The future of gamma-ray astronomy

L’avenir de l’astronomie gamma

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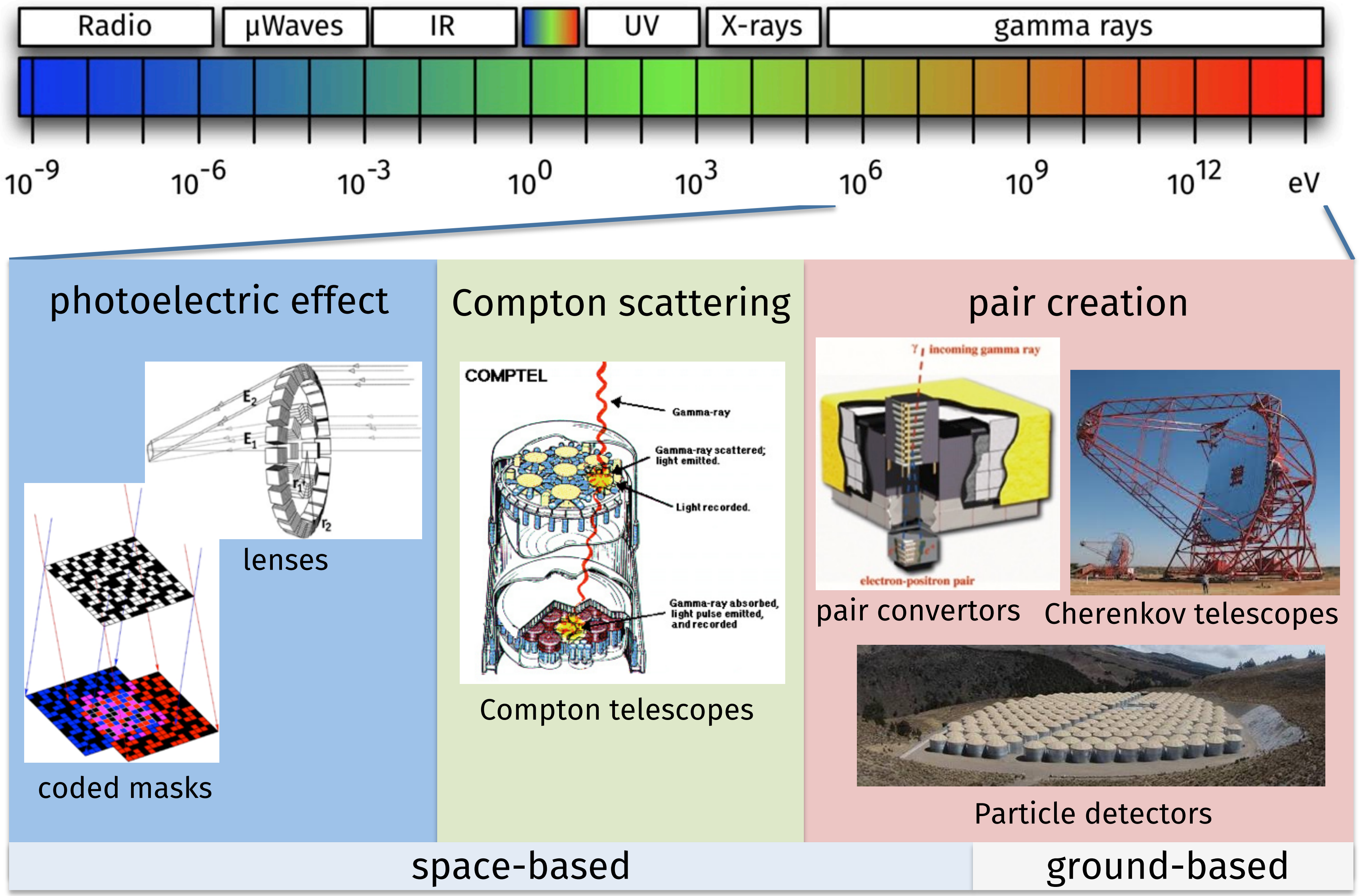
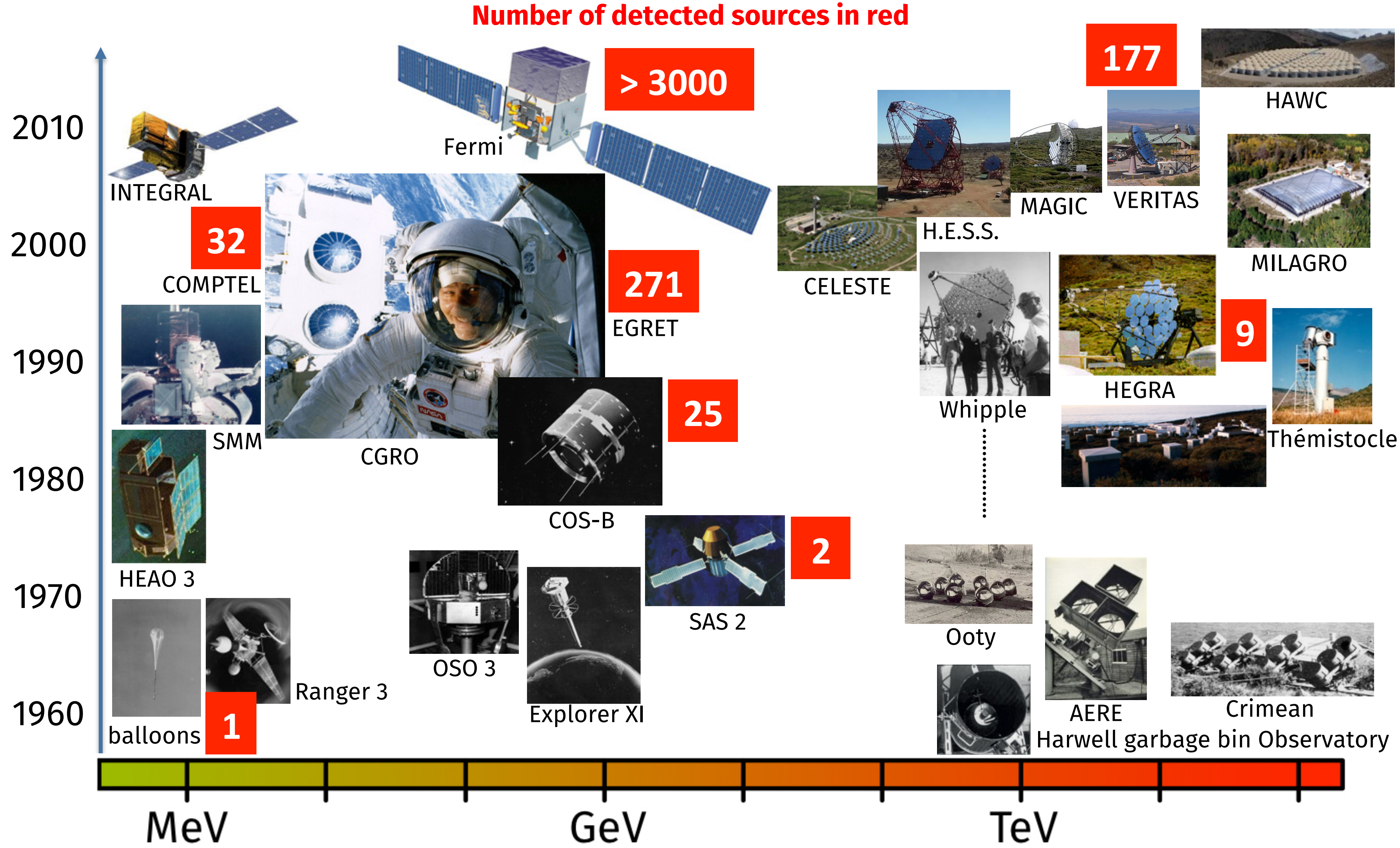
Observing gamma rays



History of gamma-ray astronomy



Achievements

2010
2000
1990
1980
1970
1960

Nucleosynthesis in the Universe

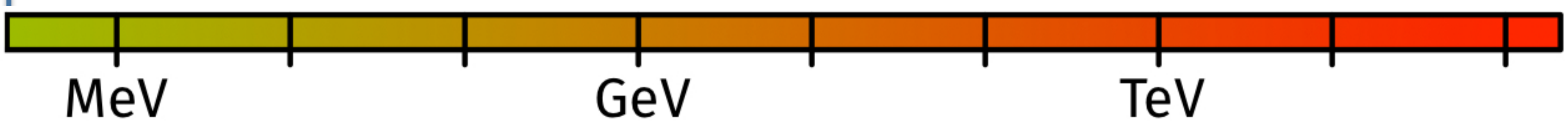
2014: ^{56}Co lines from SN Ia
2003: ^{60}Fe lines from Galaxy
1994: ^{44}Ti lines from Cas A
1988: ^{56}Co lines from SN II
1984: ^{26}Al line from Galaxy
1973: GRB, solar deexcitation lines
1972: e^+e^- 511 keV line
1969: Crab pulsar
1962: Cosmic background
1958: Solar flare

