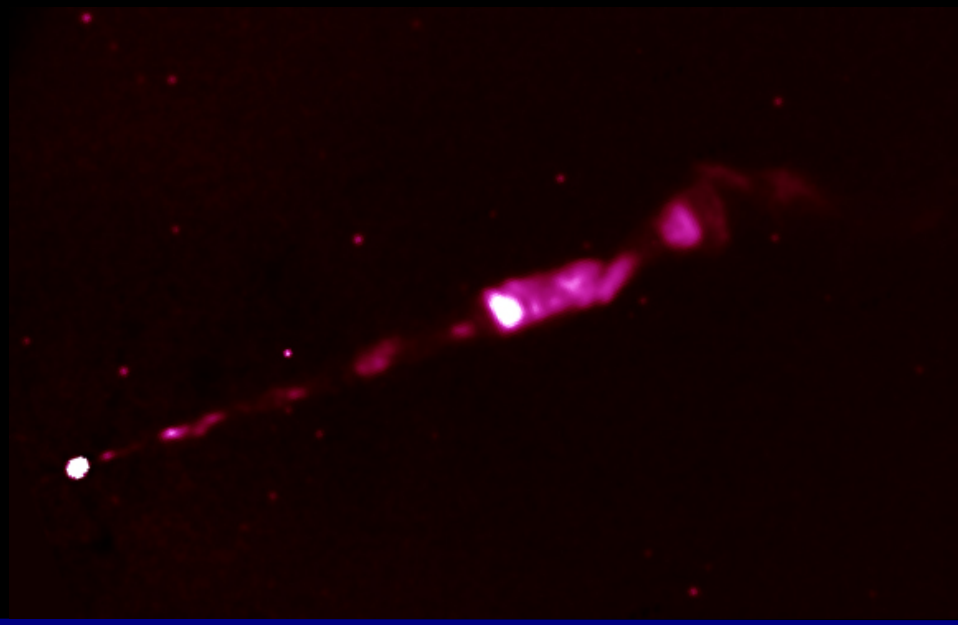
- Origin and propagation of Galactic cosmic rays (only SNR?)
- Understanding of processes around pulsars, binary systems, PWN structure (maps !)
- Starburst galaxies
- Detection of galaxy clusters ?
- Signatures of UHECR acceleration sites ?



The Big Questions

What is the nature of the different types of black hole particle accelerators ?

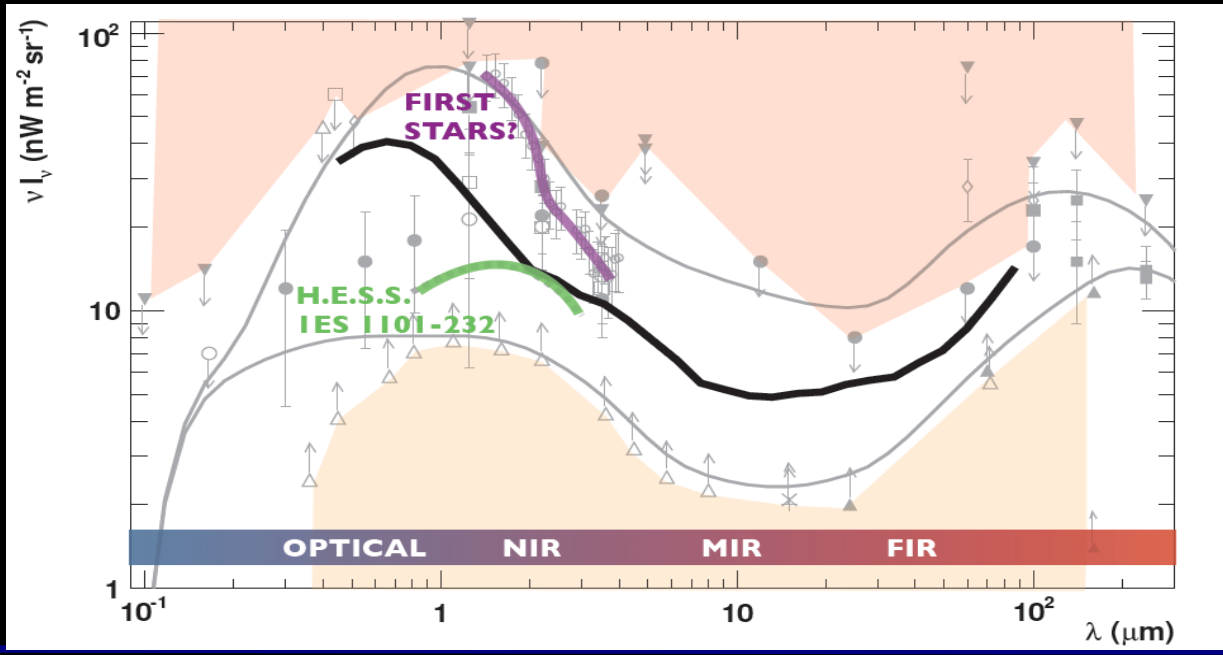
- Detailed understanding of acceleration & emission processes in different classes of AGN
- Detection of VHE gamma rays from GRBs ?



The Big Questions

What is the nature of dark matter ?
Are there other signatures of physics beyond the standard model ?

- Cosmology with VHE gamma rays (probing the EBL)
- Detection of Dark Matter ?
- Fundamental physics (test Lorentz Invariance Violation)



CTA performance goals

Gain of factor 10 in sensitivity, down to mCrab

Very large spectral coverage (a few 10 GeV to >100 TeV)

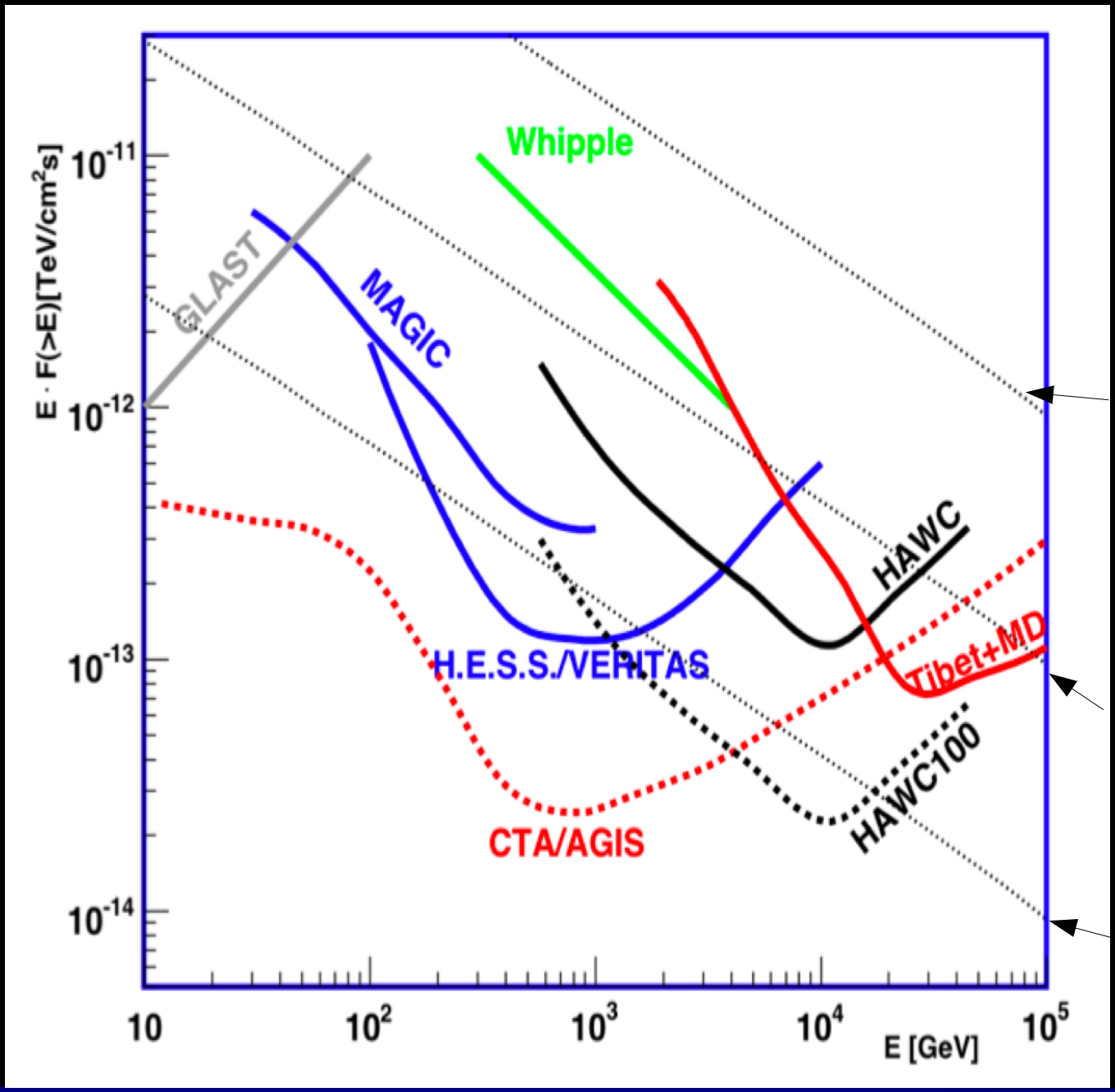
Improved angular resolution down to arc-minute range

Temporal resolution down to sub-minute time scale

Flexibility of operations

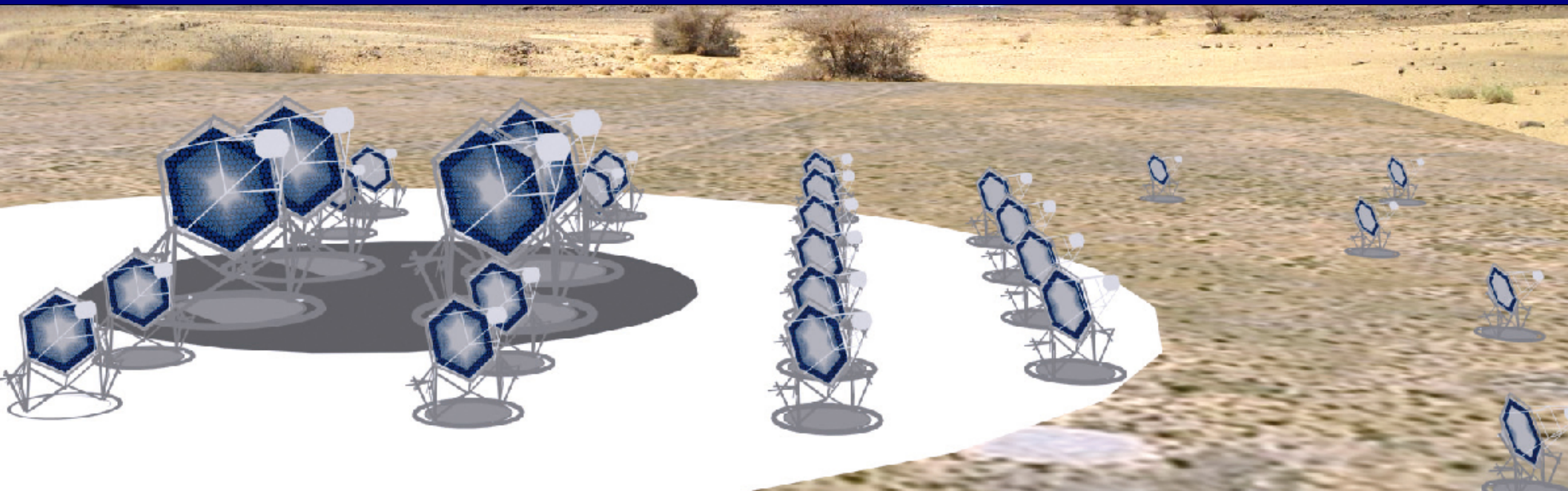
Full sky coverage using North & South installations

Expected sensitivity for CTA



1) The Cherenkov Telescope Array

b) The Project



Expected sensitivity for CTA

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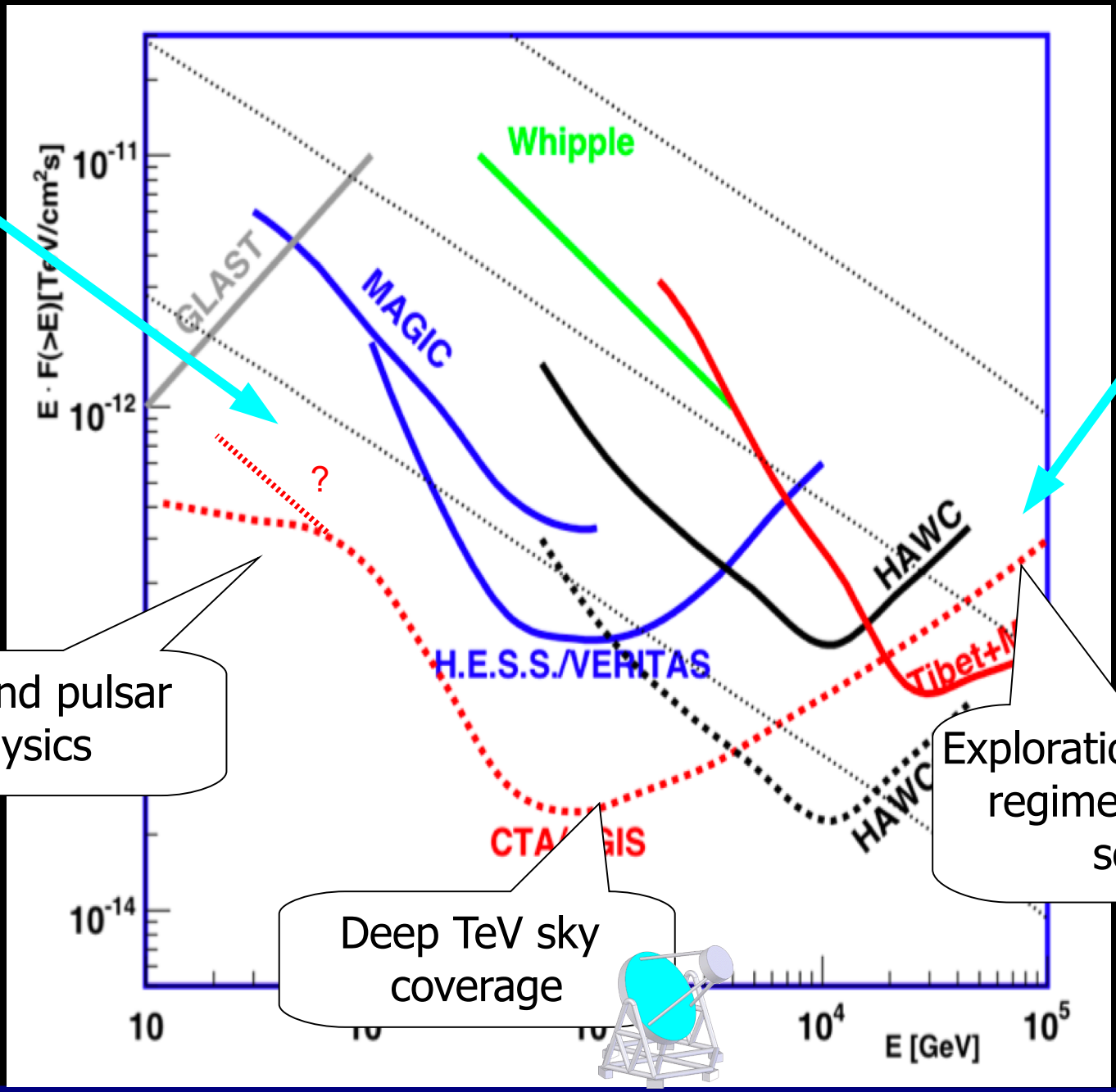


The CTA Consortium

> 100 institutes, 22 countries

Present partners :

Argentina, Armenia, Austria, Bulgaria, Croatia, Czech Republic, Finland, France, Greece, Germany, Ireland, Italy, Japan, Netherlands, Namibia, Poland, Spain, South Africa, Sweden, Switzerland, UK, USA

- Regular general CTA meetings since 2006
  next meeting in Berlin/Zeuthen (May 10 - 12, 2010)
- spokesperson: W. Hofmann (MPIK Heidelberg)
- co-spokesperson: M. Martinez (IFAE Barcelona)

- open to new members !

CTAGIS ?

Two synergetic concepts

CTA: - rely mostly on proven, low-cost technology (single mirror telescopes, PMTs,...)

