Multimessenger Astroparticle Physics

Alessandro De Angelis
Univ. PD, INFN/INAF Padova & LIP/IST Lisboa

8. A Look to the Future

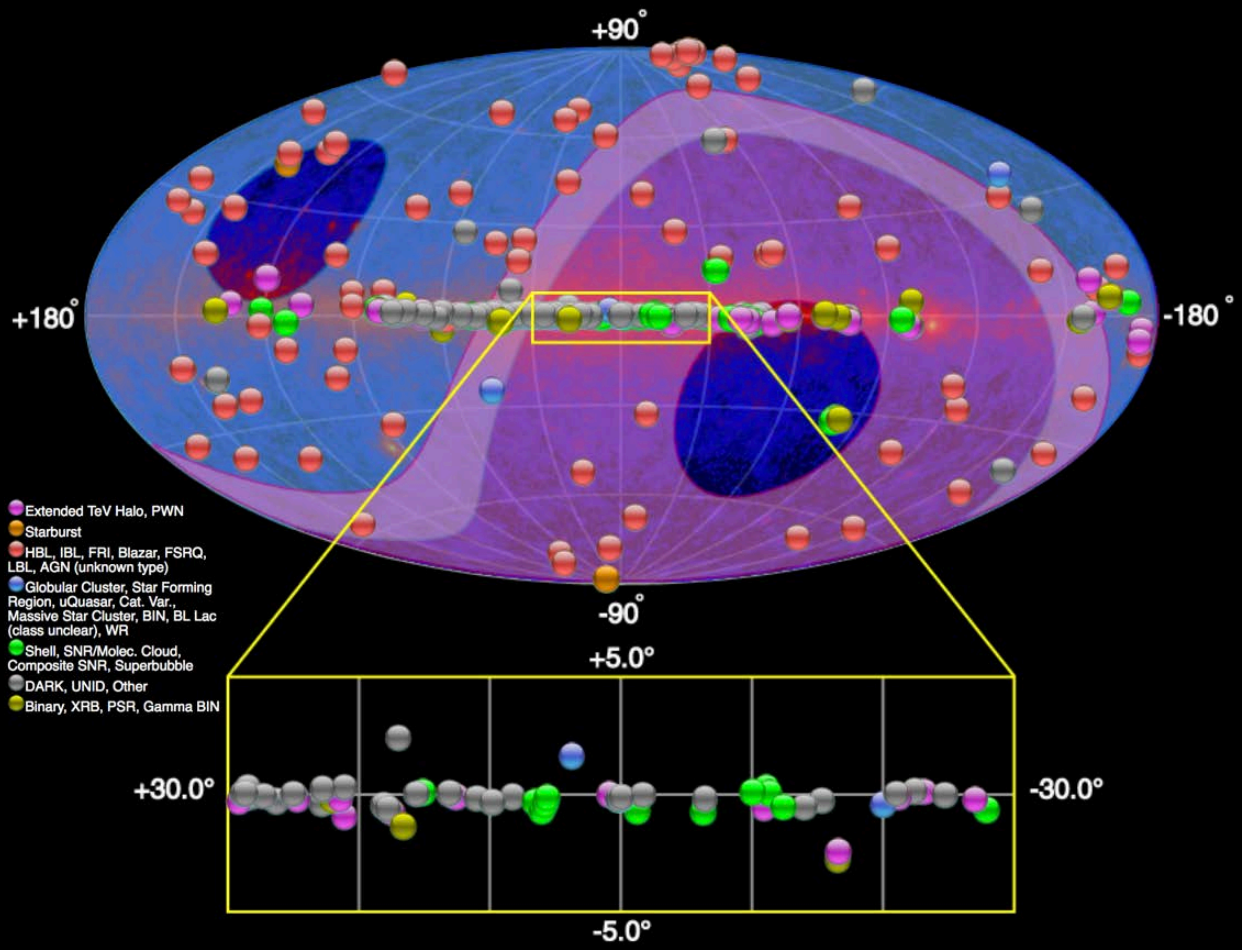
Archeology

- HE astrophysics was until 2017 essentially gamma astrophysics. Thousands of astrophysical gamma-ray emitters in the HE region and >200 in the VHE region
  - New emitters and new classes of emitters
  - A diffuse background up to the TeV, maybe the sum of unresolved point-like emitters
  - We have seen both the leptonic and the hadronic gamma-ray mechanisms at work
  - We have identified mechanisms of emission explaining cosmic rays up to the PeV – also in action, but (by far) not enough to explain the full flux
  - The SED of many emitters can be modeled in an effective way
  - Interesting prospects for fundamental physics. DM:
    - A standard WIMP below 400 GeV is on reach for HE gamma detectors, if just one WIMP and the particle was in thermal equilibrium
    - Dwarf spheroidals (no need for background models) and the GC region (a mess from the point of view of astronomy) are the favorite targets
    - Can find indirect evidence for Axion-Like Particles
- Multimessenger astrophysics (just starting) will teach us more, both from the point of view of astrophysics and of fundamental physics
  - We just detected astrophysical neutrinos [signal of ~1/month with 1km^3 detector, s/b ~ 4/1), and we know that probably a several-km^3 detector is needed do to astronomy. One neutrino event associated with gamma rays.
  - Gravitational waves: first signals (~3/year, will soon become ~0.5-1/month). One associated with gamma rays.
  - Protons cannot be used for astronomy (but they give us O(100 TeV) c.m. energies)

Instruments

- Detectors for charged cosmic rays: (1) need large effective area for the UHE, (2) smart instruments on satellite for particle identification. For (1) we are close to the limit (Auger) unless we change technology, for (2) we are close to the limit (AMS-02)
- Astrophysical neutrino detectors: we need several km^3; we are at 1 km^3 (IceCube) and still improving (IceCube -> Gen2, Antares -> km^3NeT)
- Photons:
  - In the MeV region, instruments did not reach the technological limit, yet (no new instrument since COMPTEL, 1991-2000). Proposals: ASTROGAM, AMEGO
  - In the GeV region, Fermi is close to the technological limit
  - In the TeV region, the Cherenkov technique reigns. HESS, MAGIC and VERITAS have still potential, and in addition there is room for improvement by “brute force”
  - In the PeV region, two detectors (HAWC, LHAASO) presently active, and there is room for improvement – also by “brute force”, and especially by going South

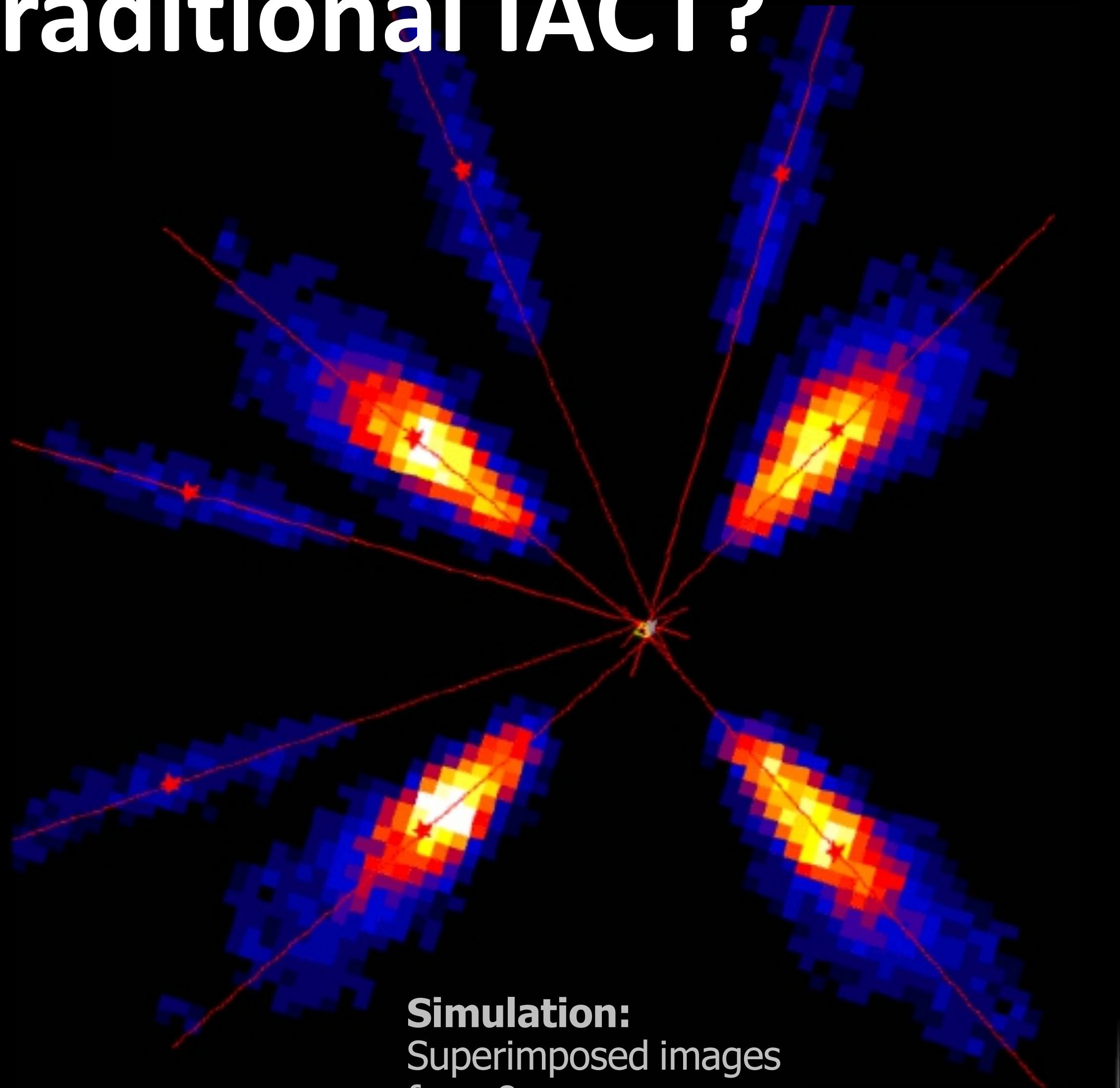
5k HE and >200 VHE photon emitters



The TeV gamma-ray region: CTA

The 20 GeV- 100 TeV region: how to do better with traditional IACT?

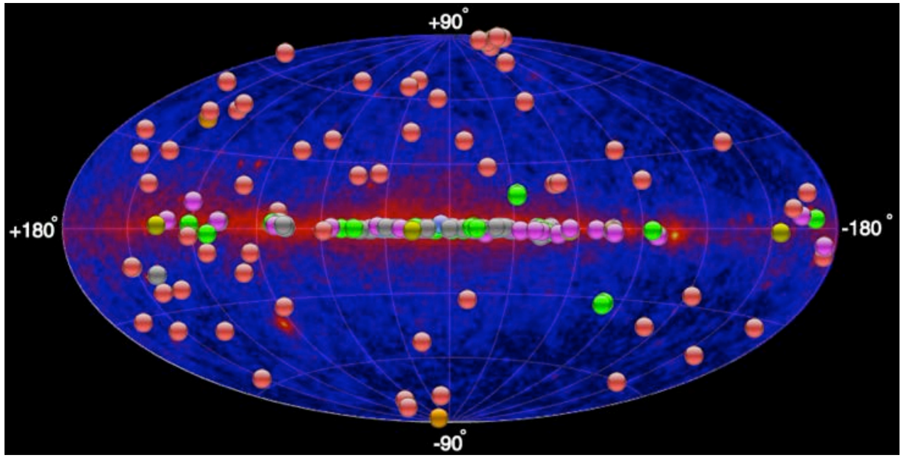
- More events
  - More photons = better spectra, images, fainter sources
    - Larger collection area for gamma-rays
- Better events
  - More precise measurements of atmospheric cascades and hence primary gammas
    - Improved angular resolution
    - Improved background rejection power

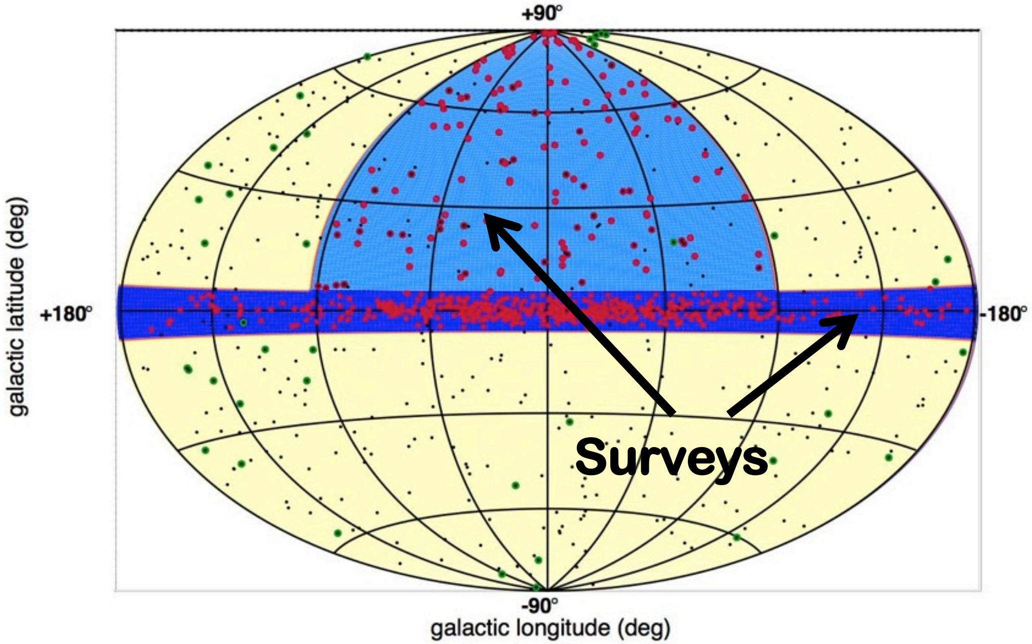


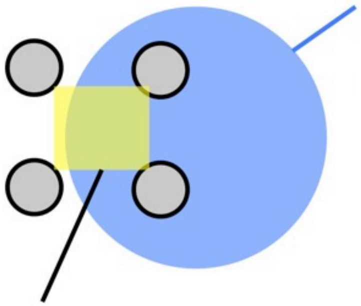
Simulation:
Superimposed images from 8 cameras

☛ The CTA solution: More telescopes !

From current arrays to CTA

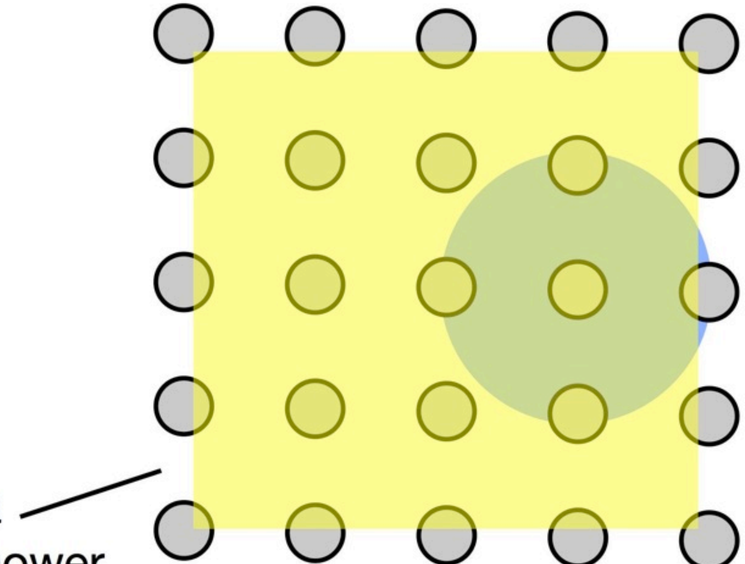






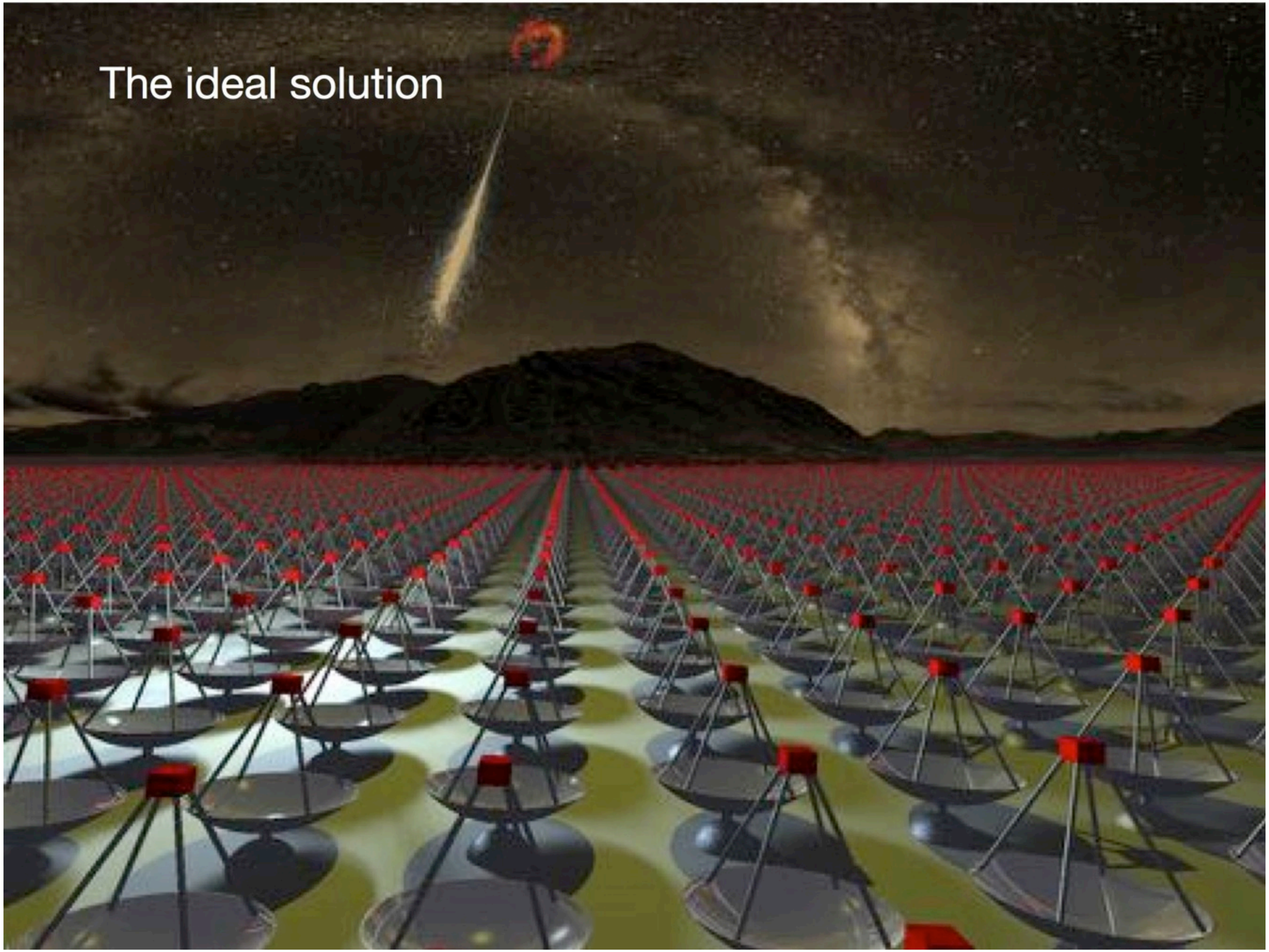
light pool radius
R ≈100-150 m
≈ typical telescope spacing

Sweet spot for
best triggering
and reconstruction:
most showers miss it!



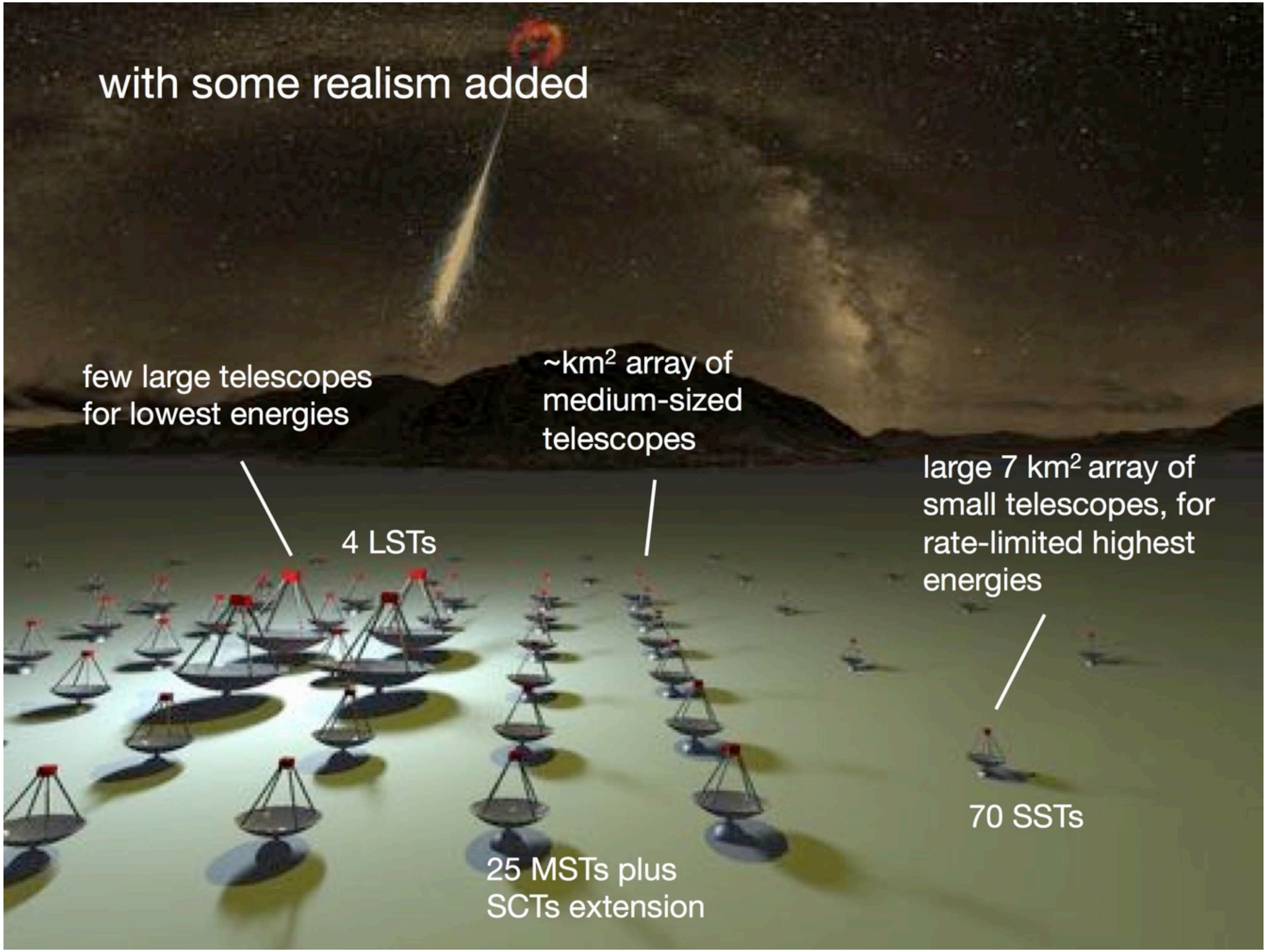
large detection area
more images per shower
lower trigger threshold

A next generation VHE facility



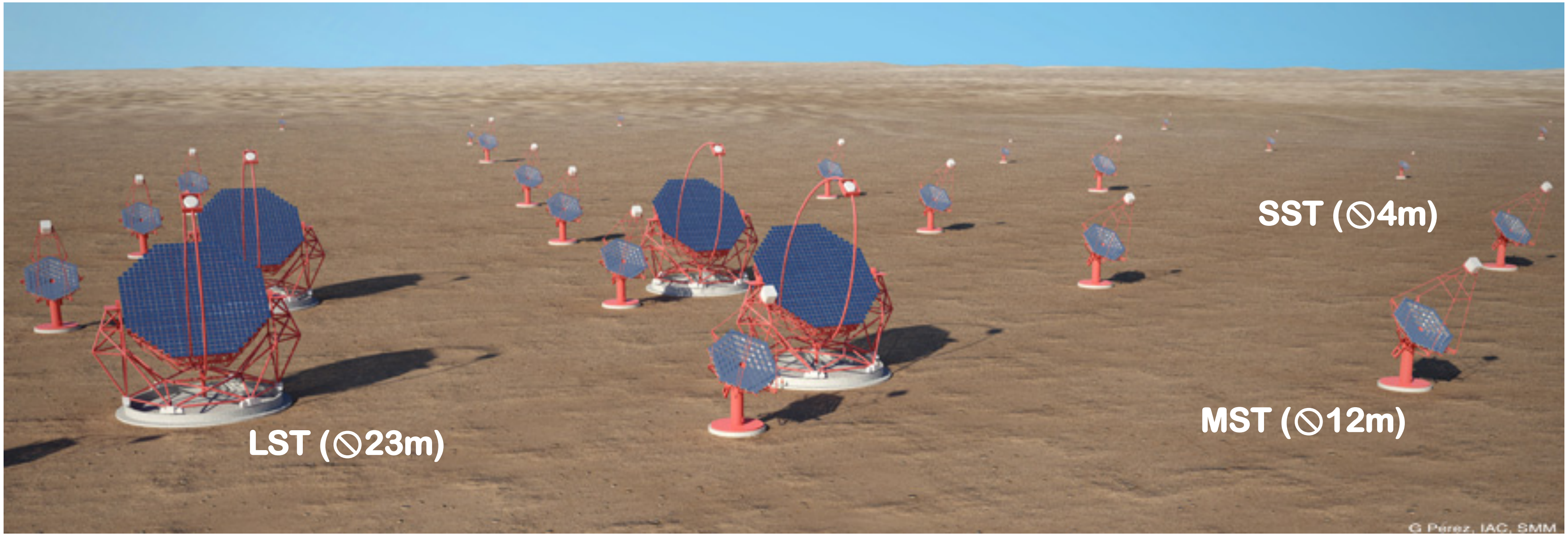
W. Hofmann

A next generation VHE facility

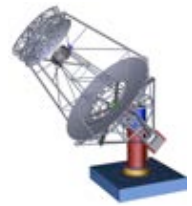


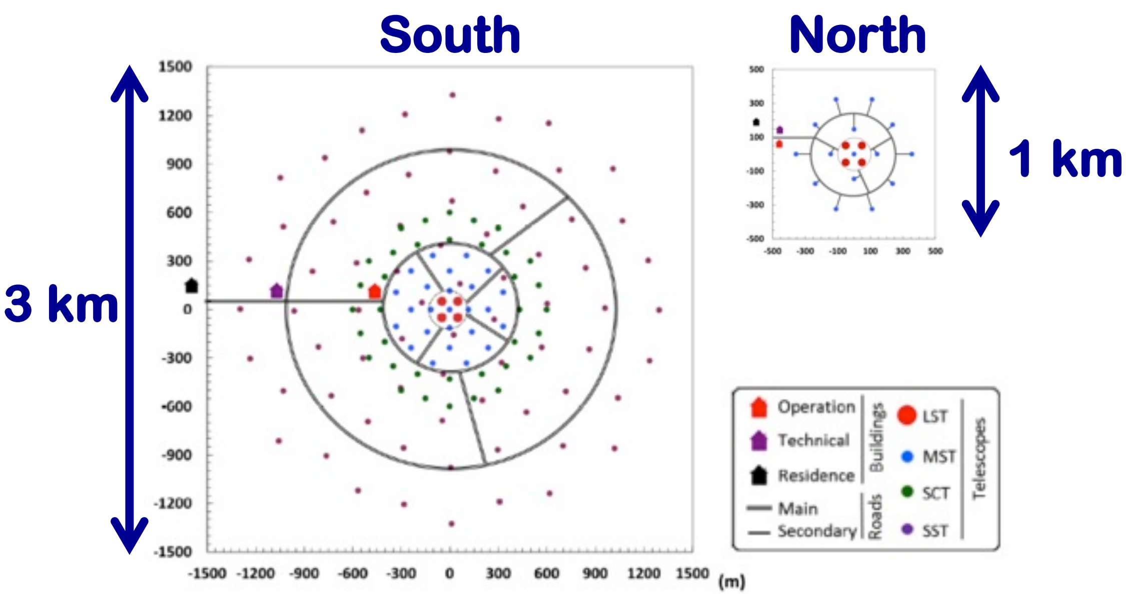
W. Hofmann

The CTA Observatory



SCT (⌀10m)