Cosmic rays in the Galaxy and beyond

2013: Proton acceleration in SNR
2011: Crab nebula flares
2010: Fermi bubbles,
First radio galaxy lobe, First nova
2009: First millisecond pulsars,
First starburst galaxies
1993: Galactic origin of cosmic rays
1992: Diffuse LMC emission
1981: 25 point-like sources
1978: First blazar
1974: Crab pulsar
1972: Diffuse Galactic emission
1961: 22 photons > 50 MeV

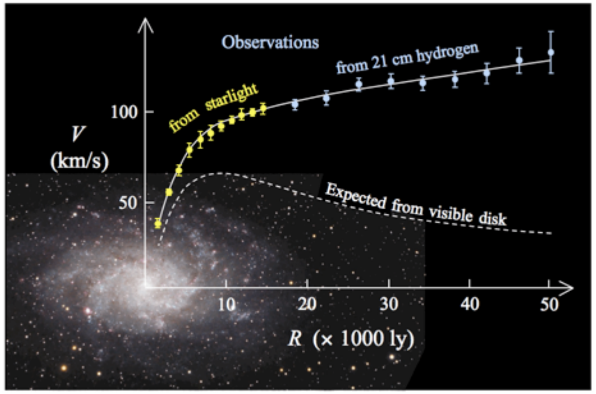
Cosmic accelerators

2009: First starburst galaxies
2008: Crab pulsar
2005: First binary
2004: First resolved SNR
2002: First unidentified TeV source
2000: First SNR
1992: Mkn 421
1989: Crab nebula



Scientific Challenges

The nature of Dark Matter



- Indicates a major flaw in our understanding of nature
- Proposed solutions include new fundamental particles (WIMPs, axions, etc.)
- Decay products of these particles may be detectable in gamma rays

Scientific Challenges

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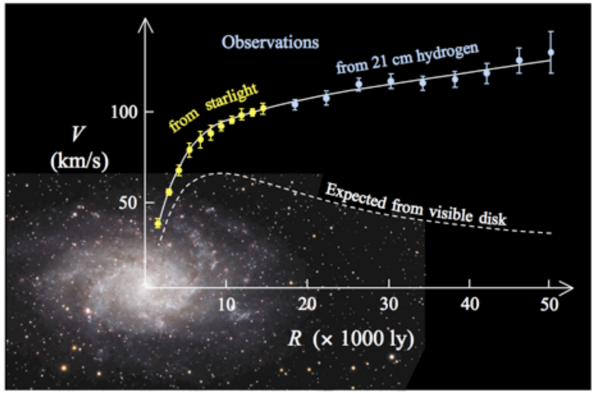

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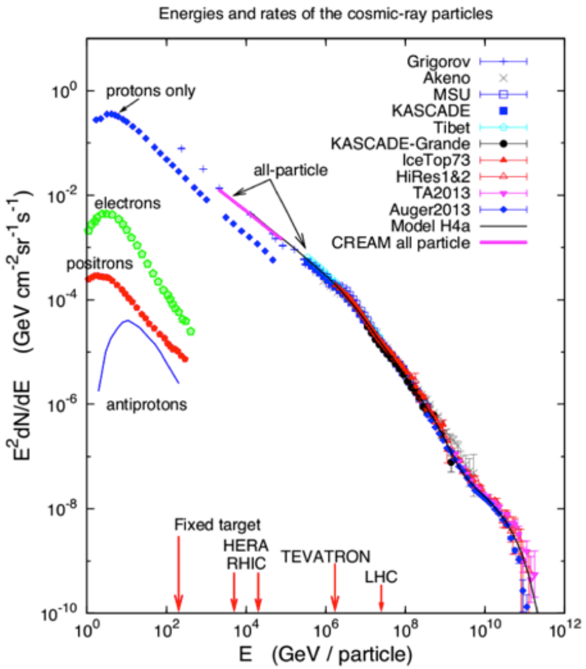
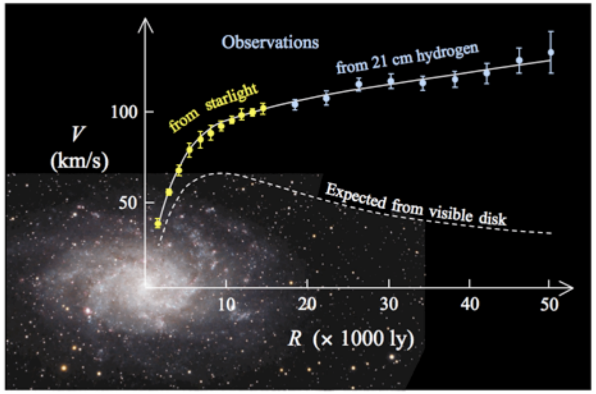
The origin of Cosmic Rays



- Unveiling the Galactic PeVatrons
- Impact of low-energy cosmic rays on interstellar chemistry
- Cosmic-ray propagation
- Impact of environment

Scientific Challenges

The nature of Dark Matter



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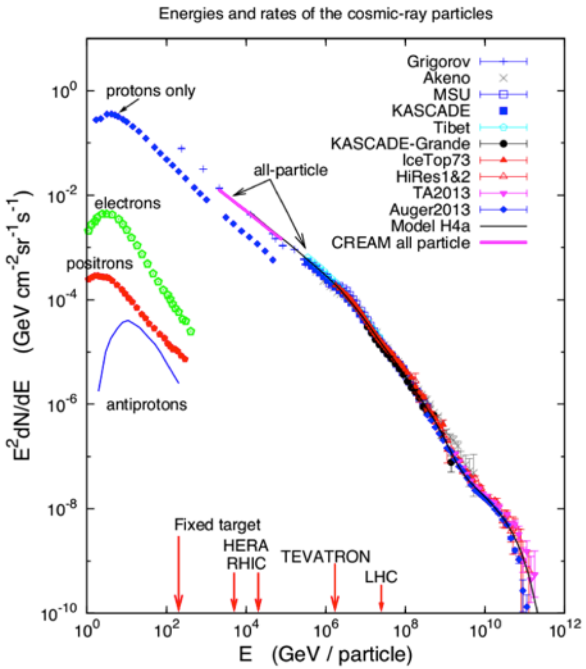

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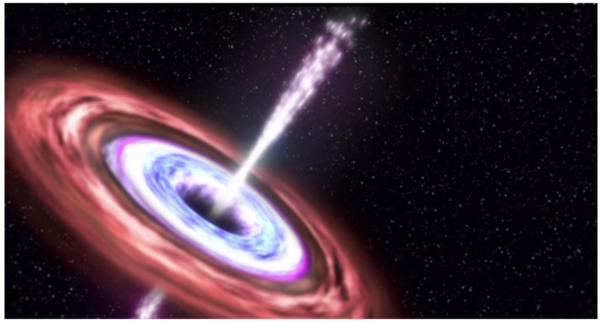
The physics of Particle Acceleration



- What mechanisms are actually at operation in a given source?
- Insights from variability (time domain astronomy)
- Elusive source classes

Space-based projects

Parameter	AdEPT	e-ASTROGAM	CALET	DAMPE	GAMMA-400	HARPO	HERD	PANGU
Context	R&D	M5?	ISS	China	Russia	R&D	China	ESA/CAS?
Launch date	–	2029?	launched	launched	$\sim$2021	–	$>$2020	2021?
Energy range (GeV)	0.005–0.2	0.0003–3	0.02–10000	2–10000	0.1–3000	0.003–3	0.1–10000	0.01–5
Ref. energy (GeV)	0.07	0.1	100	100	100	0.1	100	1
$\Delta E/E$	30%	30%	2%	1.5%	1%	10%	1%	30%
A_{eff} (cm^2)	500	1500	t.b.d.	3000	5000	2700	t.b.d.	180
Sensitivity (mCrab)	10	10	1000	100	100	1	10	t.b.d.
Field of view (sr)	t.b.d.	2.5	1.8	2.8	1.2	t.b.d.	t.b.d.	2.2
Angular resolution	1°	1.5°	0.1°	0.1°	0.02°	0.4°	0.1°	0.2°
MDP (10 mCrab)	10%	20%	–	–	–	t.b.d.	–	t.b.d.
Technology	TPC	Si + CsI	fib. + $PbWO_4$	Si + BGO	Si + CsI	TPC	Si + LYSO	Si (fib.) + **B**