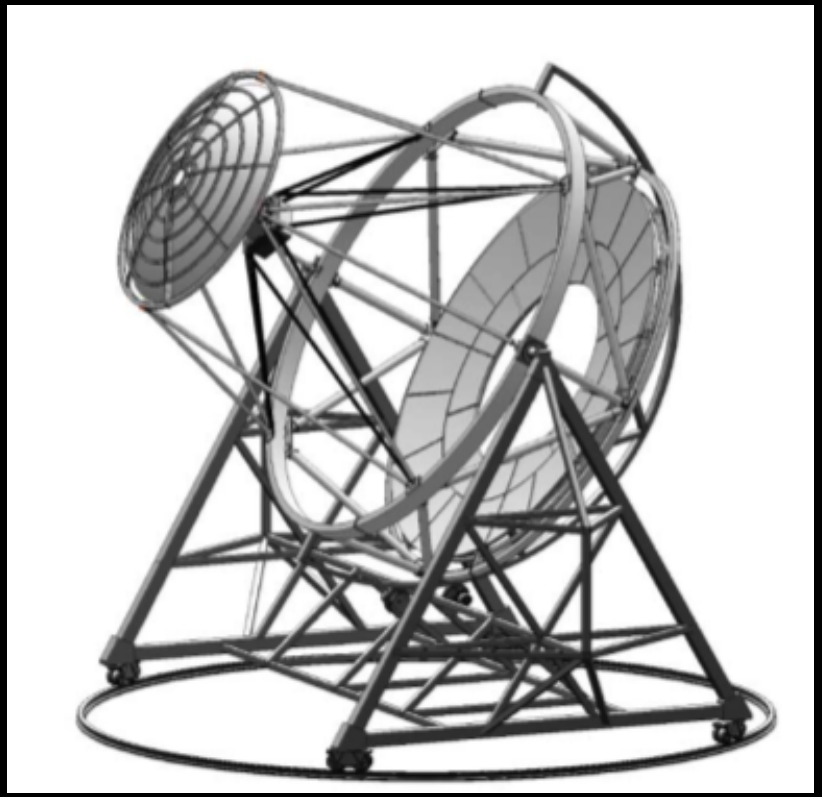
- extension of the energy coverage from a few 10 GeV to 100 TeV

AGIS: - superior telescope design (secondary mirrors)
-> better angular resolution

- but more expensive and focused on mid-E range

=> good cooperation

=> future collaboration/merger seems likely



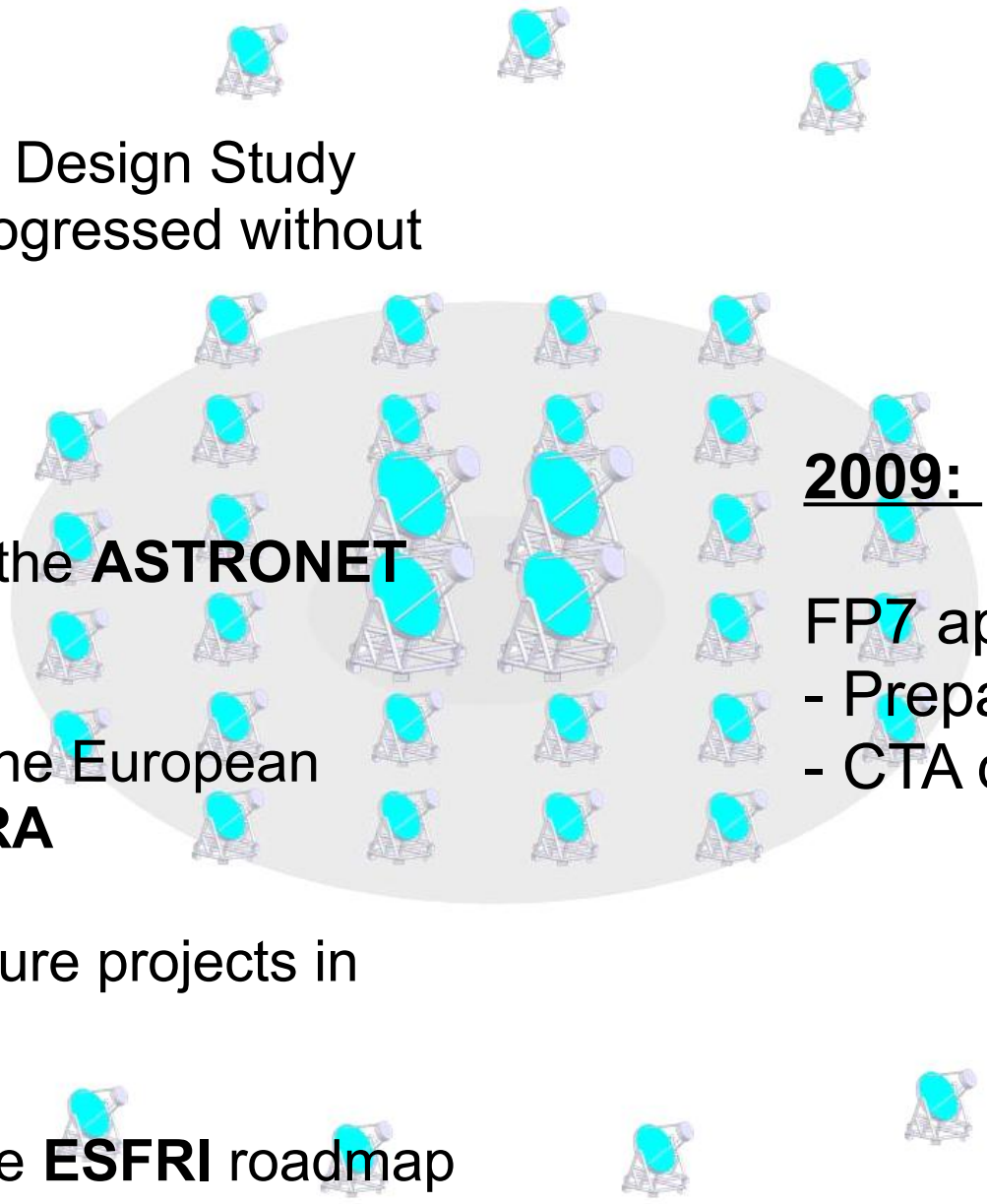
Putting CTA on the (road)map

2007:

FP7 application for Design Study rejected -> D.S. progressed without dedicated funding

since 2008:

- highly ranked on the **ASTRONET** roadmap
- highly ranked in the European Strategy of **ASPERA**
- one of the key future projects in **AppEC**
- "future goal" in the **ESFRI** roadmap

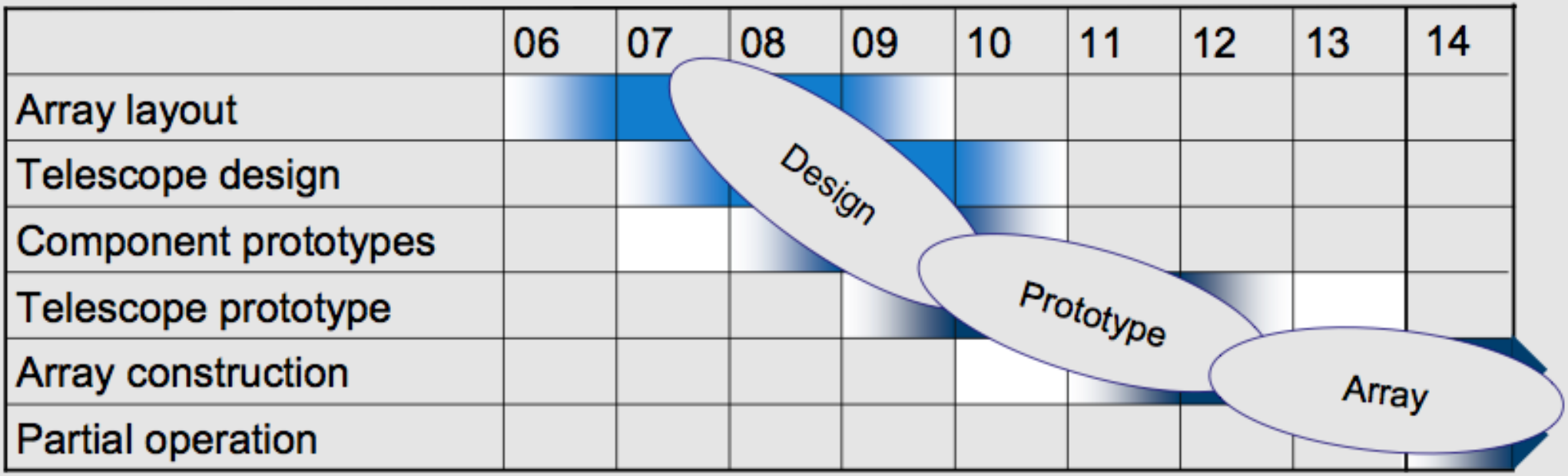


2009:

FP7 applications for
- Preparatory Phase
- CTA data infrastructure

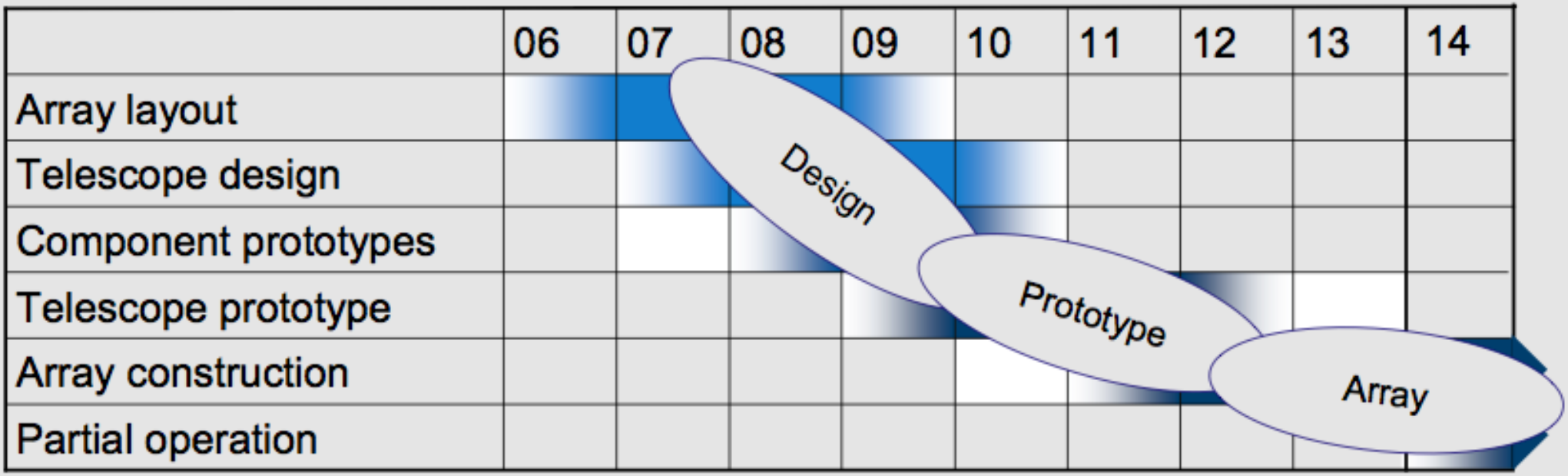
Timeline

Tentative timeline towards the *CTA* observatory



Timeline

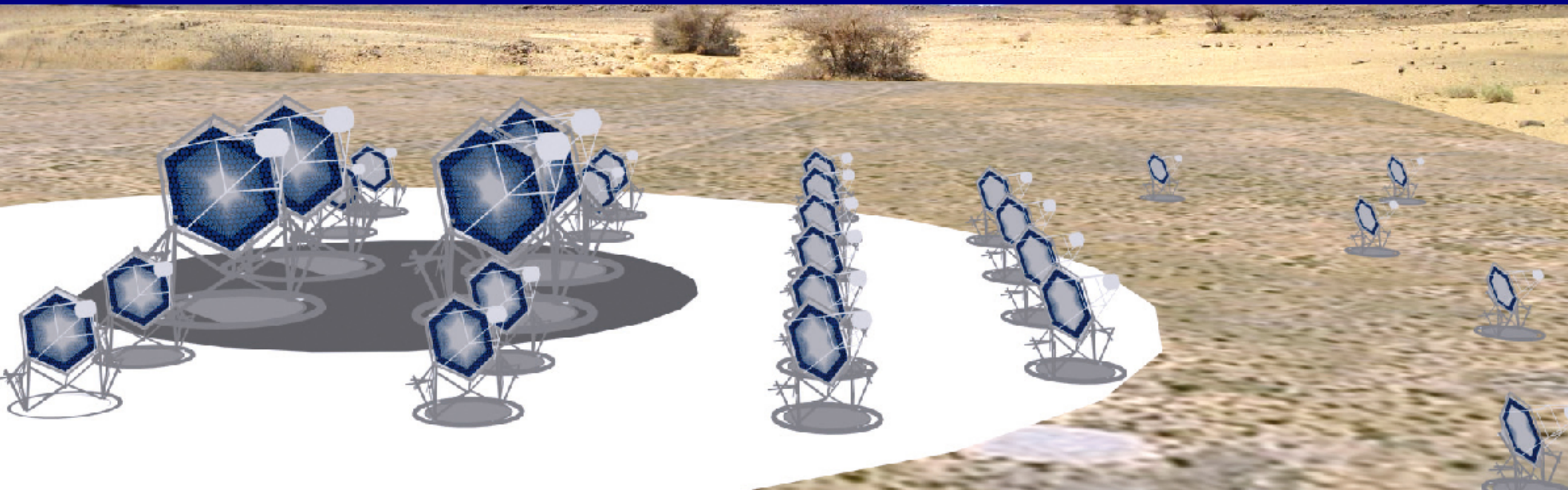
Tentative timeline towards the *CTA* observatory



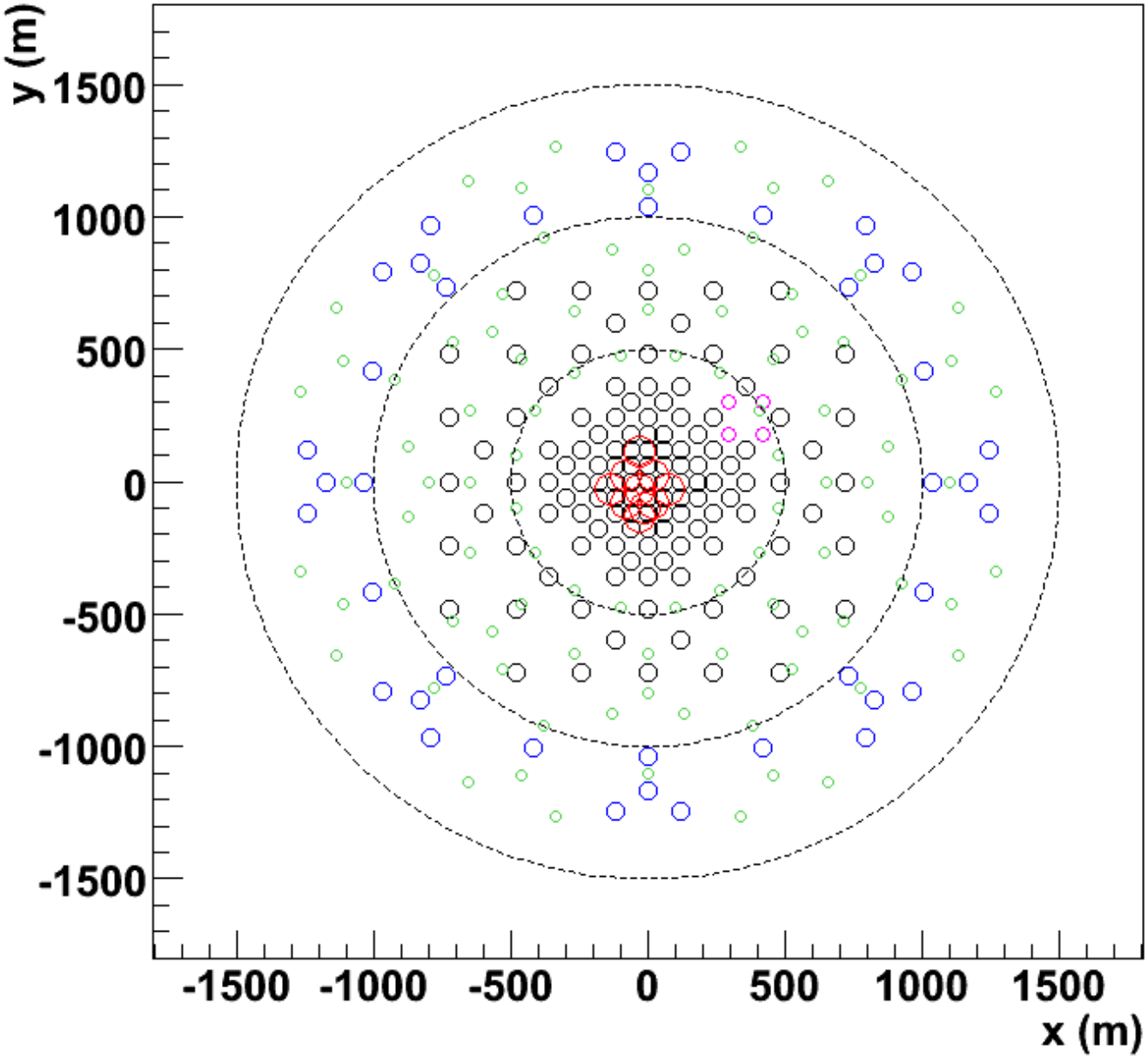
2010: - R&D ongoing on detectors, electronics, trigger, mirrors, ...
- soon publication of the Conceptual Design Report
- preparation for telescope prototypes

1) The Cherenkov Telescope Array

c) CTA Design Study (a quick look)