Characteristics

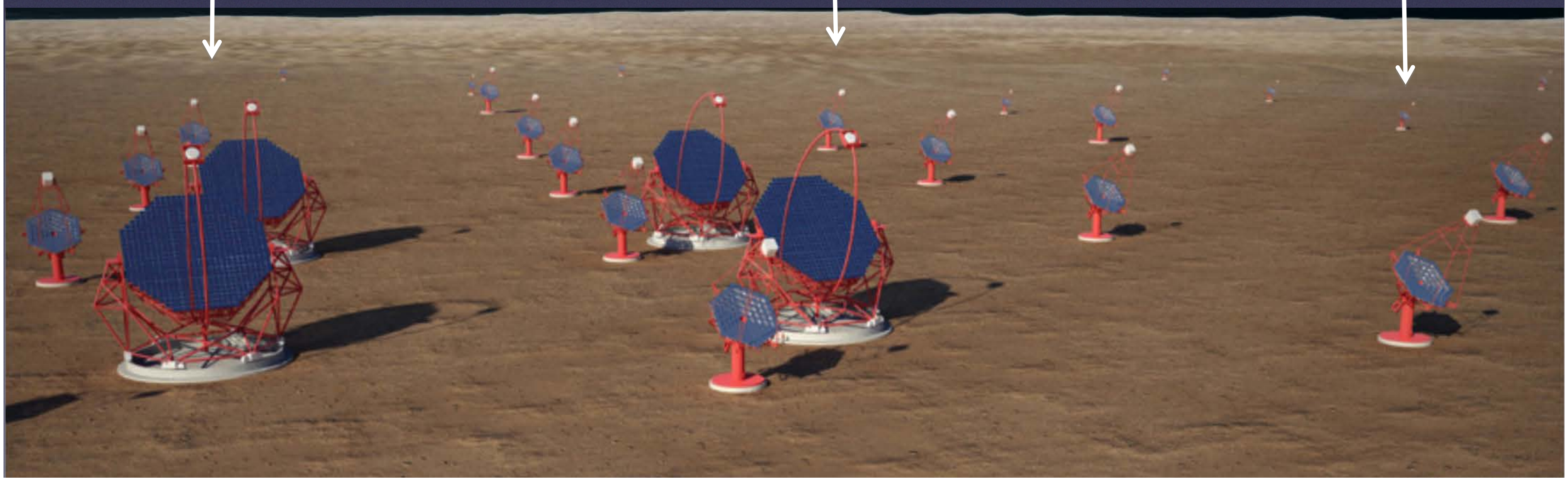
2 sites (north & south)
3 telescope size classes
About 120 telescopes in total
South U.S. extension with about 25 SCT telescopes

What is CTA? A multi-telescope Cherenkov array

<u>Low energies</u>
Energy threshold 20 GeV
23 m diameter
4 telescopes
(LST)

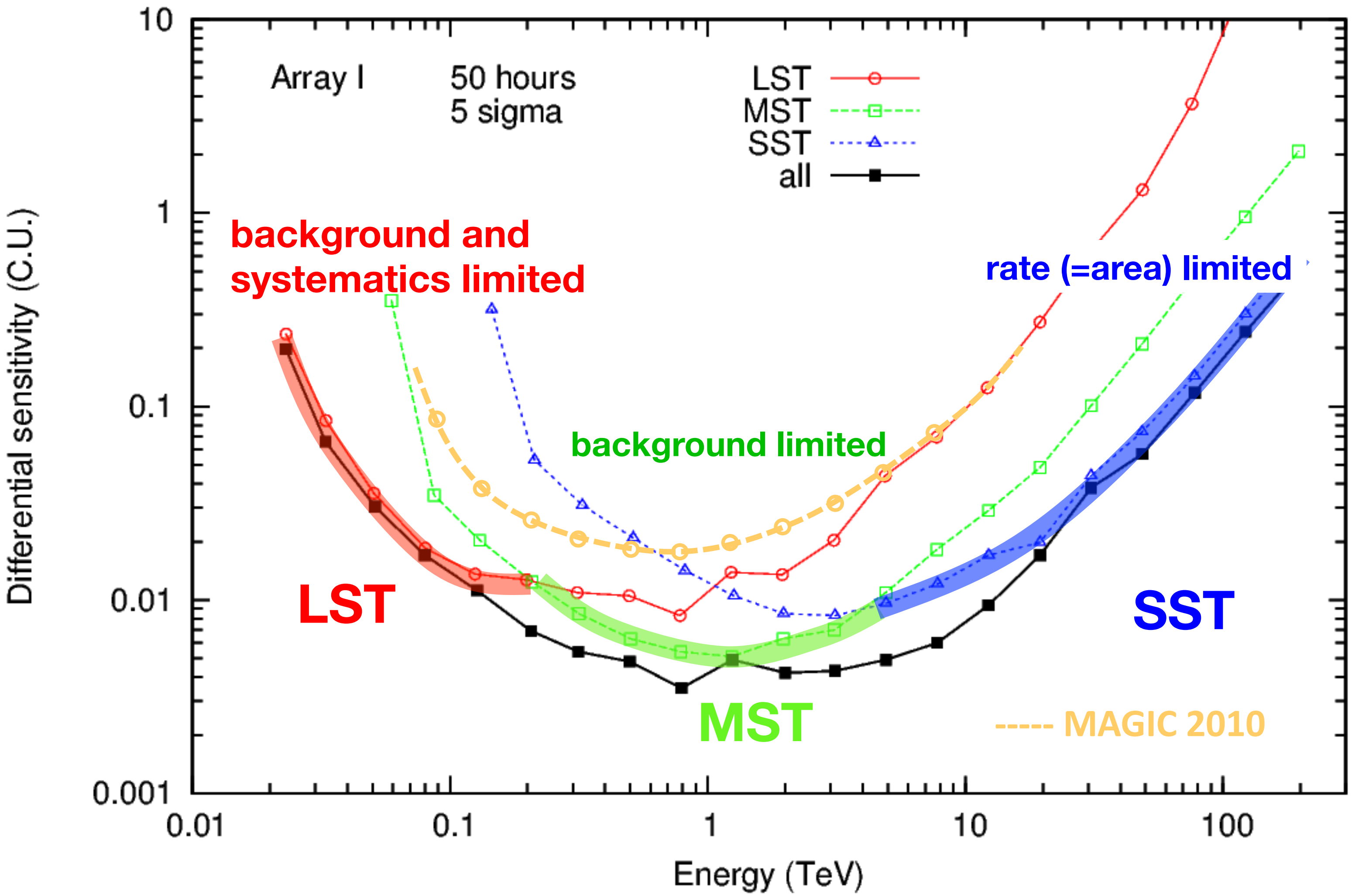
<u>Medium energies</u> (MST)
100 GeV – 10 TeV
9.5 to 12 m diameter
25 single-mirror telescopes
up to 24 dual-mirror telescopes
mCrab sensitivity in 50h at 0.1-10 TeV

<u>High energies</u>
10 km^2 area at few TeV
4 to 6 m diameter
70 telescopes
(SST)

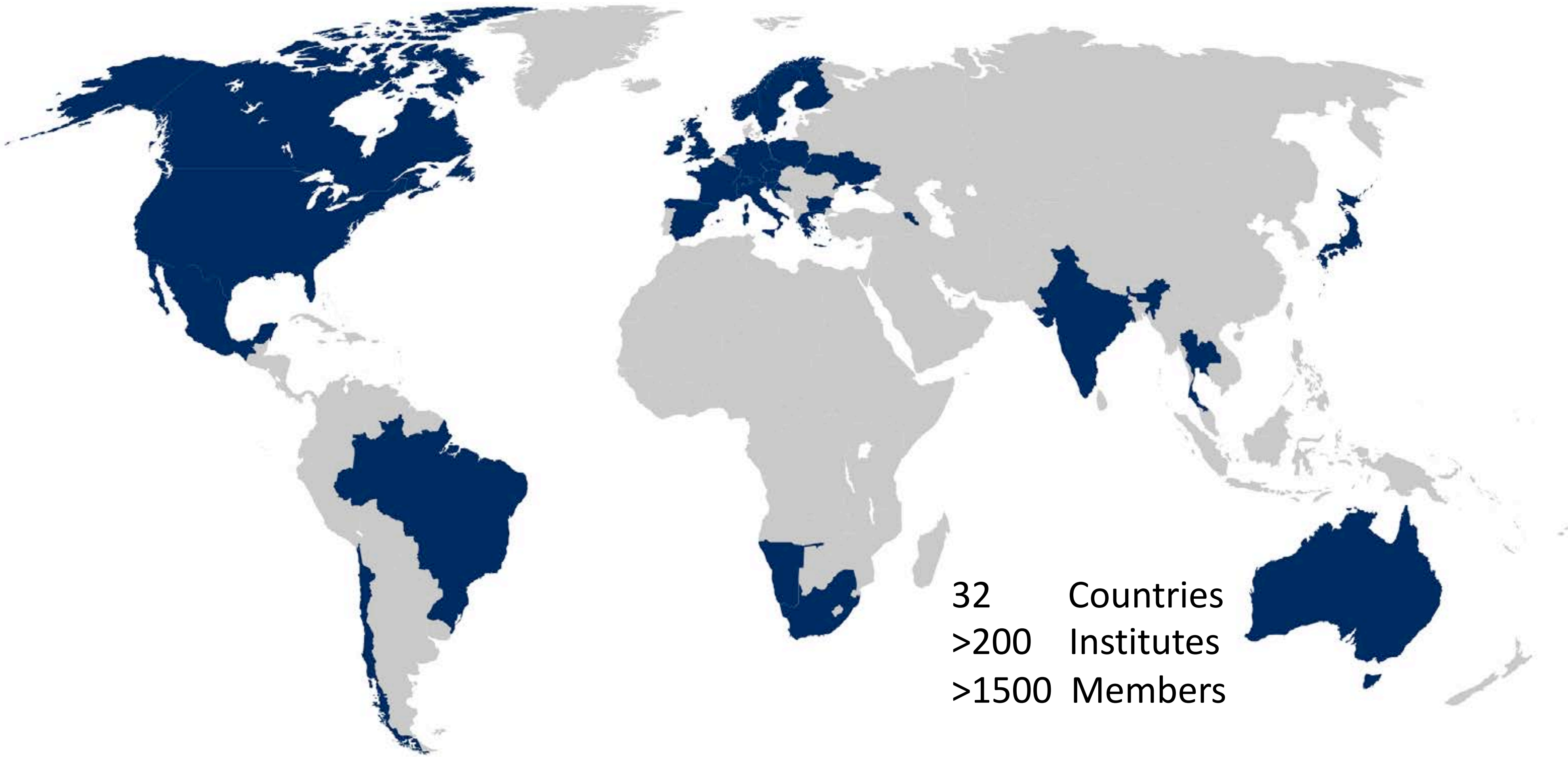


CTA sensitivity in units of Crab flux

for 5 σ detection & $N_\gamma > 10$ in each 0.2-dex bin in E, in 50 h



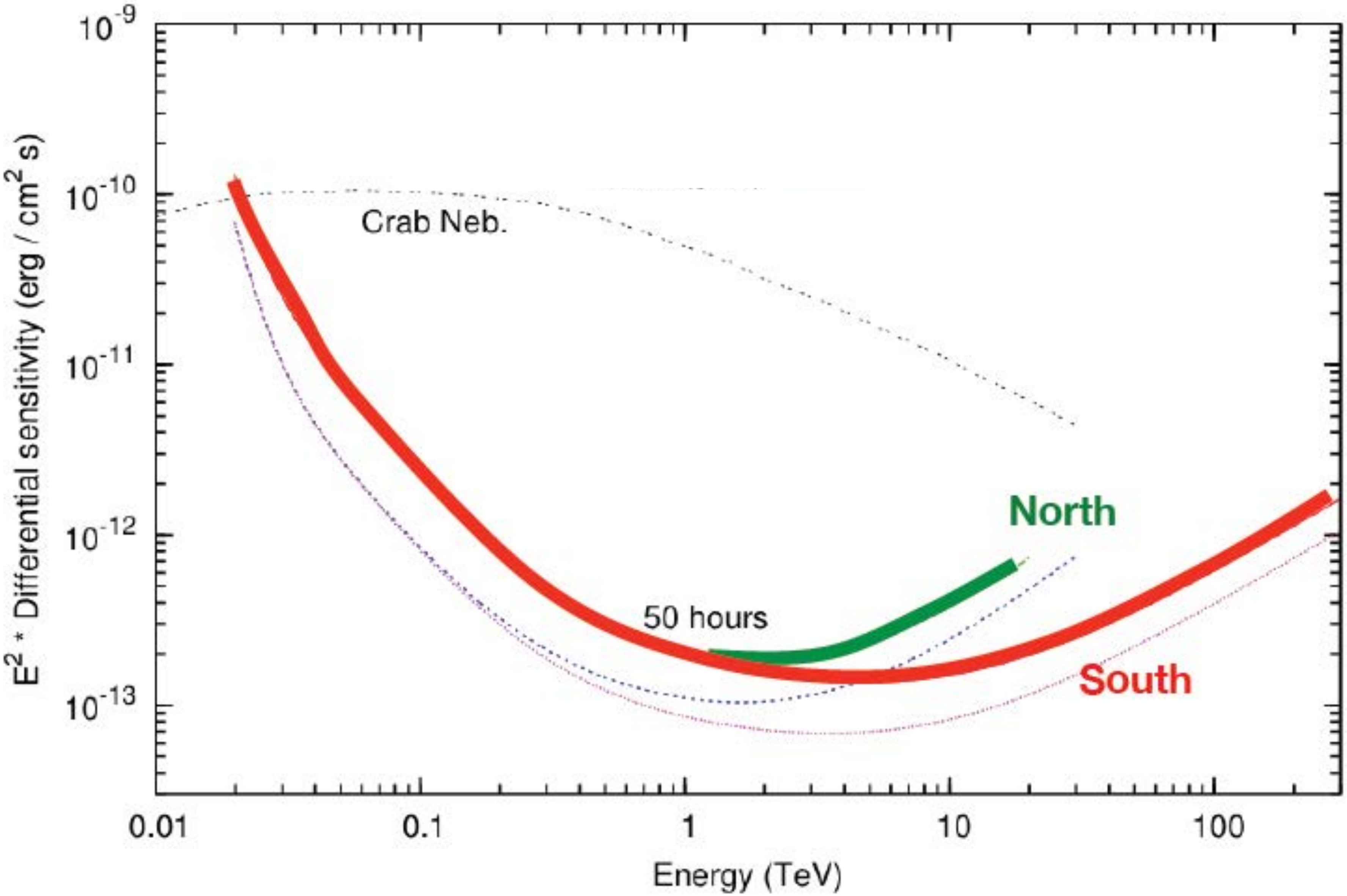
CTA consortium: a world-wide effort



32 Countries
>200 Institutes
>1500 Members

All-sky coverage: two observatories

Sensitivity for North and South



Telescope Specifications

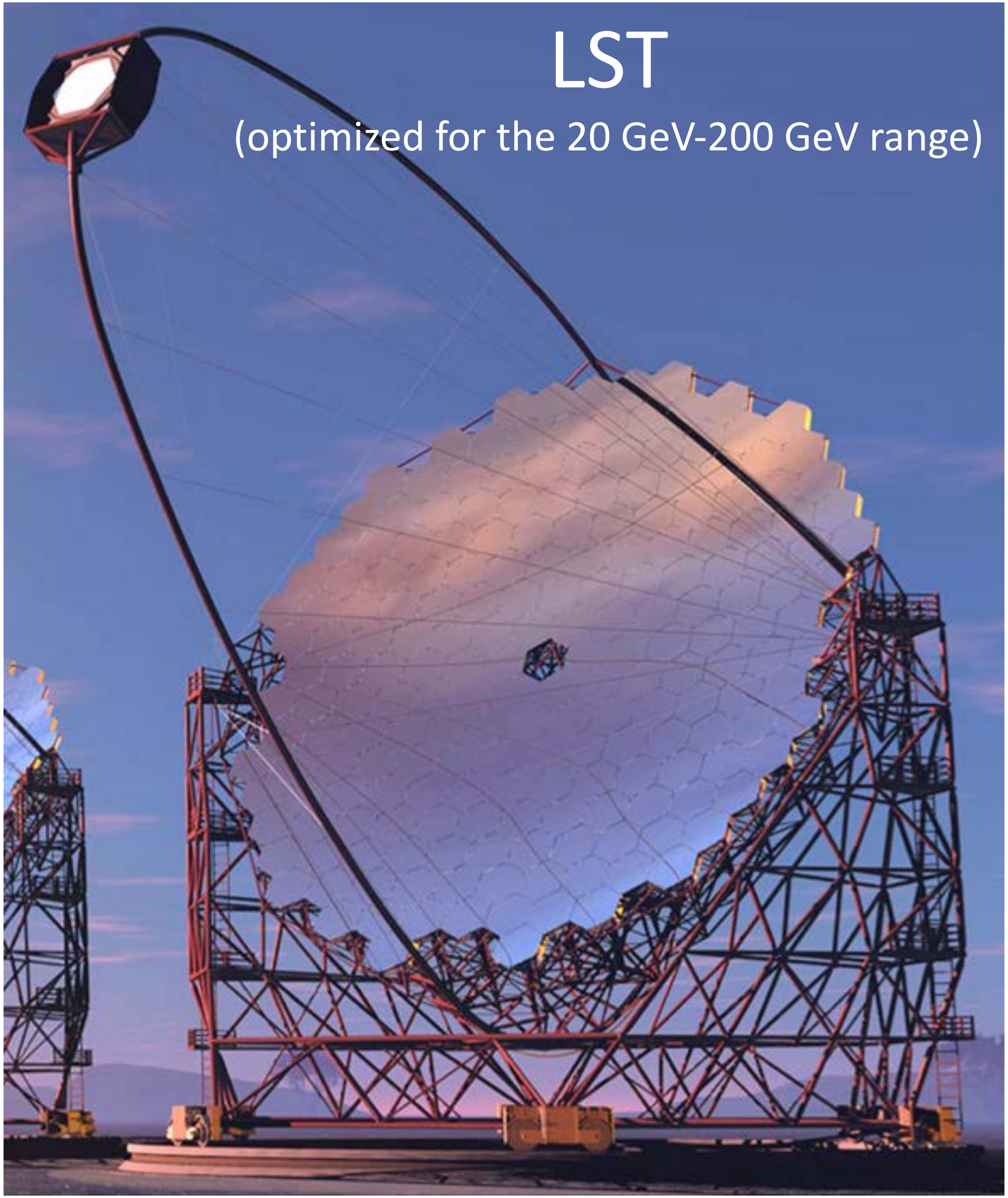
SiPM Cameras (MST, SCT, SST)

3 SST types

	LST "large"	MST "medium"	SCT "medium 2-M"	SST "small"
Number	**4 (S) 4 (N)**	**25 (S) 15 (N)**	**≤ 24 (S and N)**	**70 (S)**
Energy range	20 GeV to 1 TeV	200 GeV to 10 TeV	200 GeV to 10 TeV	> few TeV
Effective mirror area	400 m^2	100 m^2	> 50 m^2	> 5 m^2
Field of view	> 4.4°	> 7°	> 7°	> 8°
Pixel size θ_{80}	0.1°	< 0.18°	< 0.07°	< 0.25°
Positioning time	50 s, 20 s goal	90 s, 60 s goal	90 s, 60 s goal	90 s, 60 s goal
Capital cost	10 M€	2 M€	2 M€	800 k€

LST

(optimized for the 20 GeV-200 GeV range)



- 23 m diameter (400 m^2 dish area)
- 28 m focal length
- 200x2m^2 hexagonal mirrors

- 4.5 deg FoV

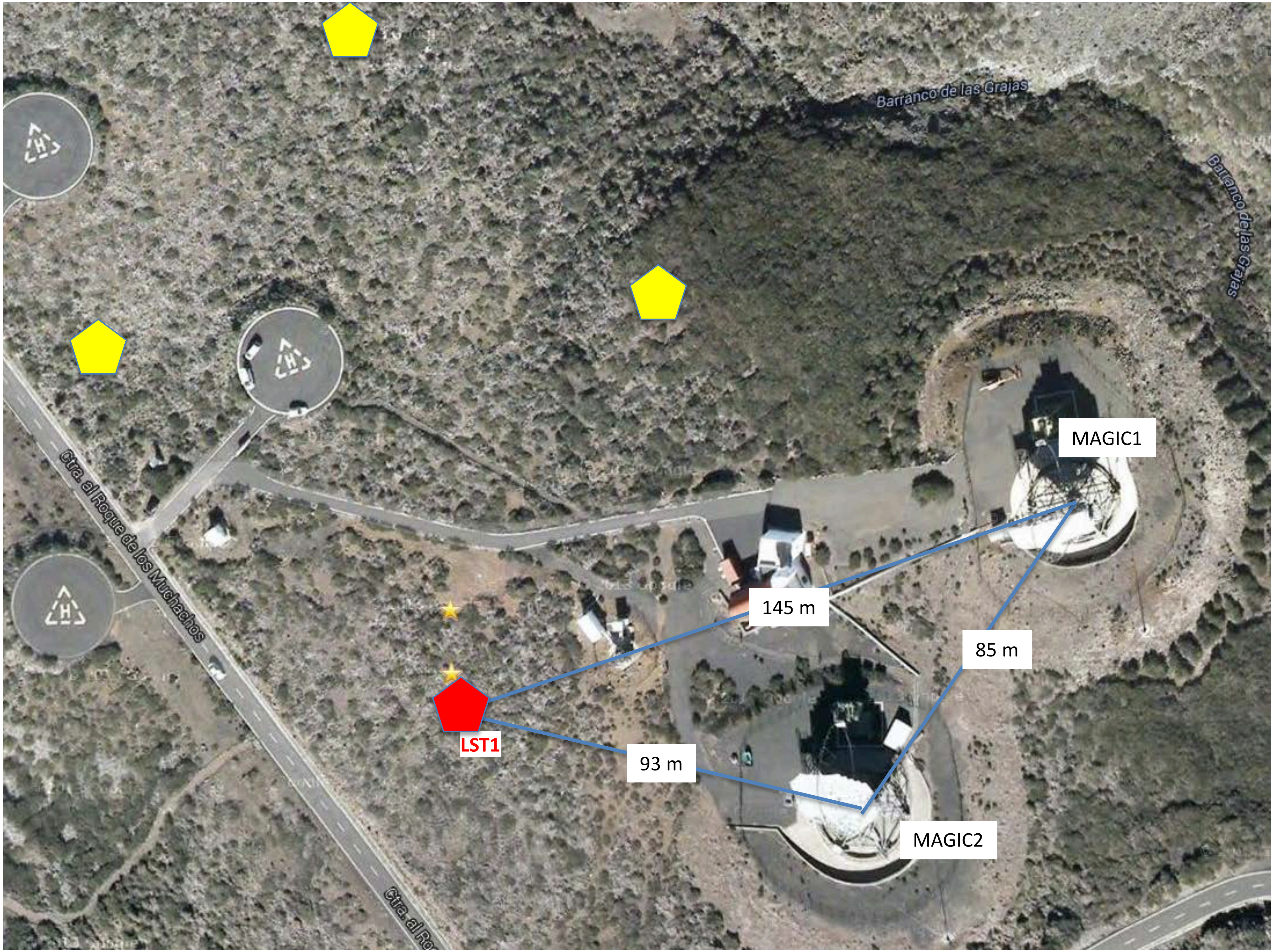
- 0.1° pixels, camera diam. 2m
- Light structure for 20 s positioning
- AMC

- 4 LSTs on North site, 4 LSTs on South site

- Prototype = 1st telescope at La Palma.
- Inaugurated October 10, 2018

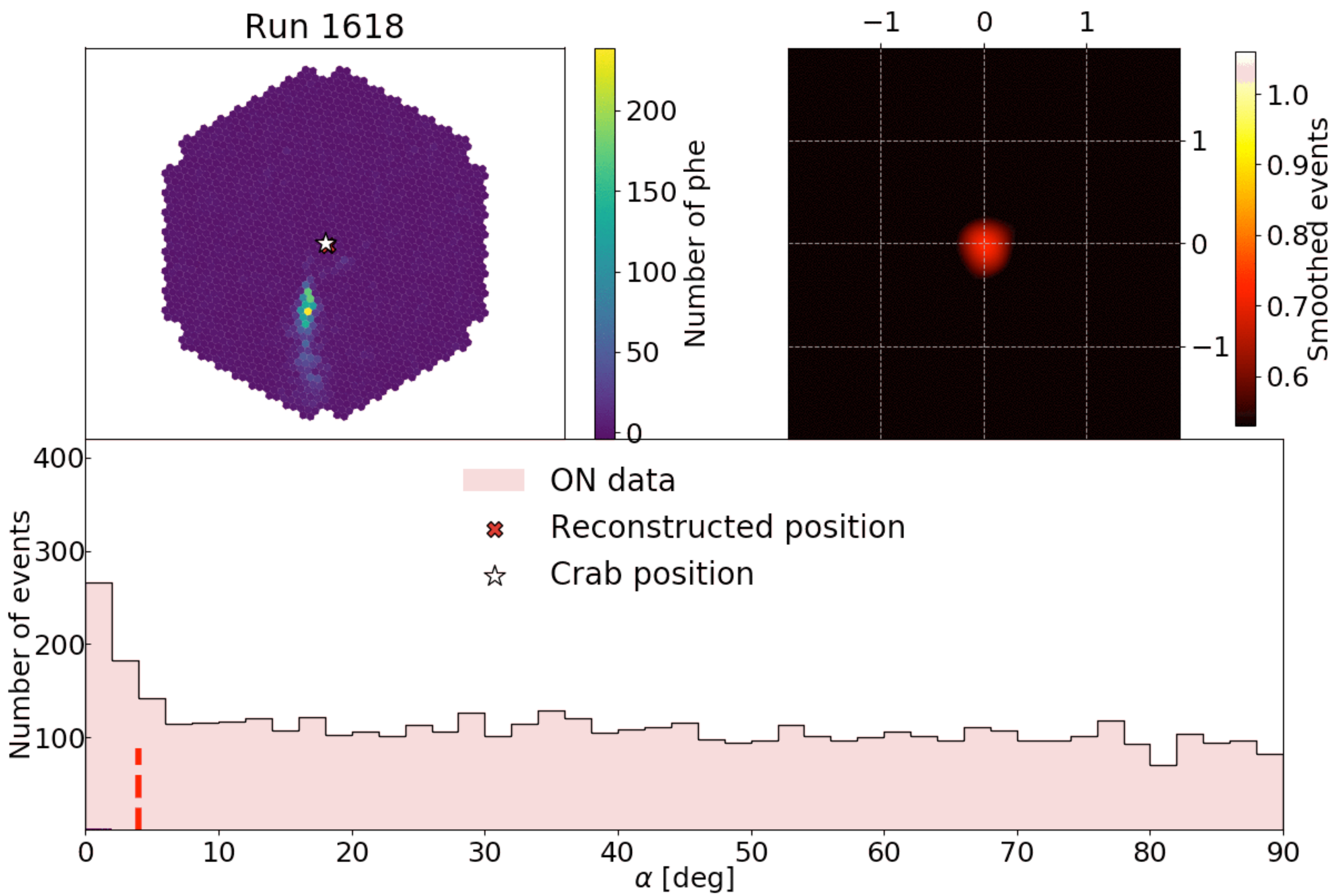
- Japan, Germany, INFN Italy, Spain, IN2P3 France, India, Brazil, Croatia, Sweden

LST1 at La Palma (near MAGIC)


Barranco de las Grajas
Barranco de las Grajas
Ctra. al Roque de los Muchachos
MAGIC1
145 m
85 m
LST1
93 m
MAGIC2

First signal announced Dec 2019!