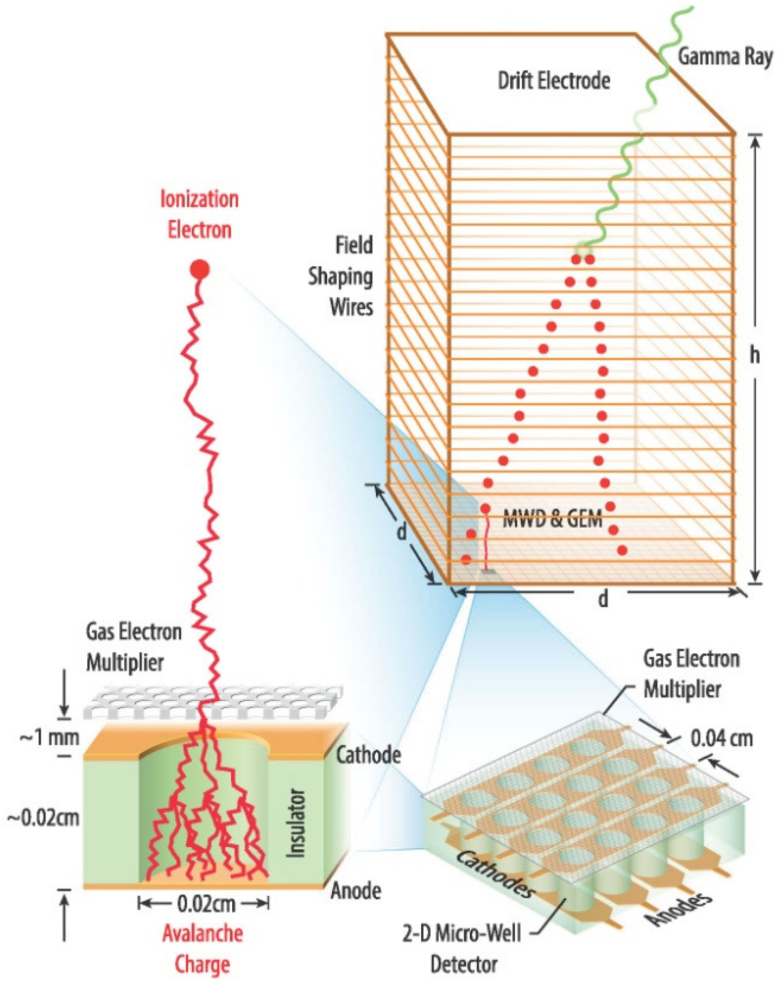
- Detection sensitivities are still poor in the MeV domain
- Considerable potential exists in using modern, **space-proven** highly pixelised semiconductor detectors in a **compact configuration** with a **minimum amount of passive material** to detect gamma rays through Compton and pair creation interactions

- At GeV energies, succeeding to Fermi-LAT will be challenging (Fermi spacecraft weight is 4.3 tons, difficult to build a much bigger detector)
- Area of improvement is angular resolution (i.e point spread function); can be achieved by **decreasing density of tracker** and **increasing spacing between tracker and calorimeter**

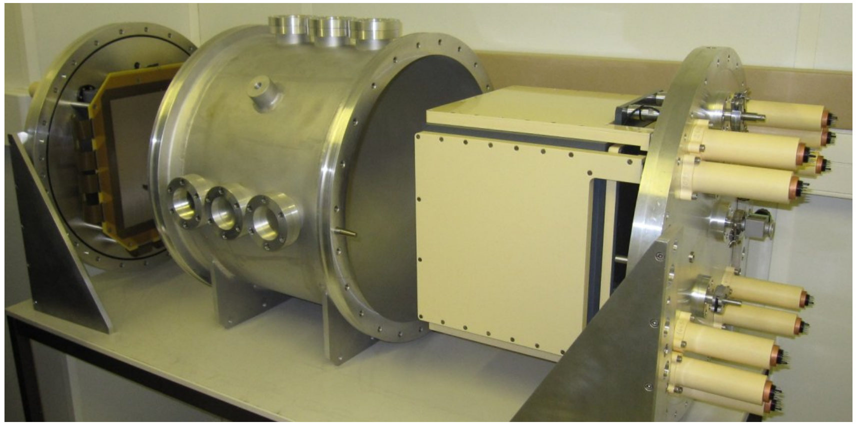
- **Potential to cover both aspects in a single mission**

