cta cherenkov telescope array

Cherenkov Telescopse Array

Ueli Straumann, 12. April 2017, PGZ

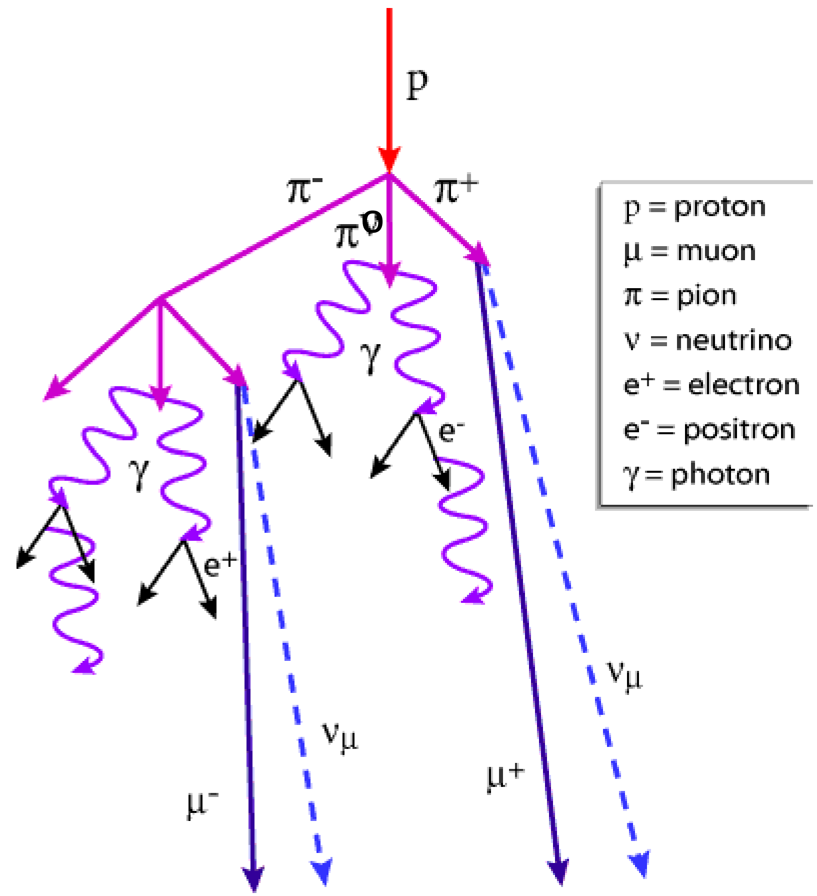
Content

- Cosmic Rays and very high energy gamma rays
- IACT and CTA measuring concept
- CTA technical project details
- Government
- Physics perspectives
- Summary

Cosmic Rays and Gamma Rays

What is a cosmic ray?

- High energy particles from Universe produce extensive air showers.
- Charged particles, mainly protons, also higher mass nuclei.
- Deflected by interstellar / intergalactiv magnetic fields -> no assignment to specific source possible
- In addition gamma rays and neutrinos arriving from outer space -> pointing to source!



Detection:

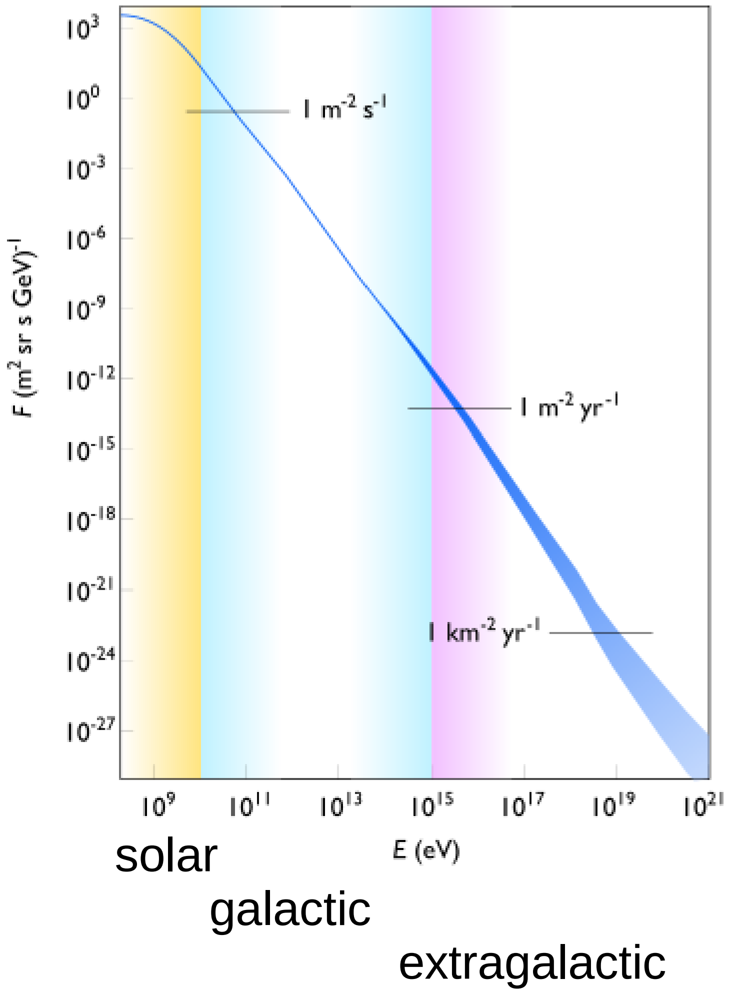
- Direct detection from satellites
- Air acts as a calorimeter for earthbound detectors.

Cosmic Rays

- Hess (1912) discovered, that ionizing radiation increases with height, Clay (1927) found deviations by geomagnetic fields. Rossi and Auger (1937) proposed the shower mechanism resulting in the extensive air showers

- Todays view:
  - Cosmic rays are composed of all atomic nuclei
  - Flux decreasing exponentially over 10 decades in Energy (about $E^{-2.8}$) with little structure
  - Extend to very high energies:
    Acceleration mechanism??
  - GZK (Greisen, Zatsepin, Kusmin, 1966) predicted cut-off at 6×10^{19} eV for protons, exp. confirmed

$$\gamma_{\rm CMB} + p \rightarrow \Delta^+ \rightarrow n + \pi^+ .$$
$$\gamma_{\rm CMB} + p \rightarrow \Delta^+ \rightarrow p + \pi^0 ,$$