- Crab at 5σ in 10 minutes
- ~half the sensitivity of MAGIC
  - But improving, and construction of LST2 starting in 2020 (end 2021/22)



MEDIUM-SIZED 12 M TELESCOPE
OPTIMIZED FOR THE 100 GEV TO ~10 TEV RANGE

$100\ m^2$ dish area
16 m focal length
1.2 m mirror facets

8º field of view
~2000 x 0.18º pixels

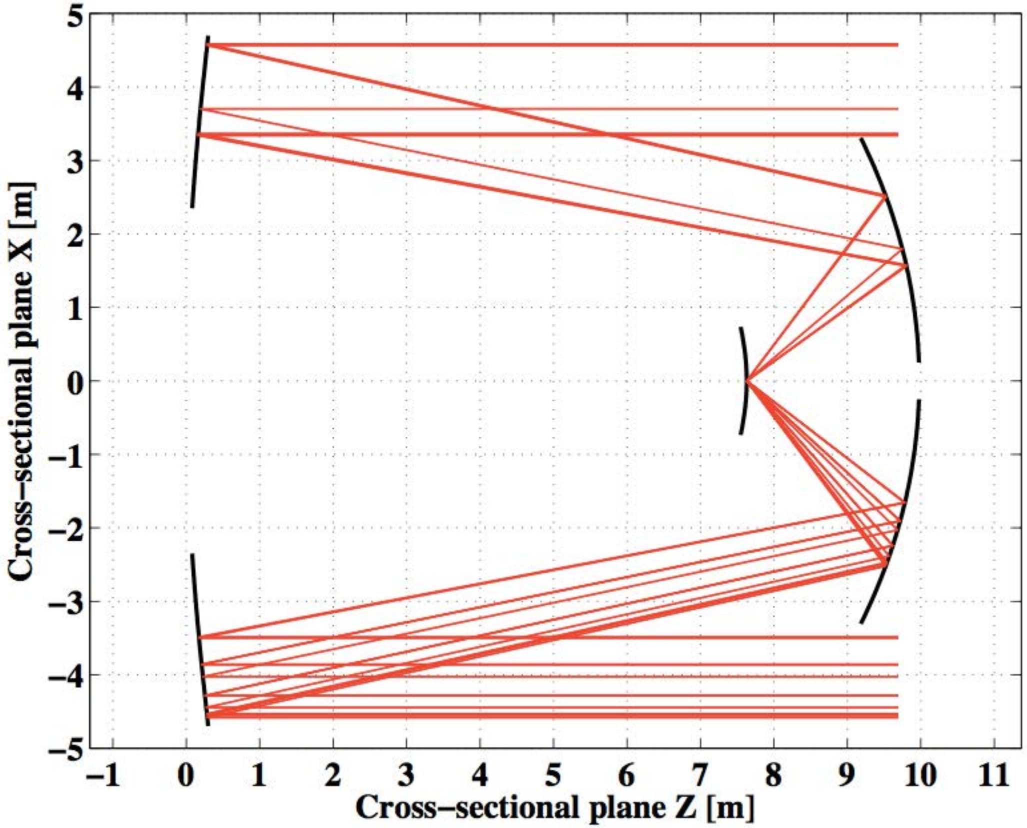
25 MSTs on South site
15 MSTs on North site

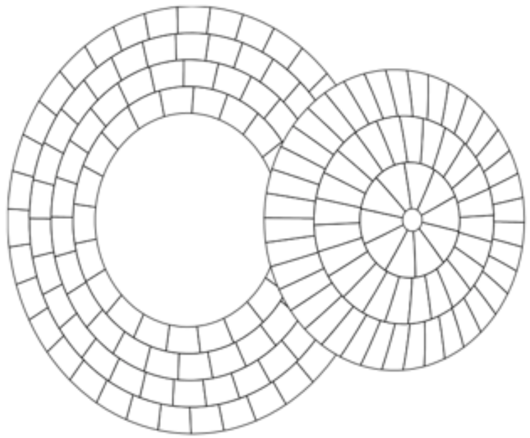
Berlin
MST prototype
operational

Two-Mirror Telescopes

Schwarzschild-Couder (SC) Design

Vassiliev, Fegan, Brousseau
Astropart.Phys.28:10-27,2007





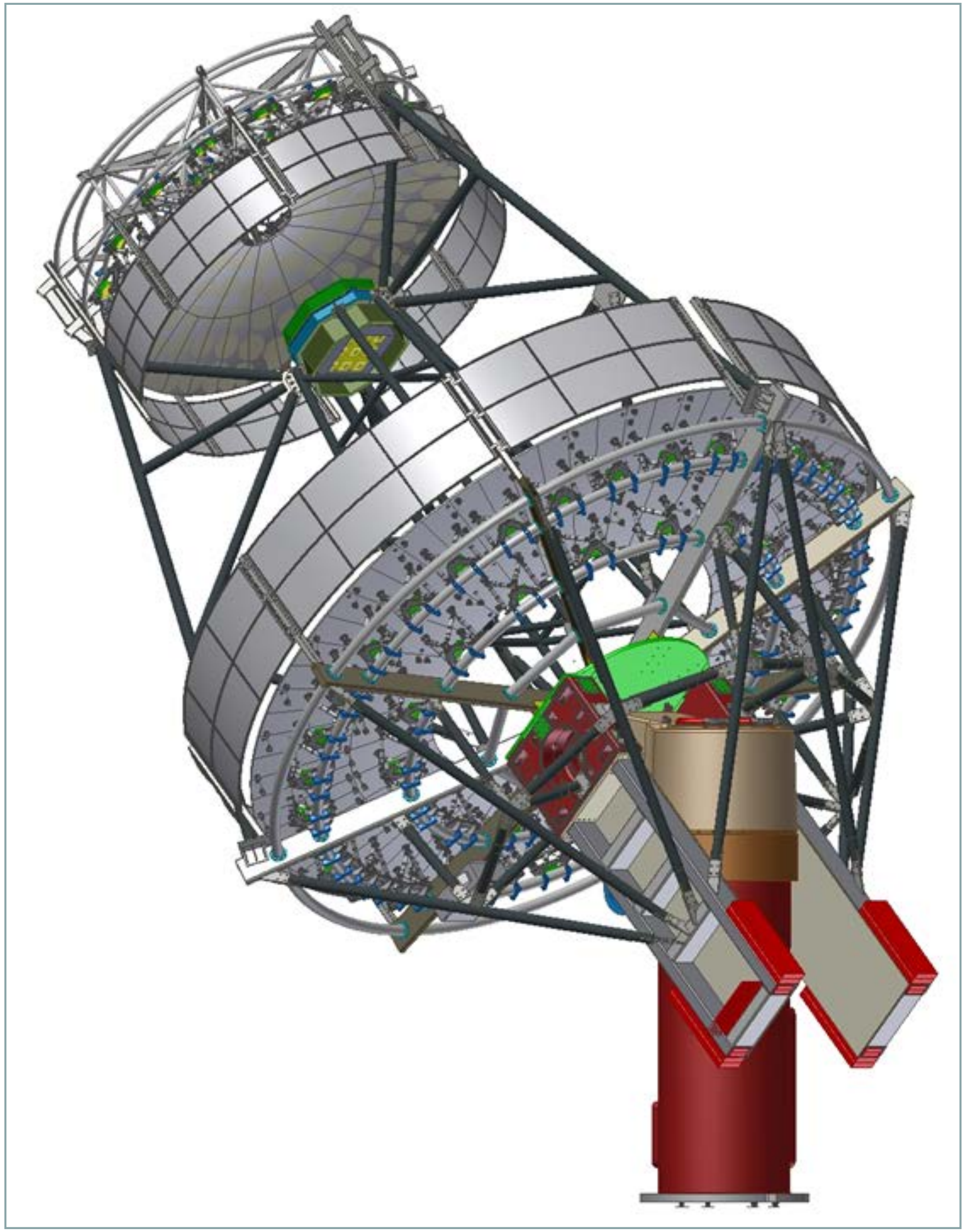
- Reduced plate scale
- **Improved PSF**
- **Uniform PSF across f.o.v.**

➜ Low-cost small telescopes with compact sensors (SST-2M)

➜ Higher-performance, cost-effective, medium telescope (MST-SCT)

3 telescope prototypes within CTA are using two mirror designs

Medium Telescope 2-mirror (SCT)



9.7 m primary
5.4 m secondary
5.6 m focal length, f/0.58
50 m^2 mirror dish area
PSF better than 4.5′
across 8° FOV

8° field of view
11328 x 0.07° SiPMT pixels
TARGET readout ASIC

SCTs can augment / replace
MSTs in either S or N
→ proposed US contribution

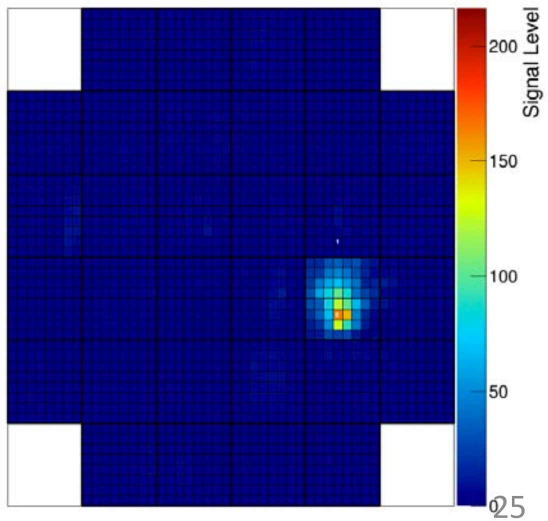
→ Increased γ-ray collection area
→ Improved γ-ray ang. resolution
→ Improved DM sensitivity

pSCT construction near Tucson

Small Telescope 2-mirror (SST-2M)

SST-2M –ASTRI Mechanical Prototype
Inauguration, 24 Sept 2014
(Serra La Nave, Sicily)

Compact, Silicon-PM
Camera

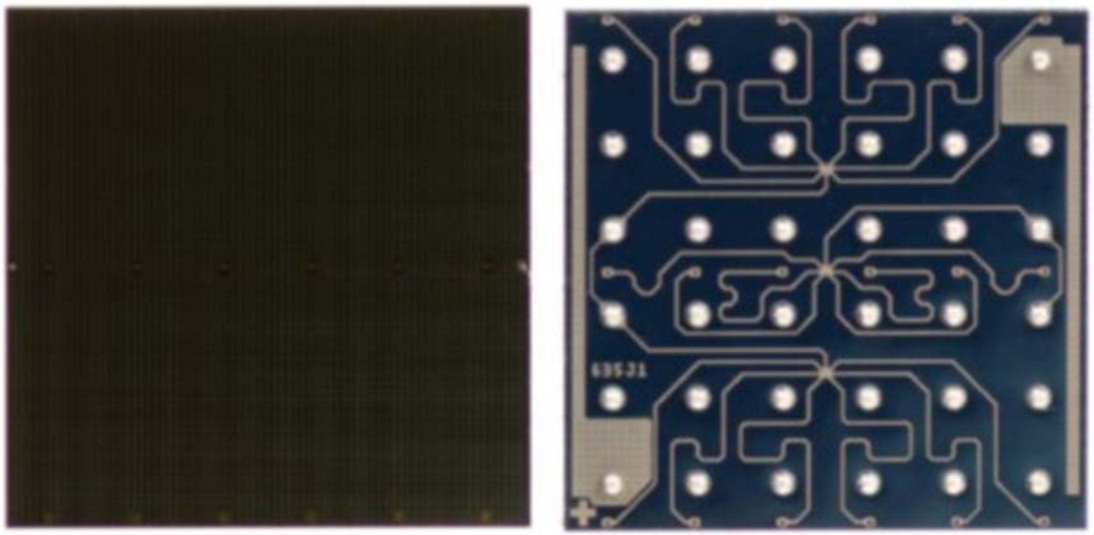


SiPM: the technological challenge for small cameras

Cameras need high granularity, and typical PMT size of 5-6 mm

Difficult to do with standard PMT

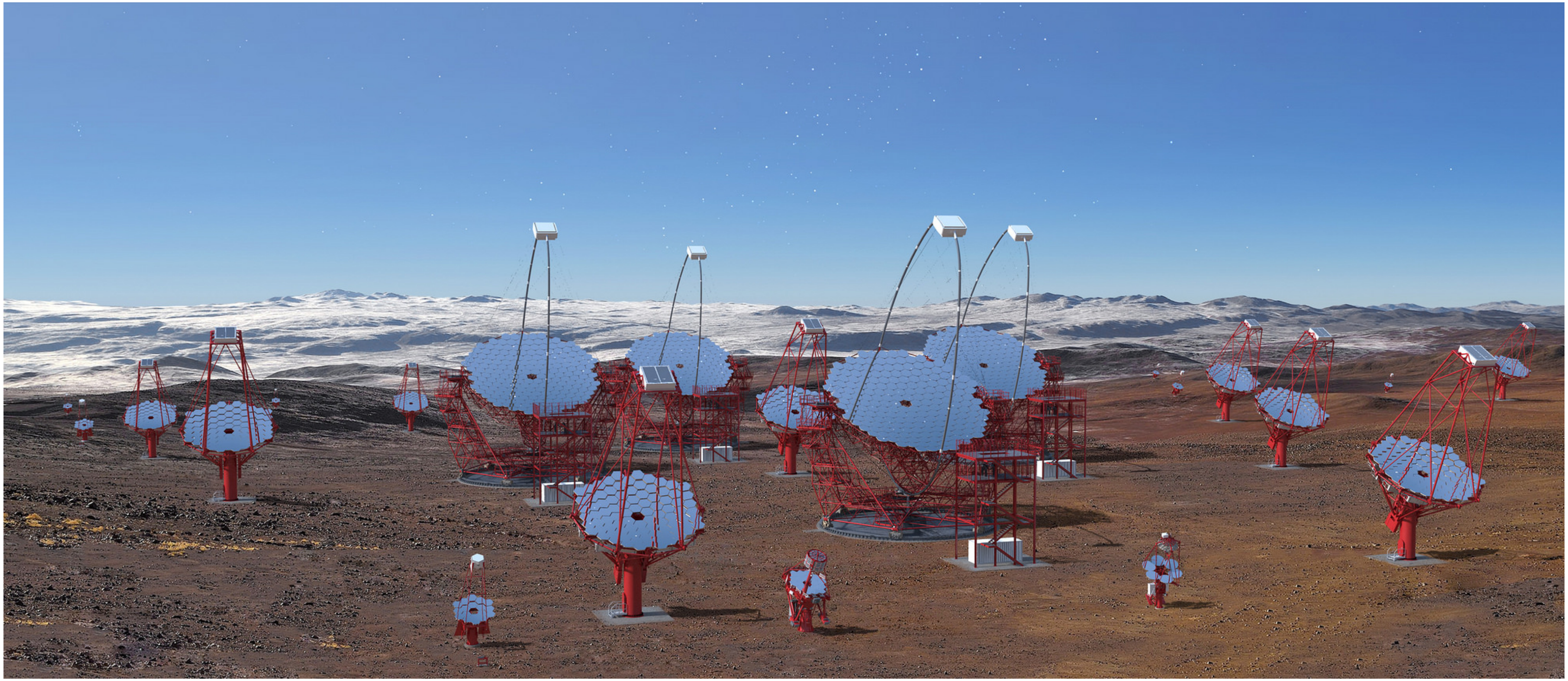
New detectors (SiPM) under development

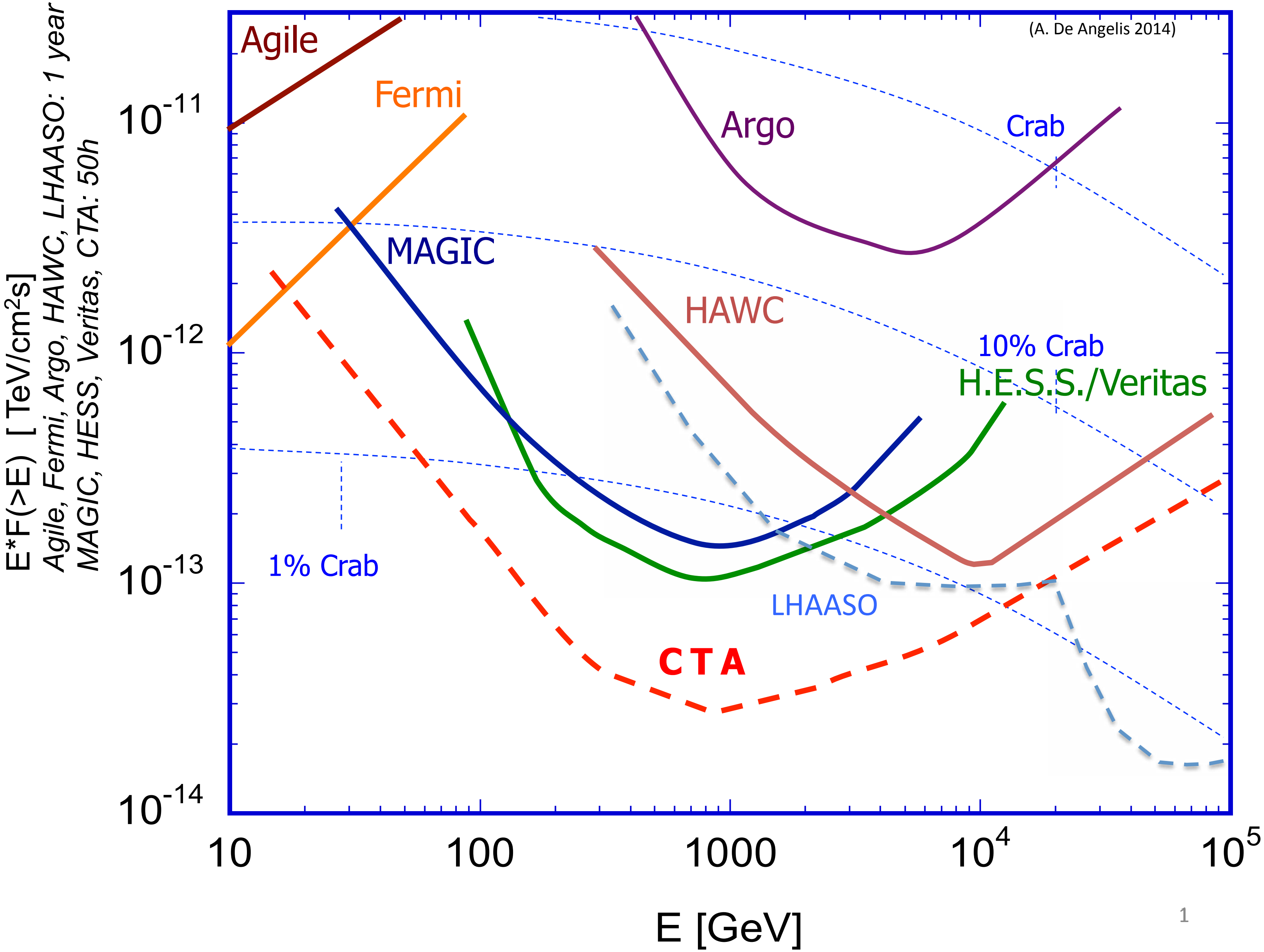


CTA-N: rendering

LST1 commissioned in 2019/20 (inaugurated October 10, 2018)
LST2-4 commissioned in 2023
First 5 MST installed in 2024-25?

CTA-S in Paranal: rendering (works starting in 2023?)





(A. De Angelis 2014)
Agile
Fermi
Argo
Crab
MAGIC
HAWC
10% Crab
H.E.S.S./Veritas
1% Crab
LHAASO
CTA
E*F(>E) [TeV/cm2s]
Agile, Fermi, Argo, HAWC, LHAASO: 1 year
MAGIC, HESS, Veritas, CTA: 50h
10-11
10-12
10-13
10-14
10
100
1000
10^4
10^5
E [GeV]

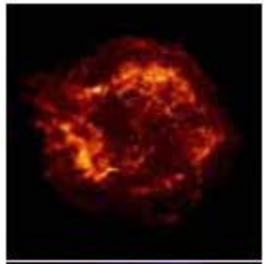
1

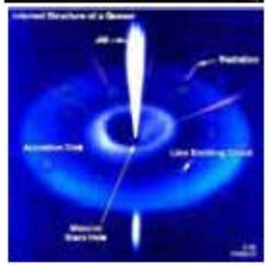
Guaranteed Science with CTA

An advanced Facility for ground-based gamma-ray Astronomy

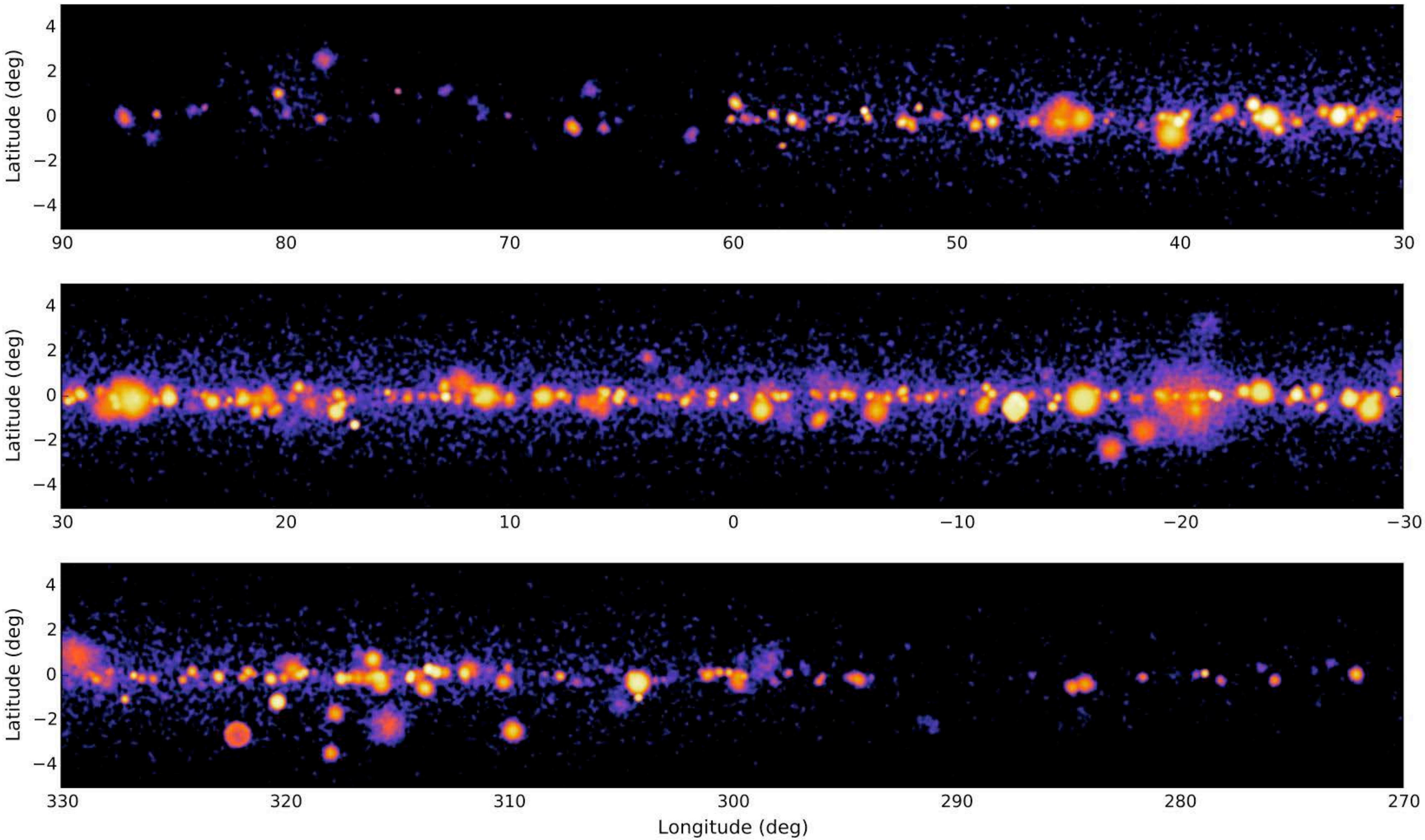
~200 -> ~2000 sources above 100 GeV

- Study of sources and propagation of high energy particles in the Cosmos, on scales ranging from compact objects to large scale structures
  - Pulsars
  - Pulsar wind nebulae
  - Stellar winds
  - Supernova remnants
  - Diffuse emission
  - Galactic center region
  - Starburst galaxies
  - Clusters of galaxies
- Black holes and their environment
  - Stellar-mass black holes
  - Supermassive black holes



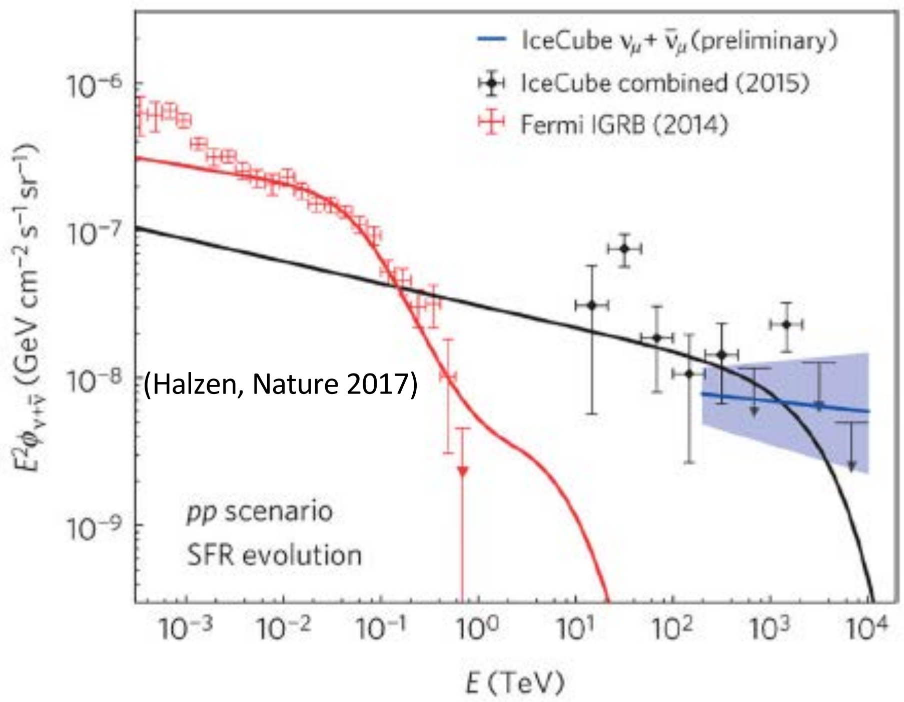


Sources of Galactic Cosmic Rays

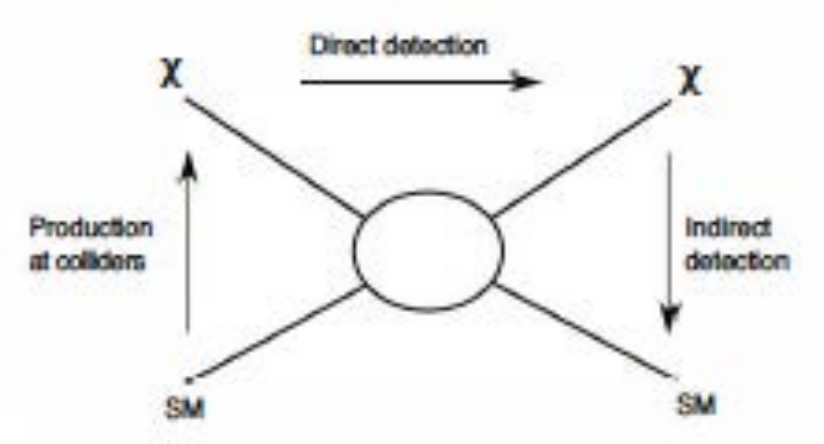


Gravity near compact objects
(in particular through multimessenger astronomy)