Time Projection Chambers

AdEPT



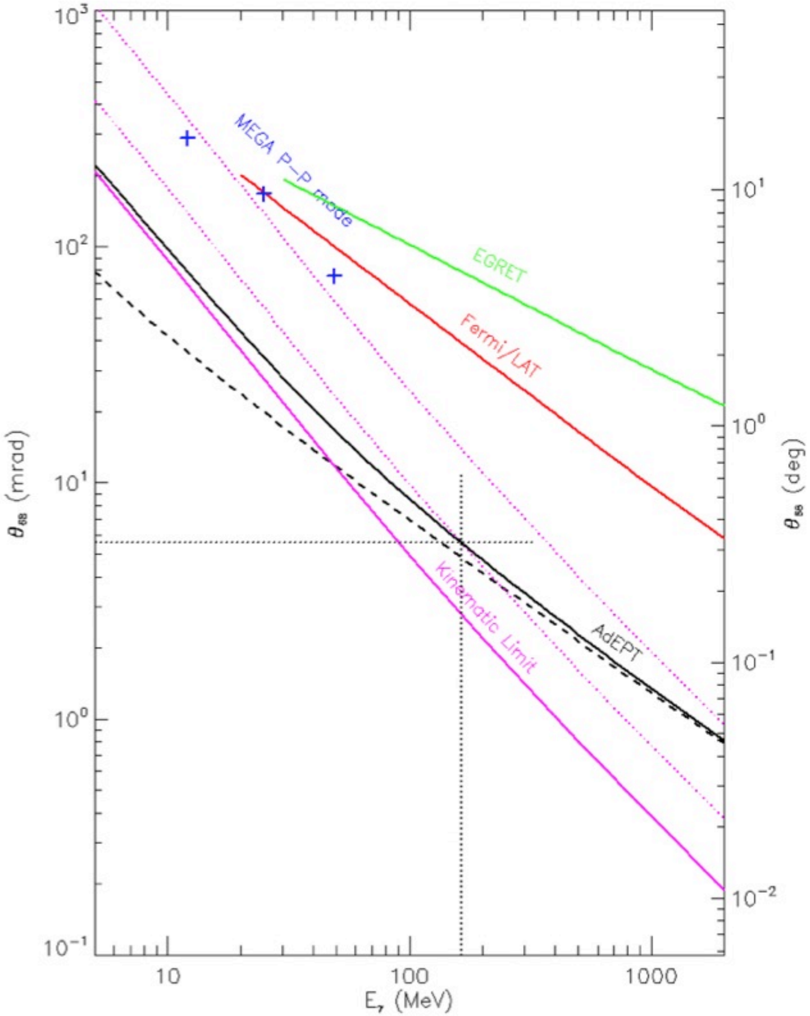
HARPO



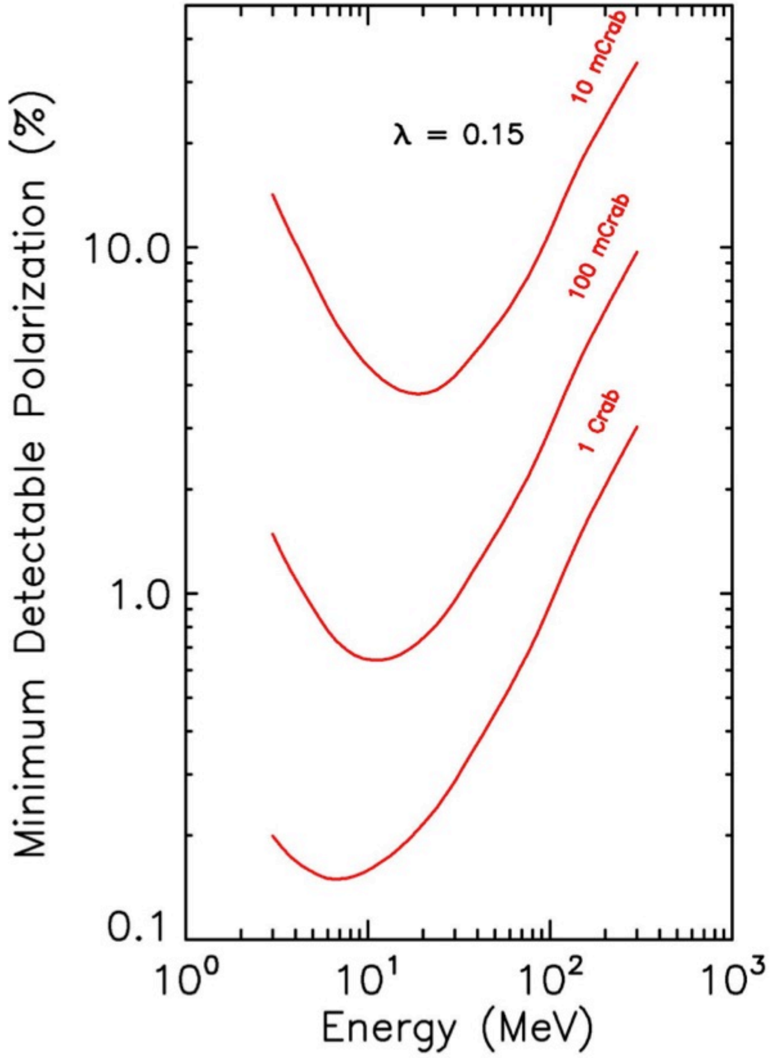
- Few MeV – GeV domain, polarimetry
- Pair conversion telescope
- Gas (Ar-based) filled TPC (few bars pressure)
- Target volume: 200 x 200 x 100 cm^3
- e^-e^+ pairs drift downwards to detector plane
- Detectors
  - Gas electron multiplier and micro-well detector (AdEPT)
  - Micro-mesh and microstrip detector (HARPO)
- Prototypes built and tested
- Stratospheric balloon flights planned
- AdEPT proposed as MIDEX in U.S.

Time Projection Chambers

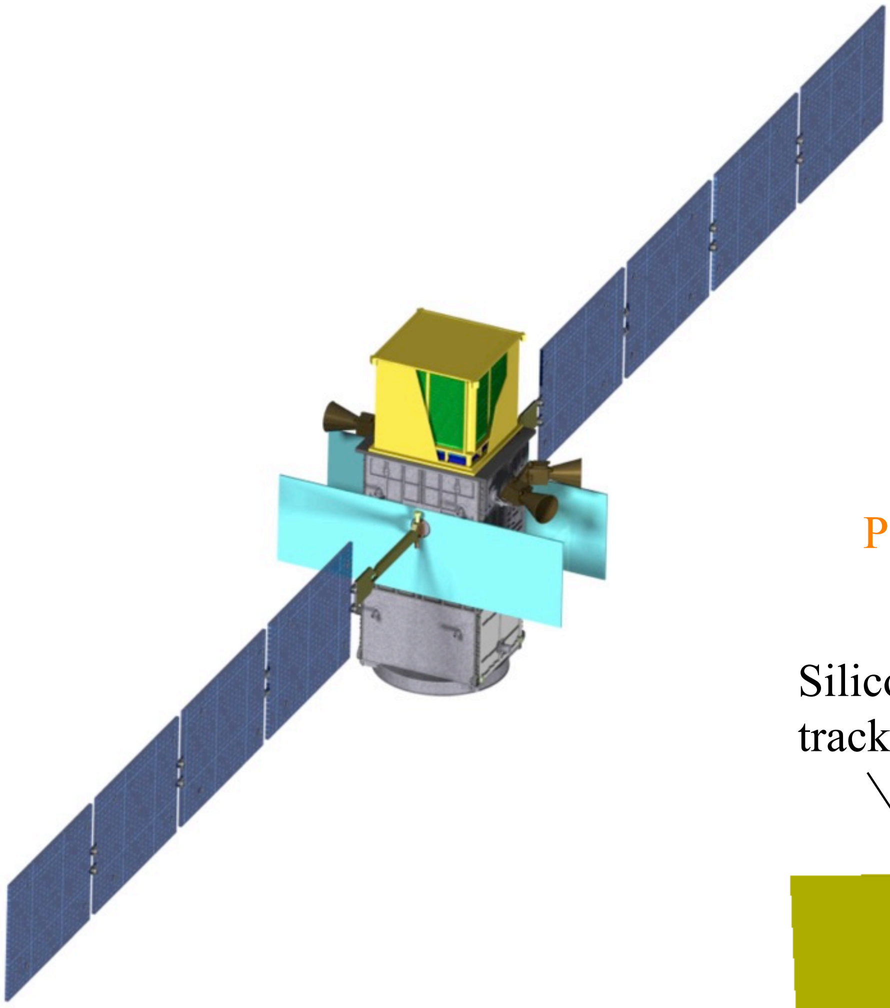
Angular resolution improvement



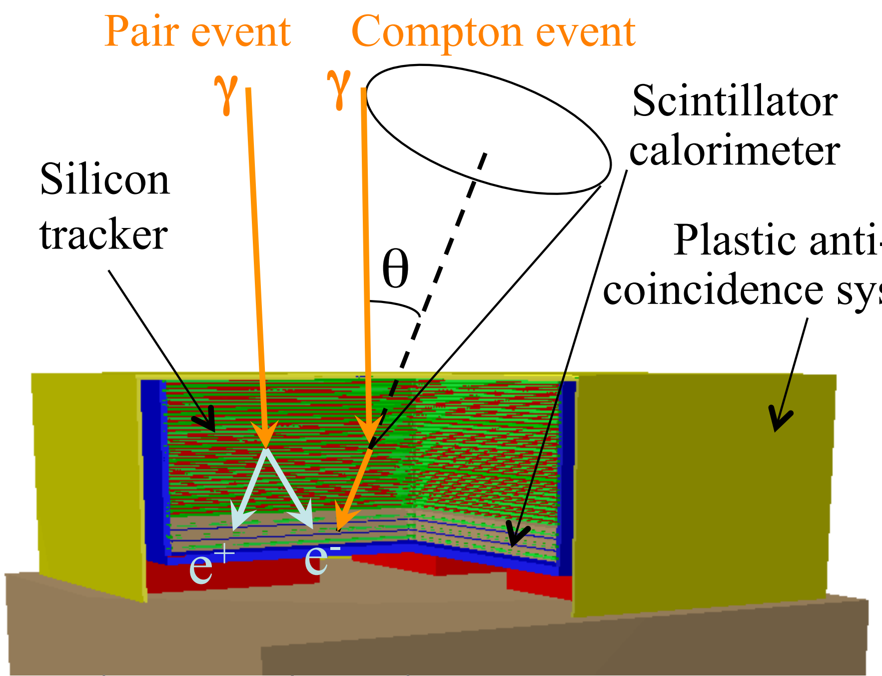
Polarisation



e-ASTROGAM

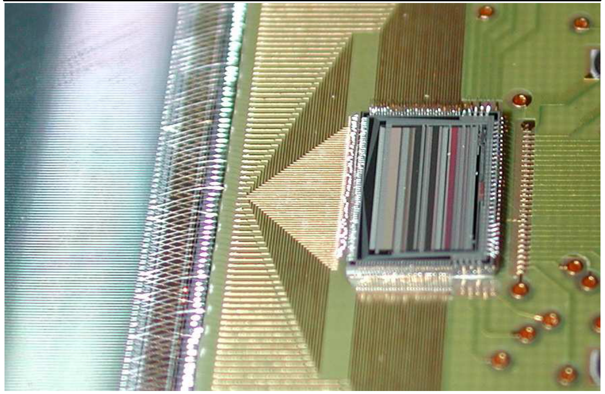


- Sub MeV – GeV domain, polarimetry
- Compton and pair conversion telescope
- Detector
    - Double sided Silicon strip (DSSD) tracker
    - 3D imaging scintillator CsI(Tl) calorimeter read out by Si drift diodes
    - Plastic anticoincidence shield read out by SiPM
- Using technology heritage from existing satellites
- Proposed as ESA M5 mission
- Similar concept proposed as NASA MIDEX (ComPair)