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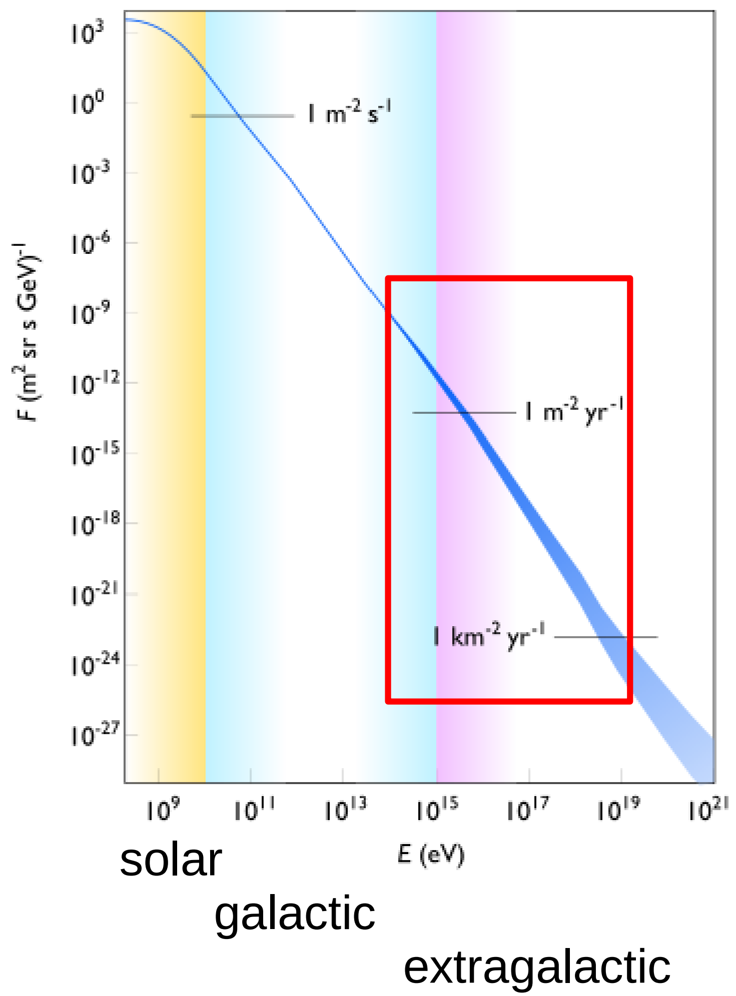
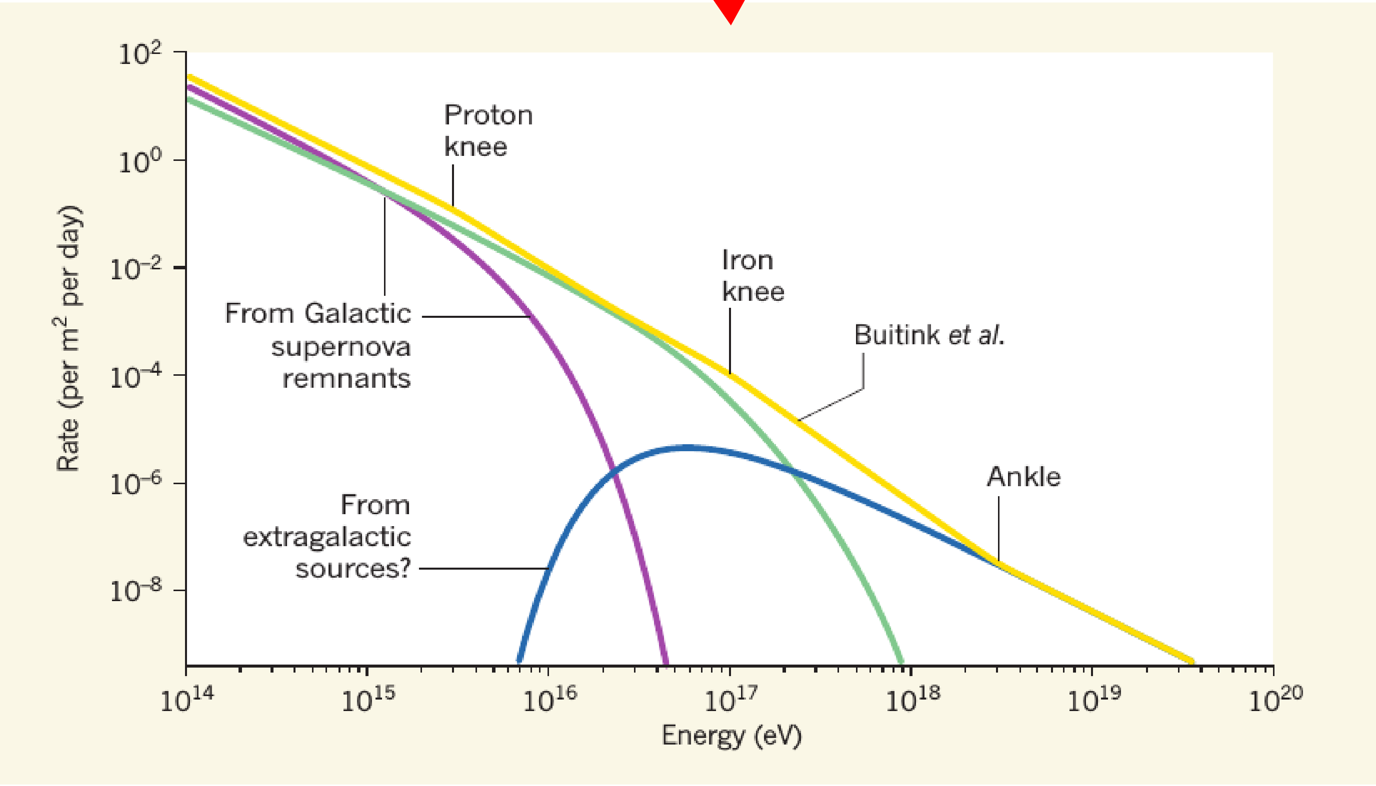


Cosmic Rays

Some structure in spectrum

- Flux decreasing exponentially about $E^{-2.8}$
- "Knee" at 10^{15} eV = limit of p confinement in galactic magnetic field: Larmor rad > Galaxy)
- second knee at 10^{17} eV (heavy elements?)
- "Ankle" at $5x10^{18}$ eV (extragalactic, protons?)