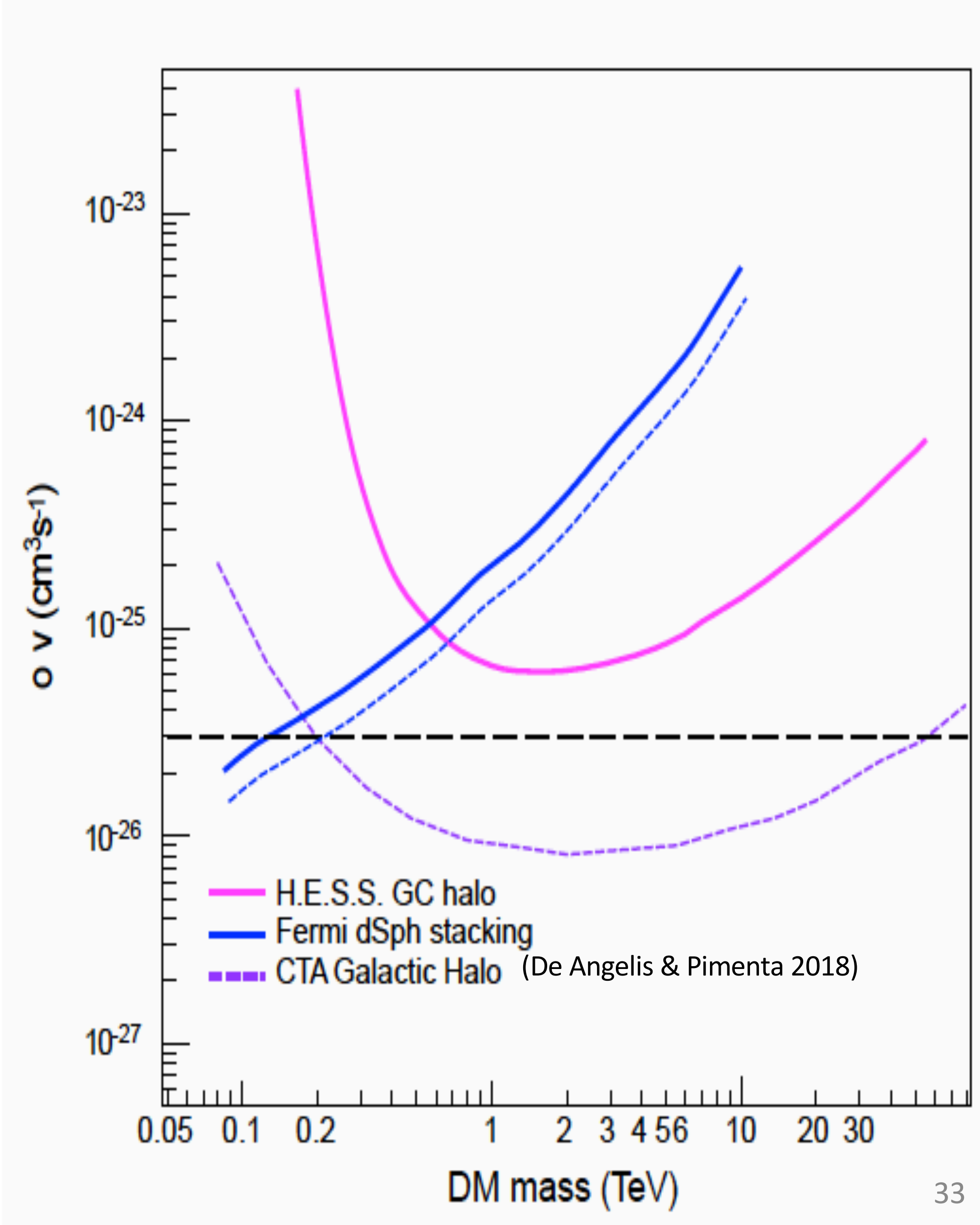
- Astrophysics has recently became multimessenger thanks to the simultaneous observations of GW/gamma rays and of neutrino/gamma ray events
- While the counterparts of GW events seem out of reach for IACTs (~MeV), IACTs are perfect for the counterparts of neutrino events



Dark Matter and New Particles



- Indirect detection of DM: CTA will reach the "thermal cross section" in 3 years
- Photon propagation: explore new regions in the axion m/coupling plane



The unexpected

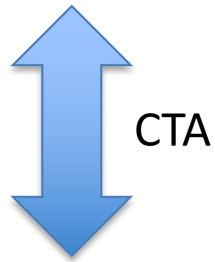
- A number 10x of sources detected
- Access to unexpected science (fast transients, new compact objects, etc.)
- Tests of fundamental symmetries of Nature in an unexplored regime

CTA is the main world effort for gamma-ray astrophysics in the near future but…

OTHER POSSIBLE DESIGNS FOR VHE GAMMA ASTROPHYSICS

An experimentalist’s view of gamma rays: different energy regions

1. MeV: 30 keV to 30 MeV
2. GeV: 30 MeV to 30 GeV
3. TeV: 30 GeV to 30 TeV
4. PeV : 300- GeV - 30+ TeV



- (subjectively) chosen from the requirements of
  - (i) detection specifics and
  - (ii) principal scientific issues

- Can CTA be helped in regions 1., 2. and 4. ?

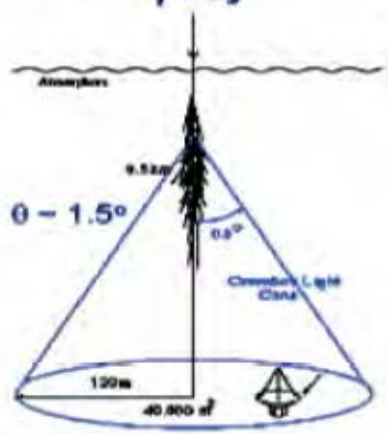
EAS-type designs (serendipity => GRB, unexpected...)

- CTA can be non optimal for PeV detection
- EAS can be the key for Pevatron studies

Air Cherenkov Telescopes

detection of the Cherenkov light from charged particles in the EAS

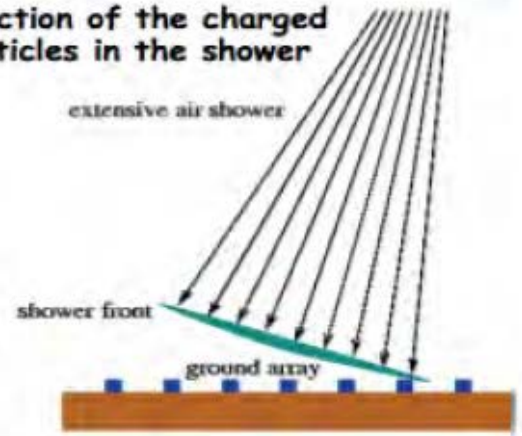
γ–ray



Very low energy threshold (≈50 GeV)
Excellent bkg rejection (>99%)
Excellent angular resolution (≈0.05 deg)
Good energy resolution (≈15%)
High Sensitivity (< % Crab flux)
Low duty-cycle (≈10%)
Small field of view (4-5 deg)

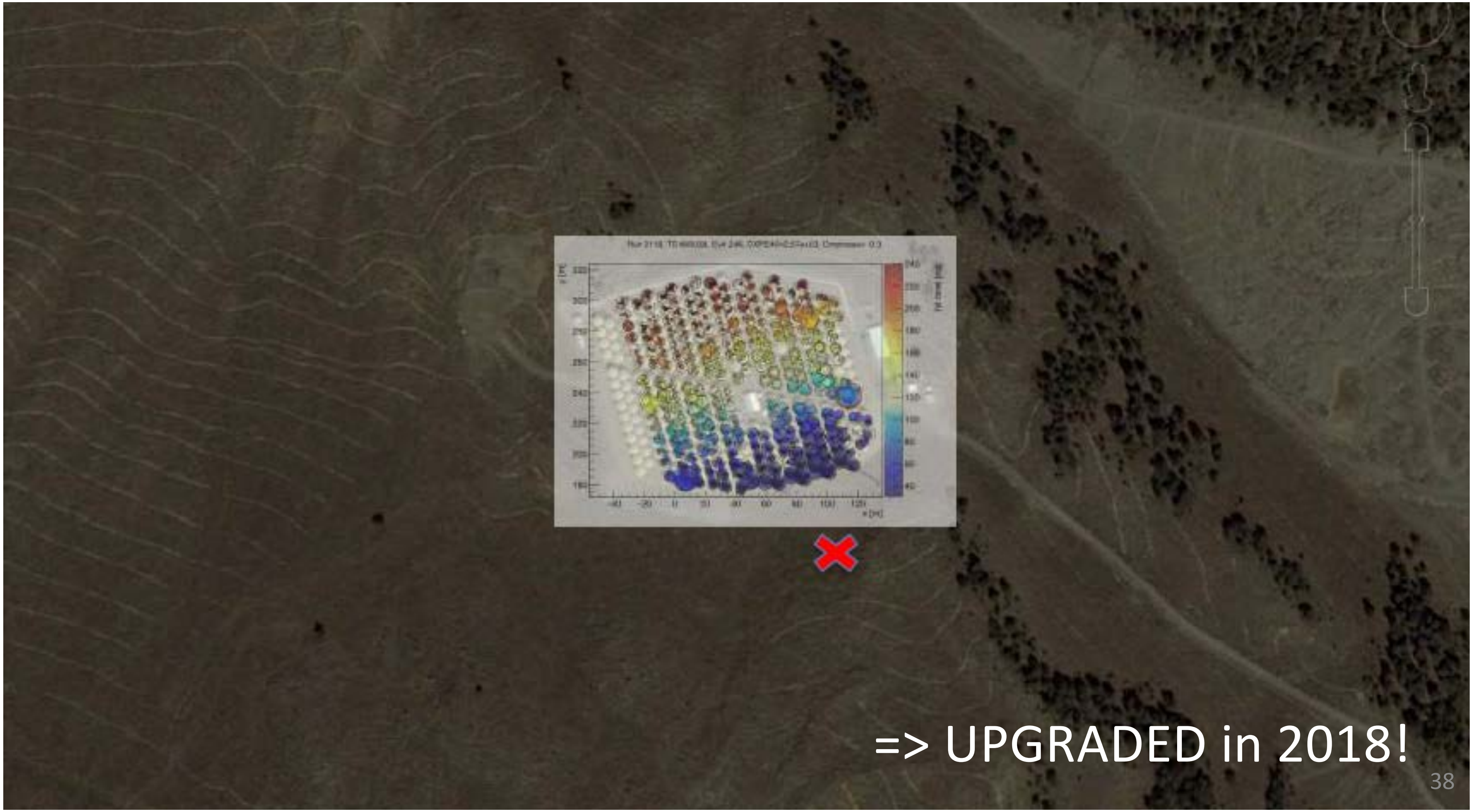
EAS arrays

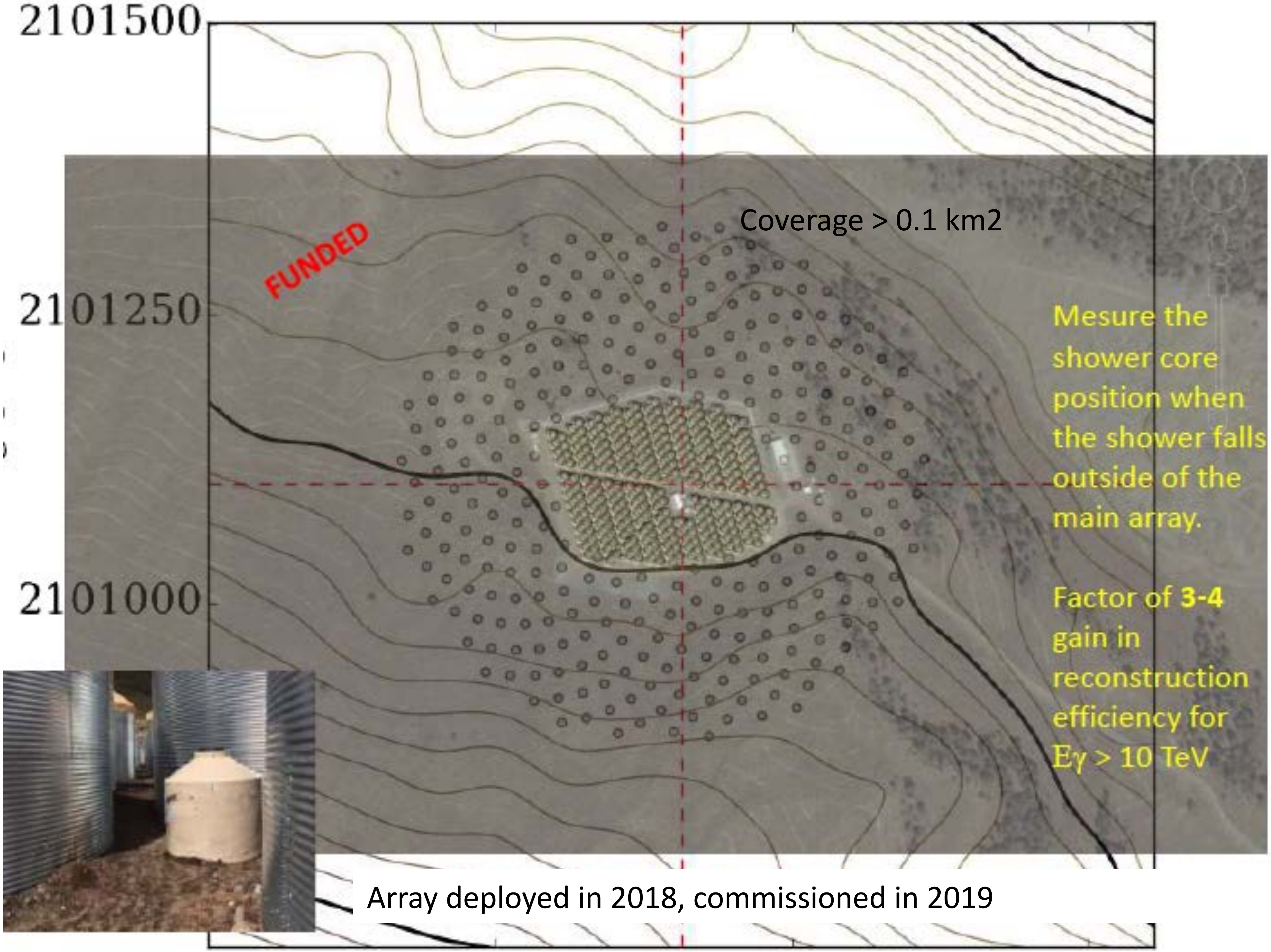
detection of the charged particles in the shower



Higher energy threshold (≈300 GeV)
Good bkg rejection (>80%)
Good angular resolution (0.2-0.8 deg)
Modest energy resolution (≈50%)
Good Sensitivity (5-10% Crab flux)
High duty-cycle (≈100%)
Large field of view (≈2 sr)

HAWC: most VHE triggered showers energy falls outside of the array



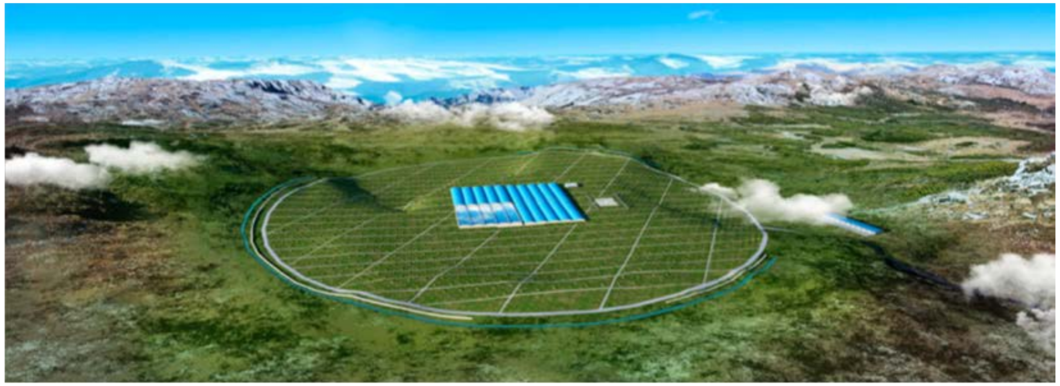


Coverage > 0.1 km2

Mesure the shower core position when the shower falls outside of the main array.

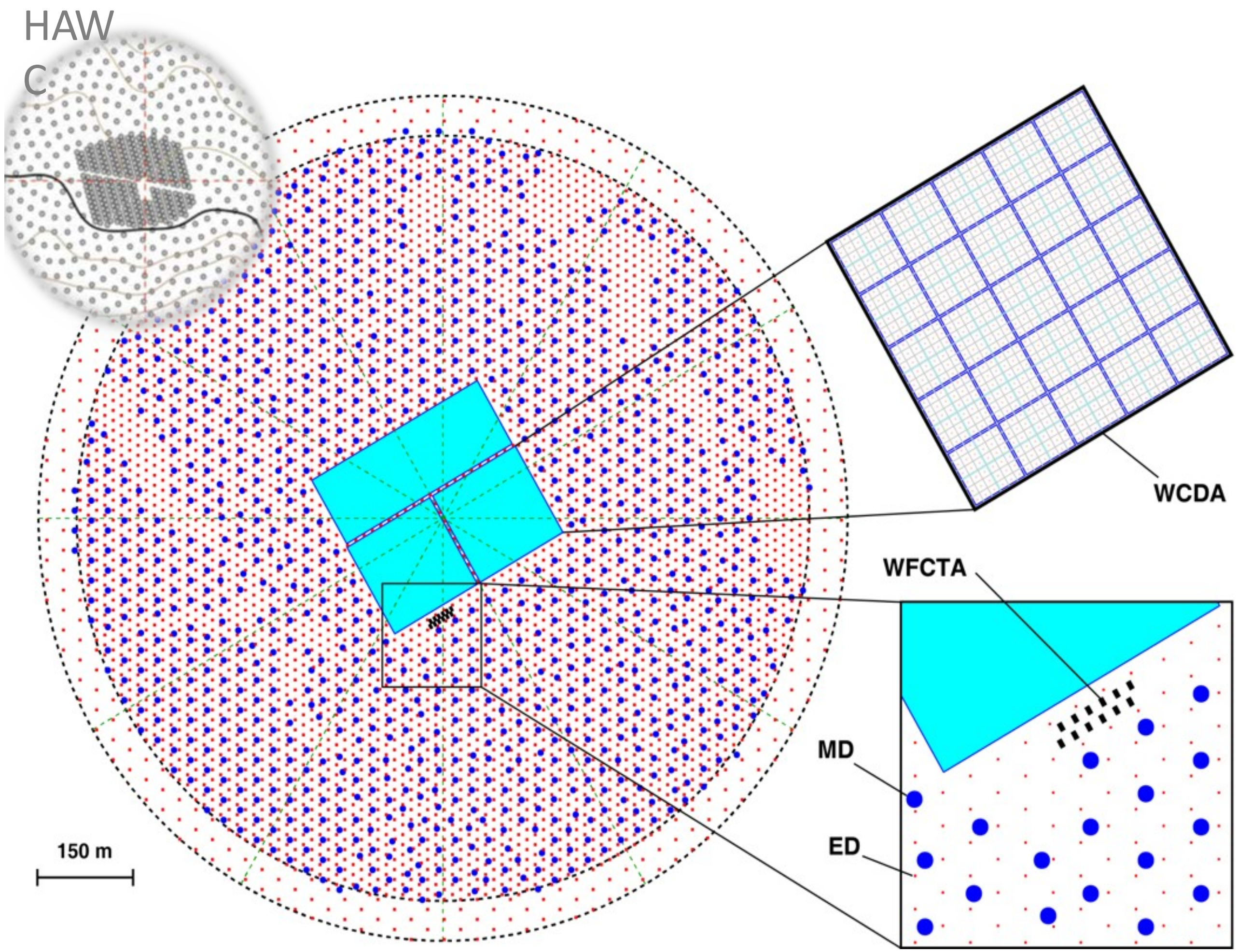
Factor of **3-4** gain in reconstruction efficiency for $E\gamma > 10$ TeV

Array deployed in 2018, commissioned in 2019



LHAASO

Sichuan, China, 4410 m asl
25% ready in 2020

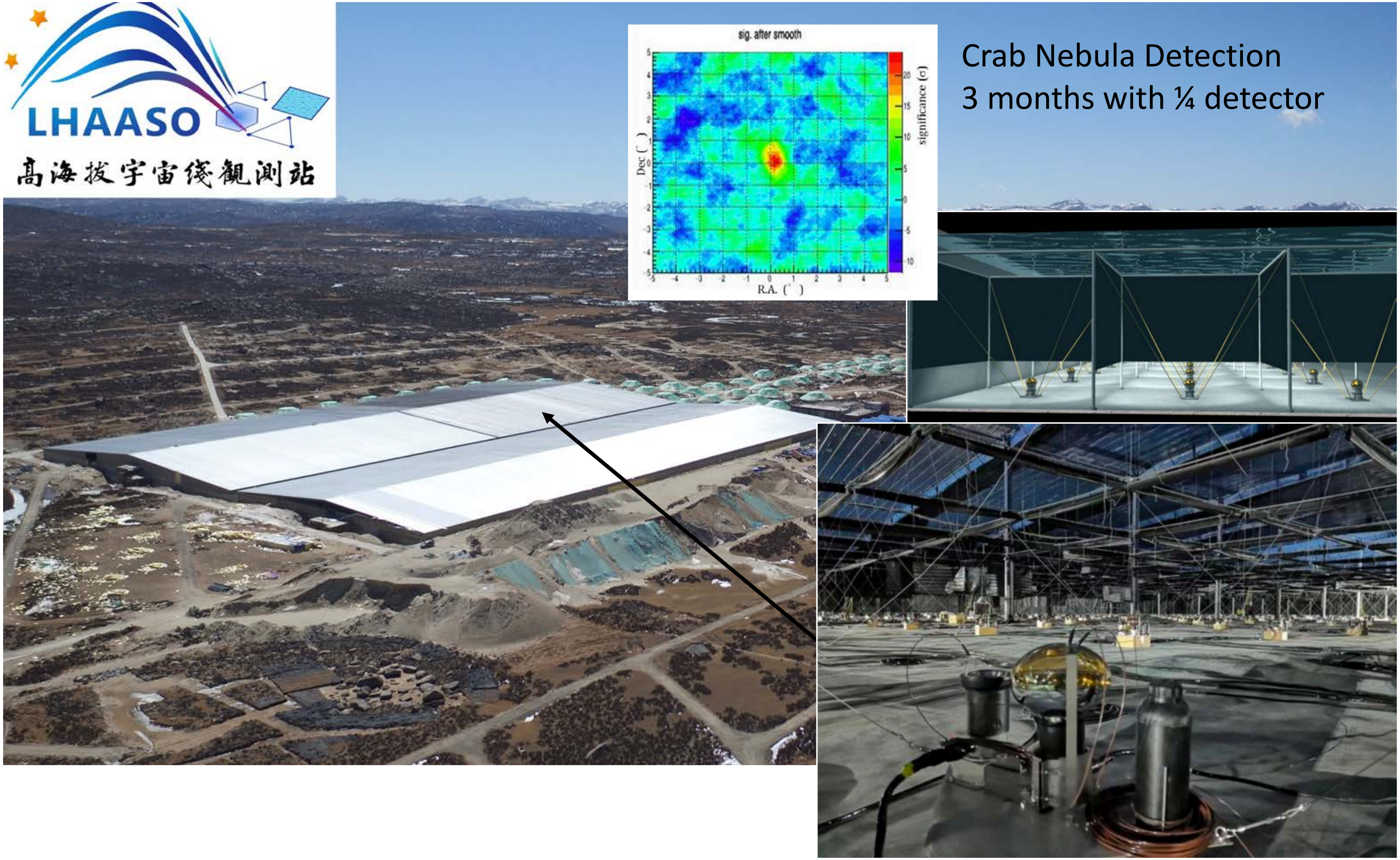


5195 Scintillators
- 1 m² each
- 15 m spacing

1171 Muon Detectors
- 36 m² each
- 30 m spacing

3000 Water Cherenkov Cells
- 25 m² each

12 Wide Field Cherenkov Telescopes



– > ¼ of central Water Cherenkov detector operational (>HAWC size)

Angular resolution:

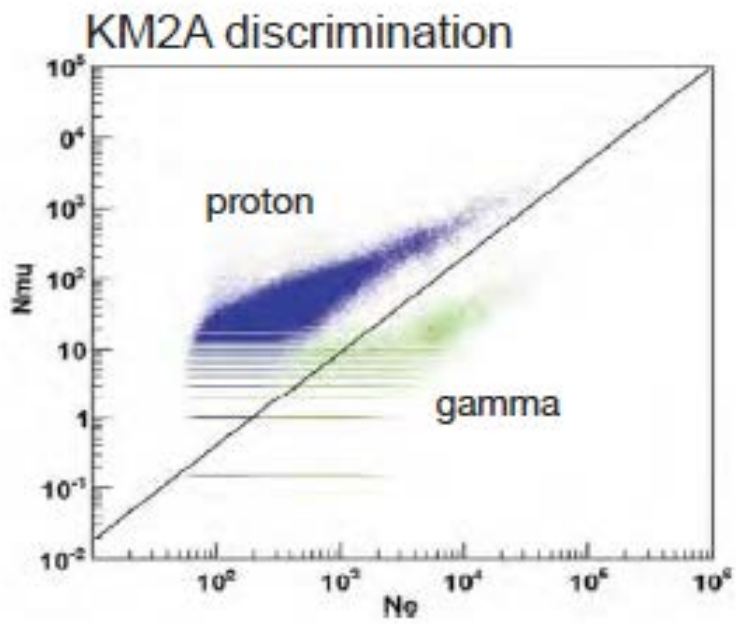
30 TeV ~0.4°

100TeV ~0.3 °

Energy relsolution:

30 TeV ~30%

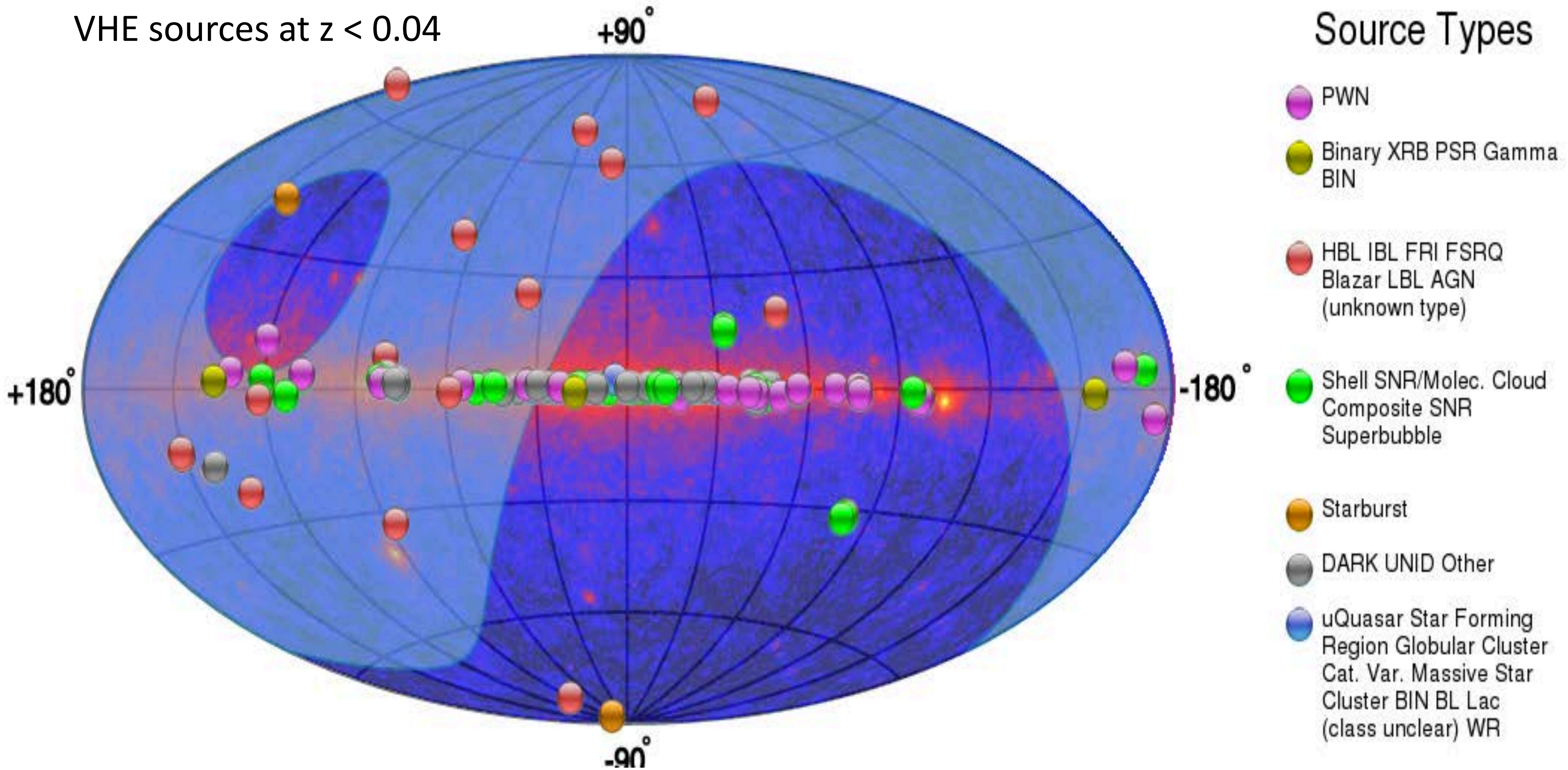
100 TeV ~20%



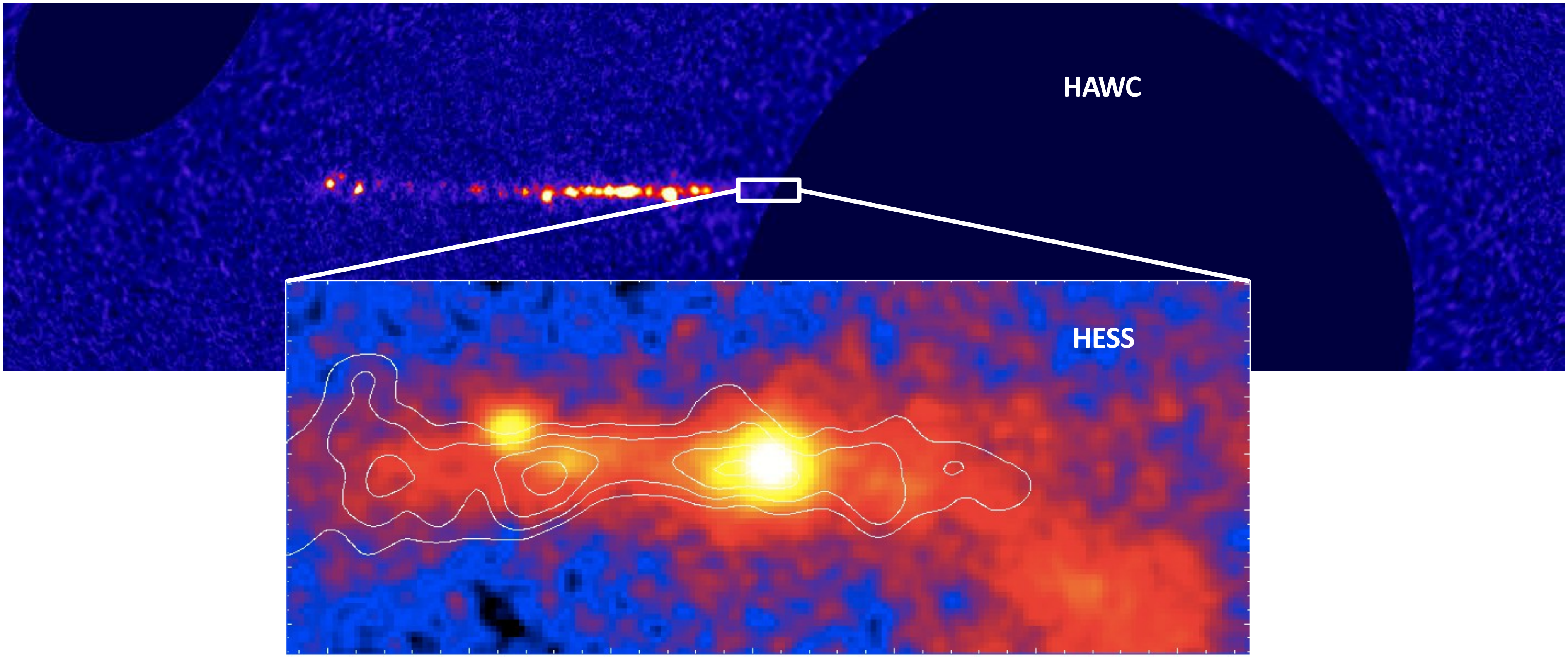
2019: start scientific operation of the first quarter of LHAASO.
2022: conclusion of the installation of all main components.

HAWC+, LHAASO, HiSCORE ~ funded, but there is a strong case for a sub-PeV experiment in the Southern hemisphere

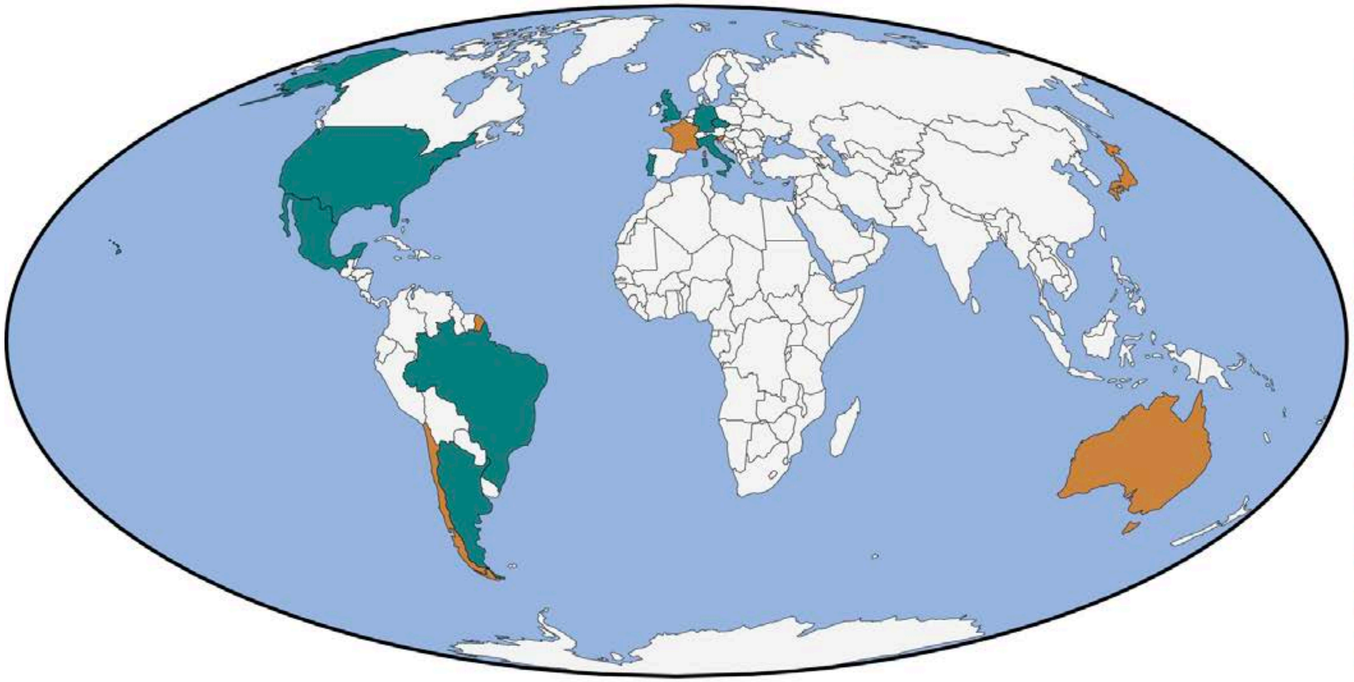
VHE sources at z < 0.04



…and in the South?



- Southern Wide-field Gamma-ray Observatory (SWGO)
  - In comparison to HAWC → Higher altitude, larger area, higher efficiency detection units – lower threshold and better sensitivity
  - Collaboration established in July 2019 to develop the design/plan
  - → **3 year programme**, 9 countries signed up + supporting scientists



Countries in SWGO

Institutes

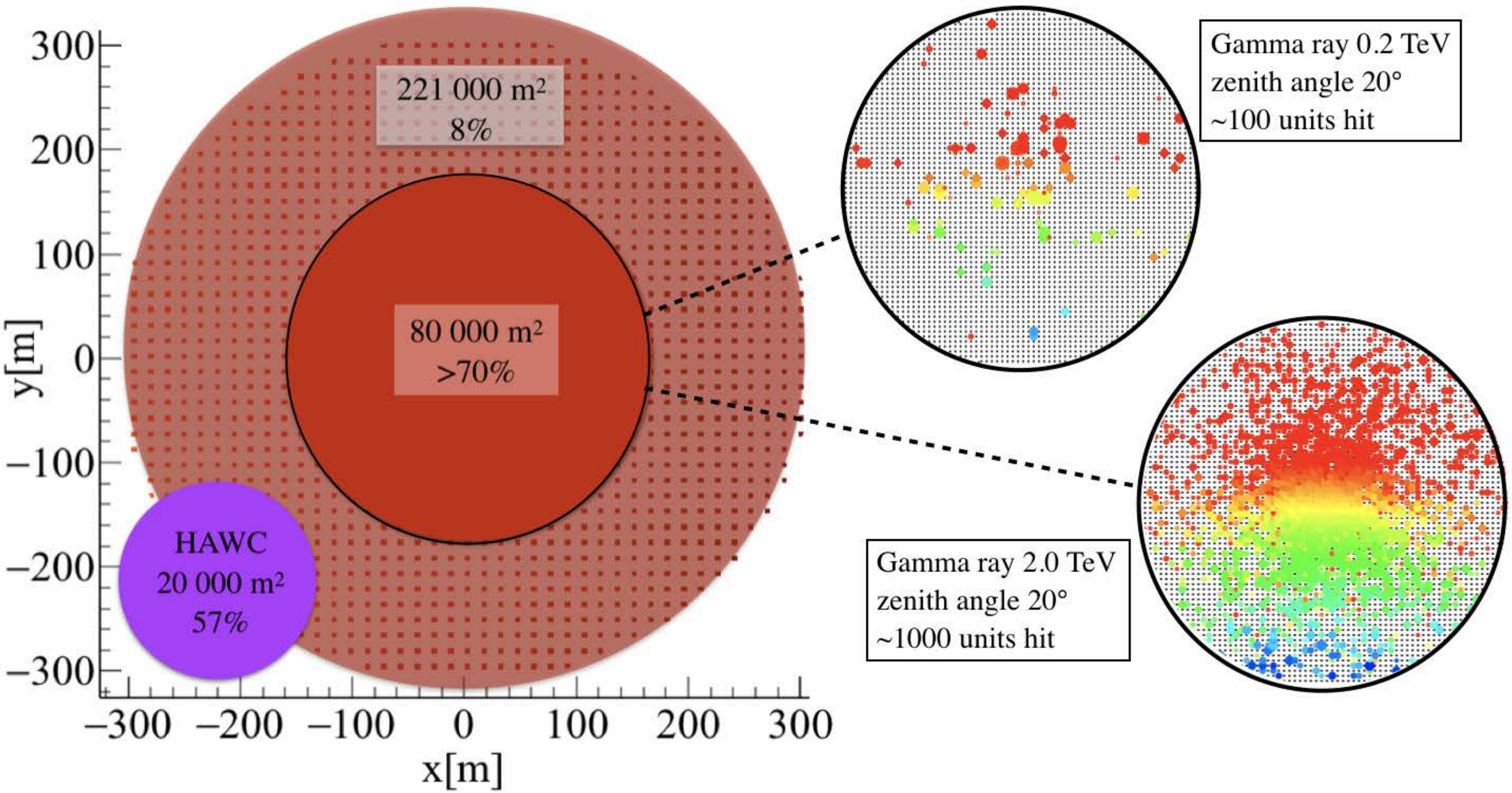
Argentina*, Brazil, Czech Republic, Germany*, Italy, Mexico, Portugal, United Kingdom, United States*

Supporting scientists

Australia, Chile, France, Japan, Slovenia

**also supporting scientists*

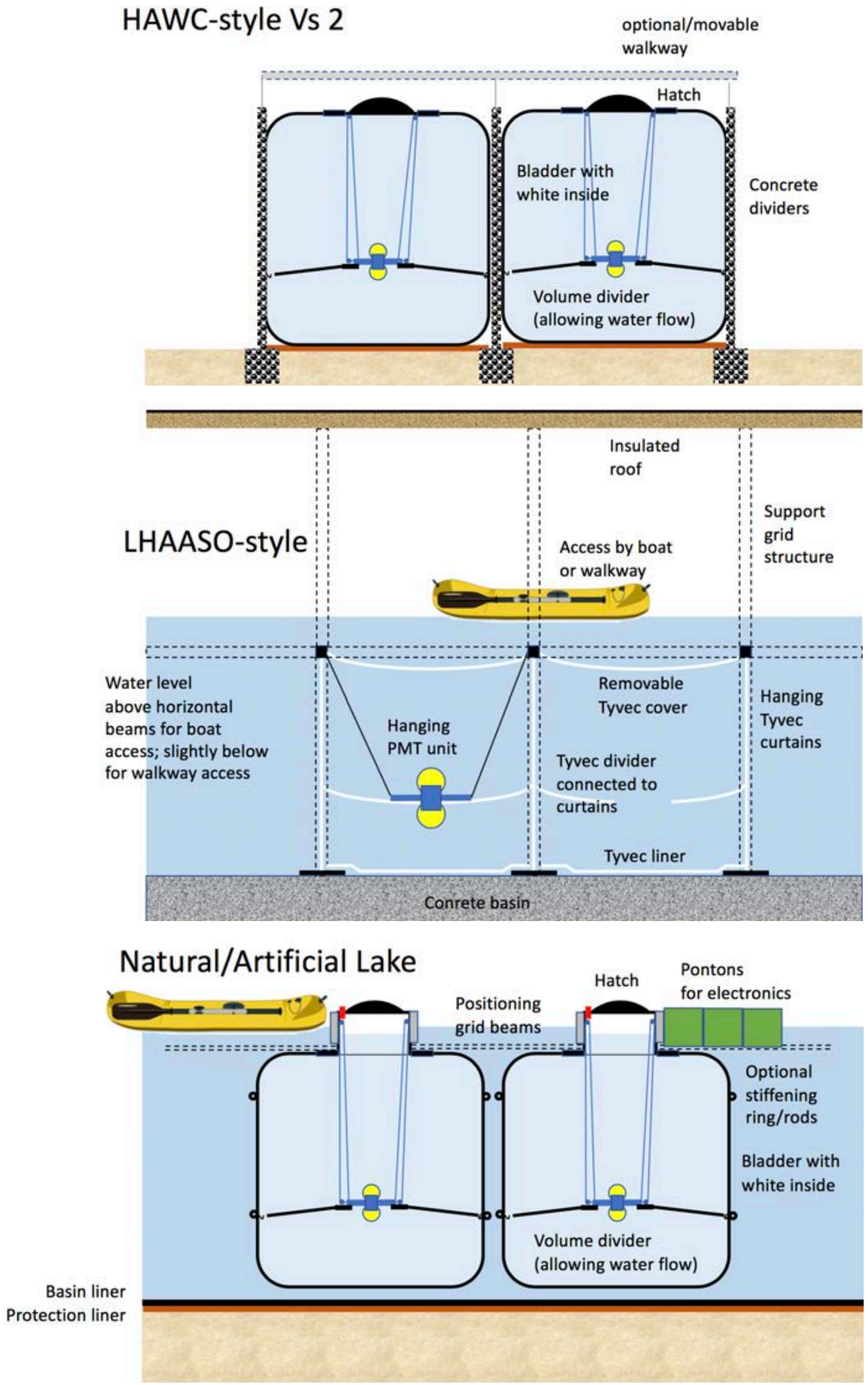
Detector Array



- ‘Strawman’ - reference detector layout

Technology?

- Water Cherenkov as main detection technique
  - Unit dimensions?
  - Construction approach?
  - Photosensor?
  - Electronics?
- Perfomance/Cost optimization process
- Can draw on a lot of experience as a well as many great new ideas



Technology?

- Water Cherenkov as main detection technique
  - Unit dimensions?
  - Cor
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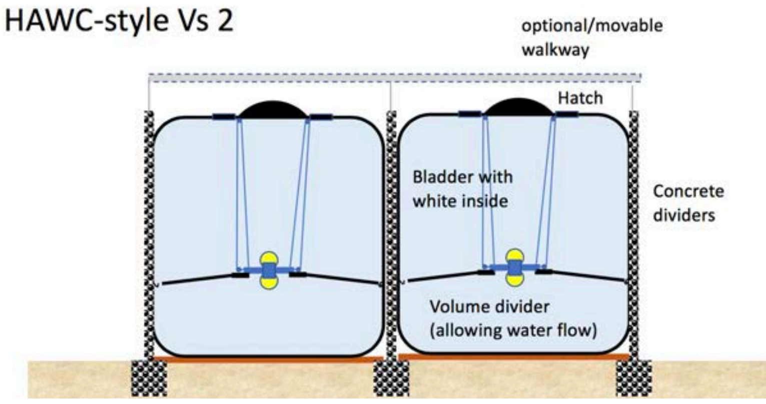
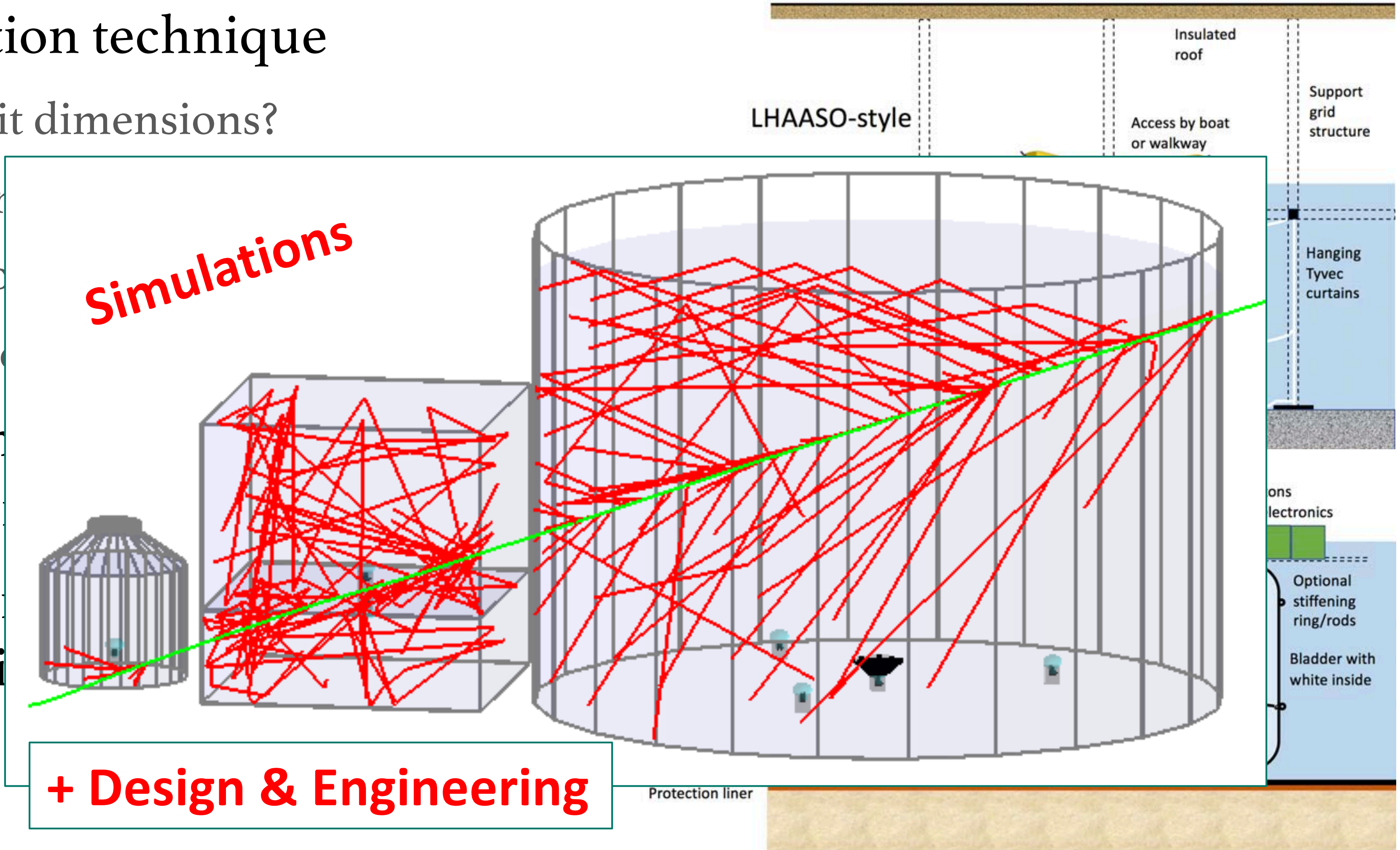
- Can d experi many

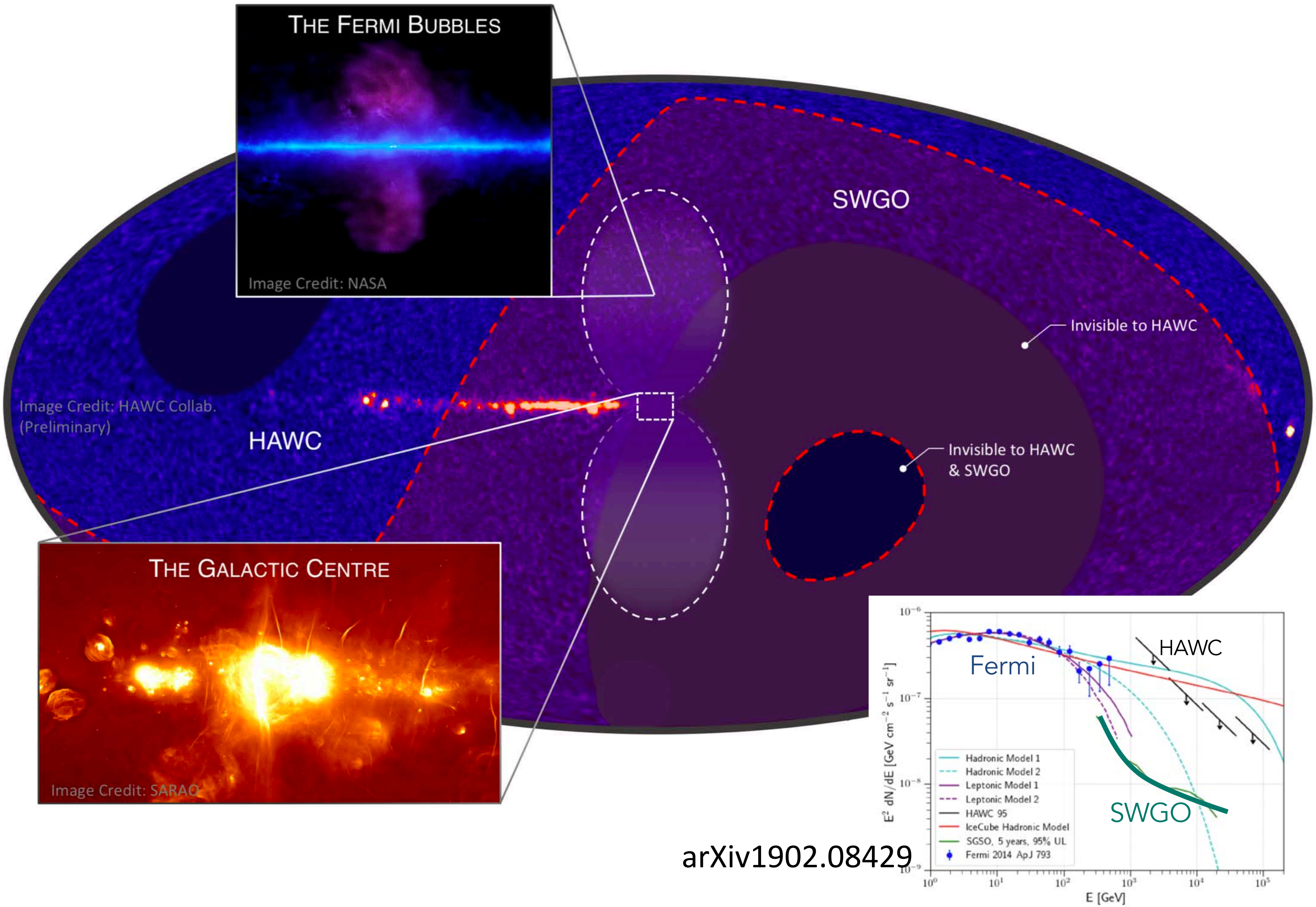




+ Design & Engineering

Site?