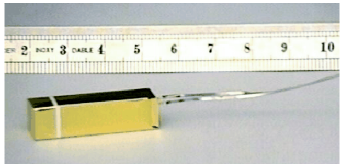


e-ASTROGAM hardware

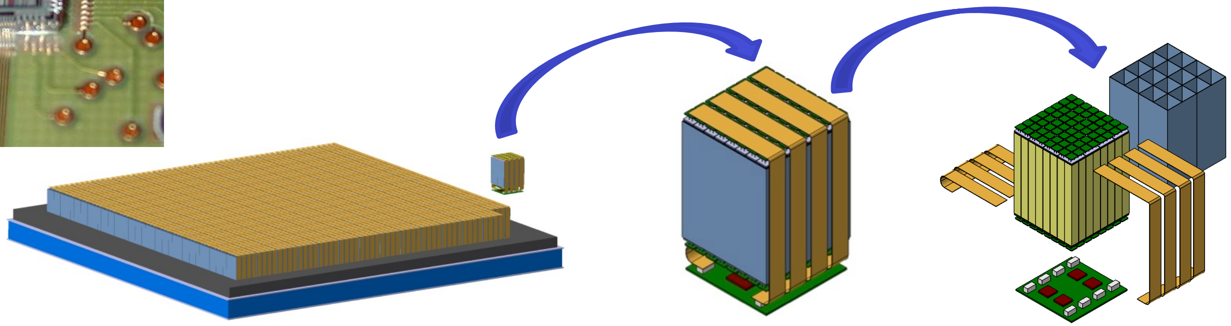
Detail of the detector-ASIC bonding in the AGILE Si Tracker

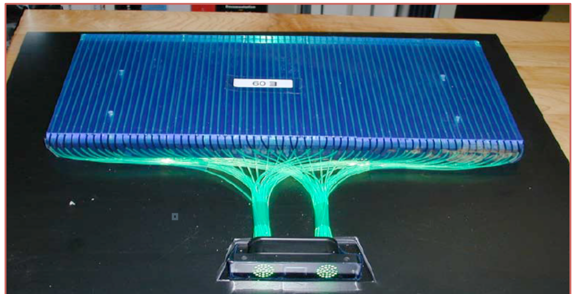


- **Tracker**: 56 layers of 4 times 5×5 DSSDs (5600 in total) of 500 μm thickness and 240 μm pitch
- DSSDs bonded strip to strip to form 5×5 ladders
- Light and stiff mechanical structure
- Ultra low-noise front end electronics



PICSiT CsI(Tl) pixel



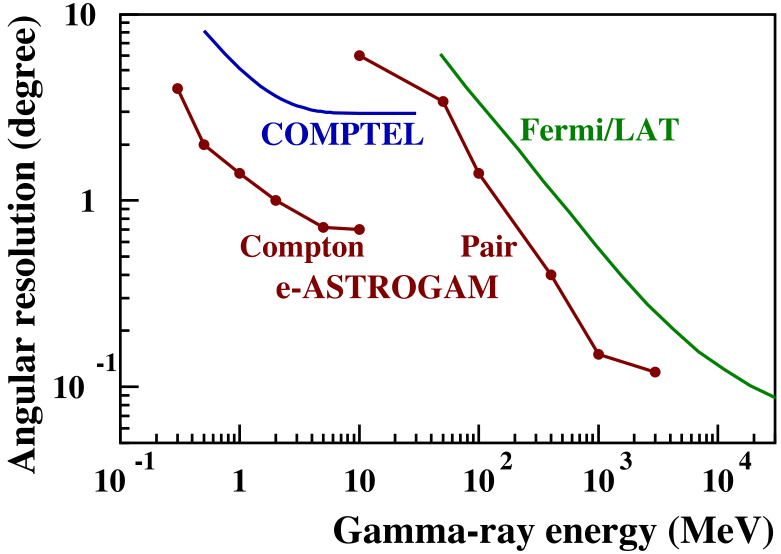


Fermi/LAT AC system

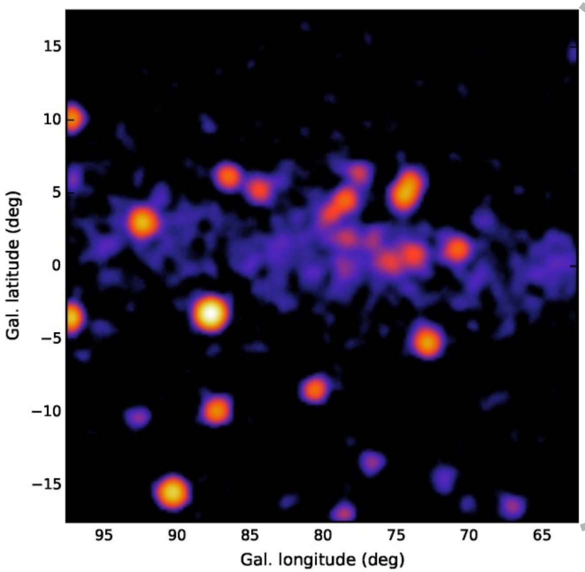
- **Calorimeter**: 8464 CsI(Tl) bars coupled at both ends to low-noise Silicon Drift Detectors
- **ACD**: segmented plastic scintillators coupled to SiPM by optical fibers
- **Heritage**: AGILE, Fermi/LAT, AMS-02, INTEGRAL, LHC/ALICE…

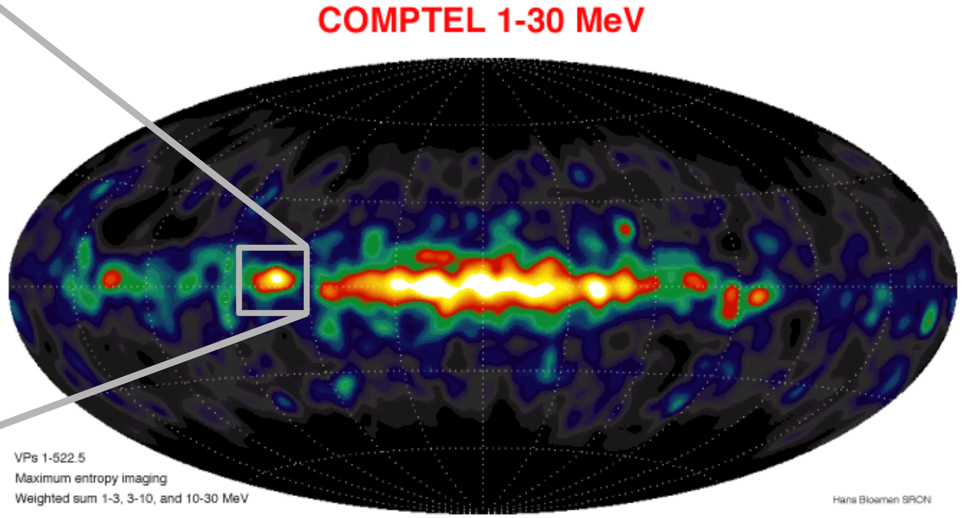
e-ASTROGAM science potential

- Improve angular resolution close to the Compton physical limits



Simulation of the Cygnus region in the 1 − 3 MeV energy band using the e-ASTROGAM PSF, from an extrapolation of the 3FGL source spectra to low energies