10^{17}eV



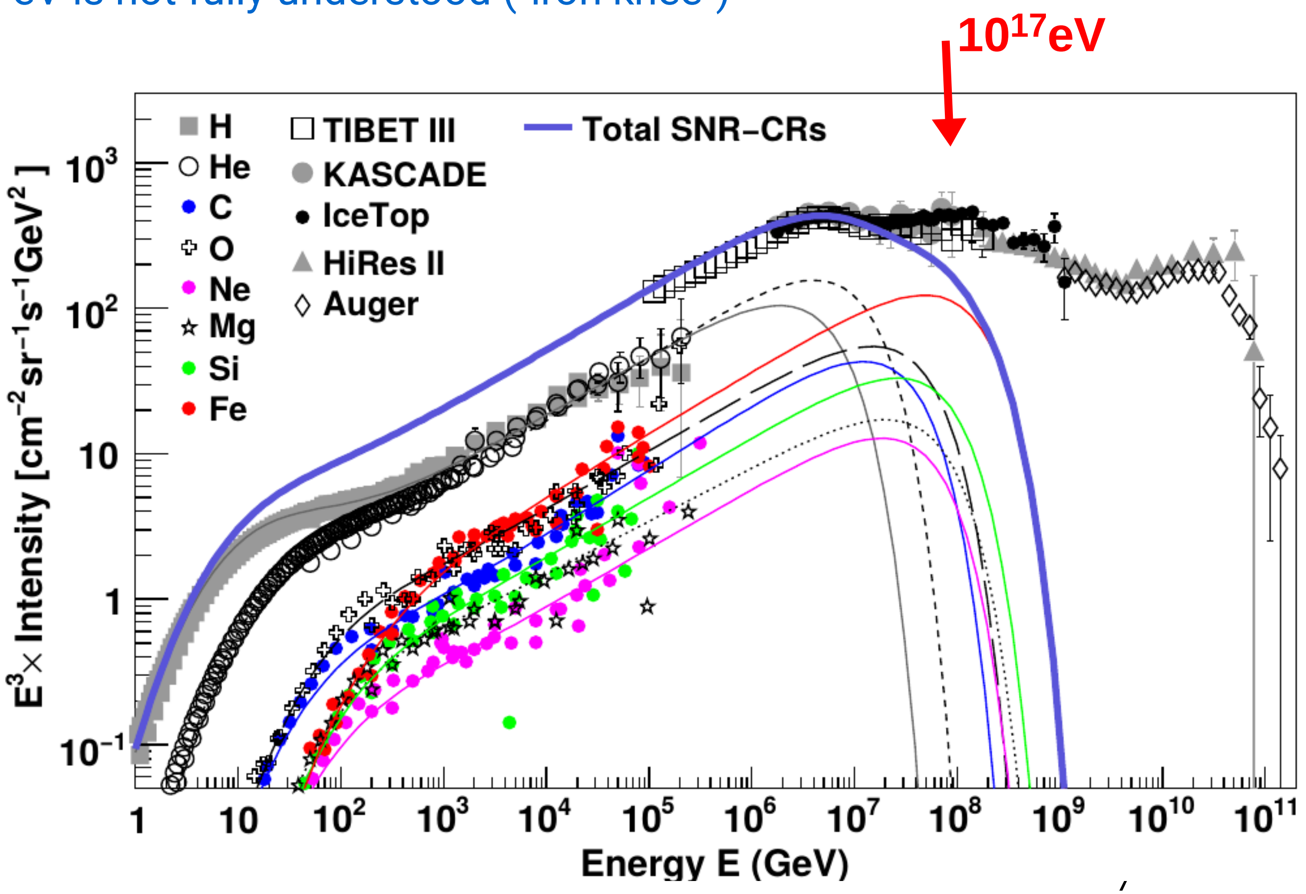
Nature, 531 (2016)