MC: mass production



Large scale simulation of "Hyper-Array" with 275 telescopes of 5 different types

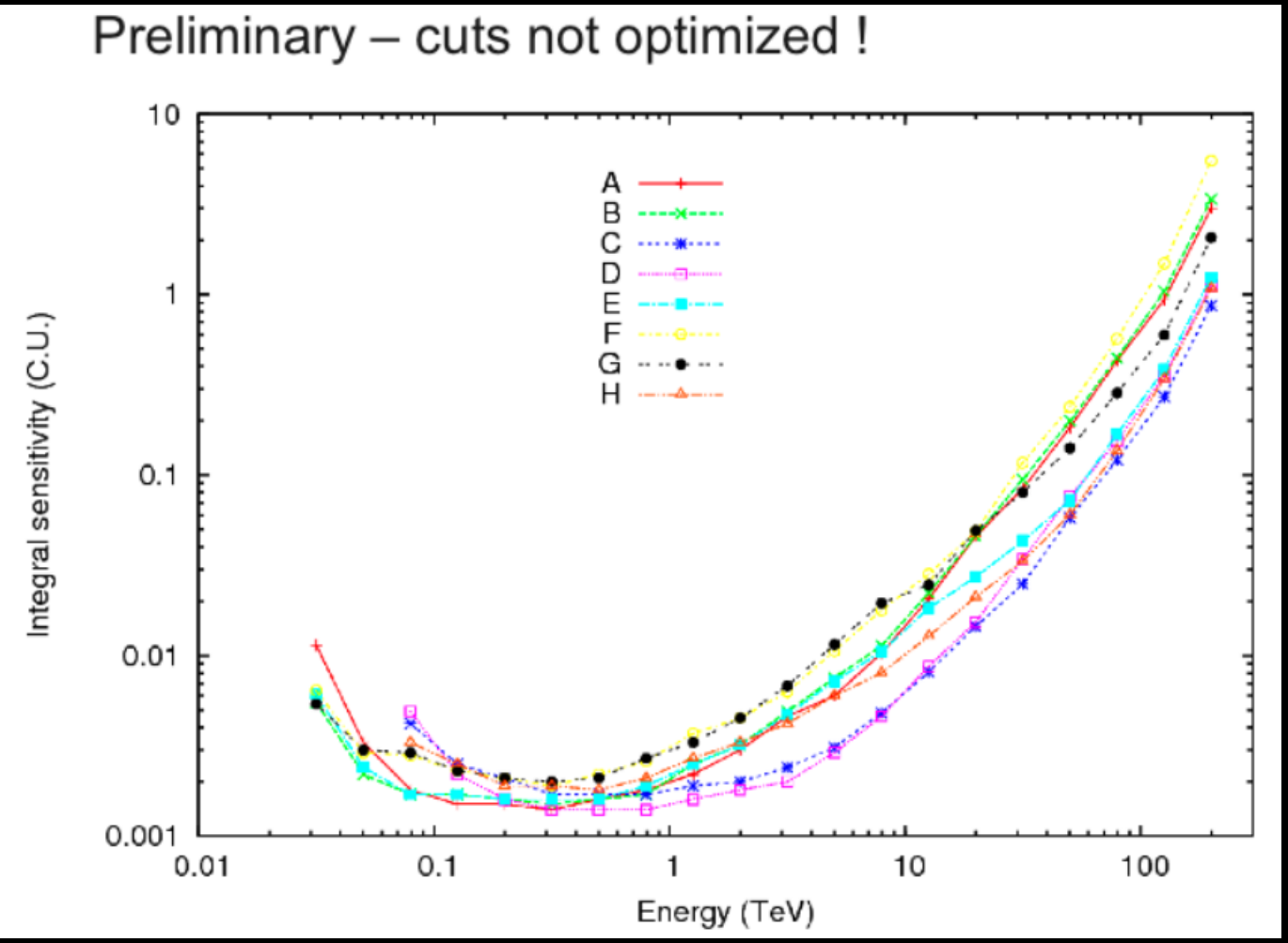
→ Selection of candidate sub-arrays under cost constraints

→ Study of performance with regard to science goals

O(10^11) events generated using the Grid (vo.cta.in2p3.fr) and offline

O(10^2) TB data stored

MC: mass production



Large scale simulation of "Hyper-Array" with 275 telescopes of 5 different types

→ Selection of candidate sub-arrays under cost constraints

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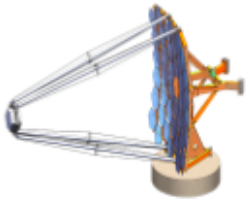
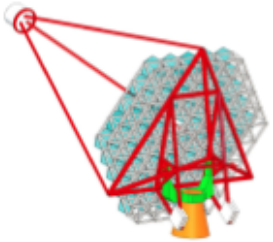
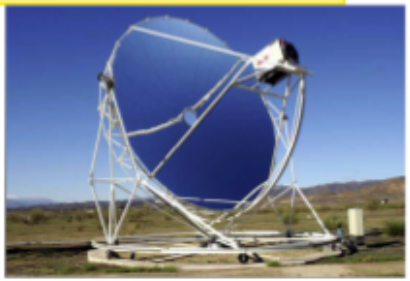
O(10^11) events generated using the Grid (vo.cta.in2p3.fr) and offline

O(10^2) TB data stored

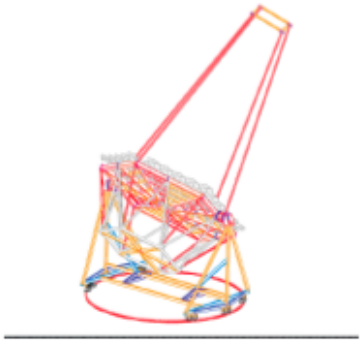
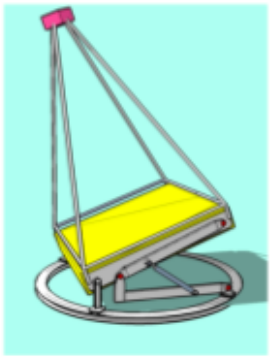
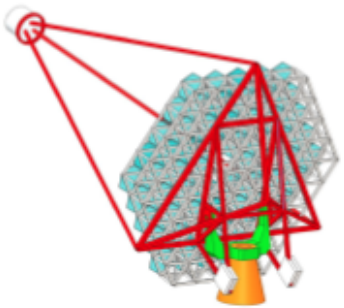
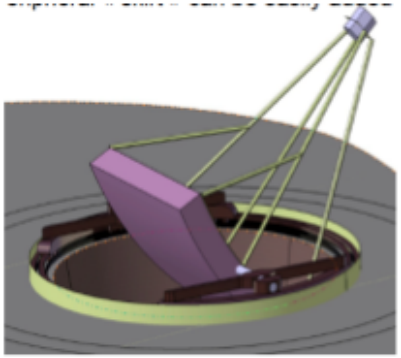
new performance curves will be published soon

Telescope Design

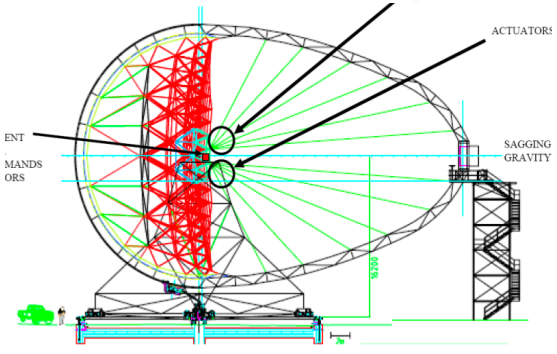
Small Size Telescope (SST)

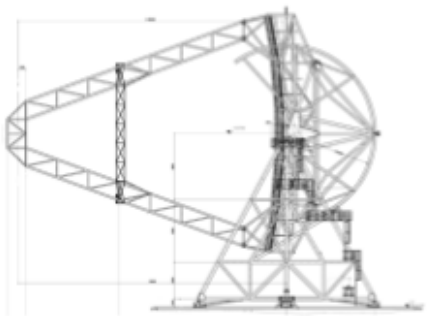





Medium Size Telescope (MST)

Large Size Telescope (LST)





Several telescope designs are being tested (current focus on 12 m, 23 m)

performance criteria:

- large f.o.v. -> large f/D (1.4 – 2)
- stiff structure
- active mirror control
- > 30 year lifetime under field conditions

Site Search

Northern Site Candidates:

Canary Islands (2400m asl)
Baja California (2800m asl)

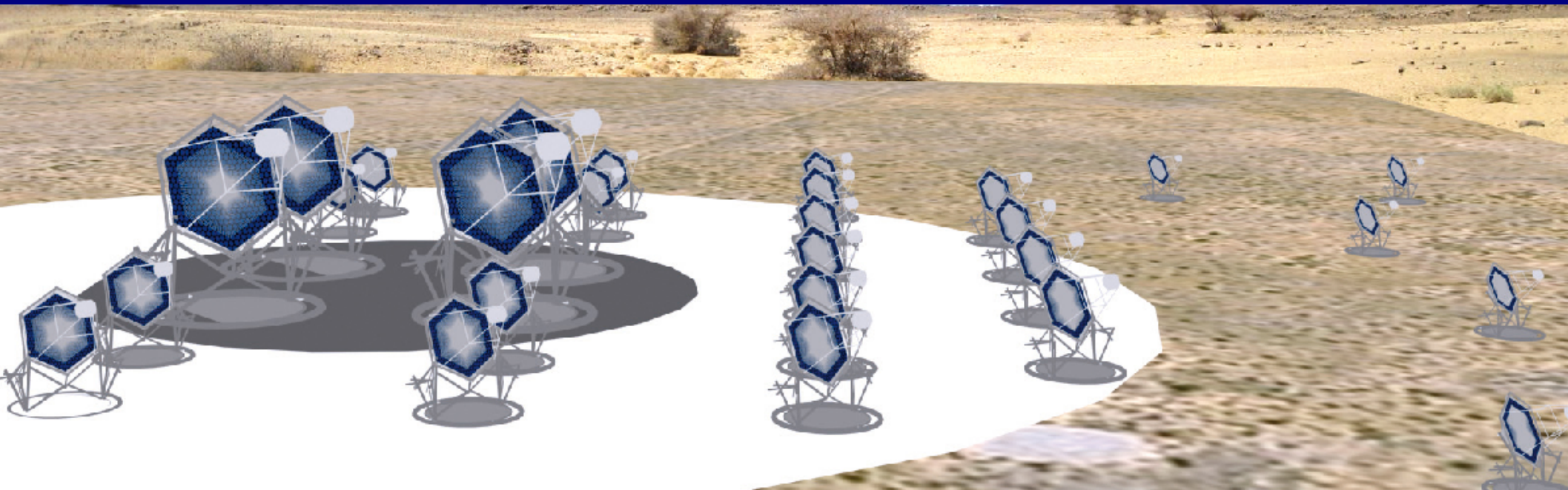
Southern Site Candidates:

Namibia (1800m asl)
Chile (2400m asl)
Argentina (2600 & 3700m asl)
South Africa ?

no decision taken yet

PRELIMINARY

2) Prospects for AGN Science with CTA



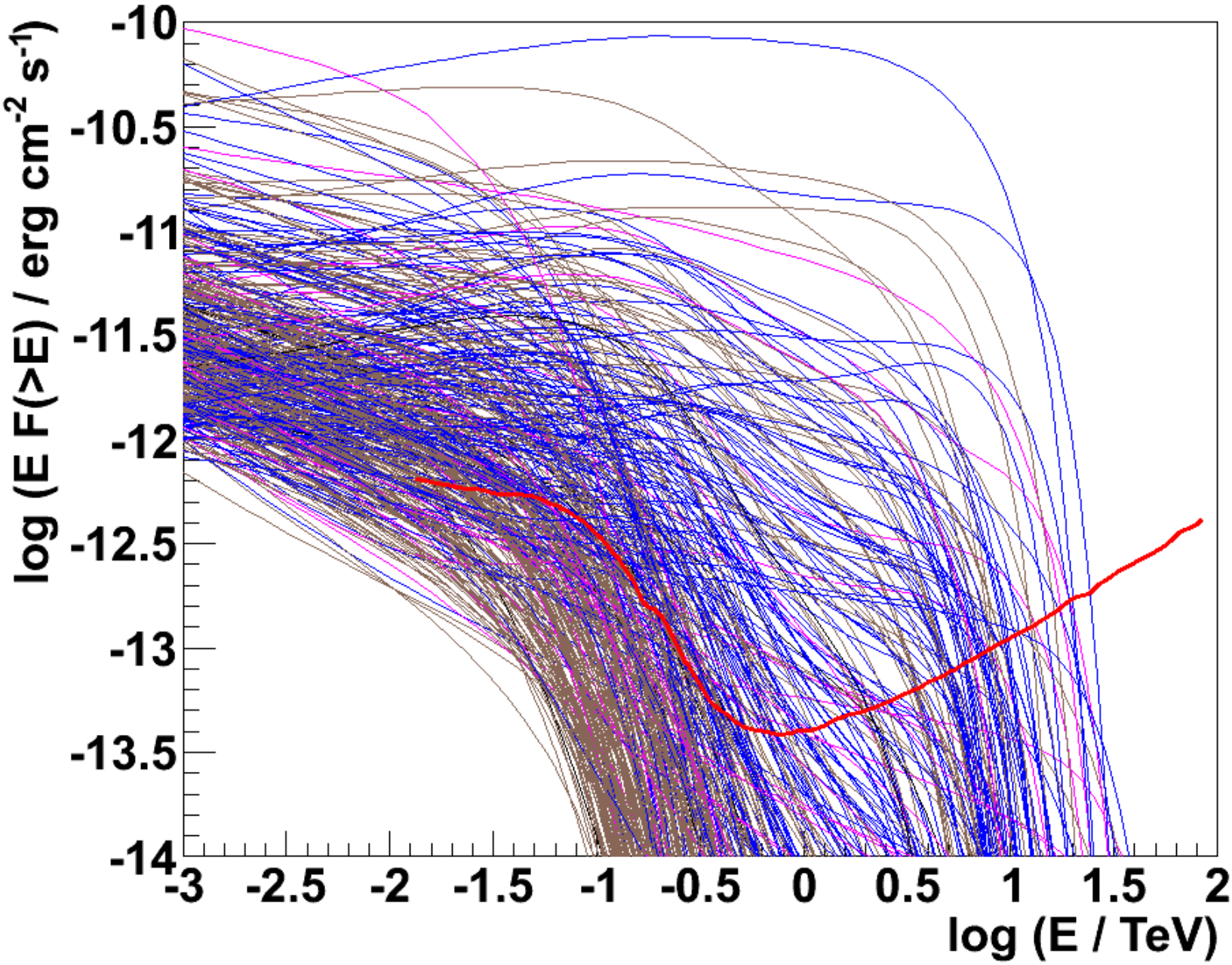
AGN physics with CTA

- study of different AGN classes at VHE (unification, "blazar sequence")
  - today: ~30 BL Lacs, 2 FSRQ, 2(3) radio galaxies, (Sgr A* ?)
- population studies, luminosity function
  - today: largely biased in redshift, small statistics
- spectral features and variability
  - information on acceleration & cooling processes
  - hadronic vs. leptonic scenarios
  - constraints on emission region
- mapping of radio galaxies
- Probing the EBL and the extragal. magnetic field

prediction with Fermi AGN

- Extrapolation of Fermi spectra (1 yr AGN catalog) to the TeV range + absorption by the EBL (Franceschini et al.)
- "clean" sample, known z, flux 1-100 GeV (418 objects)
- Overestimates the # of detectable sources !
  - possible intrinsic spectral breaks ignored
  - ideal sensitivity curve for CTA
- Underestimates the # of detectable sources !
  - not all TeV blazars have been detected by Fermi
  - does no account for flares or very active states
  - only sources with known redshift
- similar extrapolations have led to the discovery of new TeV sources (e.g. PKS0447-439, RGB J0648+152, ...)