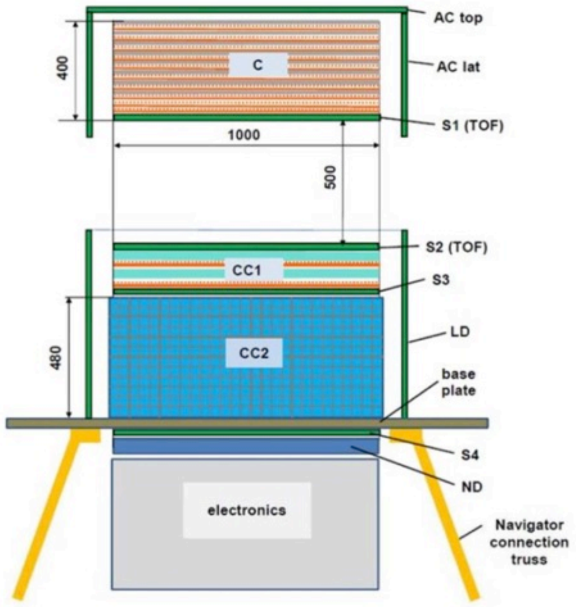




V. Tatischeff for the e-ASTROGAM Collaboration 28th Texas Symposium 13–18 December 2015

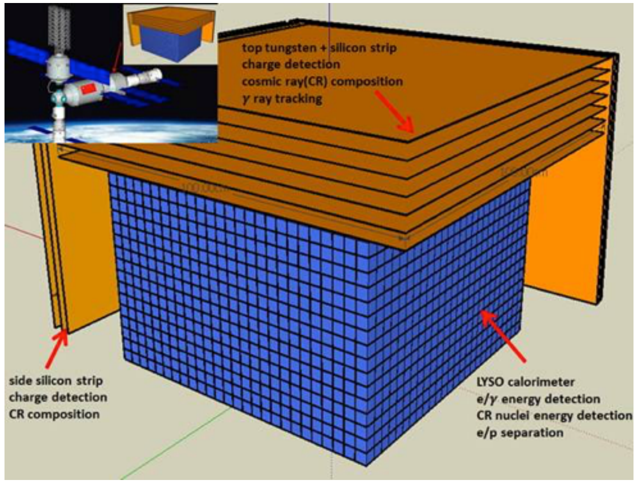
Some other projects

Gamma-400



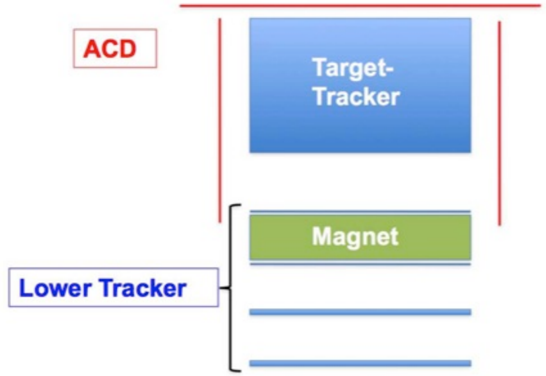
- Fermi/LAT-like with increased spacing between tracker and calorimeter
- Better angular resolution
- Poorer sensitivity
- Status unclear

HERD



- Primarily a particle detector (like CALET, DAMPE)
- GeV (- TeV) domain
- 3-D cubic calorimeter surrounded by microstrip silicon trackers from five sides
- Weight limited to 2 tons (half of Fermi-LAT)
- Will be placed aboard Chinese space station (2020+)

Pangu



- Few MeV – GeV domain, polarimetry
- Pair conversion telescope
- Tracker combined with magnetic spectrometer to fit into 60 kg payload allocation
- Submitted unsuccessfully to joint ESA/CAS small mission call

Ground-based projects

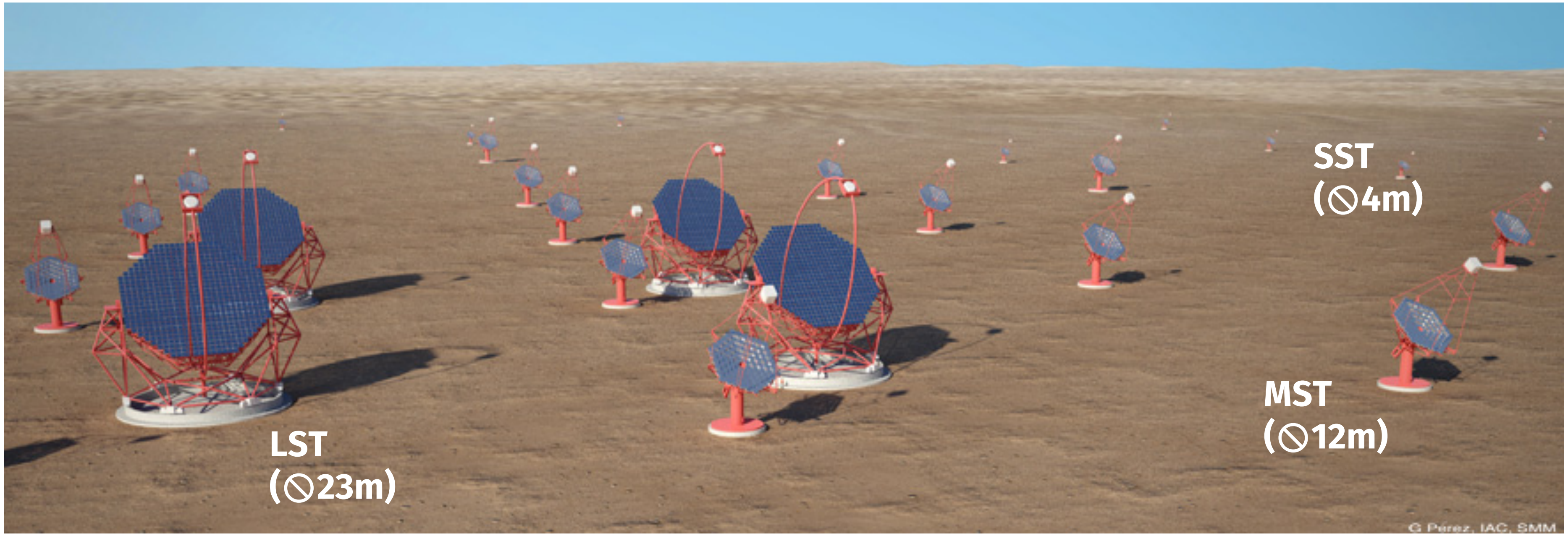
Parameter	CTA	HAWC	HiSCORE	LHAASO	MACE
Site(s)	t.b.d.	Sierra Negra (Mexico)	Tunka Valley (Russia)	Daocheng (China)	Hanle (India)
Altitude (m)	~ 2000	4100	675	4300	4270
Latitude	t.b.d.	19°N	51.8°N	29°N	32.8°N
Start of operations	2020	started	t.b.d.	2020?	2016
Lifetime (years)	30	10	t.b.d.	> 10	t.b.d.
Energy range (TeV)	0.02–300	0.1–100	50–10 000	0.1–1000	t.b.d.
$\Delta E/E$	10%	50%	10%	20%	t.b.d.
A_{eff} (m^2)	3×10^6	30 000	10^8	8×10^5 (KM2A) 10^6 (WCDA)	t.b.d.
Sensitivity (mCrab)	1	50	100	10	t.b.d.
Field of view	5°–10°	1.8 sr	0.6 sr	1.5 sr	4°
Angular resolution	0.05°	0.5°	0.1°	0.3°	t.b.d.

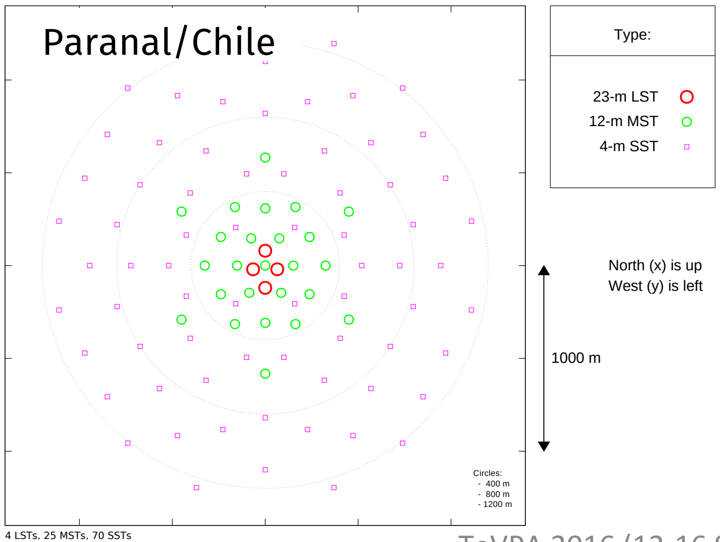
- Imaging Air Cherenkov Telescopes (IACTs) have been proven most efficient to study gamma-ray induced atmospheric Cherenkov light (excellent angular resolution, strong background rejection power)
- Drawbacks are low duty cycles (~10%) and narrow fields of view (~5°)
- Performance increase through **more telescopes** covering a **larger area** and eventually using **SiPM instead of PMTs**