Cosmic Rays: below knee

confined in galaxy by magnetic field

- comparable energy density in interstellar medium as thermal gas and magnetic fields
- heavy elements contribute (some composition data from satellites at low E)
- second knee at 10^{17} eV is not fully understood ("iron knee")

aceleration model in shockwaves of Supernova remnants



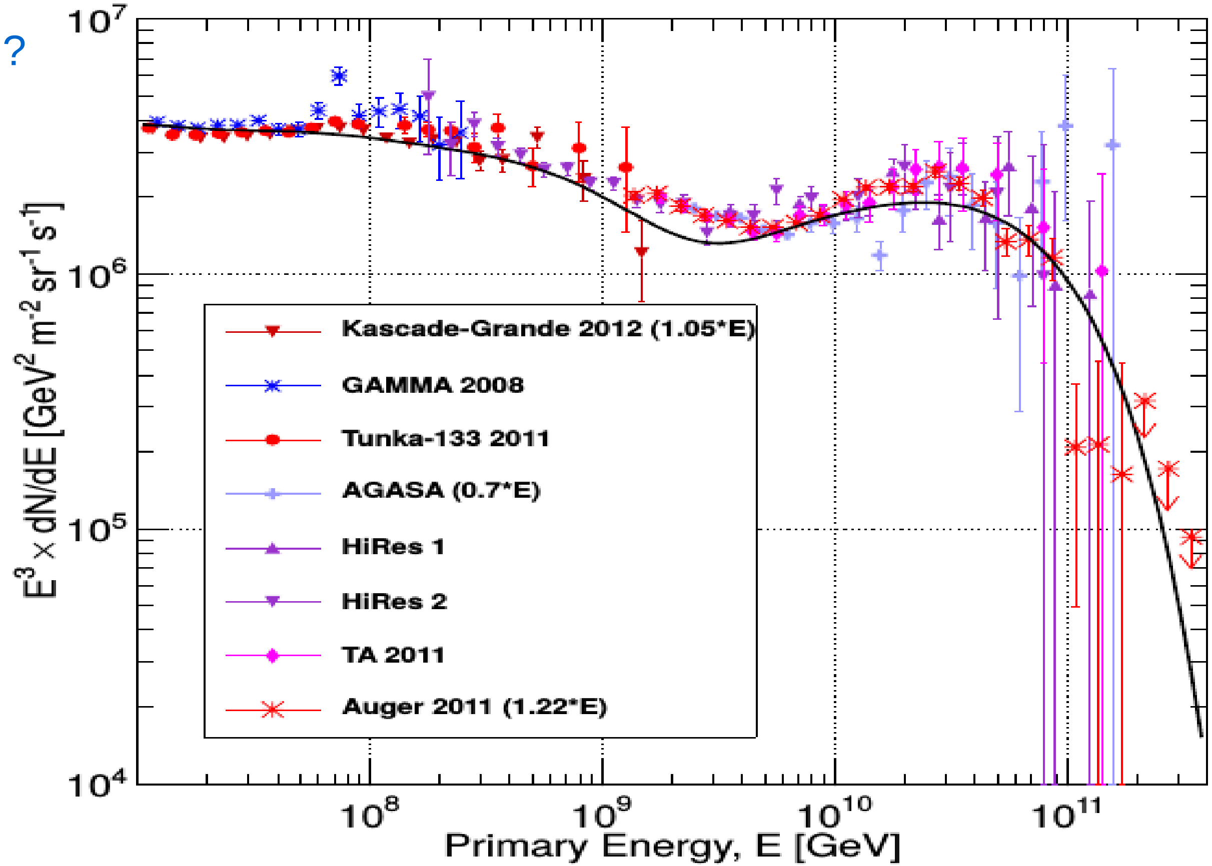
S. Thoudam et al., arXiv:1605.03111v2

Cosmic Rays: data above knee

Auger data: Water Cherenkov tanks, 3000 km^2 in Argentinia
Telescope array: 500 scintillator detectors, 1000 km^2 in Utah

- extensive studies about energy calibration
- GZK cut-off confirmed
- Most likely extragalactic
- Acceleration mechanism?