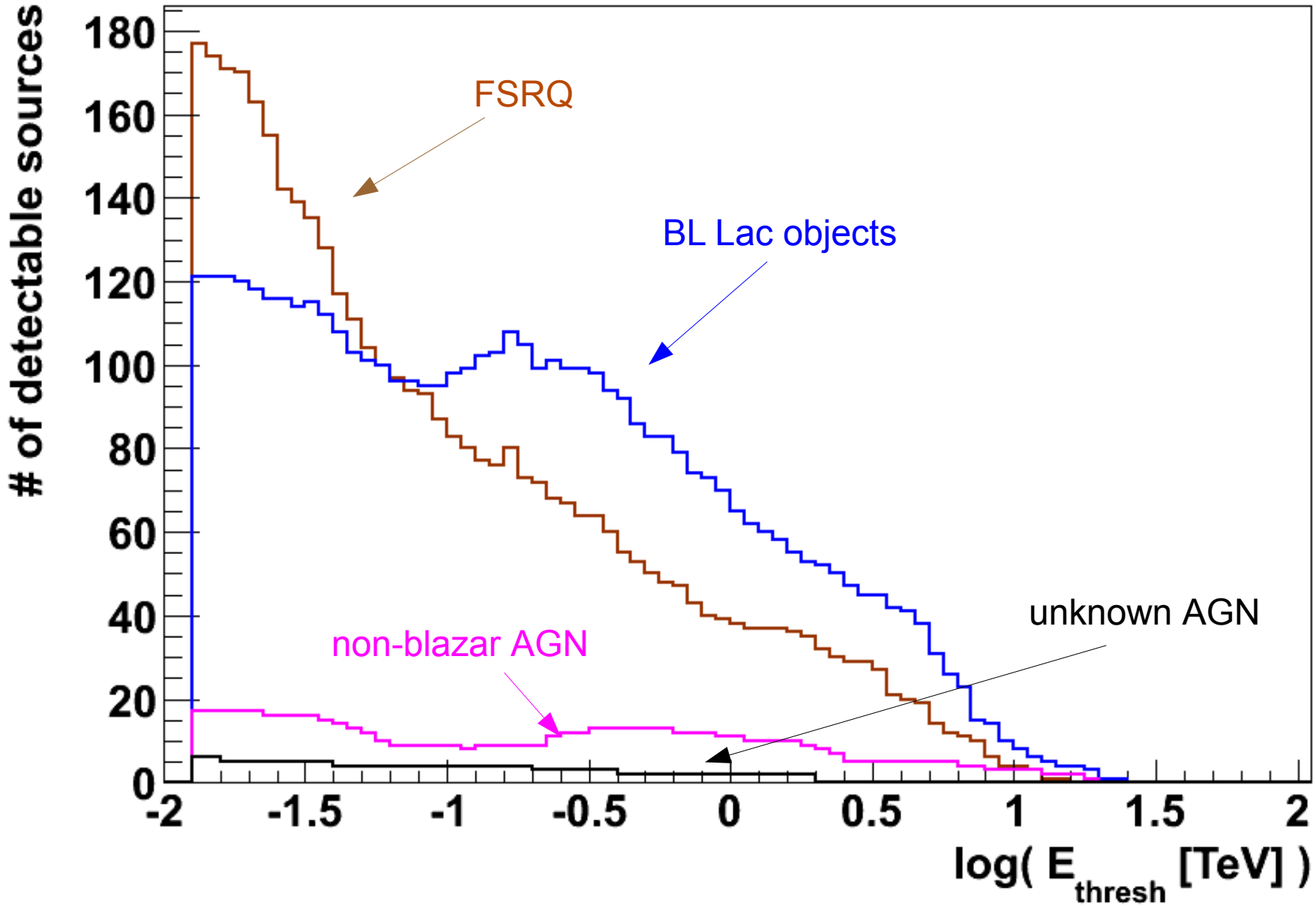
prediction with Fermi AGN



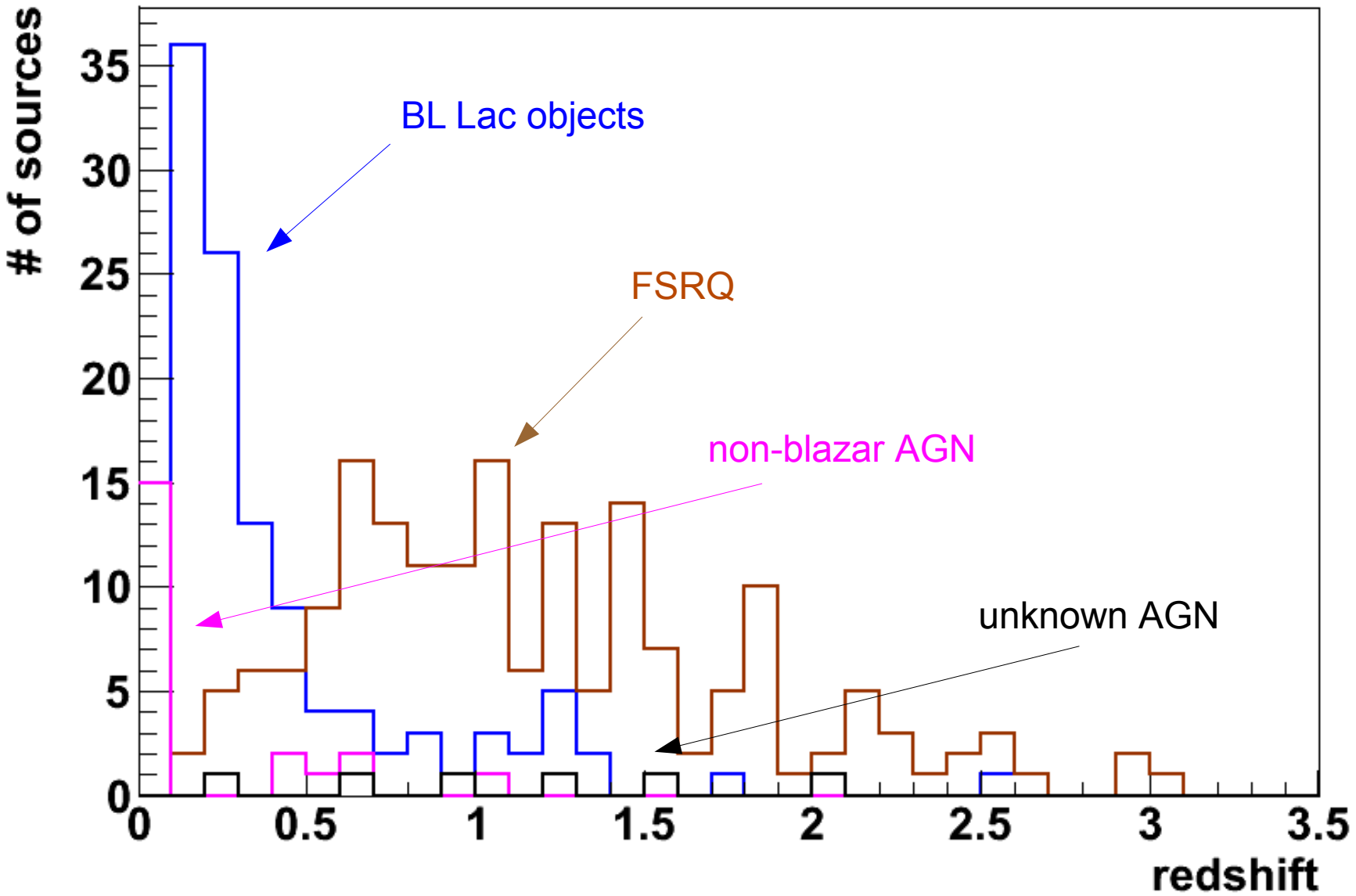
BL Lacs
FSRQ
other AGN
unknown type

CTA sensitivity (goal)

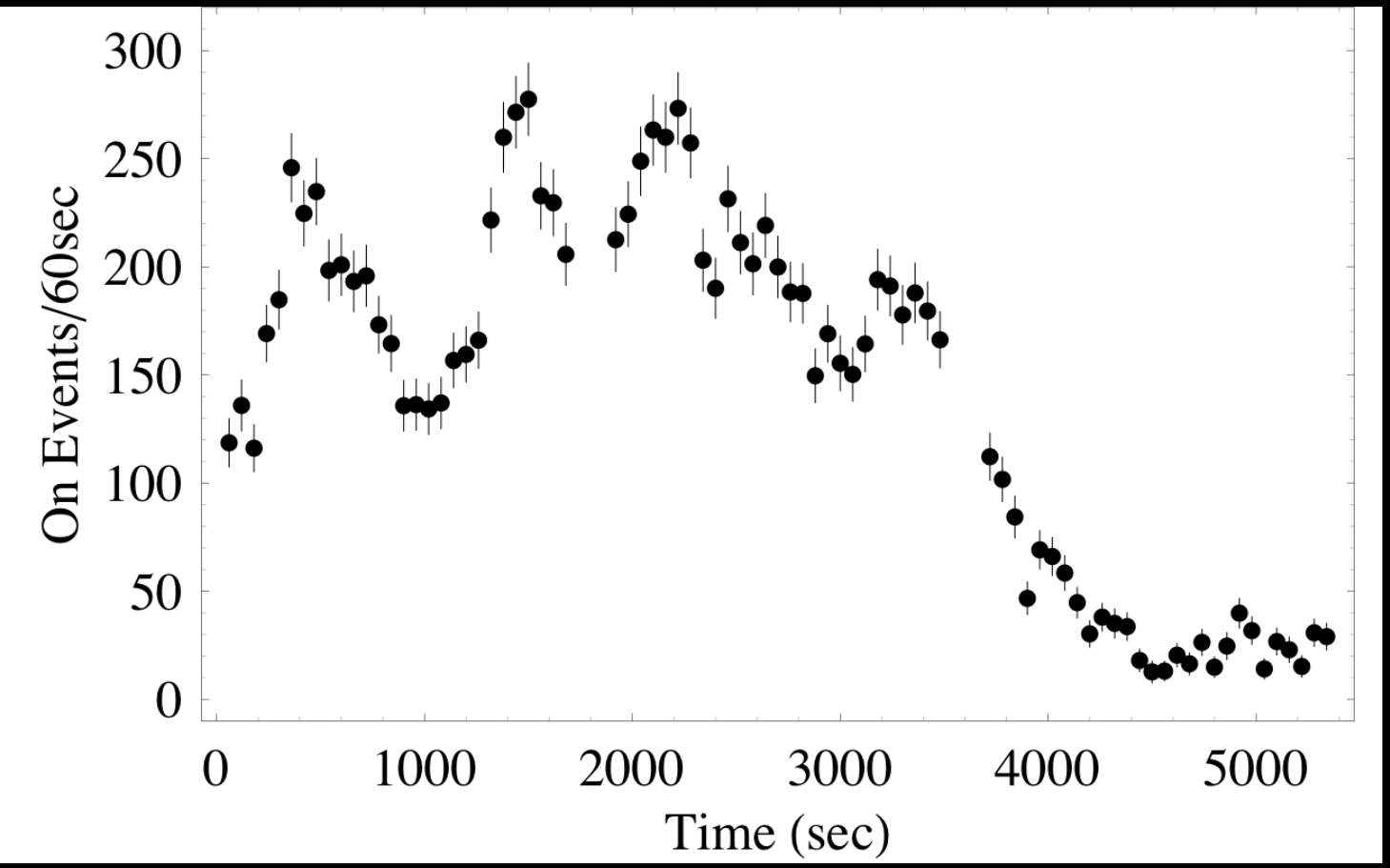
prediction with Fermi AGN



prediction with Fermi AGN



Variability

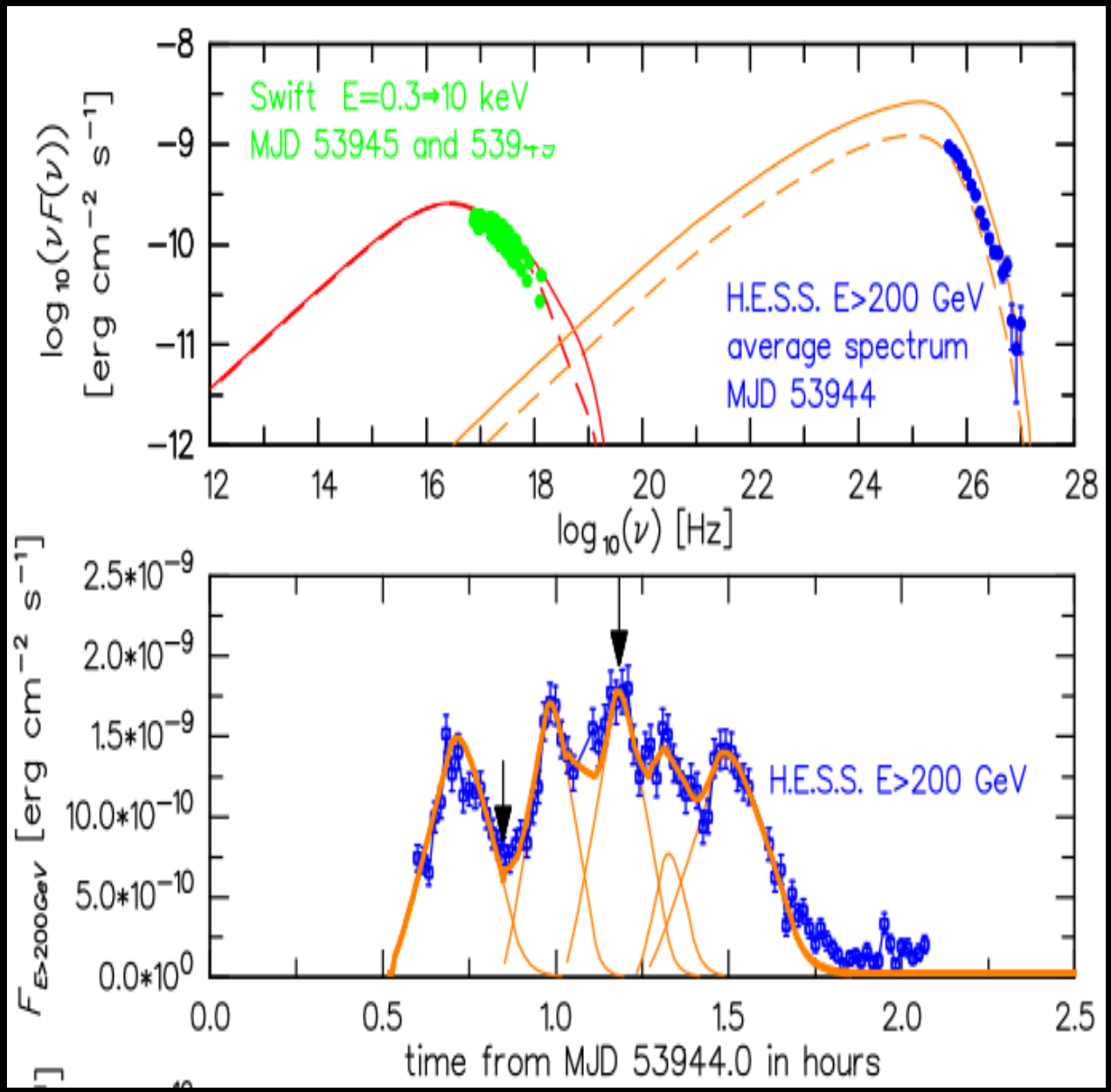


- e.g. 2006 flare of PKS 2155-304:

  H.E.S.S. detected > 100 gammas/min. => good statistics down to the 1 min. scale
- With CTA, the rate would be a factor of ~ 10 higher

  => good statistics down to a few seconds
- CTA will allow us to test the low state for the existence of rapid variability.

Variability



Katarzynski, K., Lenain, J.-P., AZ., et al. 2008, MNRAS, 390, 371

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- With CTA, the rate would be a factor of ~ 10 higher

  => good statistics down to a few seconds

- CTA will allow us to test the low state for the existence of rapid variability.

- CTA will establish the first VHE gamma-ray **observatory**.
- The CTA Design Study is advancing quickly and CTA is now entering its Preparatory Phase.
- CTA will present a huge advancement for astro(particle) physics, cosmology and fundamental physics.

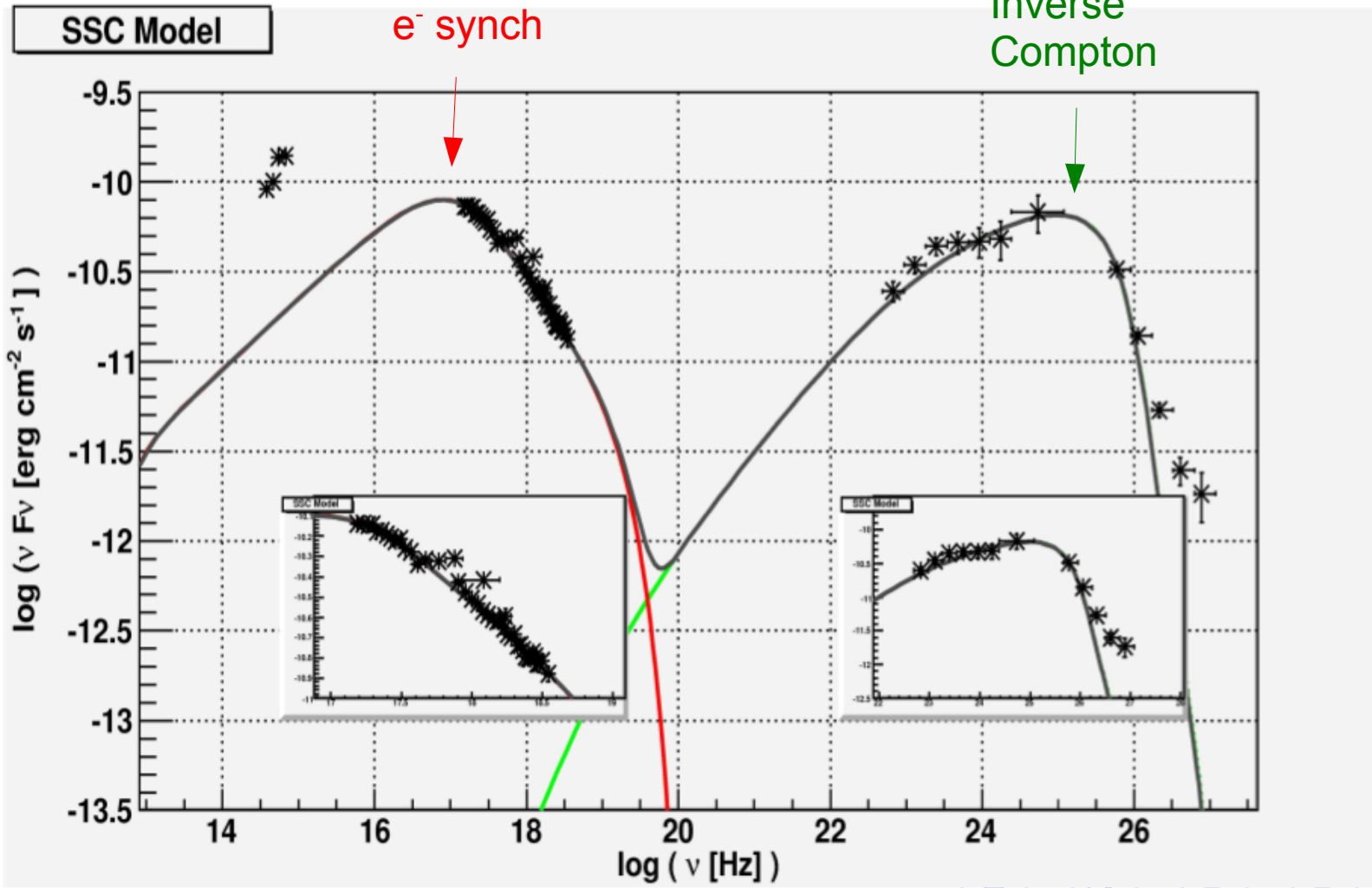
Many thanks to the organisers !

Special thanks to the Meudon CTA group (C. Boisson, H. Castarede, M. Cerruti, H. Sol) and to A. Neronov !