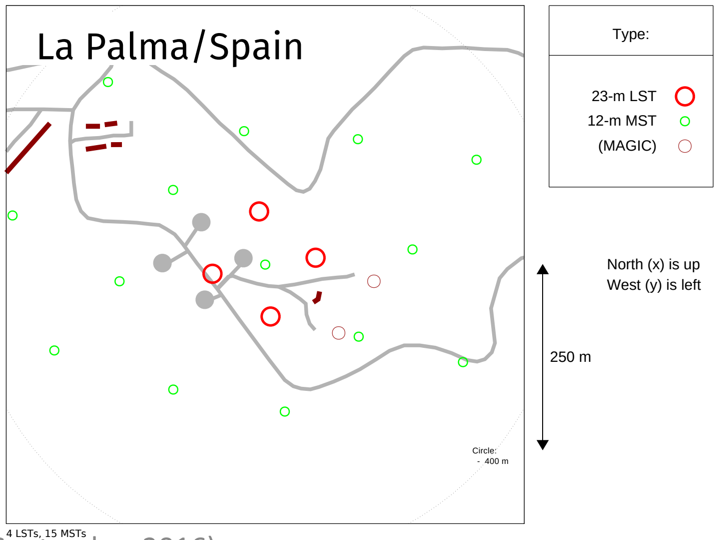
- Water Cherenkov Detectors (WCDs) are most successful devices for studying the tails of extended air showers ("tail catcher detectors")
- While modest in angular resolution and background rejection, they have excellent duty cycles and wide field of view (complementary to IACTs)
- Performance increase through **larger surface areas**, moving the detector to **higher altitude**, and improving the **detector configuration**

- **Open access observatories**

Cherenkov Telescope Array

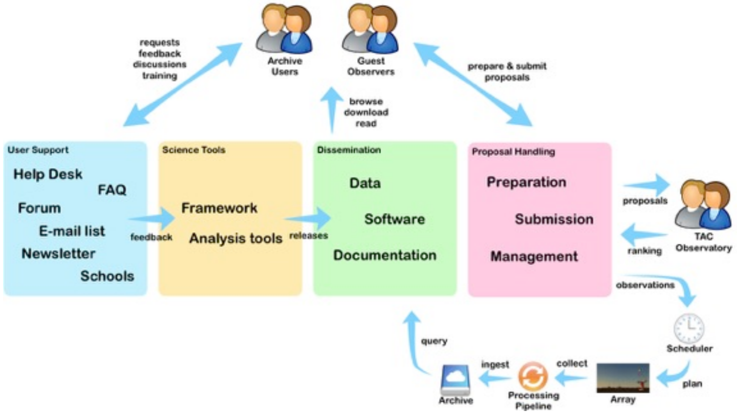






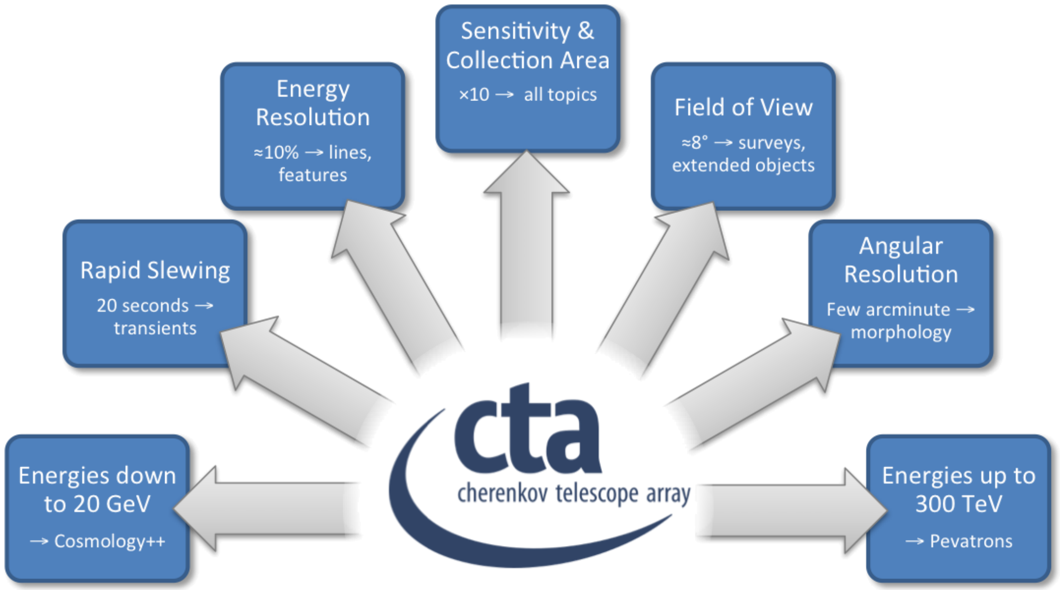
Cherenkov Telescope Array

An Open Observatory



A world-wide endeavour

Improvements everywhere



Large size telescopes

Science drivers

- Lowest energies (< 200 GeV)
- Transient phenomena
- DM, AGN, GRB, pulsars

Characteristics

- Parabolic design
- 23 m diameter
- 370 m^2 effective mirror area
- 28 m focal length
- 1.5 m mirror facets
- 4.5° field of view
- 0.11° PMT pixels
- active mirror control
- Carbon-fibre arch structure (fast repointing)

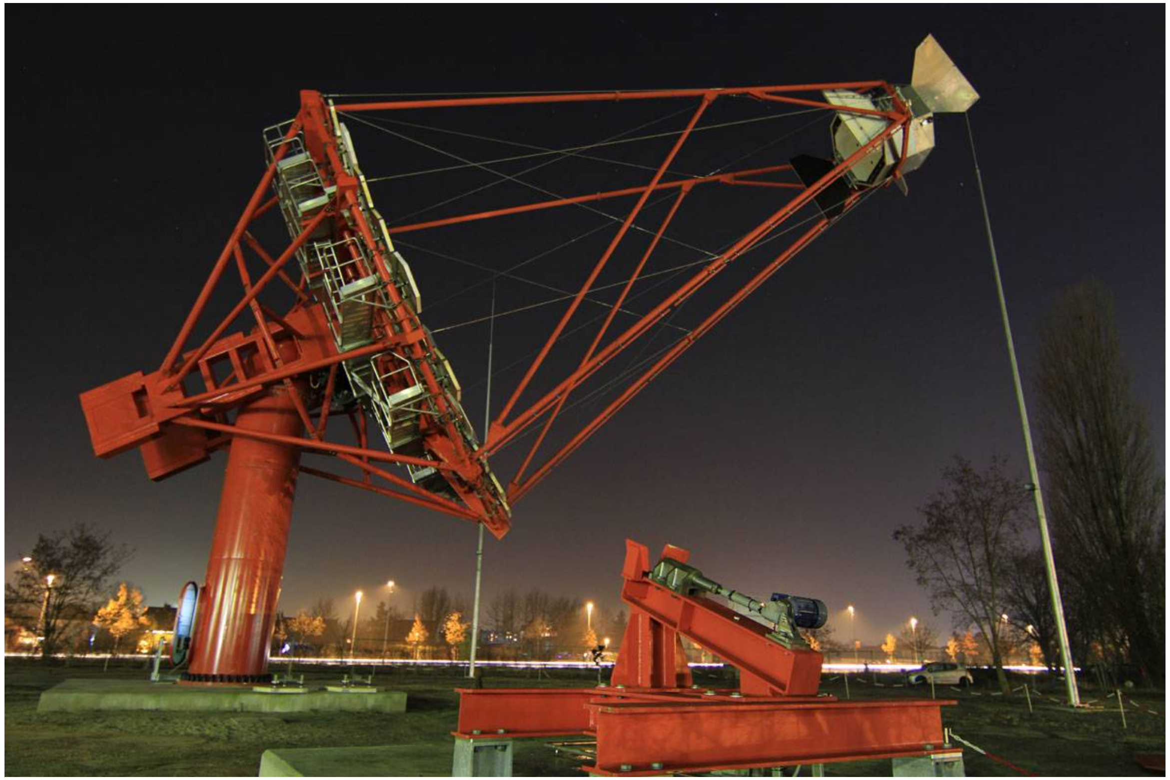
Array layout

- South site: 4
- North site: 4

Status

- Some elements prototyped
- First full telescope under construction in La Palma (http://www.lst1.iac.es/webcams.html)

Mid size telescopes



Science drivers
- Mid energies (100 GeV – 10 TeV)
- DM, AGN, SNR, PWN, binaries, starbursts, EBL, IGM

Characteristics
- Modified Davies-Cotton design
- 12 m diameter
- 90 m^2 effective mirror area
- 1.2 m mirror facets
- 16 m focal length
- 8° field of view
- 0.18° PMT pixels

Array layout
- South site: 25
- North site: 15

Status
- Telescope prototyped (Berlin-Adlershof)
- Prototype cameras under construction (2 types: NectarCAM & FlashCam)