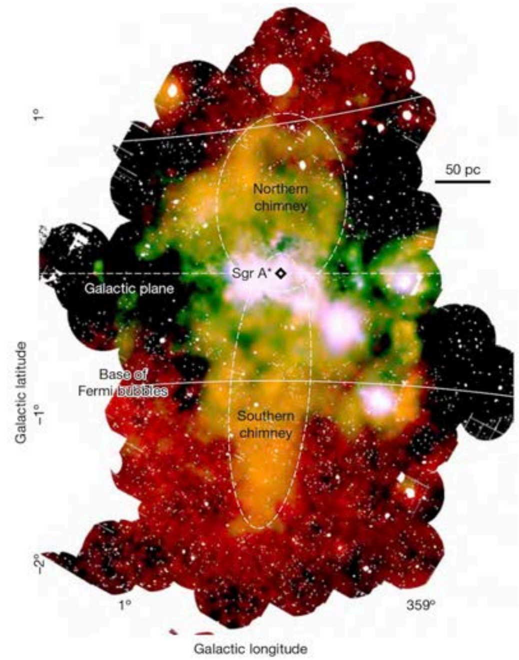

Laguna Sibinacocha, Peru
4.9 km
ALPACA site
near Mt Chacaltaya, Bolivia
4.7 km
CUBIC site, Salta, Argentina
4.8 km
Chajnantor region, Chile
5.0 km
Caribbean Sea
North Atlantic Ocean
South Pacific Ocean
South Atlantic Ocean
VENEZUELA
COLOMBIA
ECUADOR
PERU
BRAZIL
BOLIVIA
PARAGUAY
CHILE
ARGENTINA
URUGUAY
AMAZON BASIN
BRAZILIAN HIGHLANDS
ANDES
Scale 1:35,000,000
Azimuthal Equal-Area Projection

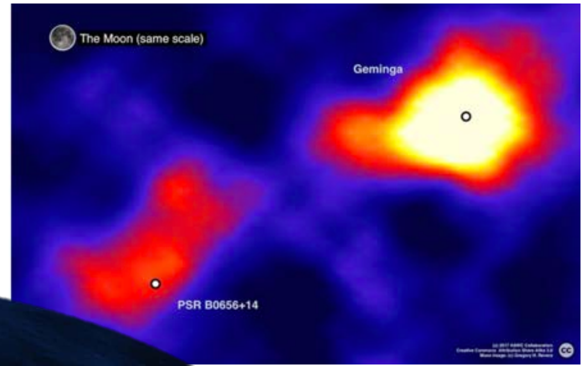


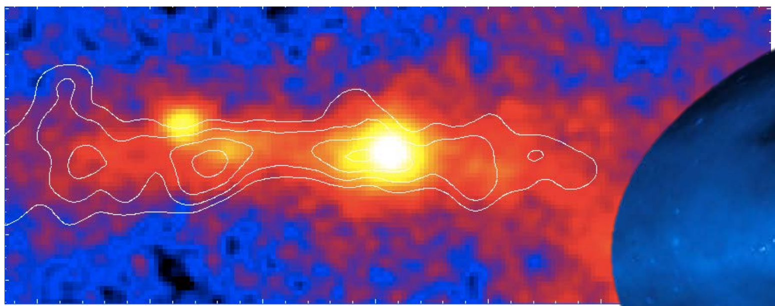
THE FERMI BUBBLES
Image Credit: NASA
SWGO
Invisible to HAWC
Image Credit: HAWC Collab.
(Preliminary)
HAWC
Invisible to HAWC
& SWGO
THE GALACTIC CENTRE
Image Credit: SARAO
HAWC
Fermi
SWGO
Hadronic Model 1
Hadronic Model 2
Leptonic Model 1
Leptonic Model 2
HAWC 95
IceCube Hadronic Model
SGSO, 5 years, 95% UL
Fermi 2014 ApJ 793
E [GeV]
E² dN/dE [GeV cm⁻² s⁻¹ sr⁻¹]
arXiv1902.08429

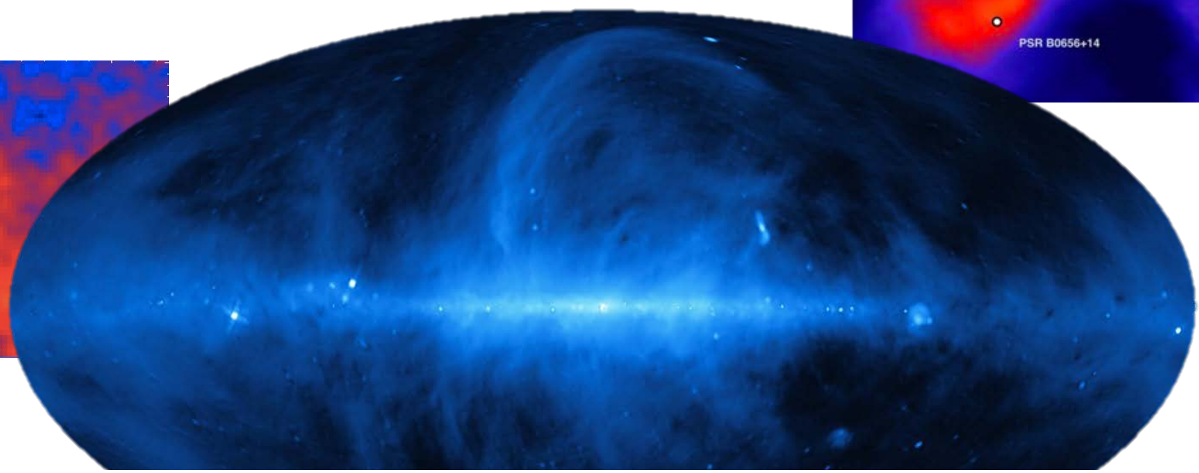
Large scale Galactic emission

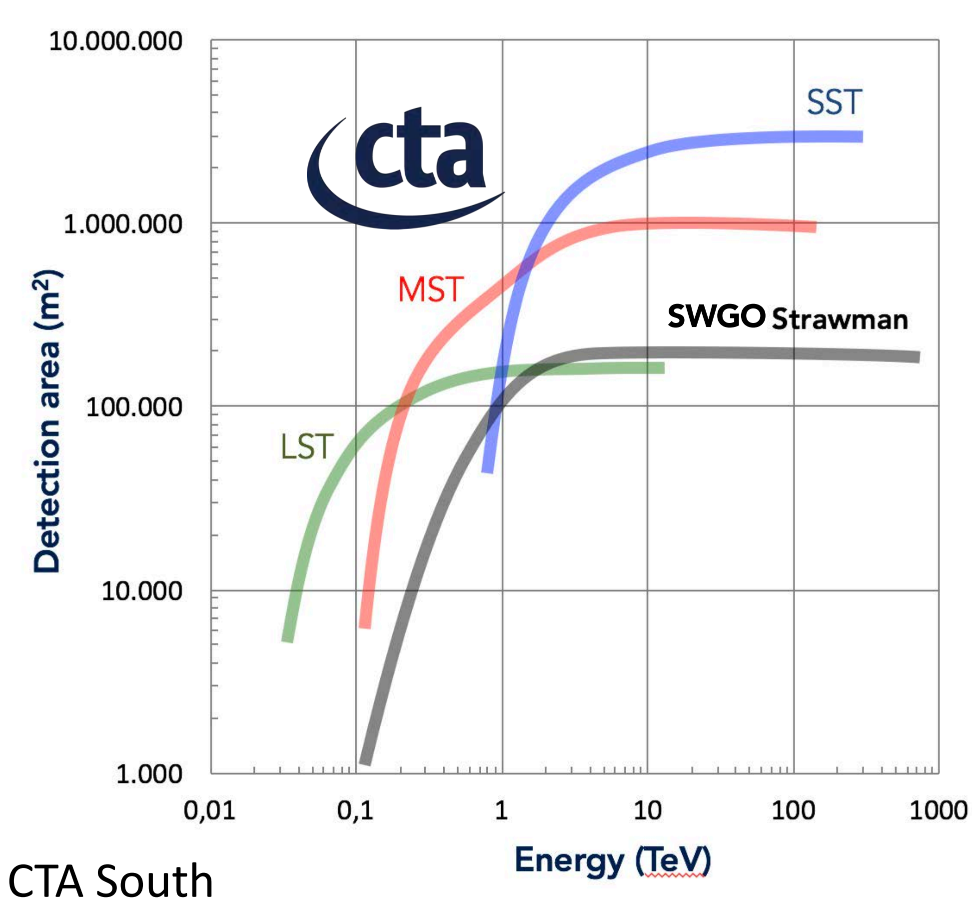
- Local (off-plane, large angular size) sources
- Diffuse Galactic Emission (e.g. atomic gas and IC emission up to large scale heights)
- Fermi Bubbles
- ‘Halos’ around CR accelerators

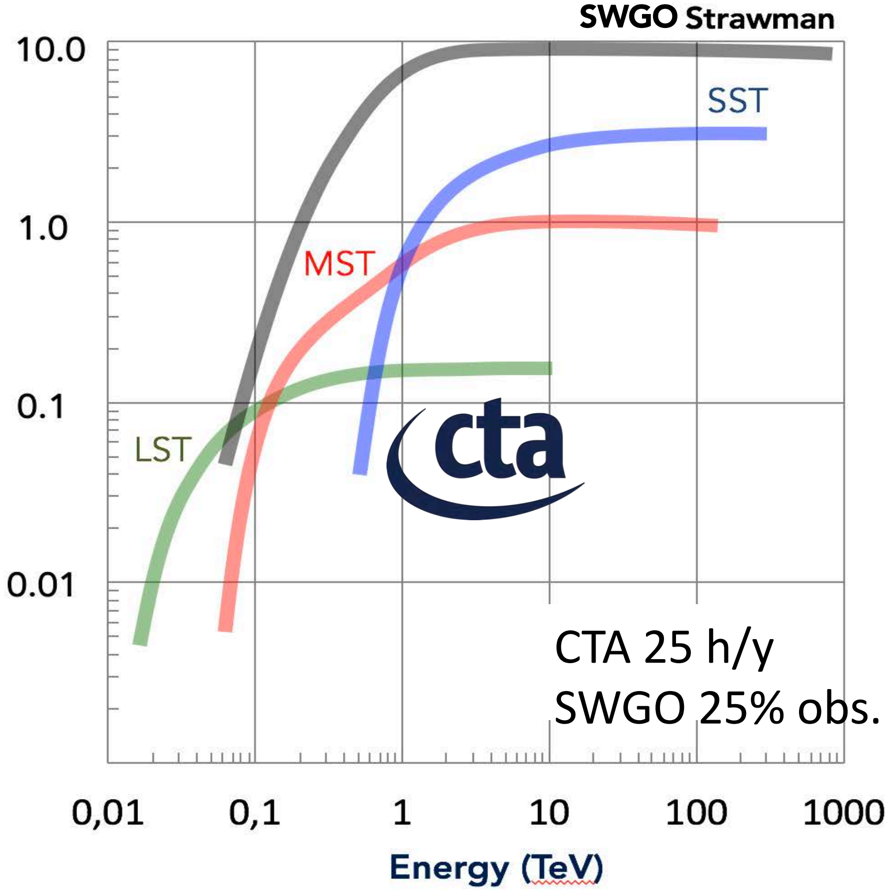








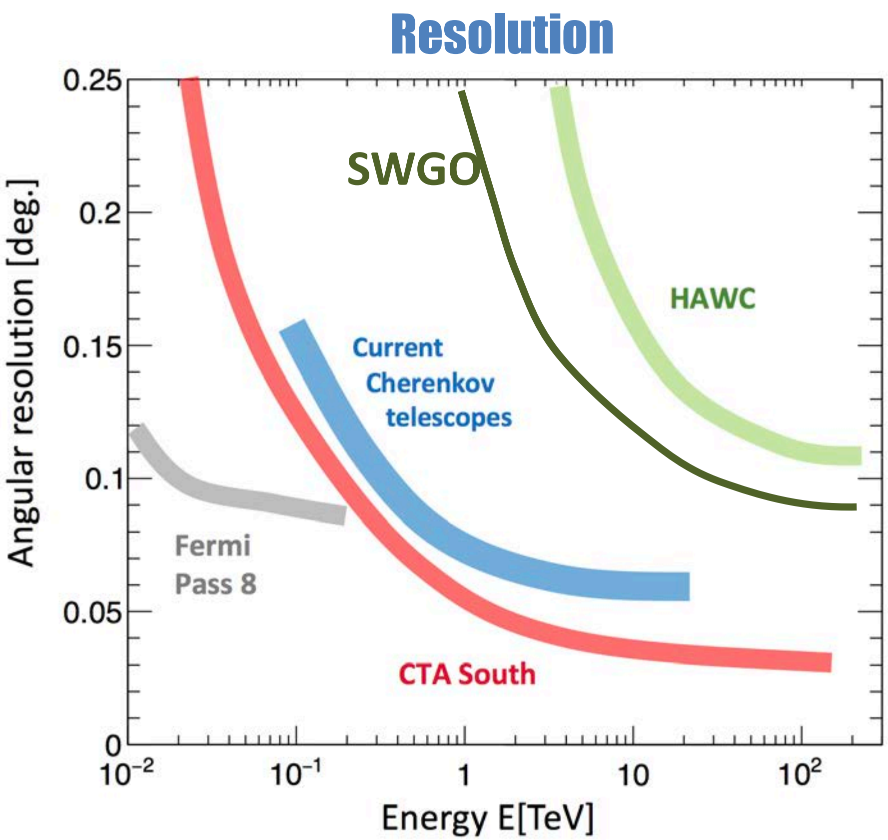


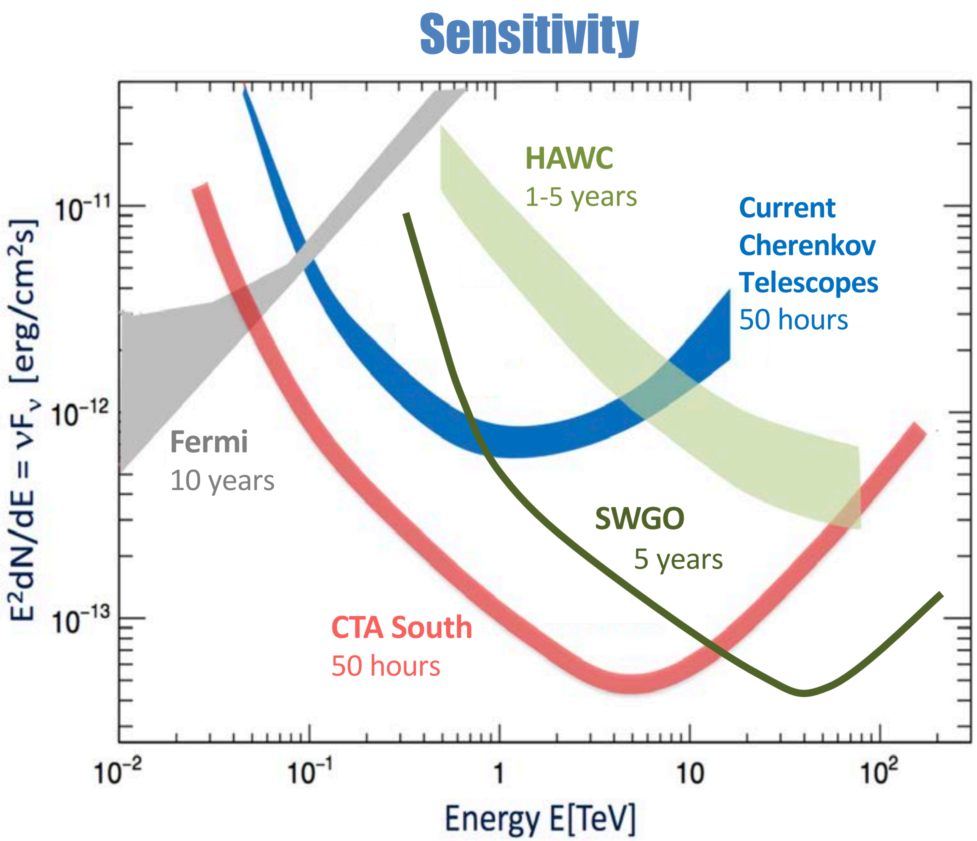


Detection Area **Annual Exposure**

- Short timescales: **If** CTA can get there → more sensitivity
- Steady sources: **If** background can be suppressed → more sensitivity than CTA over several years

Performance Comparison





www.cta-observatory.org

www.swgo.org

SWGO + CTA Summary

- Transients
  - SWGO advantage over CTA for:
    - Short timescales (<5 minutes) – do such events exist above a few 100 GeV?
    - Events without MWL triggers – frequency depends on future MWL coverage
      – would hope this happens less often – but e.g. hard X-ray future uncertain
- Variable sources
  - O(10) objects bright enough for SGSO monitoring – trigger CTA
- Large scale emission
  - Will be very difficult with CTA beyond ~few degrees
  - e.g. Fermi Bubbles, IC component of diffuse emission, …
- High(est) energy sources
  - Strategy of CTA follow-up of SGSO sources looks promising
    - Efficient use of CTA resources CF deep HE survey of whole Gal.
    - High resolution maps, high quality spectra for highest energy sources
- Possible sites

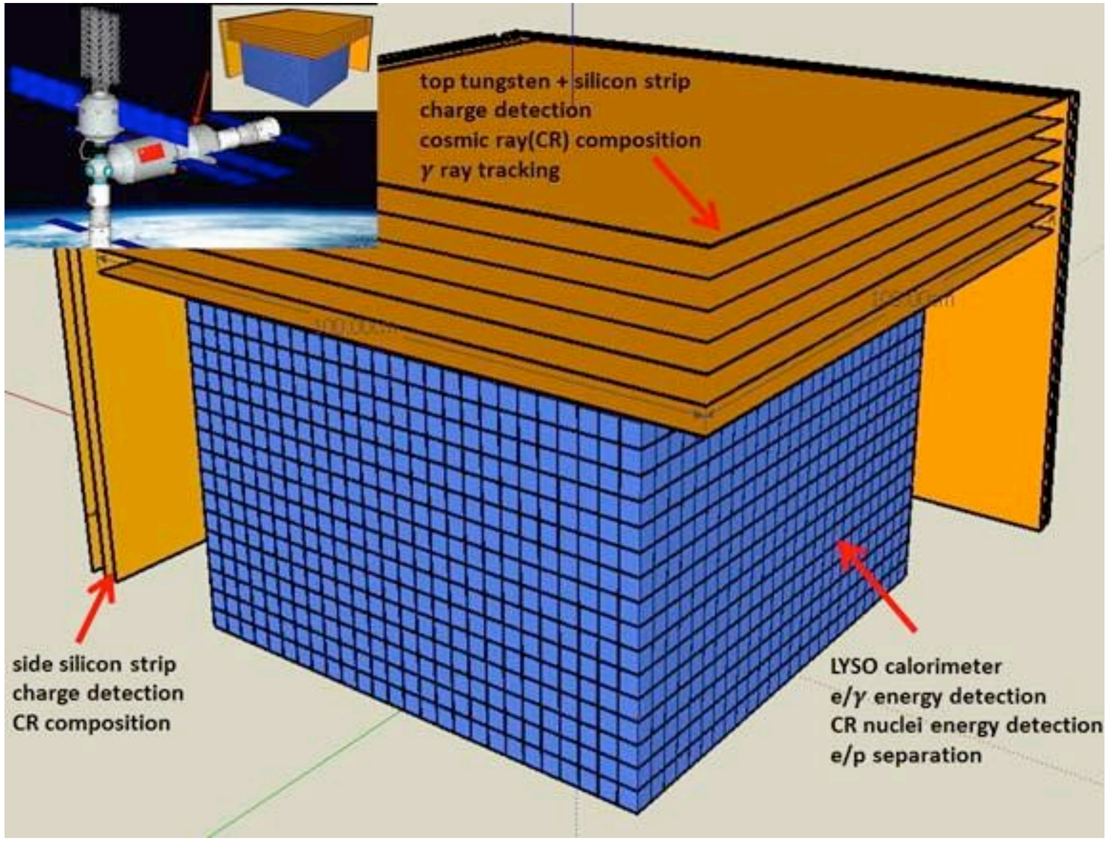
  Argentina (near Salta, 4800 m asl)
  Bolivia (Chacaltaya site, latitude 16.3 S, altitude 5200 m asl)
  Chile (Atacama desert, latitude 23.7 S, altitude 5060 m asl)

LOWER ENERGIES (GeV and MeV)

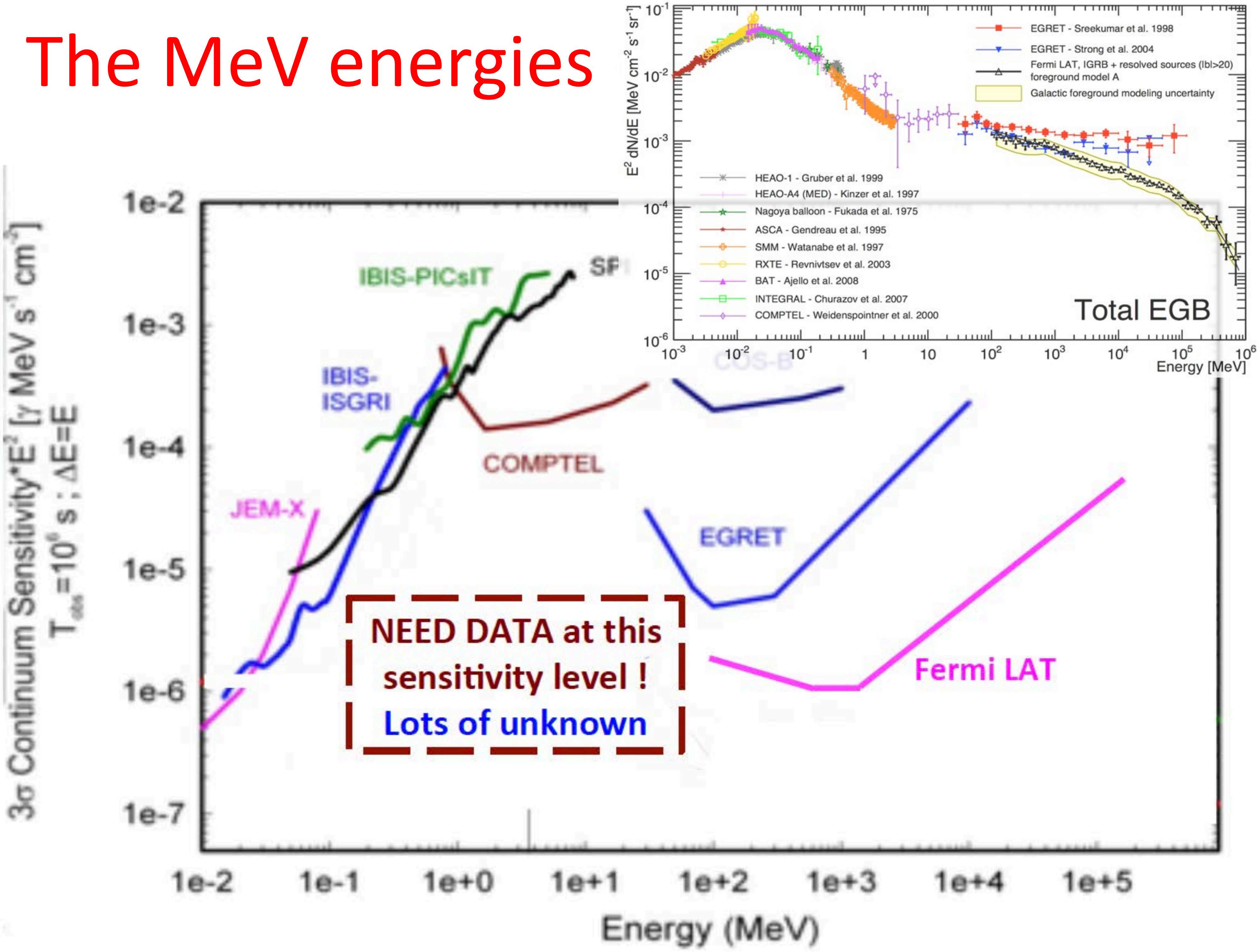
GeV region from space

- Fermi can fly till 2028 (granted till 2020)
- Difficult to find a successor…
- Only one super-Fermi project on the field: the Chinese-Italian HERD
  - A Fermi with better calorimetry
  - A few years after the CSS
  - Approved in 2017
  - Operational 2024?

- Also useful for observing charged cosmic rays up to ~ the knee

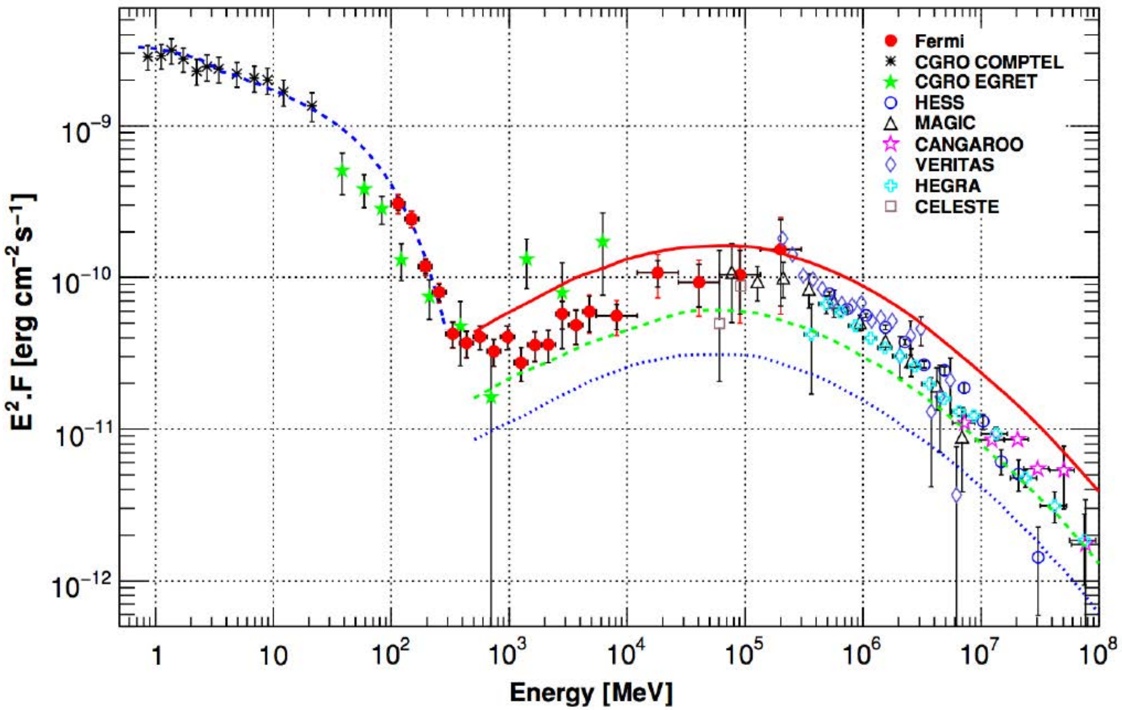


The MeV energies



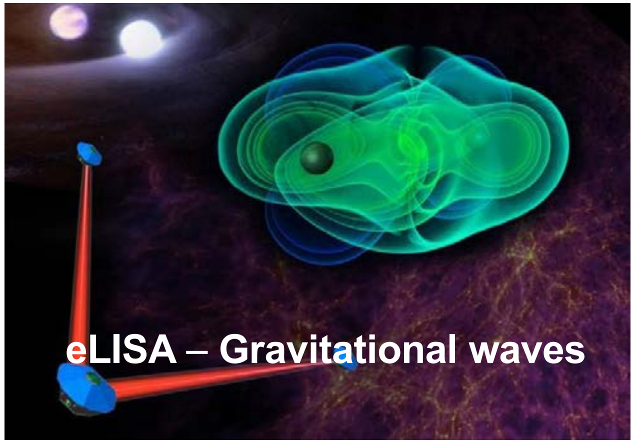
O(1 MeV)

- The MeV region is the less known, and its knowledge has large impact on the modeling of SEDs