BACKUP SLIDES

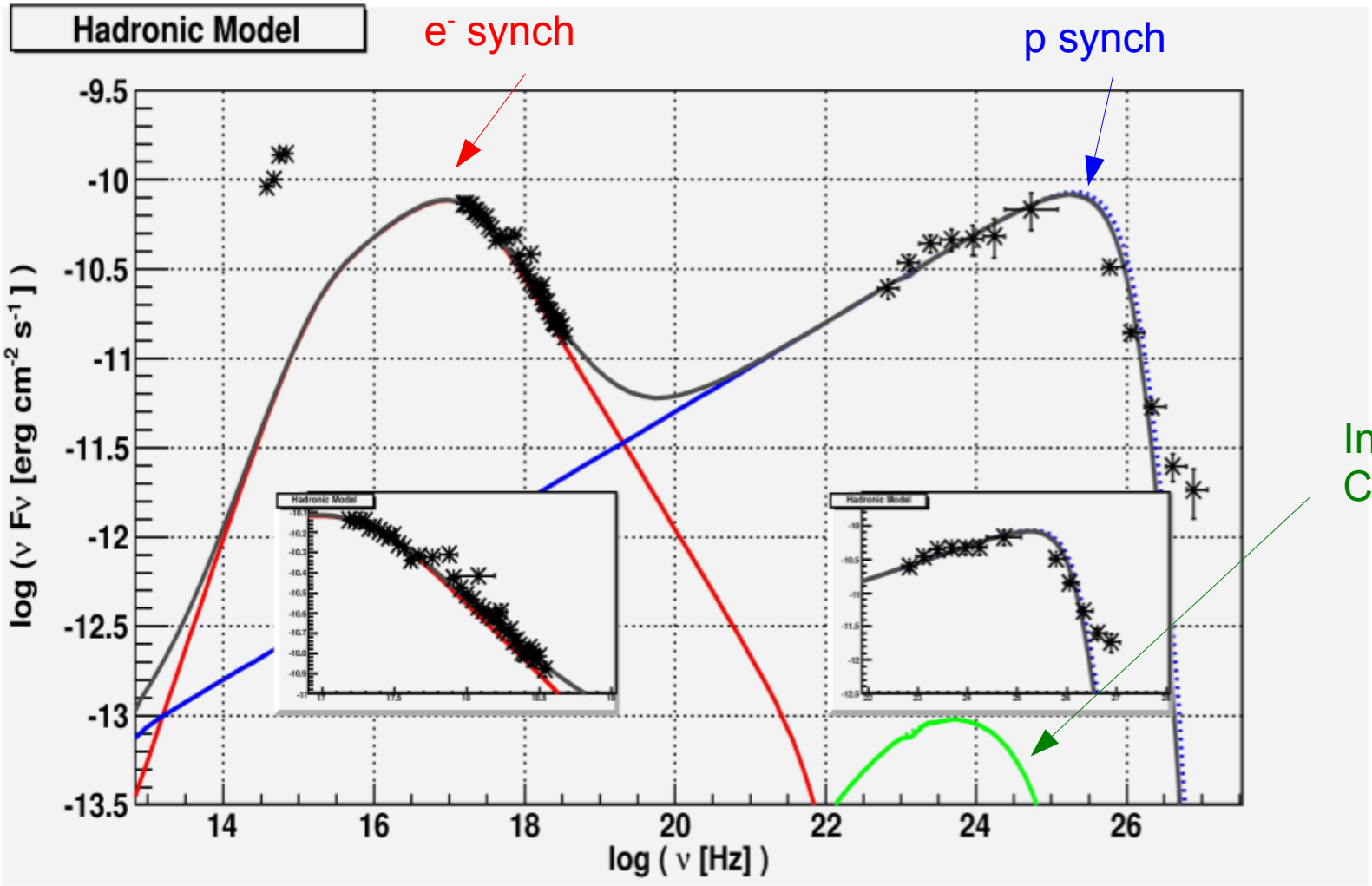
Spectrum signatures - an example

SSC Model



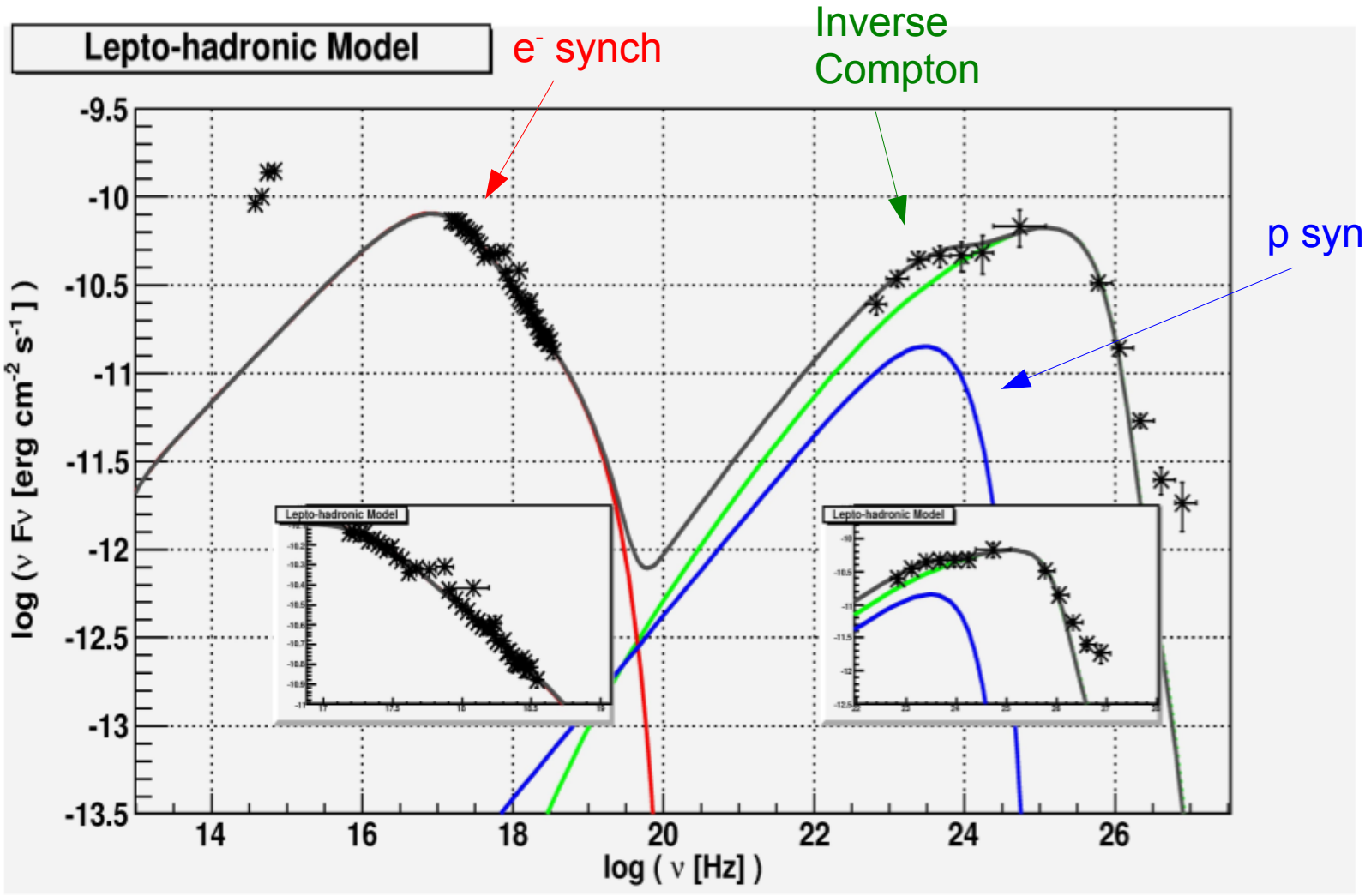
Spectrum signatures - an example

Hadronic Model



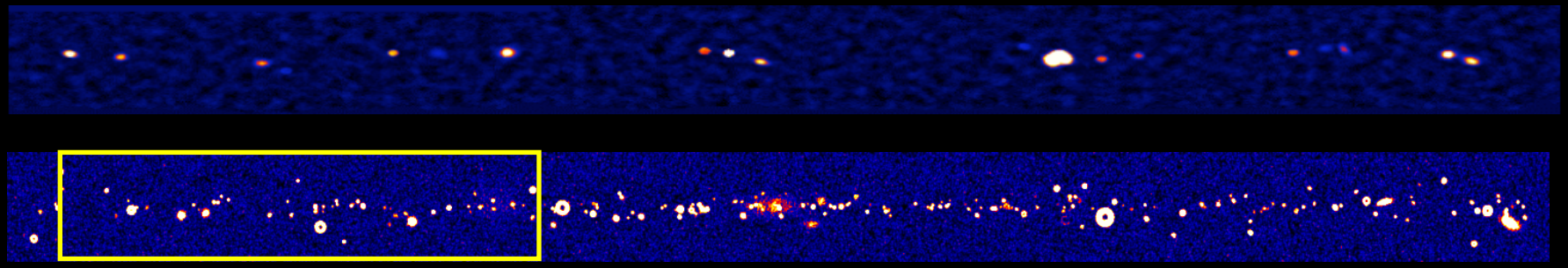
Spectrum signatures - an example

Lepto-Hadronic Model

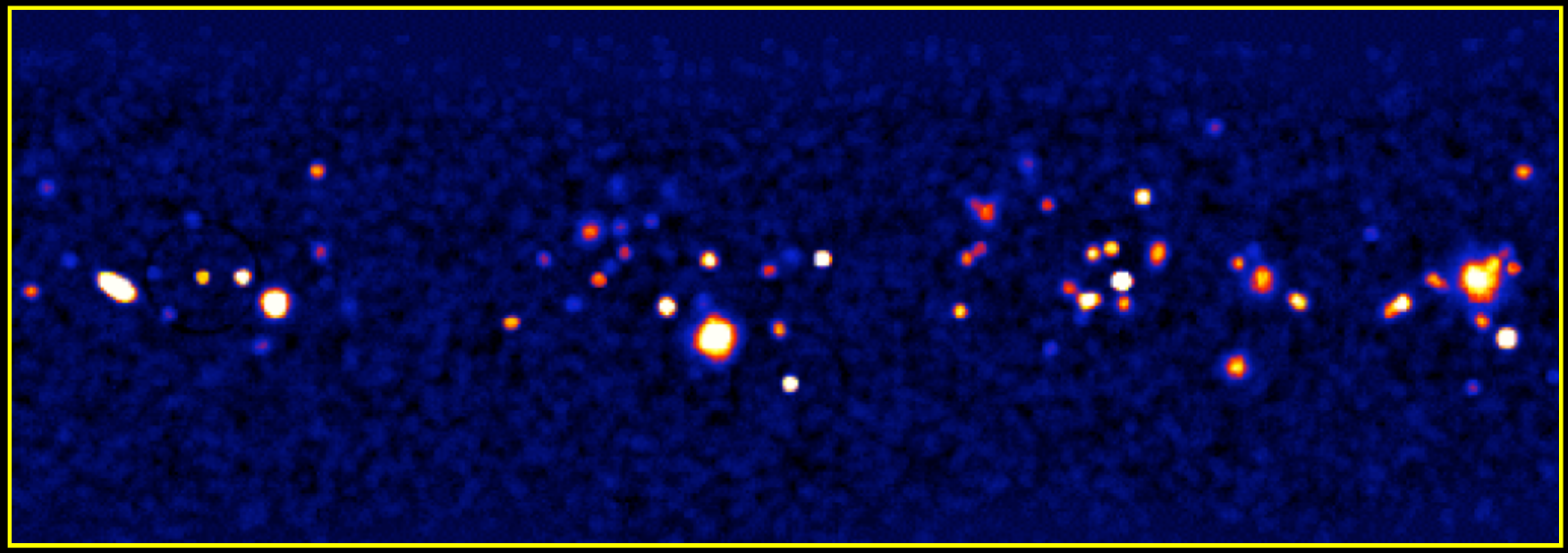


The Milky Way as CTA would see it

Galactic plane as seen by H.E.S.S.



CTA/AGIS view



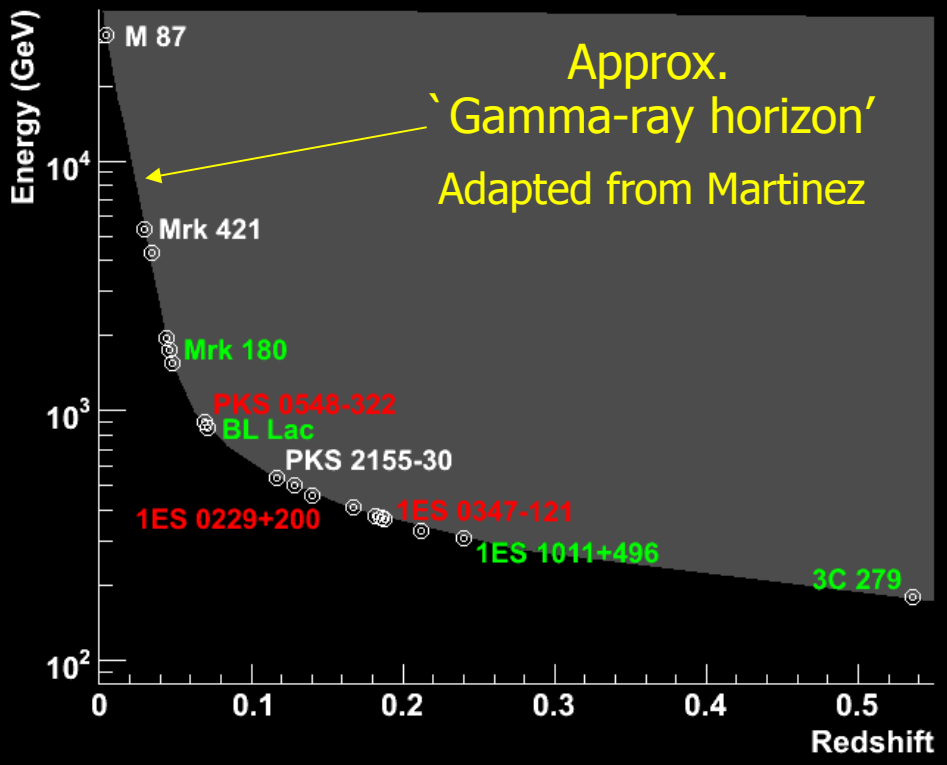
CTA/AGIS Simulations

Digel + Funk (Stanford) + Hinton (Leeds)

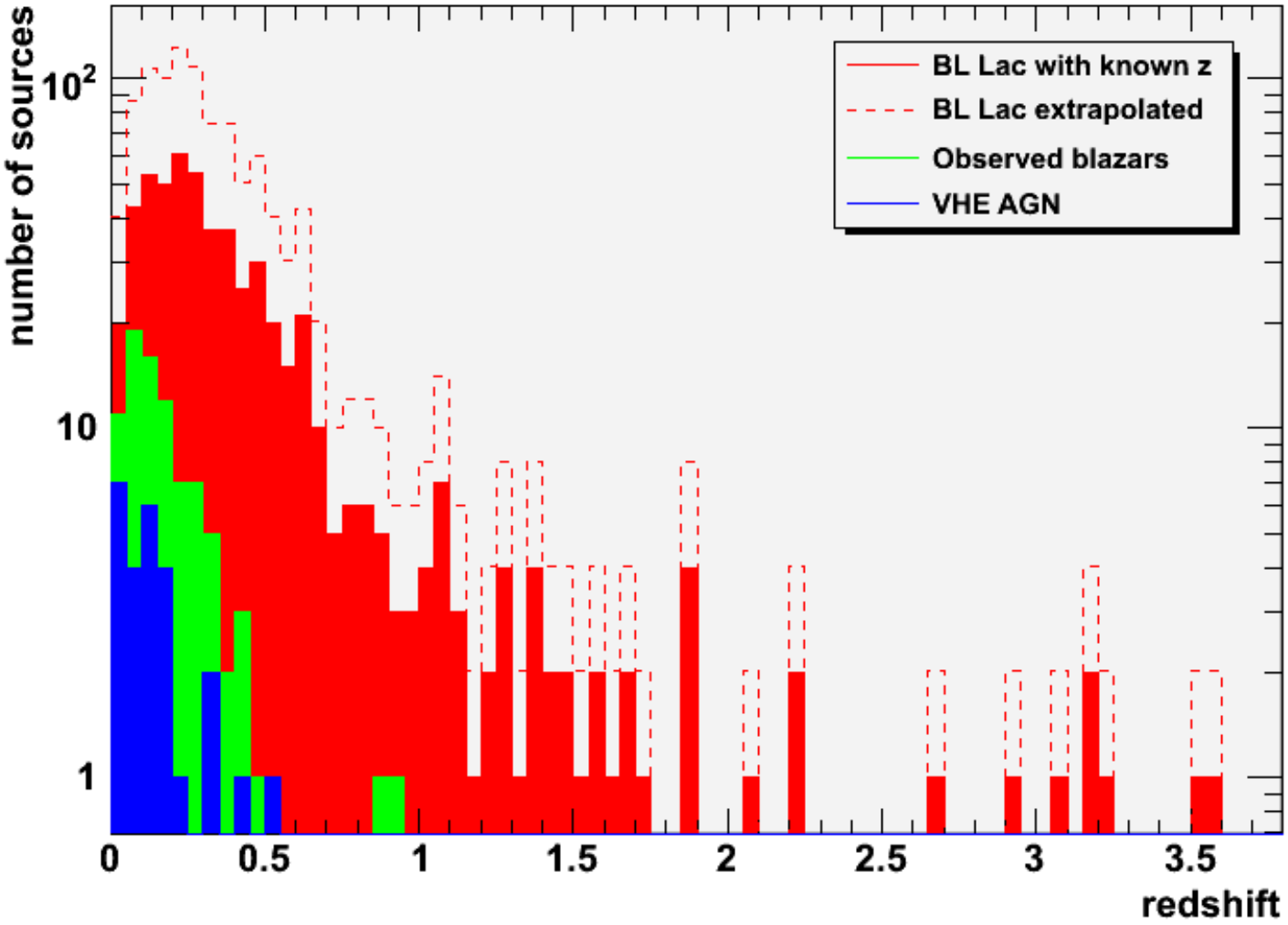
The Big Questions

What is the nature of dark matter ?
Are there other signatures of physics beyond the standard model ?