Small size telescopes

Characteristics
- Davies-Cotton design
- 4 m diameter
- 8.5 m^2 effective mirror area
- 5.6 m focal length
- 9° field of view
- 0.24° SiPM pixels

Status
- Prototype telescope built
- Camera prototype under construction

Characteristics
- Schwarzschild-Couder design
- 4.3 m primary diameter
- 1.8 m secondary diameter
- 6 m^2 effective mirror area
- 2.2 m focal length
- 9.6° field of view
- 0.17° SiPM pixels

Status
- Prototype telescope built
- Camera prototype under construction

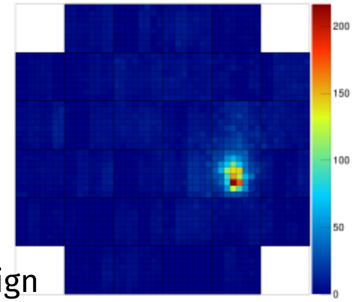
Characteristics
- Schwarzschild-Couder design
- 4 m primary diameter
- 2 m secondary diameter
- 6 m^2 effective mirror area
- 2.3 m focal length
- 8.6° field of view
- 0.16° SiPM pixels

Status
- Prototype telescope structure built
- Tested with MAPMT-based CHEC camera

Science drivers
- Highest energies (> 5 TeV)
- Galactic science, PeVatrons

Array layout
- South site: 70
- North site: -

First CTA light



Some other projects

HiSCORE

- Non-imaging air-shower Cherenkov light-front sampling
- Up to 100 km^2 area covered
- Wide field of view (~0.6 sr)
- Extend sensitivity to the PeV regime
- Complemented by IACTs and surface & underground stations for measuring muon component of air showers

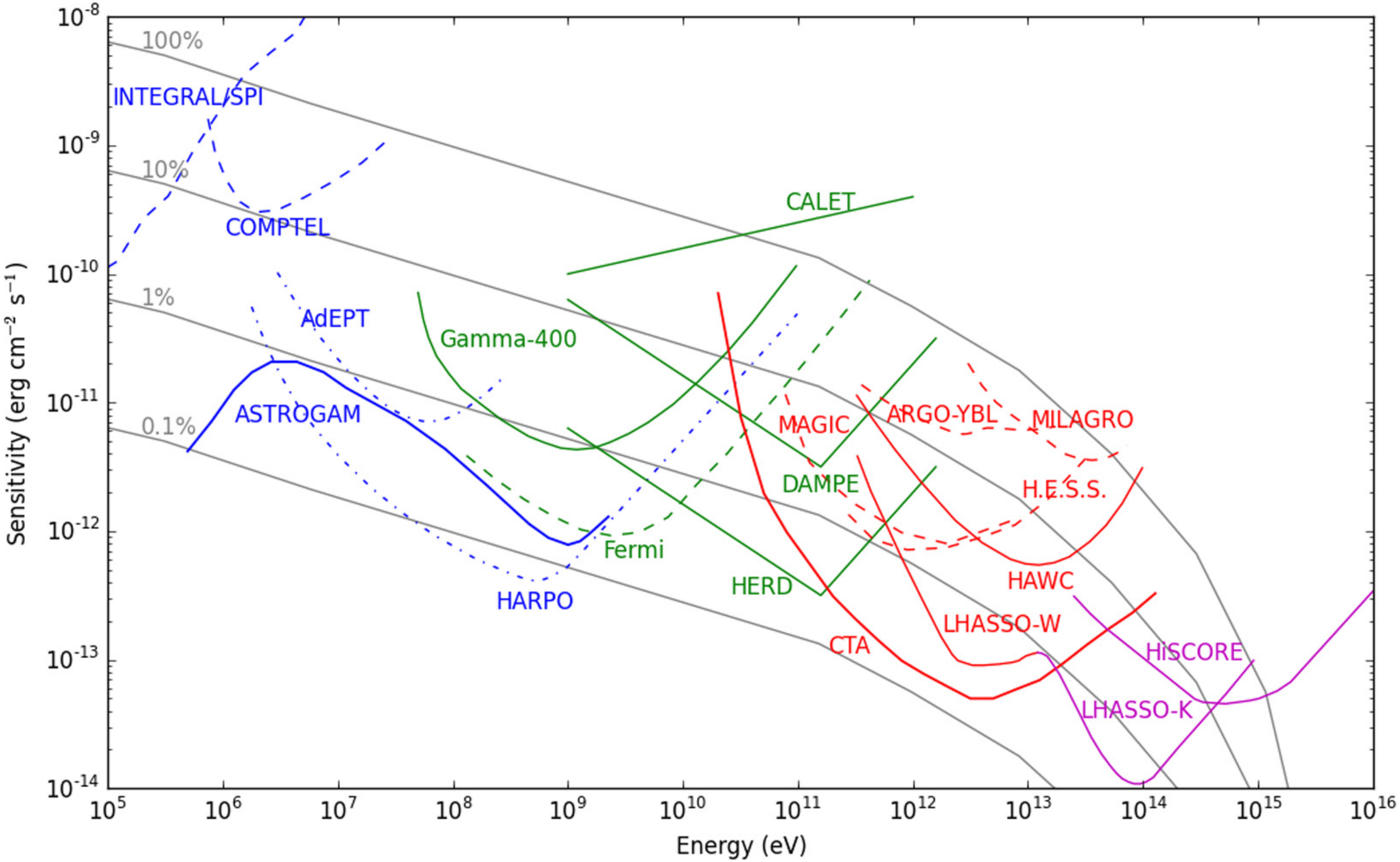
LHAASO

- Hybrid detector array
- Gamma ray detectors
  - Large (4 x HAWC) Water Cherenkov detector array (0.1-30 TeV)
  - Electromagnetic particle detectors and muon detectors (30-1000 TeV)

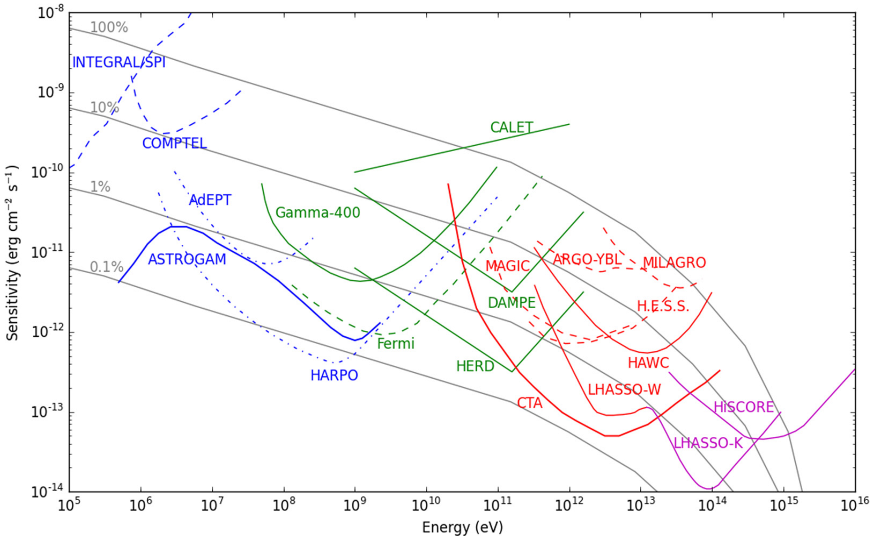
MACE

- 21 m diameter IACT to be installed at Hanle (4270 m a.s.l)
- Design inspired from H.E.S.S. II

Sensitivity: past – present – future



Conclusions



Ground-based

- The **Cherenkov Telescope Array** will expand on all aspects of current IACTs (**sensitivity**, **energy range**, **angular resolution**)
- Will enable
  - **WIMP detections** from few 100 GeV to few TeV
  - search of **PeVatrons** in the entire Galaxy
  - measurement of **sub-minute variability** in AGN
  - comprehensive **population studies** of particle accelerators
  - studies of **particle acceleration** in and **particle propagation** near individual sources

Space-based

- An instrument covering the **MeV – GeV** energy range has the **highest discovery potential (e.g. e-ASTROGAM, ComPair)**
- Will enable
  - measurement of **pion-bumps** characteristic of hadronic accelerators in many sources
  - study of the still elusive **low-energy cosmic-ray component**
  - observation of **gamma-ray lines** (nucleosynthesis, de-excitation, e^+e^- annihilation)
  - **gamma-ray polarisation** measurements