- As a bonus, Compton photons are naturally polarized

e-ASTROGAM (Europe, De Angelis et al.) and AMEGO (US, McEnery et al.) – 2028/29

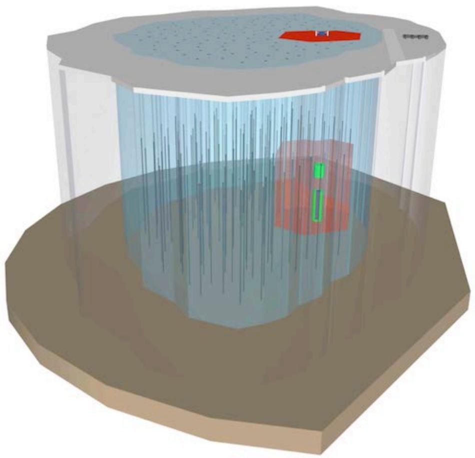


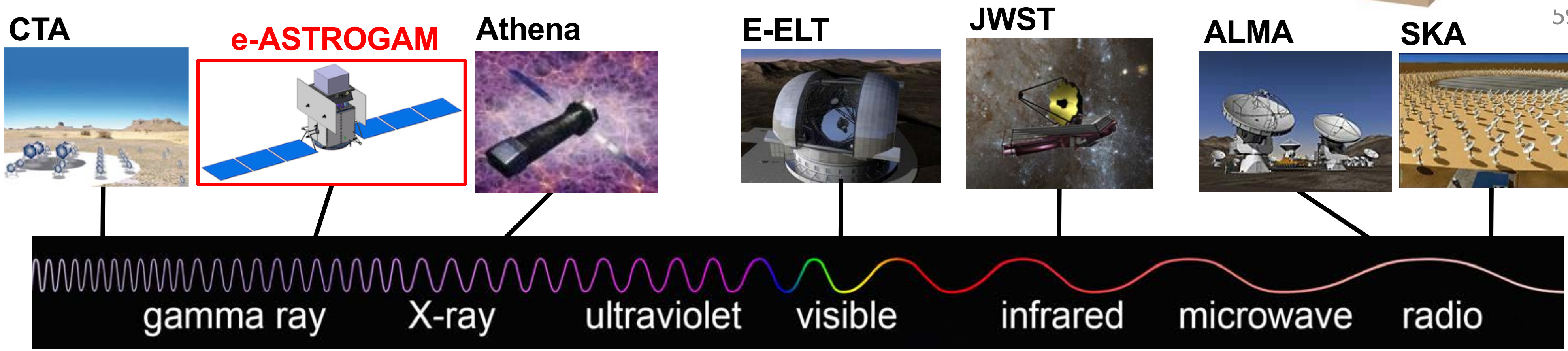
1. Processes at the heart of the extreme Universe (AGNs, GRBs, microquasars): prospects for the Astronomy of the 2030s
   - Multi-wavelength, multi-messenger coverage of the sky (with CTA, SKA, eLISA, □ detectors...), with special focus on transient phenomena

2. The origin of high-energy particles and impact on galaxy evolution, from cosmic rays to antimatter

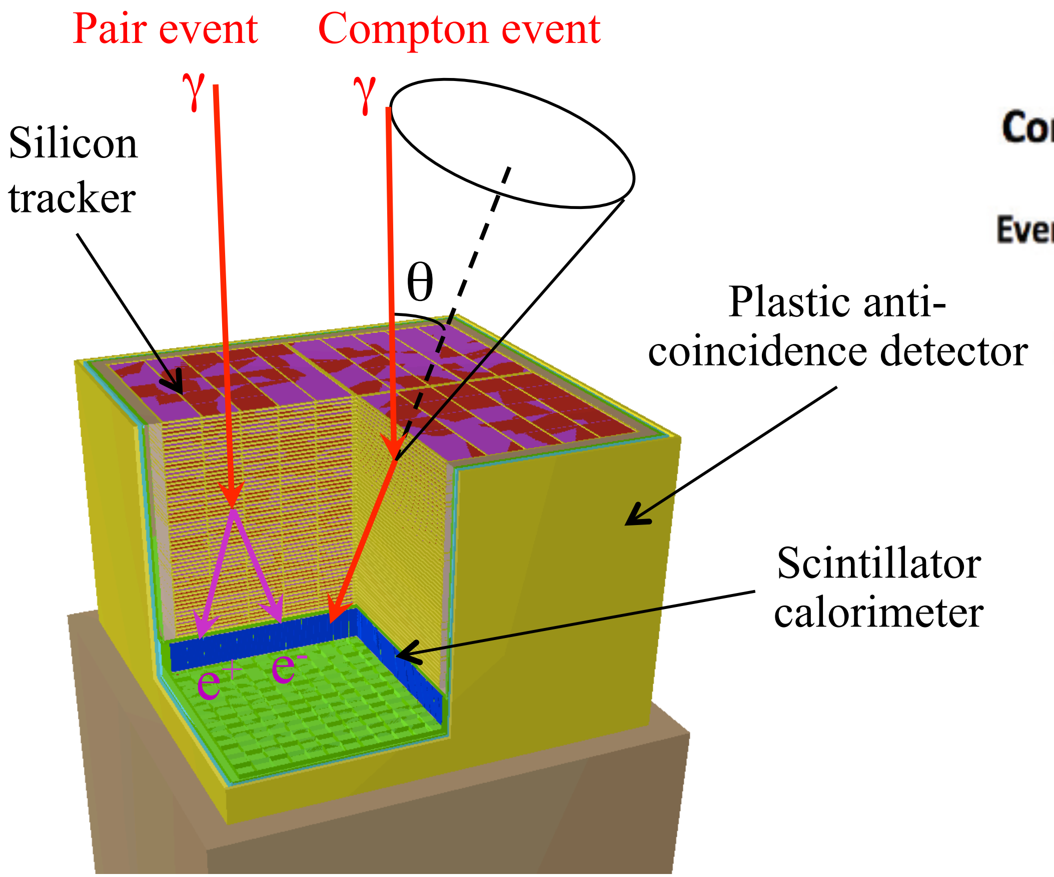
3. Nucleosynthesis and the chemical enrichment of our Galaxy

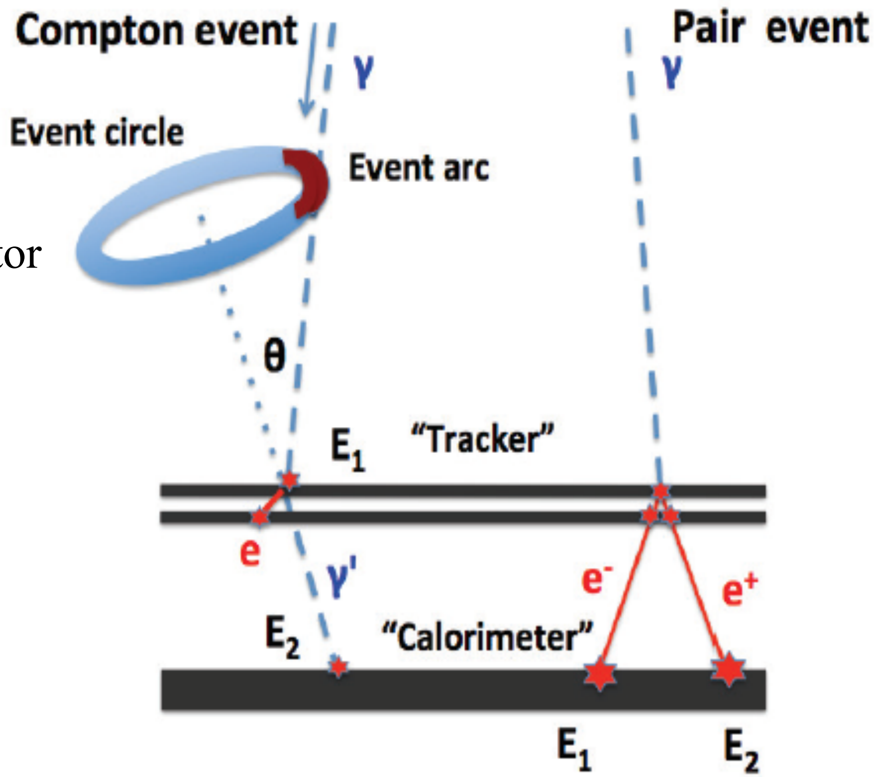
Km3Net/IceCube-Gen2 - ν





How to measure gamma rays in the MeV-GeV?

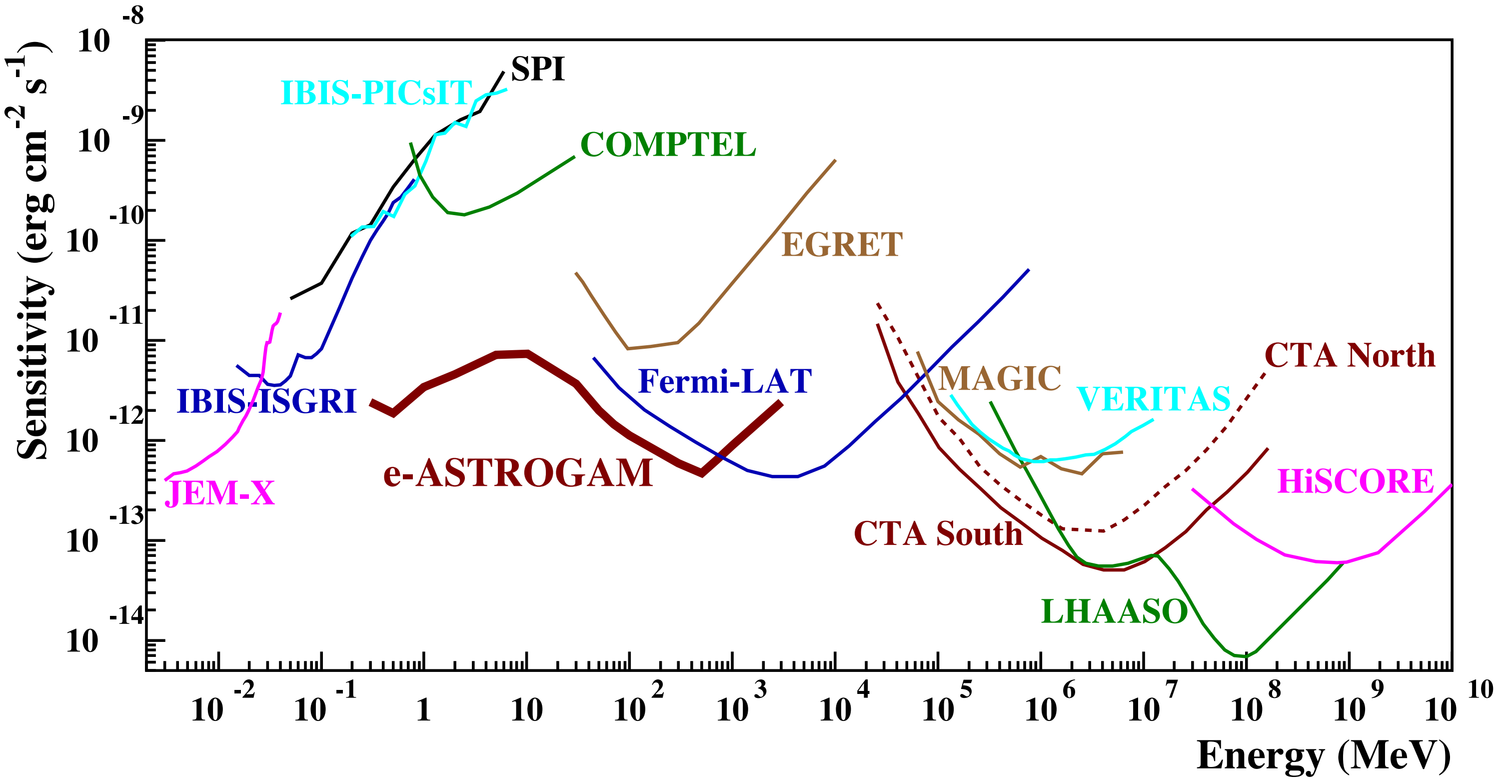




- **Tracker** – Double sided Si strip detectors (DSSDs) for excellent spectral resolution and fine 3-D position resolution ($1 m^2$, 500 μm thick, 0.3 Xo in total)
- **Calorimeter** – High-Z material for an efficient absorption of the scattered photon ⇒ CsI(Tl) scintillation crystals readout by Si drift detectors or photomultipliers for best energy resolution. 8 cm (4.3 Xo)
- **Anticoincidence detector** to veto charged-particle induced background ⇒ plastic scintillators readout by Si photomultipliers

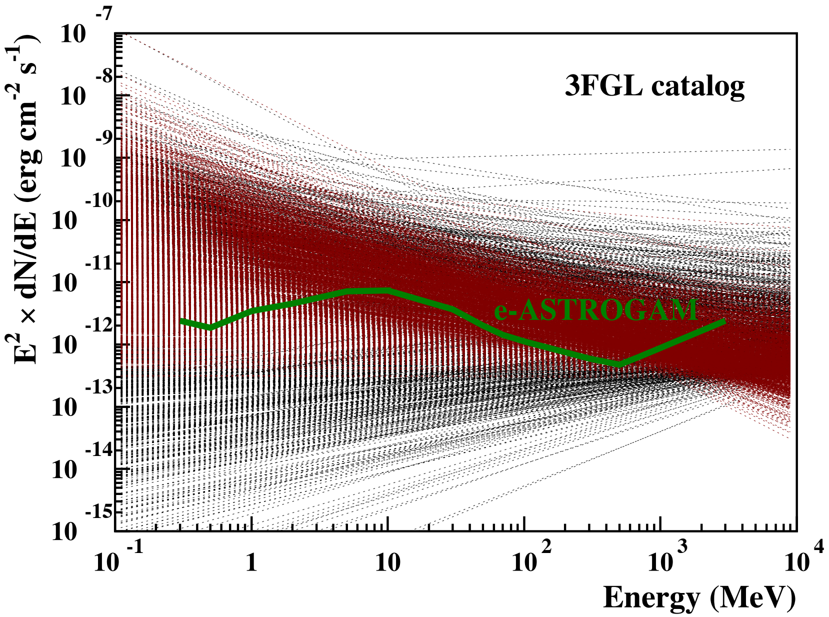
e-ASTROGAM scientific requirements

1. Achieve a sensitivity better than that of INTEGRAL/CGRO/COMPTEL by a factor of 20 - 50 – 100 in the range 0.2 – 30 MeV
2. Fully exploit gamma-ray polarization for both transient and steady sources
3. Improve significantly the angular resolution (to reach, e.g., ~ 10' at 1 GeV)
4. Achieve a very large field of view (~ 2.5 sr) ⇒ efficient monitoring of the γ-ray sky
5. Enable sub-millisecond trigger and alert capability for transients



e-ASTROGAM discovery space

- Over 2/3 of the 3033 sources from the 3rd *Fermi* LAT Catalog (3FGL) have power-law spectra (E_γ > 100 MeV) steeper than E_γ^{-2}, implying that their peak energy output is below 100 MeV



- These includes about 1100 (candidate) blazars and more than **720 unassociated sources**
- Most of these sources will be detected by **e-ASTROGAM** ⇒ large discovery space for new sources and source classes

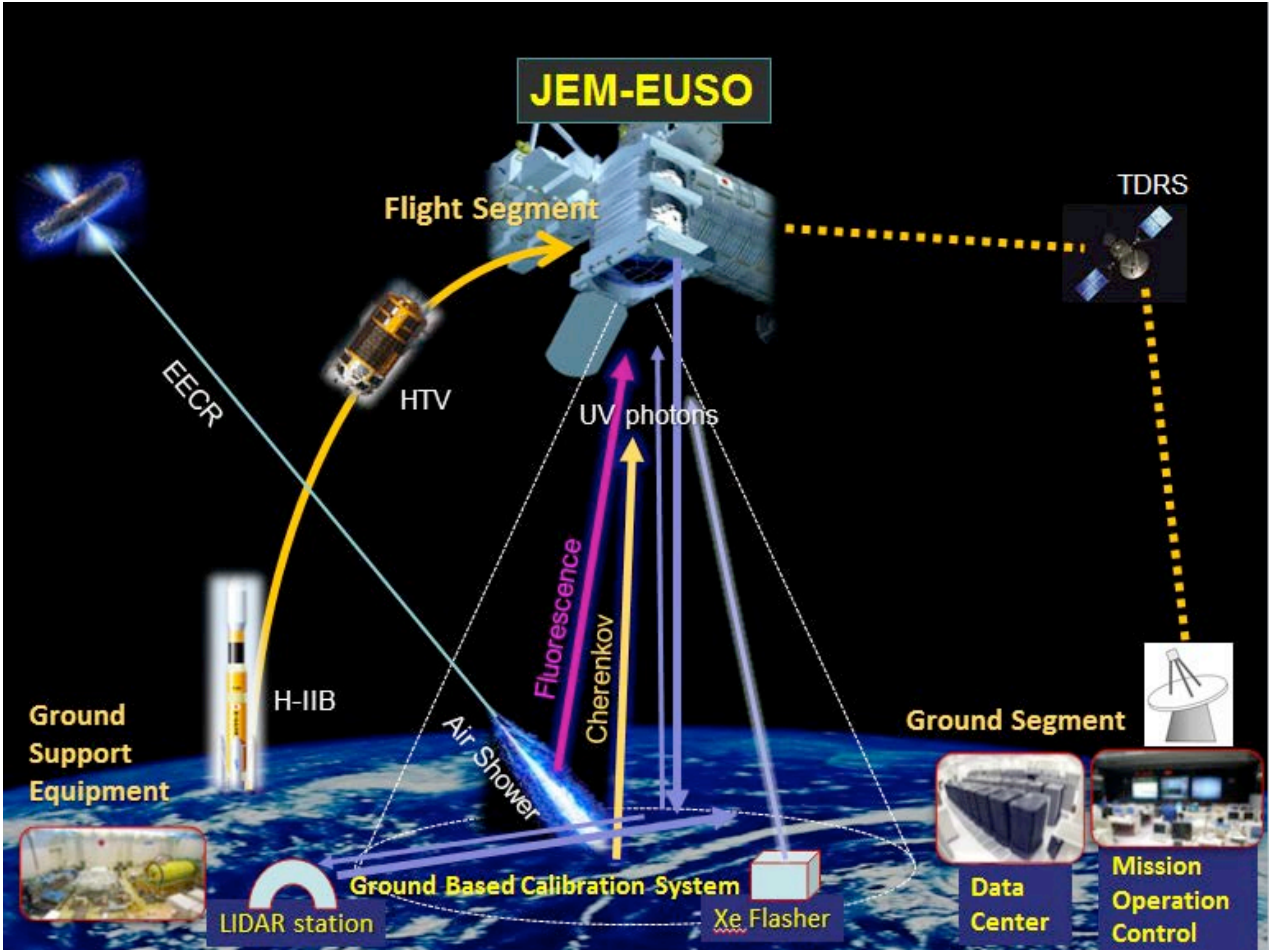
Type	3 yr	New sources
Total	3000 – 4000	~1800 (including GRBs)
Galactic	~ 1000	~400
MeV blazars	~ 350	~ 350
GeV blazars	1000 – 1500	~ 350
Other AGN (<10 MeV)	70 – 100	35 – 50
Supernovae	10 – 15	10 – 15
Novae	4 – 6	4 – 6
GRBs	~600	~600

NEUTRINOS

Astrophysical neutrinos: the future

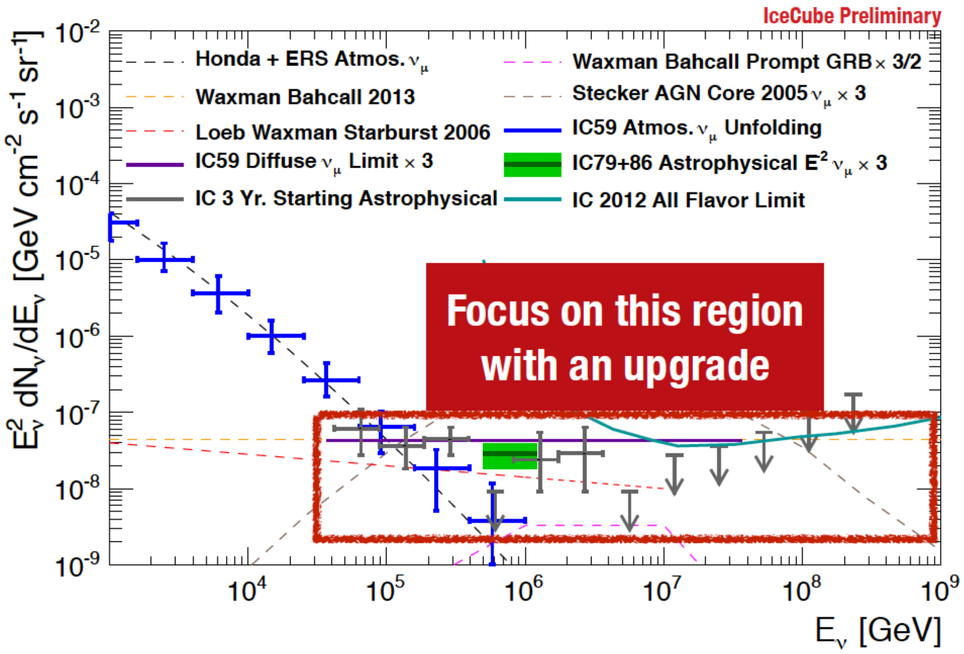
- Three lines of development:
  1. Large volume
  2. High precision
  3. New technologies
- At extremely high energies, above 100 PeV, a cosmogenic neutrino flux is expected from the interaction of highest energy cosmic-ray protons with the CMB. Predicted are in a range of approximately 1 event/year/km3 or lower. The idea to increase the effective volume of detectors to be sensitive to such rates seems feasible only:
  - Adopting the EUSO concept
  - Detecting coherent radio emission up to GHz originated by the ν interaction in dense, radio-transparent media (Askar'yan effect).

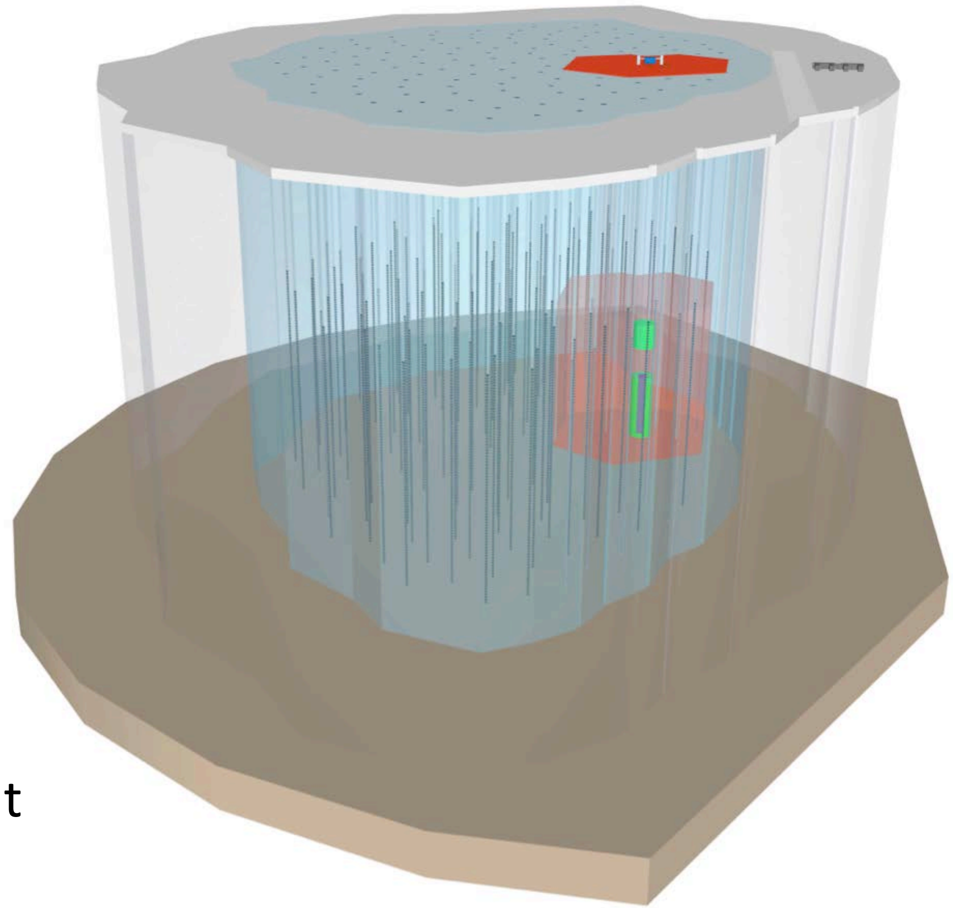
    Several prototype detectors are being developed.
- ν Astronomy has just started and a rich physics program is ahead of us. A global neutrino network (IceCube-Gen2 in the South Pole, Gigaton Volume Detector (GVD) in the lake Baikal and KM3NeT in the Mediterranean sea) will operate.



JEM-EUSO
Flight Segment
TDRS
EECR
HTV
UV photons
Fluorescence
Cherenkov
H-IIB
Air Shower
Ground Support Equipment
Ground Segment
Ground Based Calibration System
LIDAR station
Xe Flasher
Data Center
Mission Operation Control

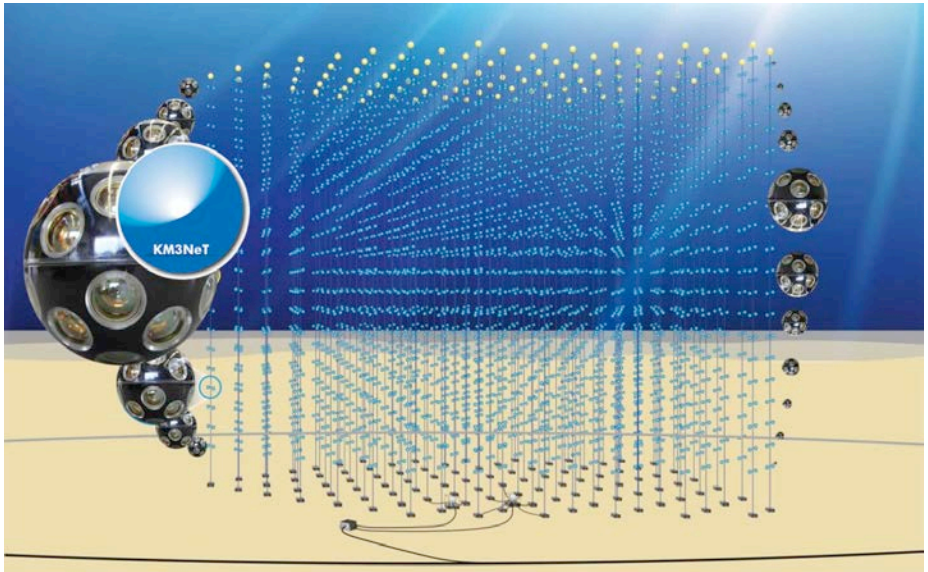
IceCube-Gen2, a 10-cubic-kilometer detector

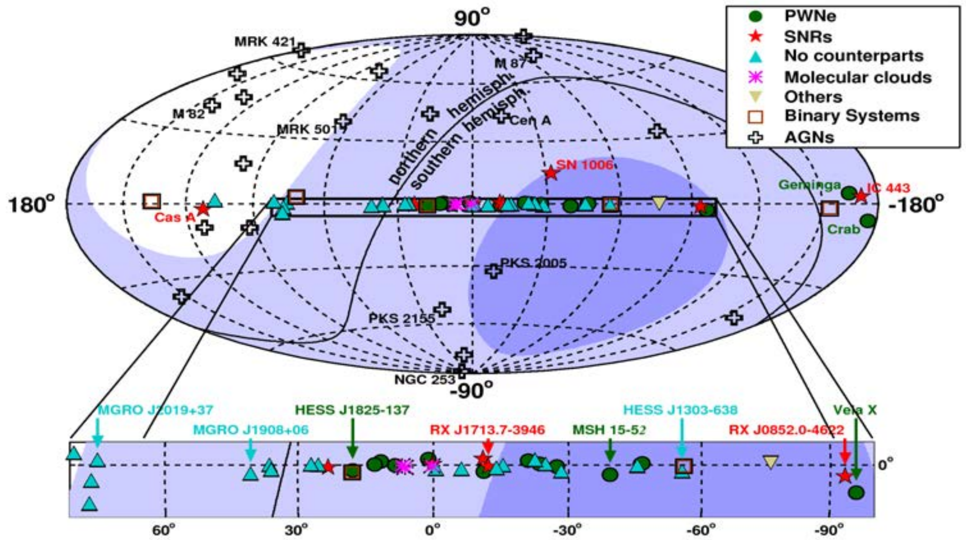




- Spacing between light sensors ~ 250 meters, instead of the current 125 meters in IceCube. The IceCube-Gen2 instrumented volume might rapidly grow at modest costs.
- By ~ doubling the instrumentation already deployed, the telescope will achieve a tenfold increase in volume to about 10 cubic kilometers, aiming at a 10x increase in neutrino detection rates.