- Cosmology with gamma rays (probing the EBL)
- Detection of Dark Matter ?
- Fundamental physics (test Lorentz Invariance Violation -> quantum gravity...)



Population Studies

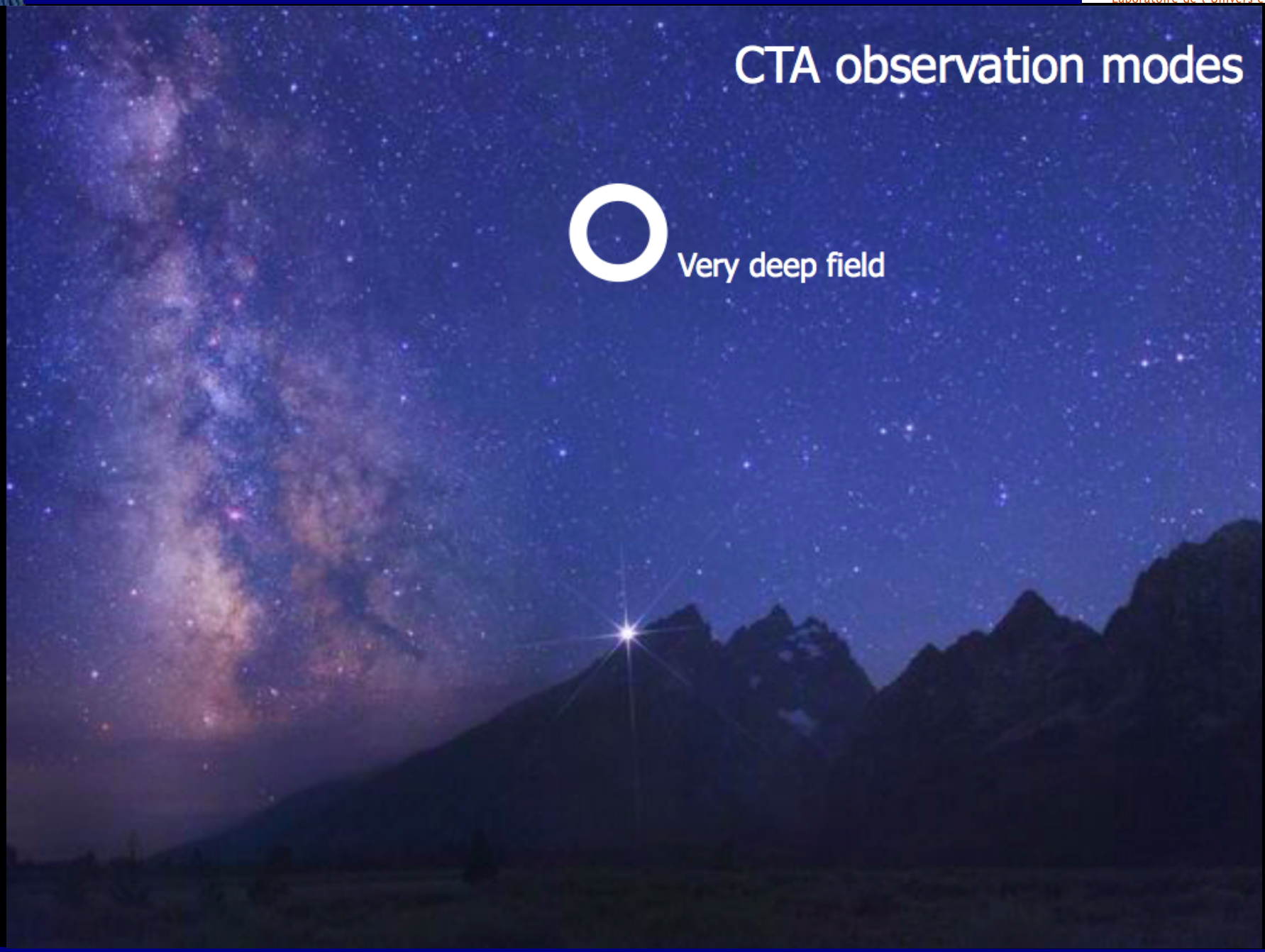


Veron-Cetty & Veron BLLAC catalog (12th edition)

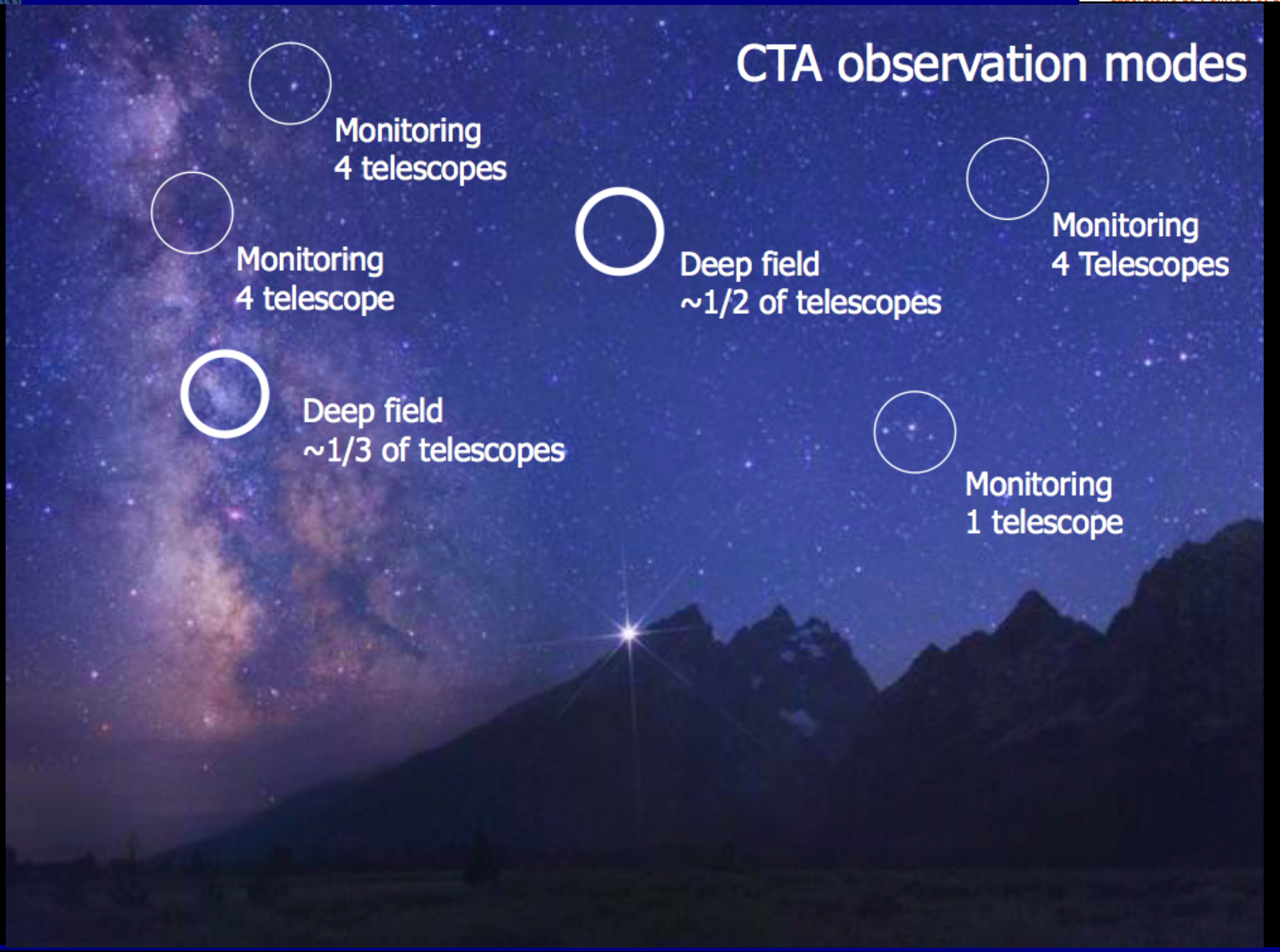
=> still many blazars to discover at TeV energies !

=> and maybe other types of AGN ?

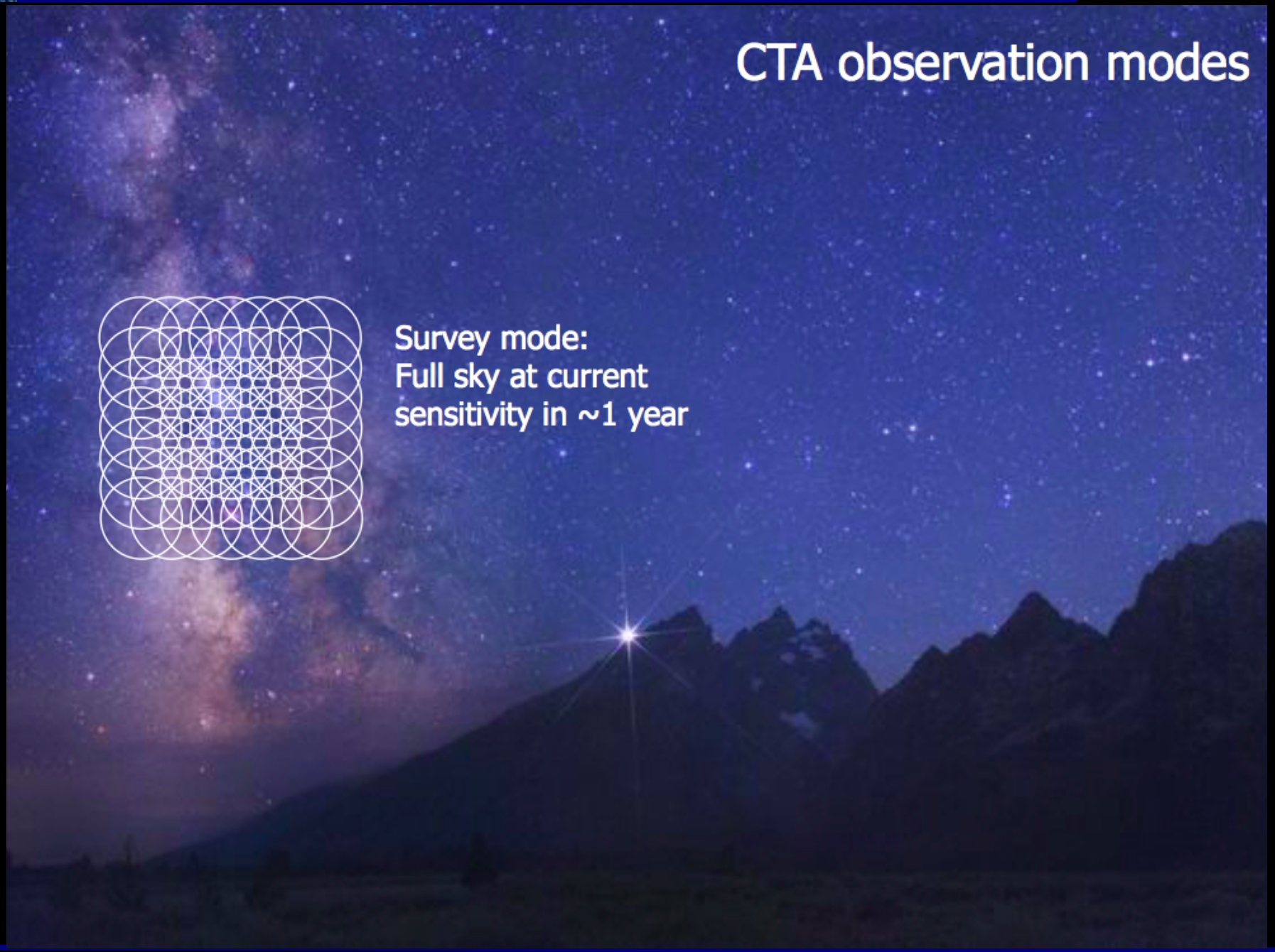
Different observation modes



Different observation modes



Different observation modes



Southern Site: galactic & extragalactic sources
Northern Site: extragalactic sources (no high E)

Low-energy section:
few O(20-30) m tel. (LST)
=> push low threshold
- Parabolic reflector
- FOV: O(3-4) degrees
- f/D: O(1.2-1.5)

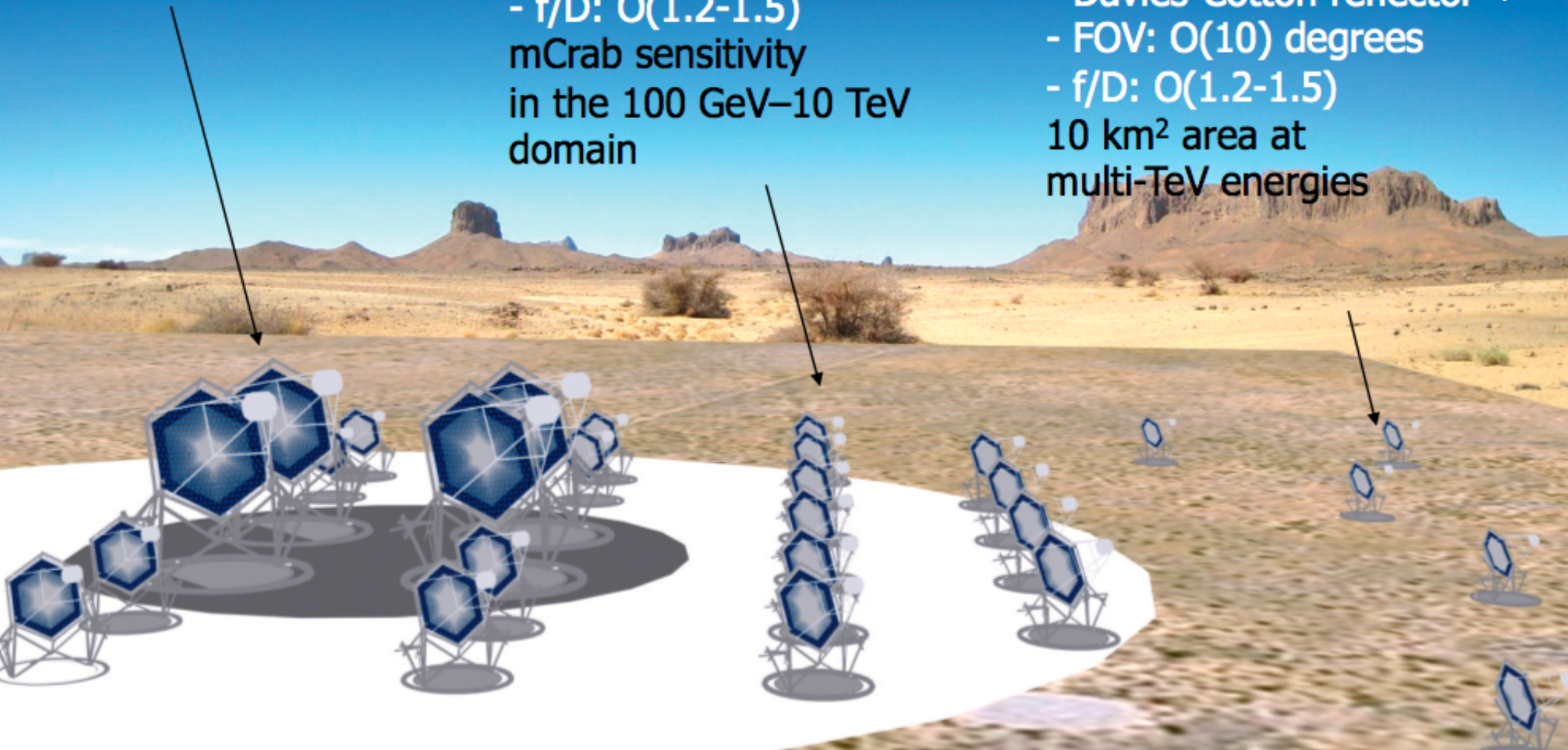
energy threshold
of some 10 GeV

Core-energy array:
many O(10-12) m tel. (MST)
=> workhorse of CTA
-> push cost & reliability
- Davies-Cotton reflector ?
- FOV: O(6-8) degrees
- f/D: O(1.2-1.5)

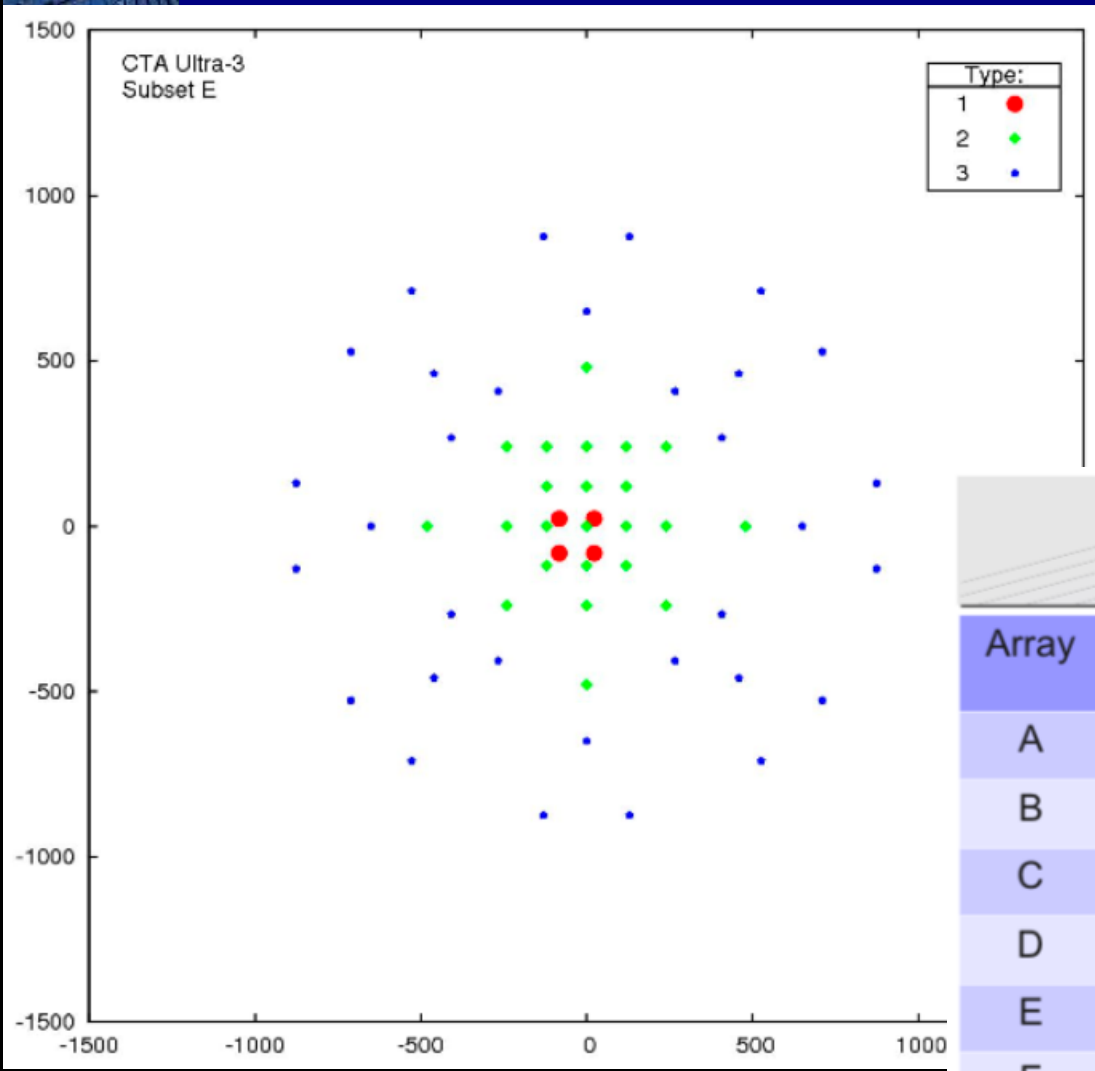
mCrab sensitivity
in the 100 GeV–10 TeV
domain

High-energy section:
some O(5-6) m tel. (SST)
=> push low-cost
- Davies-Cotton reflector ?
- FOV: O(10) degrees
- f/D: O(1.2-1.5)

10 km^2 area at
multi-TeV energies



MC: Comparison of Arrays



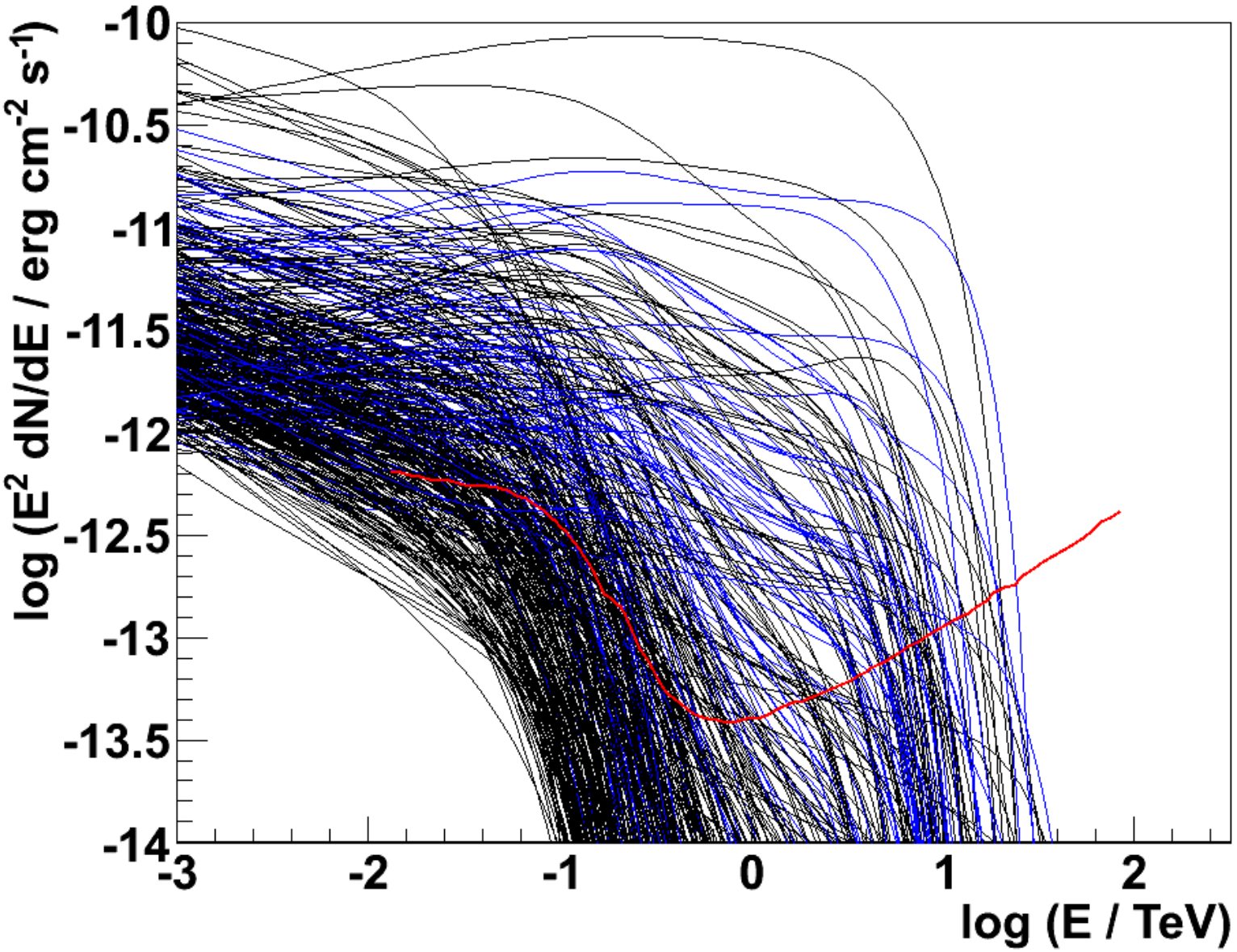
Array comparison: A-H

Array	Type 1 (23 m)	Type 2 (12 m)	Type 3 (6.7 m)	Type 4 (12 m)	Type 5 (10 m)	Dmin [m]	Rmax [m]
A	3	41	-	-	-	32	480
B	5	37	-	-	-	32	380
C	-	29	-	26	-	170	1250
D	-	41	-	16	-	170	1090
E	4	23	32	-	-	32	880
F	6	29▼	-	-	-	32	680
G	6	9	16	-	-	32	490
H	-	25	48	-	-	85	1100

▼: reduced f.o.v.

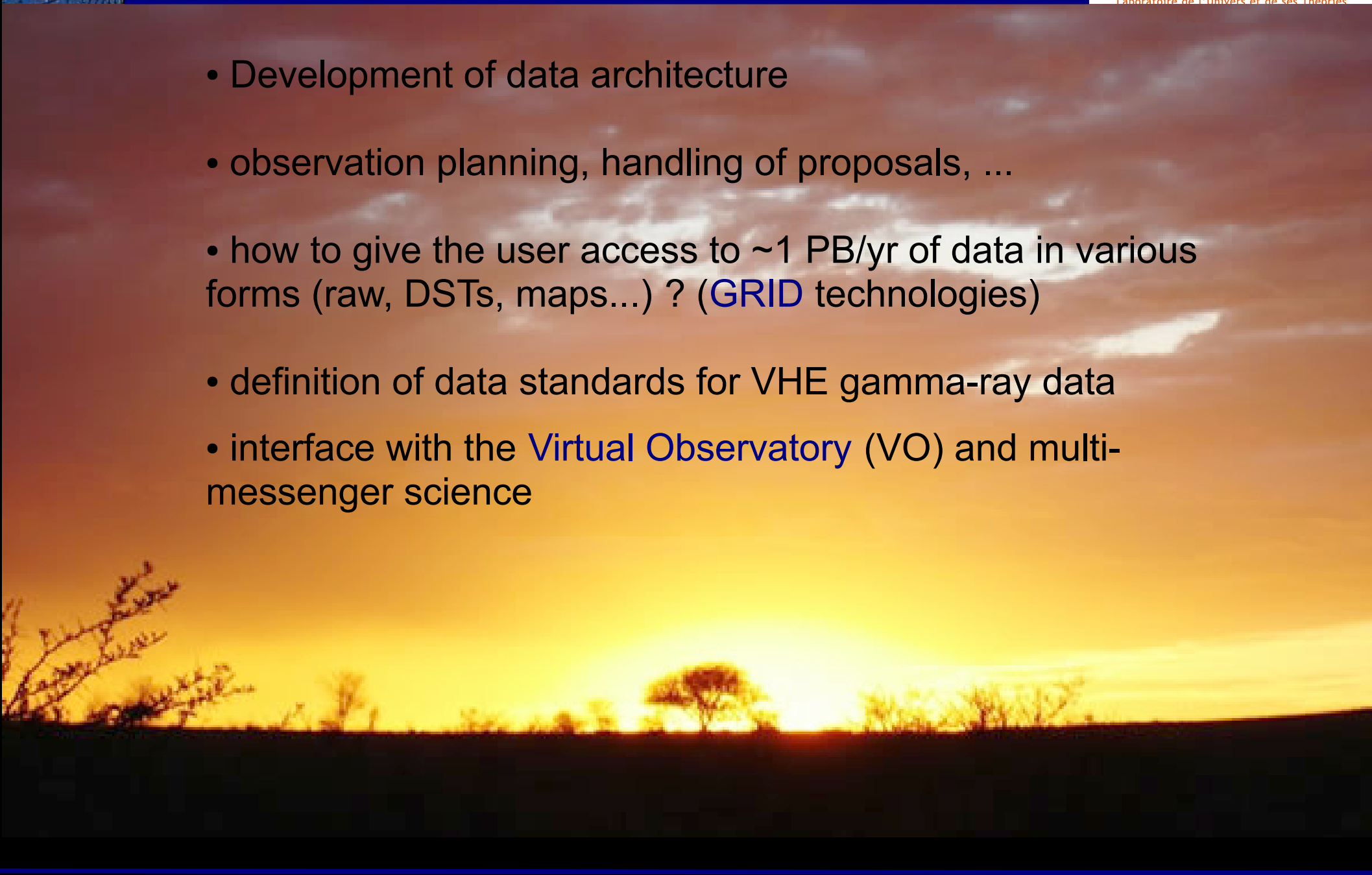
K. Bernlöhr, CTA Meeting, Cracow, 2009-05-12

prediction with Fermi AGN



blue: 115 sources with signal above 10 GeV

Data Management



- Development of data architecture
- observation planning, handling of proposals, ...
- how to give the user access to ~1 PB/yr of data in various forms (raw, DSTs, maps...) ? (GRID technologies)
- definition of data standards for VHE gamma-ray data
- interface with the Virtual Observatory (VO) and multi-messenger science

Mirror, Camera

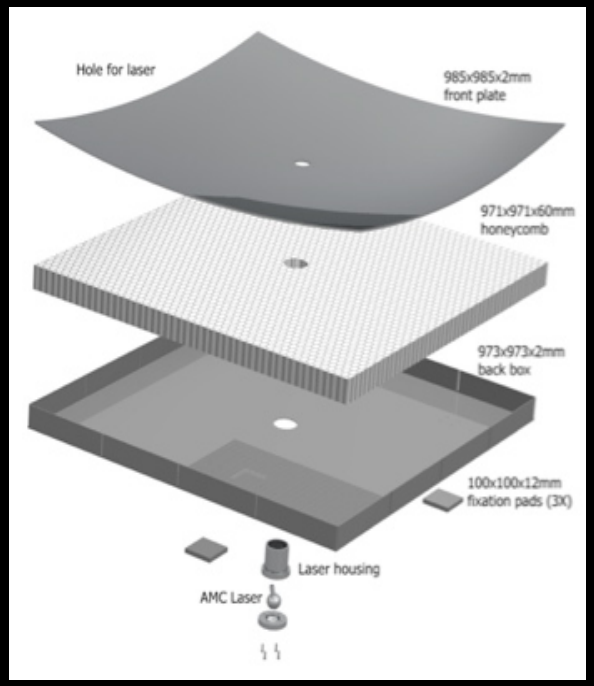
MIRRORS

Proven Solutions:

- Aluminzed glass (H.E.S.S.)
  -> Average cost, suffers from ageing, high weight
- Machined Aluminium on alu honeycomb (MAGIC)
  -> High cost, low ageing, low weight

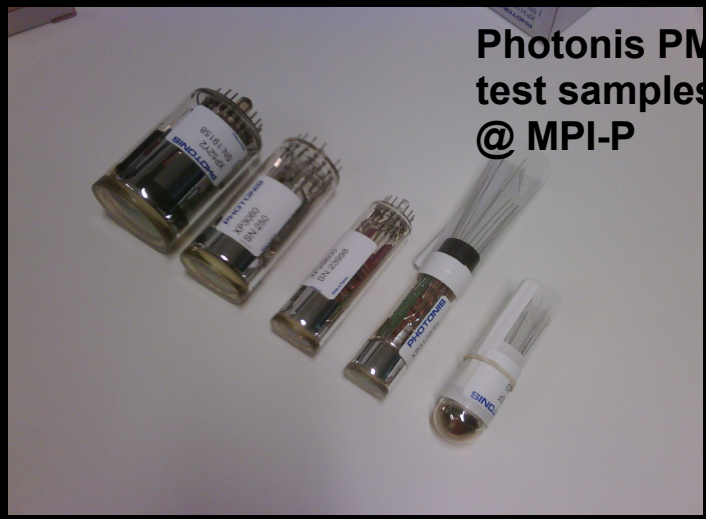
New Solutions proposed:

Mirrors in carbon-epoxy composite or PE foam
-> Probably low cost, low weight, performance ?



CAMERA

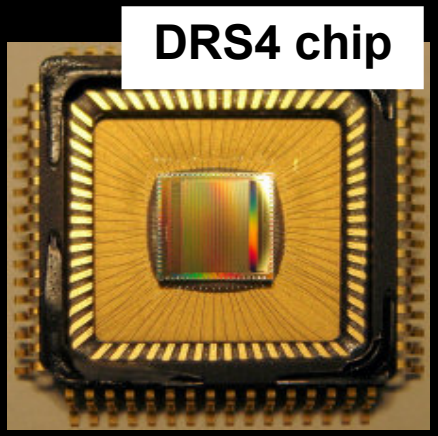
- Decision to have a fully-integrated camera
- PMT measurement of many samples (standard, super/ultra-bialkali, hemispherical window, multi-anode, flat-panel...) under way.
- Studies of new technologies (e.g. SiPM) a future upgrade option



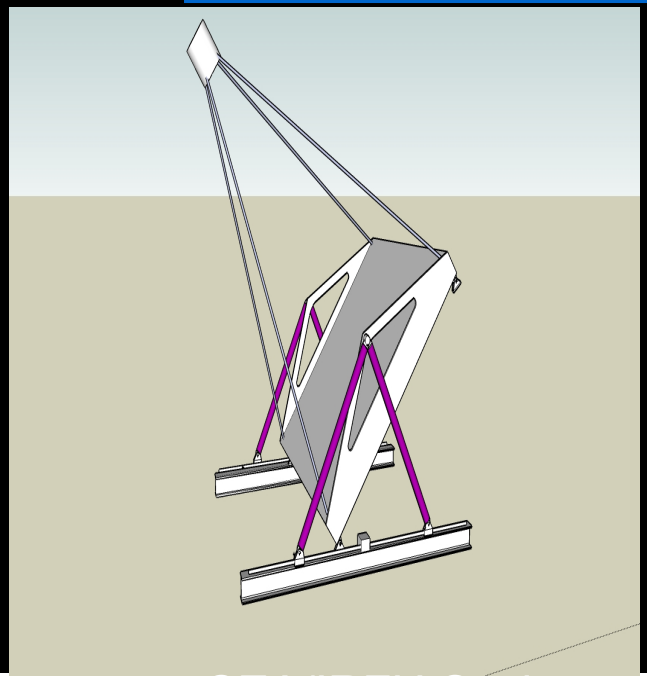
Electronics, Trigger

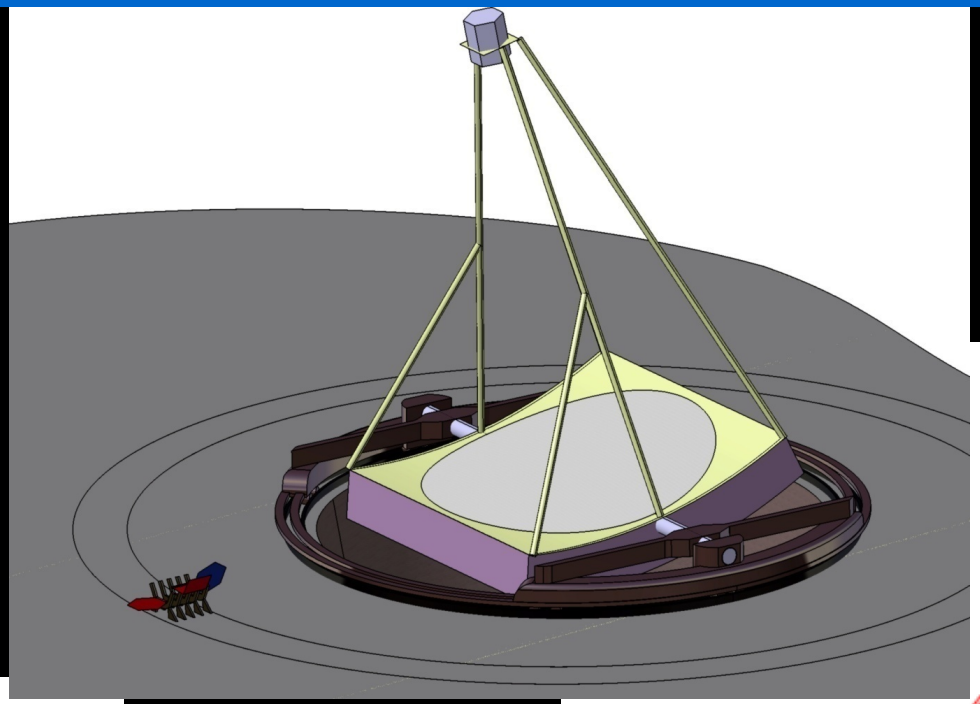
Analogue pipeline solution for the in-camera acquisition,
several GHz-sampling most probable solution (existing SAM, DRS3, future DRS4, NeCTAr).
Aim to integrate the maximum functionality in ASIC (=cost+reliability)