Km3Net in the Mediterranean Sea





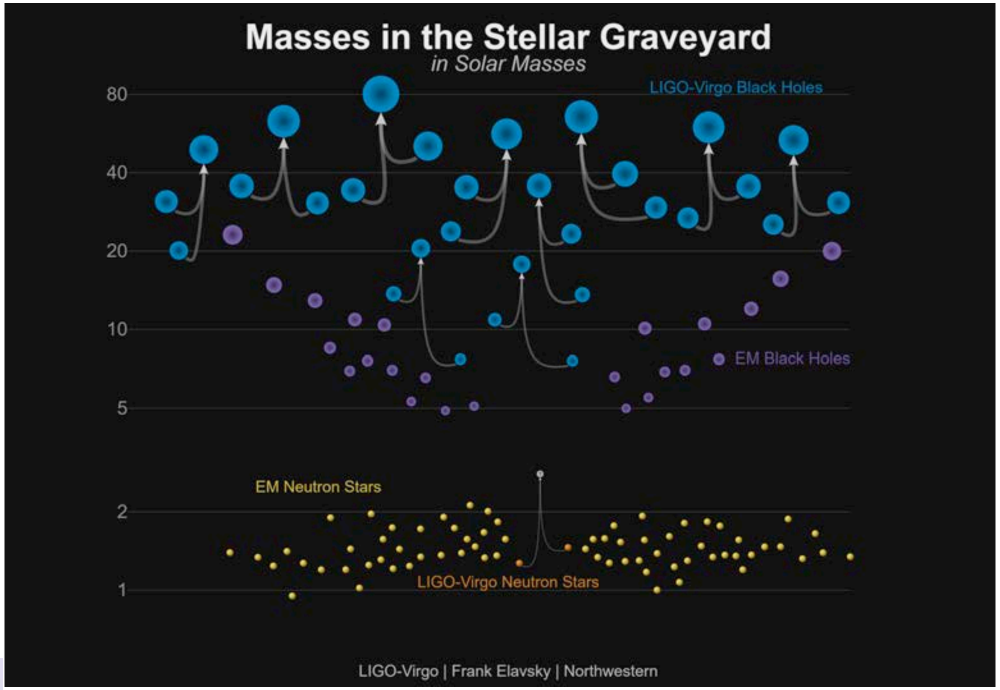
- Plan to reach ~3km^3
- Better angular resolution
- Better visibility of the GC region

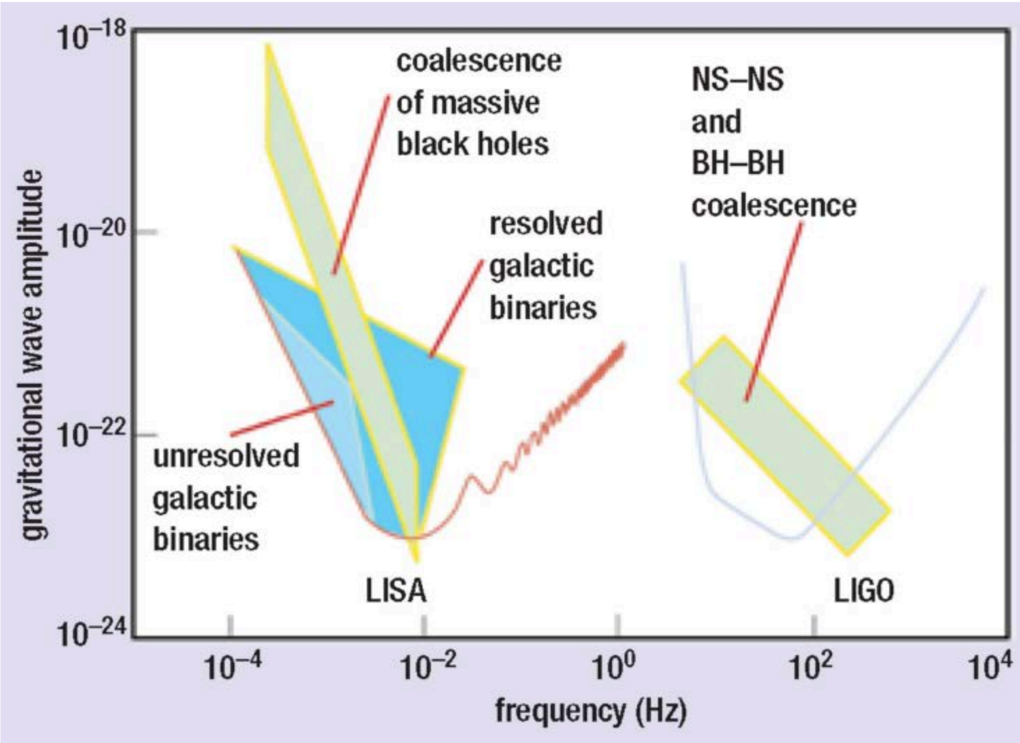
Source Name	Source radius (°)	Visibility	Number of events per year For E_ν> 5 TeV	
			Signal ν	Atm ν
RX J1713.7–3946	0.7	0.74	4 – 11	6.4
RX J0852.0–4622	1.0	0.84	2 – 6	17
HESS J1745–303	0.2	0.66	0 – 22	1.4
HESS J1626–490	< 0.1	0.91	4 – 9	1.6
Vela X	0.4	0.81	4 – 15	3.5
Crab Nebula	< 0.1	0.39	1 – 3	0.8

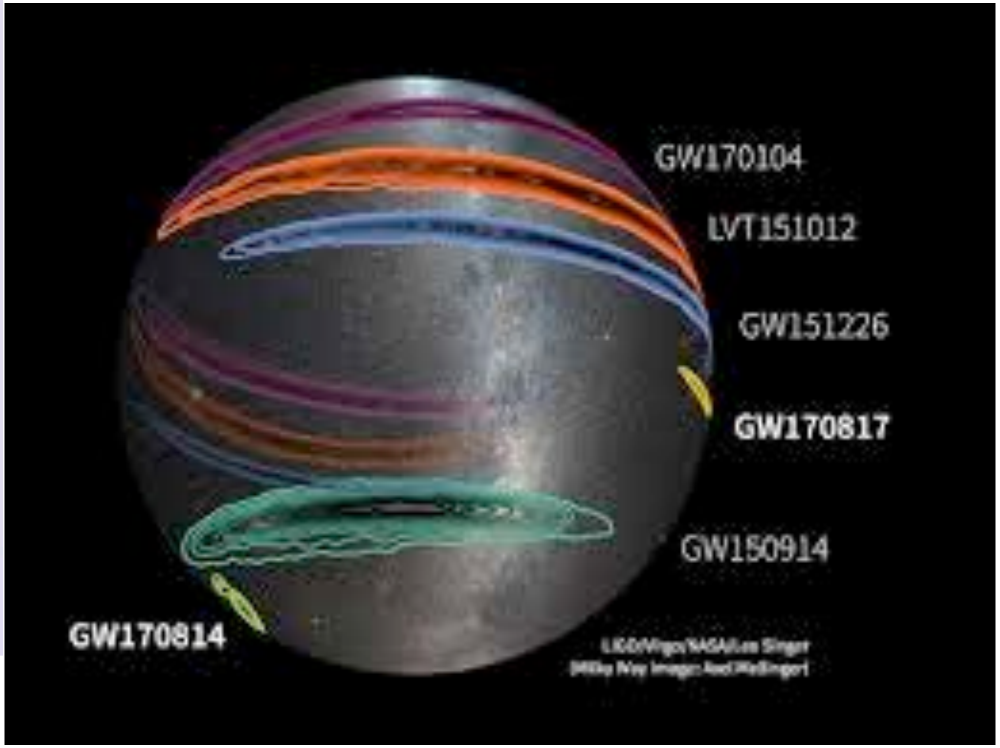
GRAVITATIONAL WAVES

Lessons learned: how to improve from the few events detected

- Increase sensitivity
- Improve localization
- Open new frequency/strain ranges (observe new phenomena)

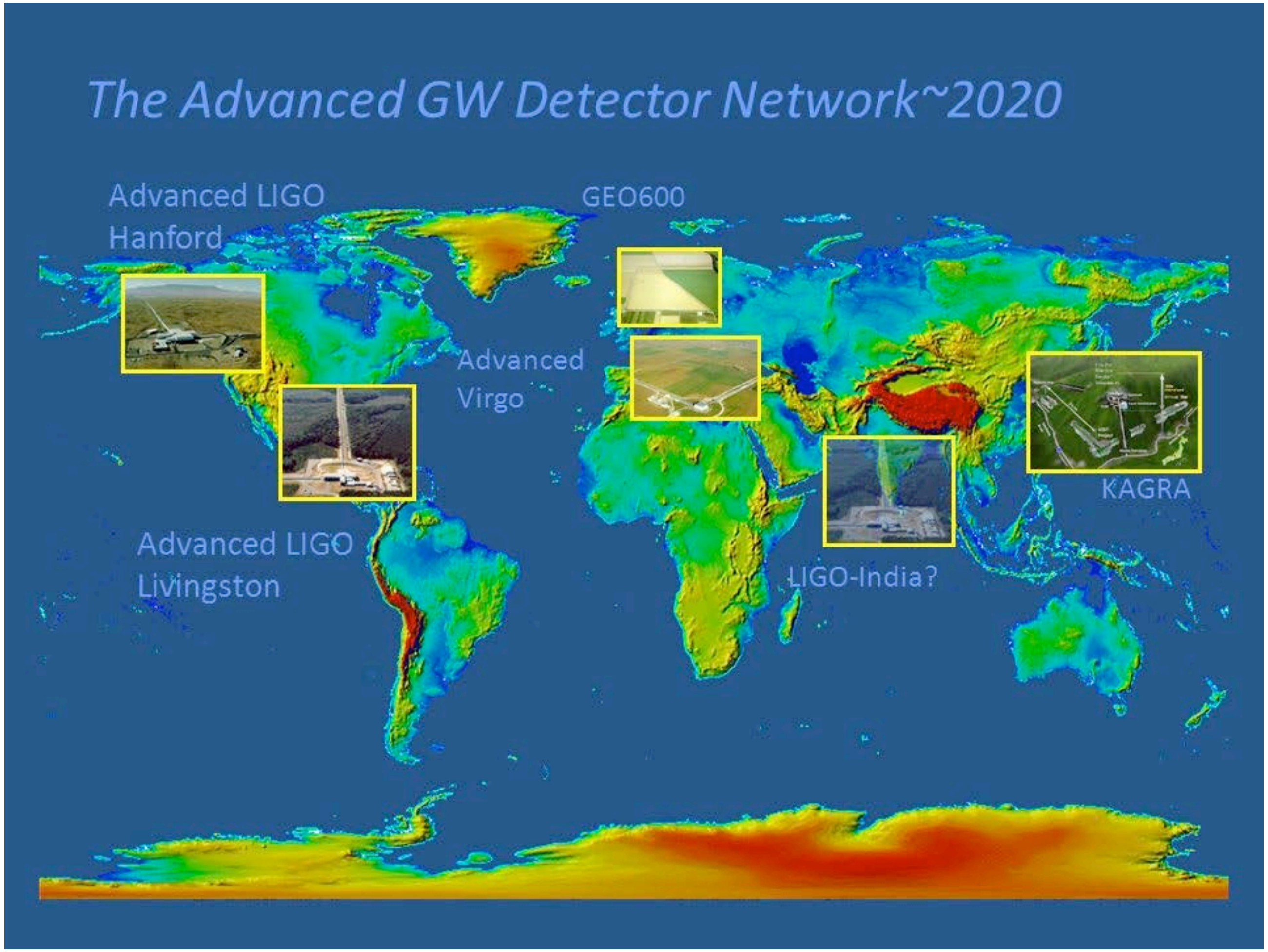


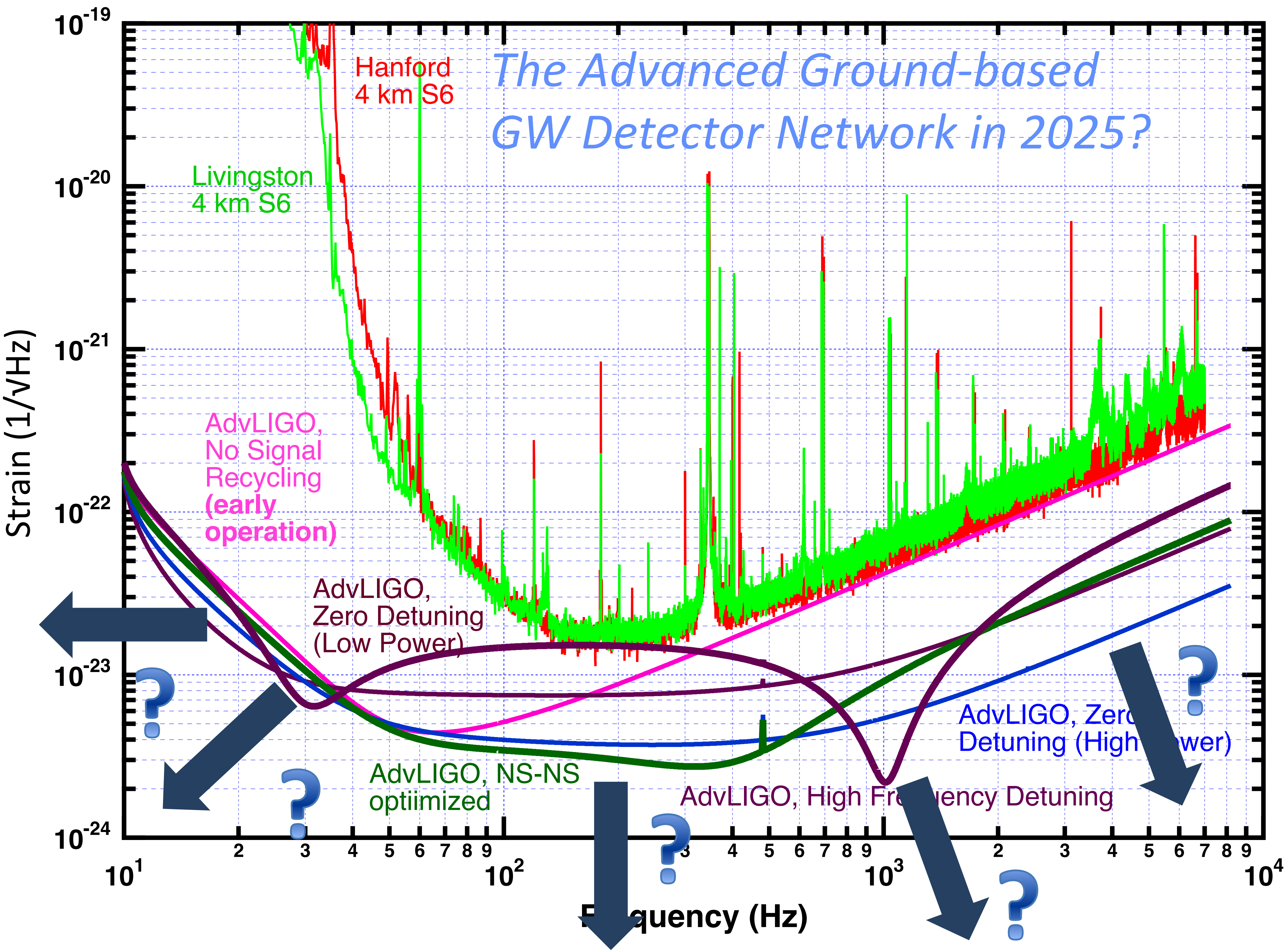




The future - 0

- The LIGO/VIRGO system will double its efficiency by ~2021-2025, incorporating KAGRA, INDICO, GEO600

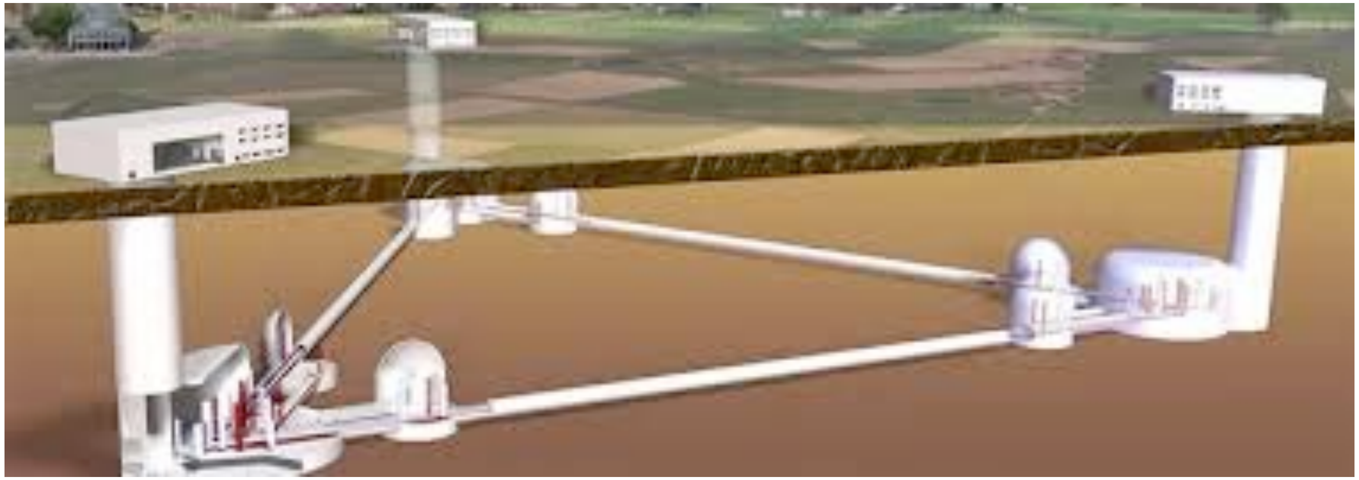




The Advanced Ground-based GW Detector Network in 2025?
Hanford 4 km S6
Livingston 4 km S6
AdvLIGO, No Signal Recycling (early operation)
AdvLIGO, Zero Detuning (Low Power)
AdvLIGO, Zero Detuning (High Power)
AdvLIGO, NS-NS optiimized
AdvLIGO, High Frequency Detuning
Strain (1/√Hz)
Frequency (Hz)
?

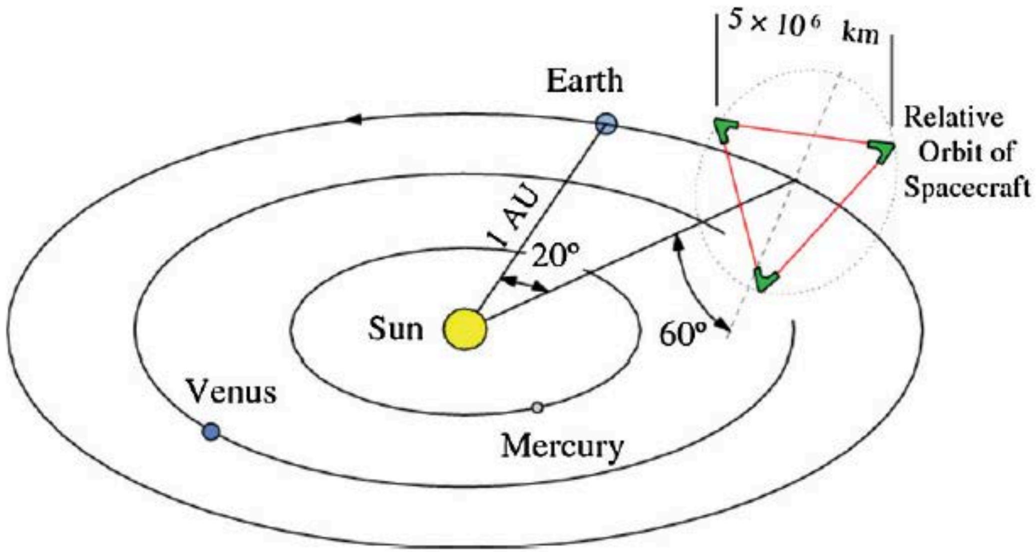
The future – I
Einstein Telescope and Cosmic Explorer (>2025)

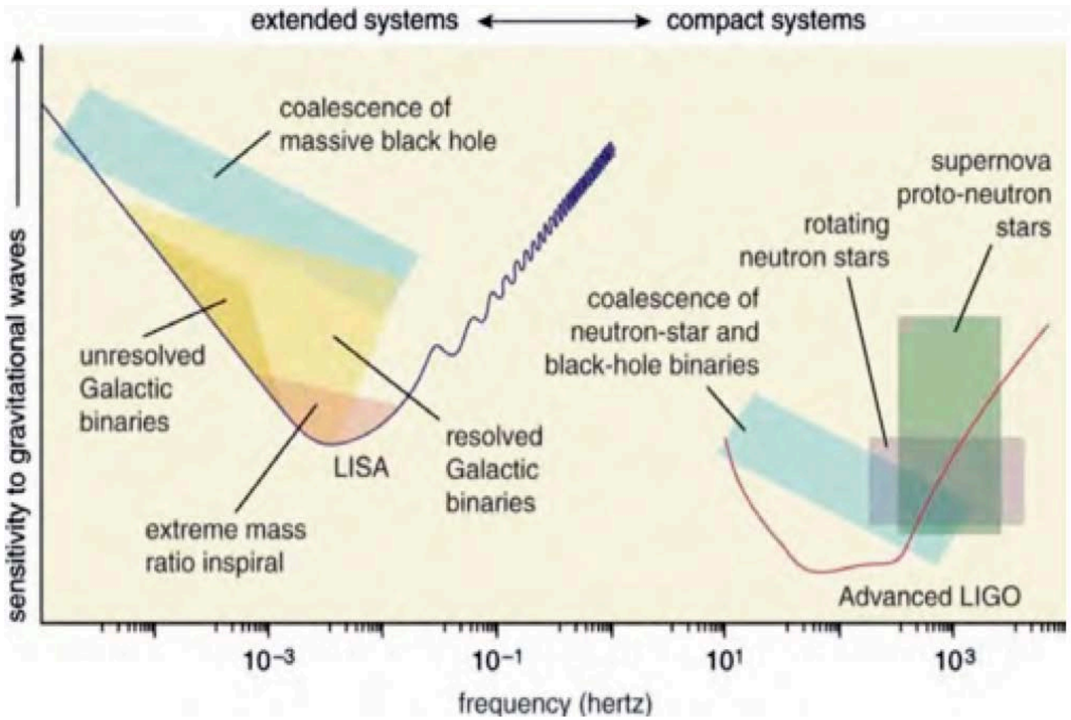
- 3-arm interferometers allow standalone pointing
- A US equivalent also under evaluation



The future – II: LISA

- In a more distant future a space observatory will be built extending the detection sensitivity to a much lower frequency range (0.1 mHz – 100 mHz).
- The LISA project, comprising three satellite detectors spaced by more than 2.5 million km, has been approved by ESA; launch is scheduled in 2034





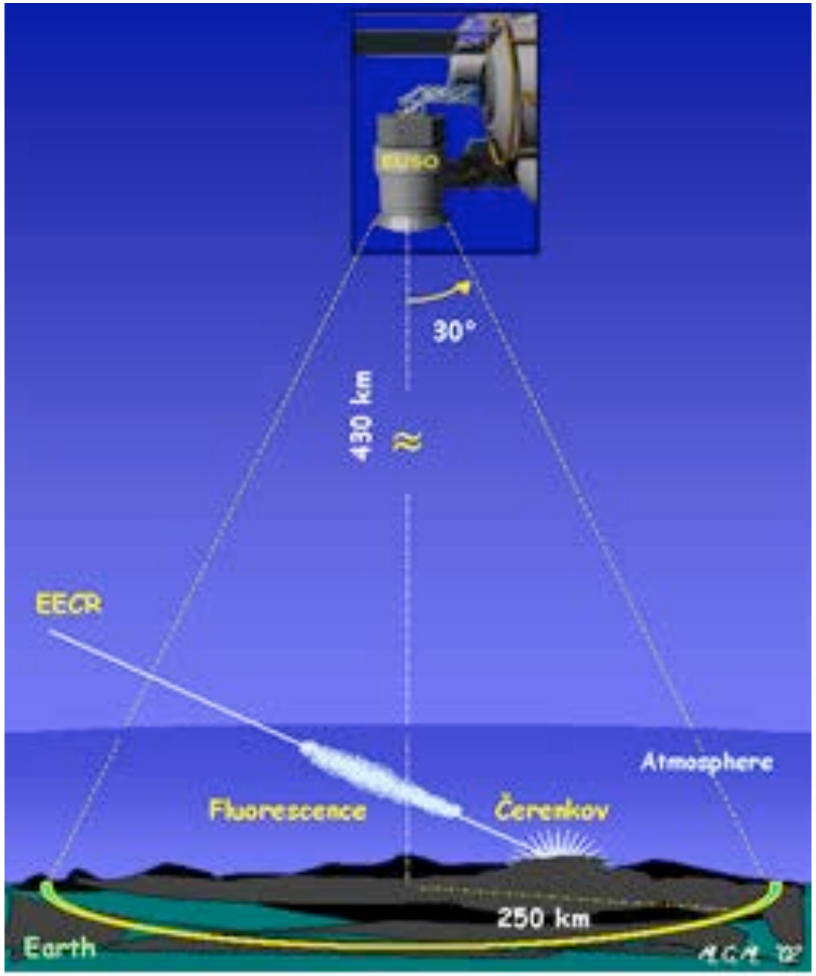
UHE COSMIC RAYS

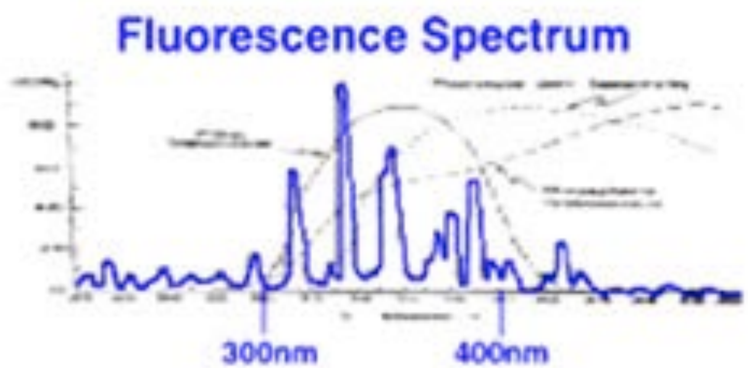
Upgrade of Auger (completed in 2019)

- Auger's surface (3000 km2) unbeatable
- Upgrade in the next years: scintillators coupled to the tanks to improve the capability of hadron classification, presently based on the shower shape

New concepts: space

- Increase the effective area by looking from space
- The EUSO concept
  - Problem: sensitivity starts oly at some EeV
  - No clear schedule





CONCLUSIONS

- Gamma rays:
  - A rich panorama of gamma experiments at VHE gamma proposed for the future. CTA will lead the field.
    - Besides CTA, new techniques. Exploration of the PeV region is fundamental – and feasible. Northern projects approved, will produce nice science. Need to converge to a Southern 100 GeV-100 TeV EAS array.
  - In the longer term, need taking care of multiwavelength aspects: priority is
    - A MeV mission (room for smart improvement; 2 missions proposed)
- Neutrino detectors will grow (at high price), and we know what we can get for astronomy
- Auger to be upgraded, but new technologies look far away in time
- Multimessenger astronomy gamma/neutrinos can help our understanding of cosmic accelerators, of physics under extreme environments and of fundamental particle physics

Planned investment in astroparticle physics for the next years

(budget excluding manpower, labs, regional funds, and competitive calls by NASA/ESA)

(M/L space missions approved can be ~50 MEUR/year on top of this)