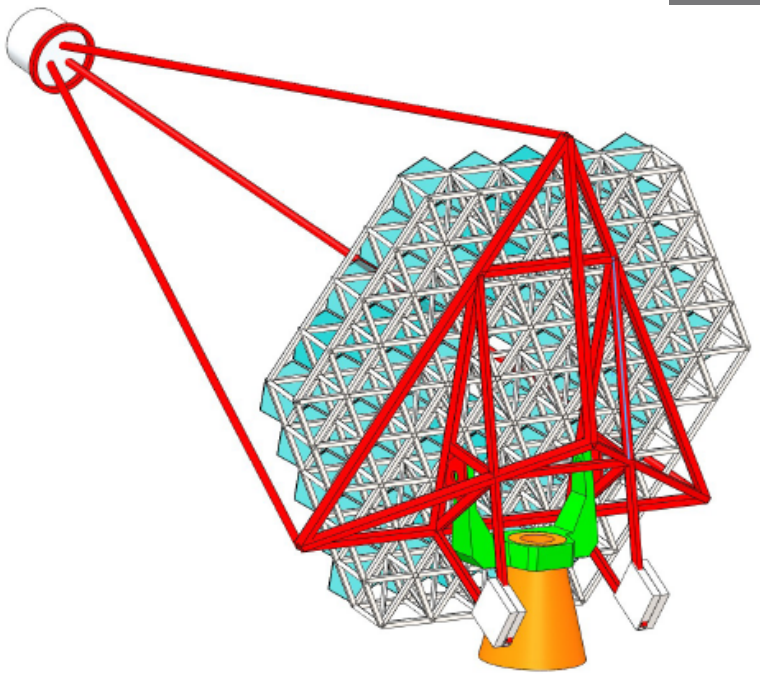
Camera-level Trigger, by sectors / clusters
Read-out using the maximum of commercial components / protocols...
Inter-telescope trigger with central array clock-distribution over fibre (à la Antares), event time-stamping

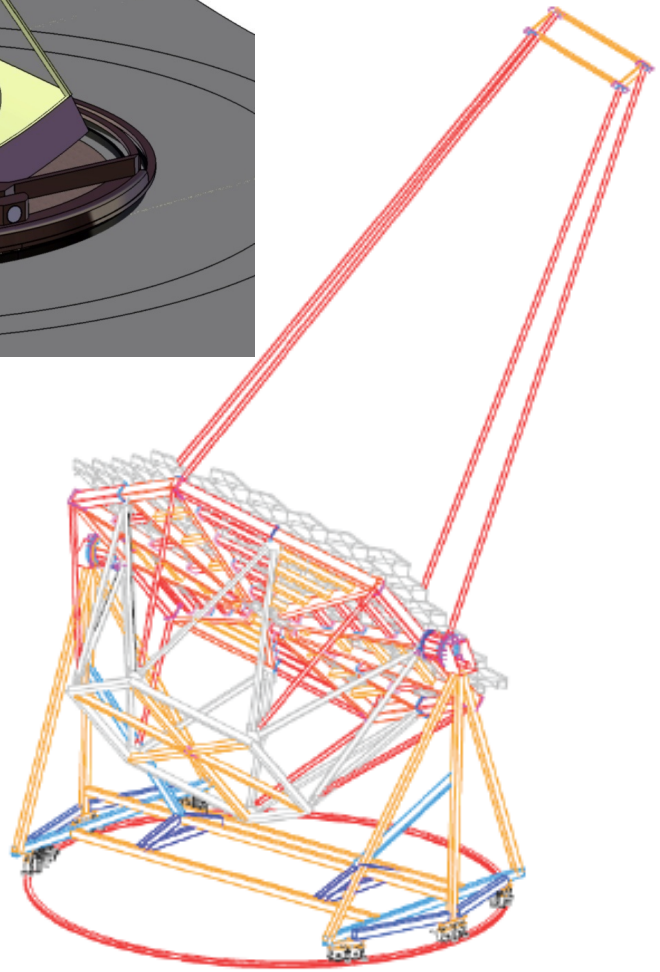


WP TEL/MIR: MST mounting scheme



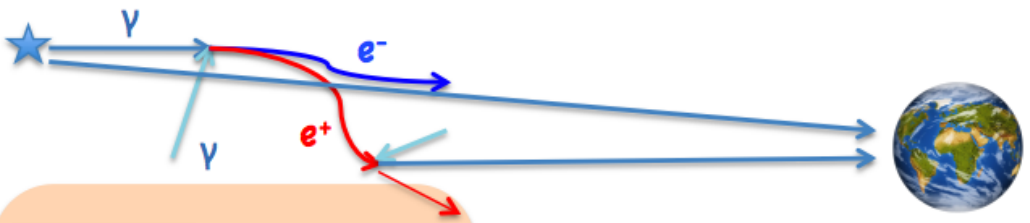






Extragalactic magnetic field

Attenuation of γ-rays via pair production on EBL



TeV γ-ray

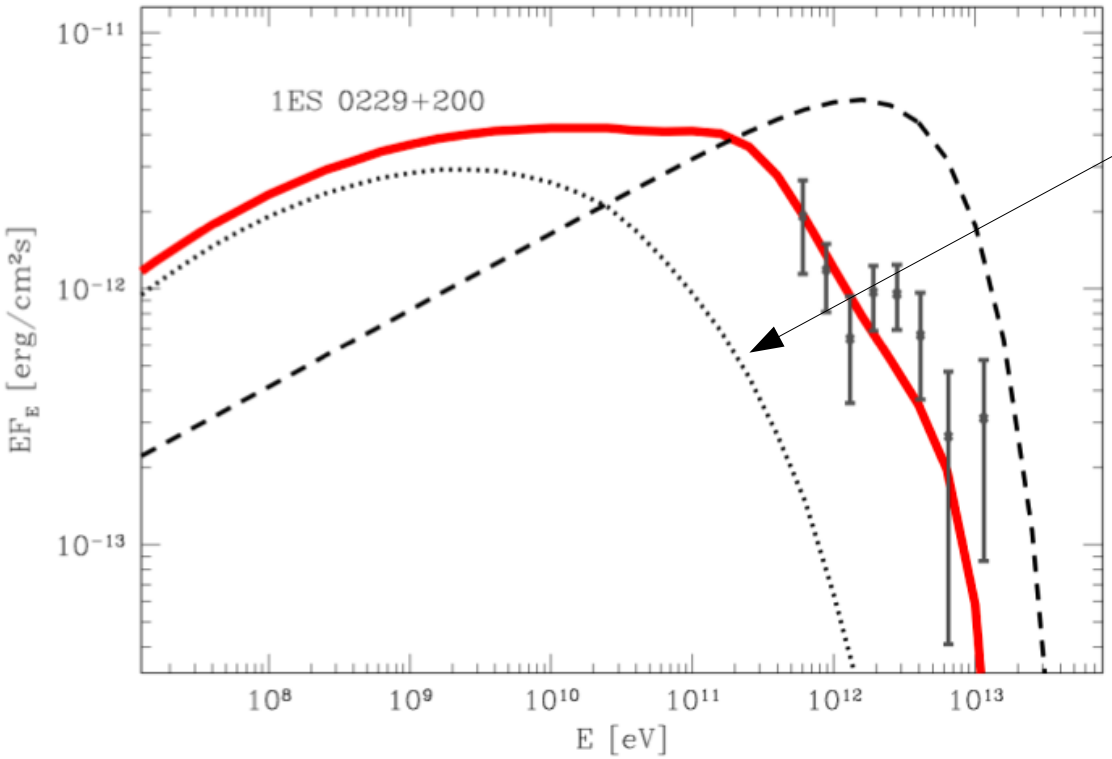
$$\gamma + \gamma \rightarrow e^+ + e^-$$

1 eV photon

GeV γ-ray

$$e^\pm + \gamma \rightarrow e^\pm + \gamma$$

CMB photon

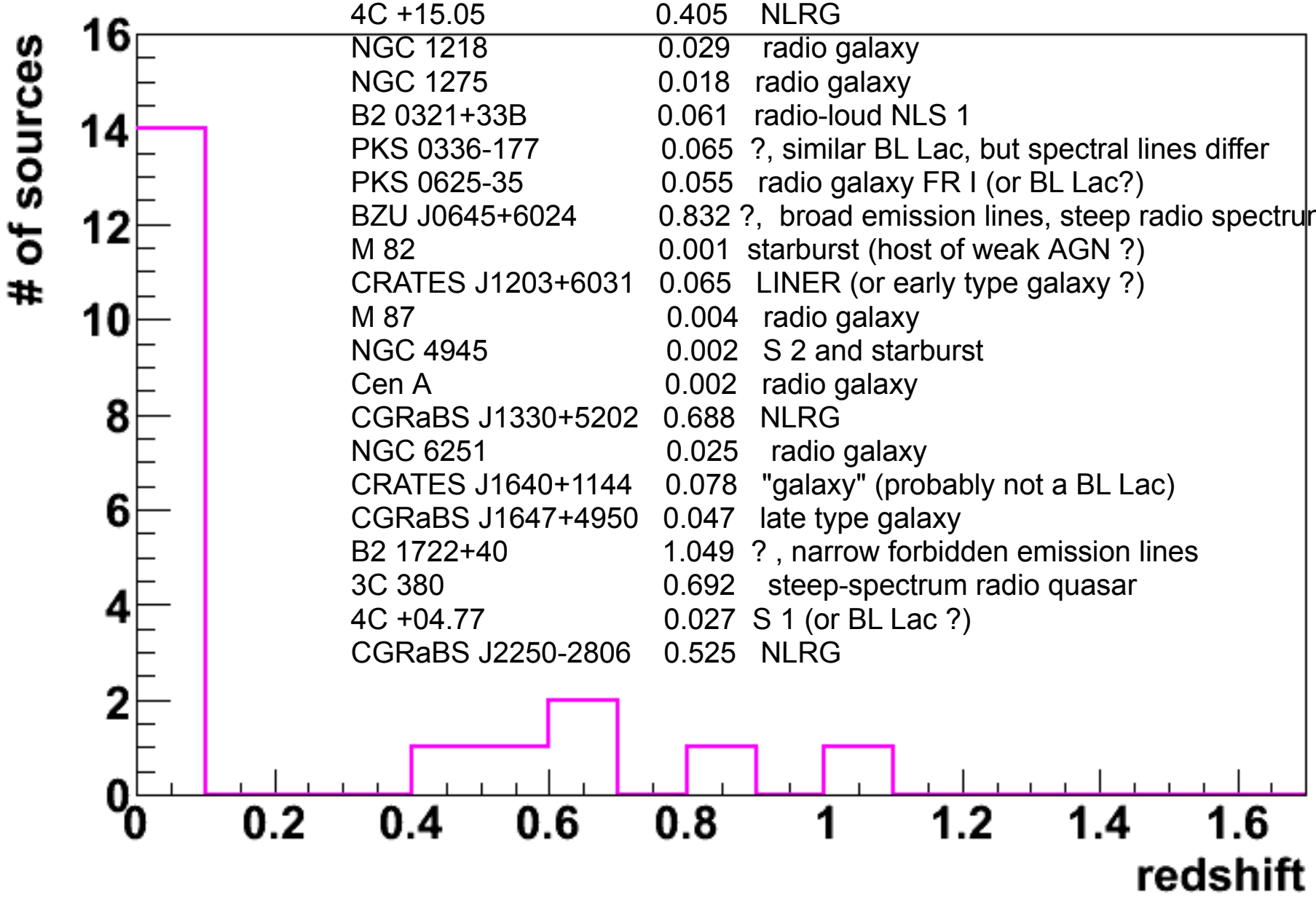


A. Neronov, Meudon workshop 2010

observation of pair halos should give valuable information on extragal. magnetic fields

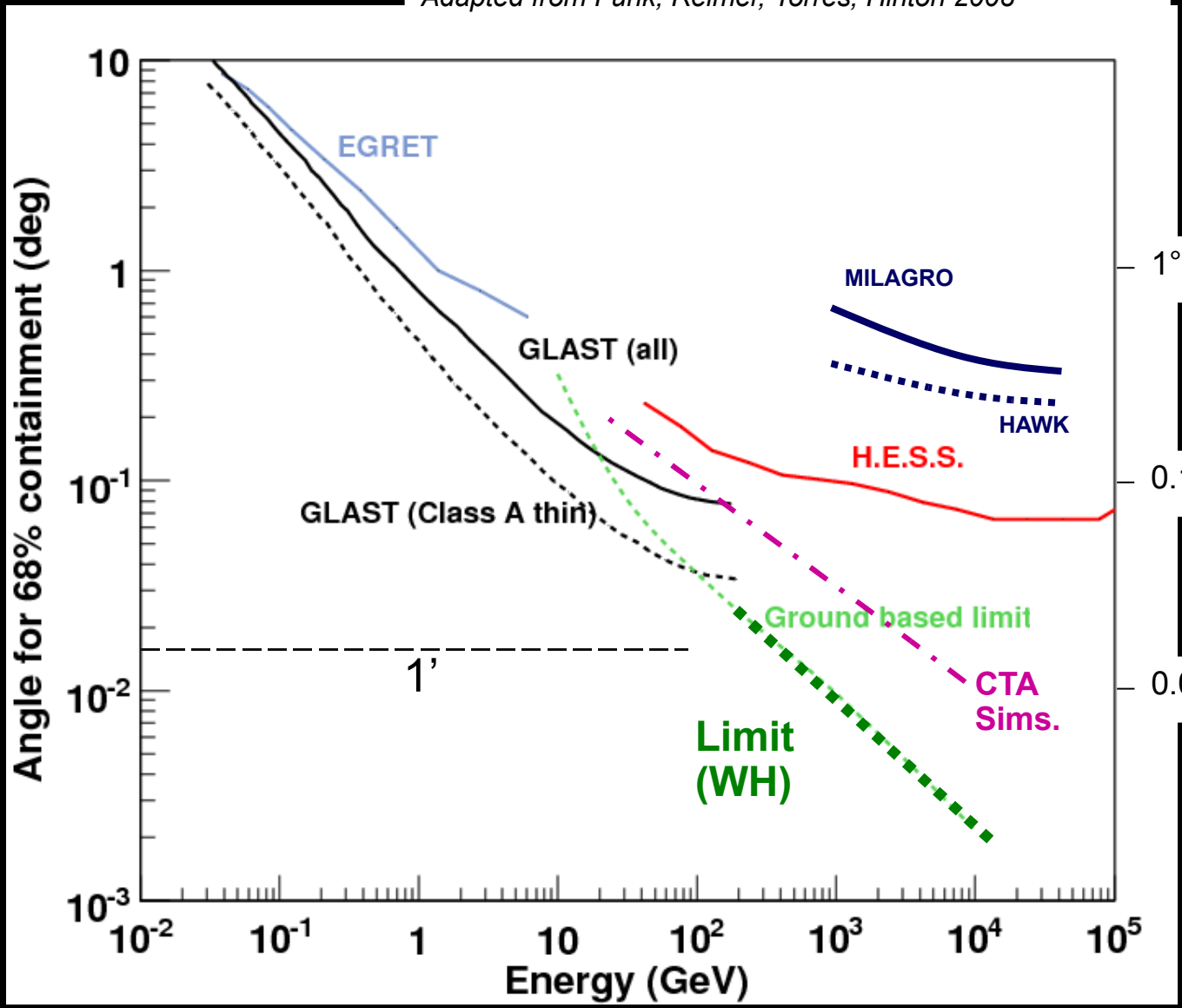
Non-blazar AGN

4C +15.05	0.405	NLRG
NGC 1218	0.029	radio galaxy
NGC 1275	0.018	radio galaxy
B2 0321+33B	0.061	radio-loud NLS 1
PKS 0336-177	0.065	?, similar BL Lac, but spectral lines differ
PKS 0625-35	0.055	radio galaxy FR I (or BL Lac?)
BZU J0645+6024	0.832	?, broad emission lines, steep radio spectrum
M 82	0.001	starburst (host of weak AGN ?)
CRATES J1203+6031	0.065	LINER (or early type galaxy ?)
M 87	0.004	radio galaxy
NGC 4945	0.002	S 2 and starburst
Cen A	0.002	radio galaxy
CGRaBS J1330+5202	0.688	NLRG
NGC 6251	0.025	radio galaxy
CRATES J1640+1144	0.078	"galaxy" (probably not a BL Lac)
CGRaBS J1647+4950	0.047	late type galaxy
B2 1722+40	1.049	? , narrow forbidden emission lines
3C 380	0.692	steep-spectrum radio quasar
4C +04.77	0.027	S 1 (or BL Lac ?)
CGRaBS J2250-2806	0.525	NLRG



angular resolution

Adapted from Funk, Reimer, Torres, Hinton 2008



The ongoing mass production of simulated events will provide more detailed predictions.