10^{17}eV



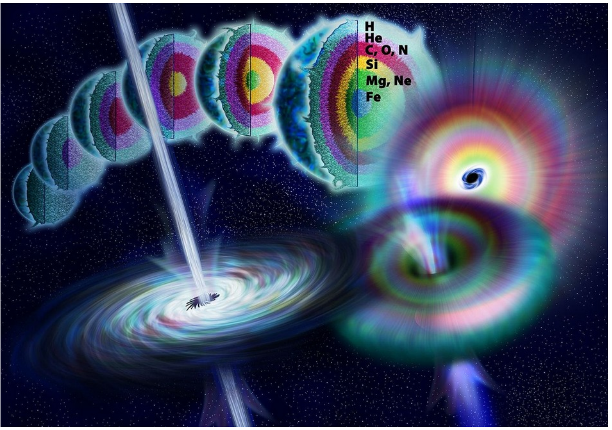
Gaisser et al.,
arXiv:1303.3565v1

Cosmic Rays: above knee

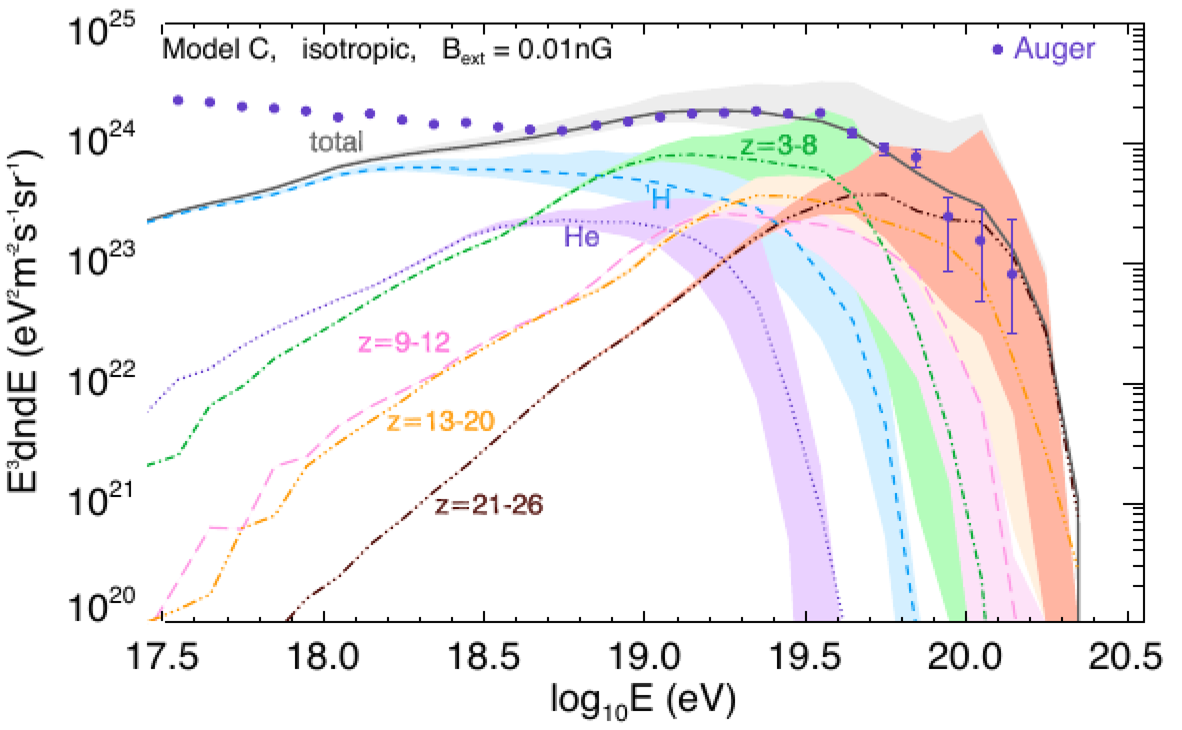
Gamma Ray Bursts?

- Speculations about originating from gamma ray bursts (GRB) brightest electromagnetic events in the Universe
- Heavy nuclei may explain some data beyond proton GZK cut-off

Artist view of GRB:



- SLSN collapsing into black hole
- Very far away, very high energy
- Energy release along the axis of rotation
- Last 10 msec to hours



N. Globus et al., arXiv:1409.1271v1

Detect very high energy Gamma Rays!

To improve knowledge on origin of cosmic rays, accelerator mechanisms, and other high energy sources

- Cosmic rays are charged, thus deviated by magnetic fields -> no way to know origin -> Use neutrinos or photons
- Other fundamental physics: Dark matter annihilation, Possible energy dependance of travel time (Quantum gravity).

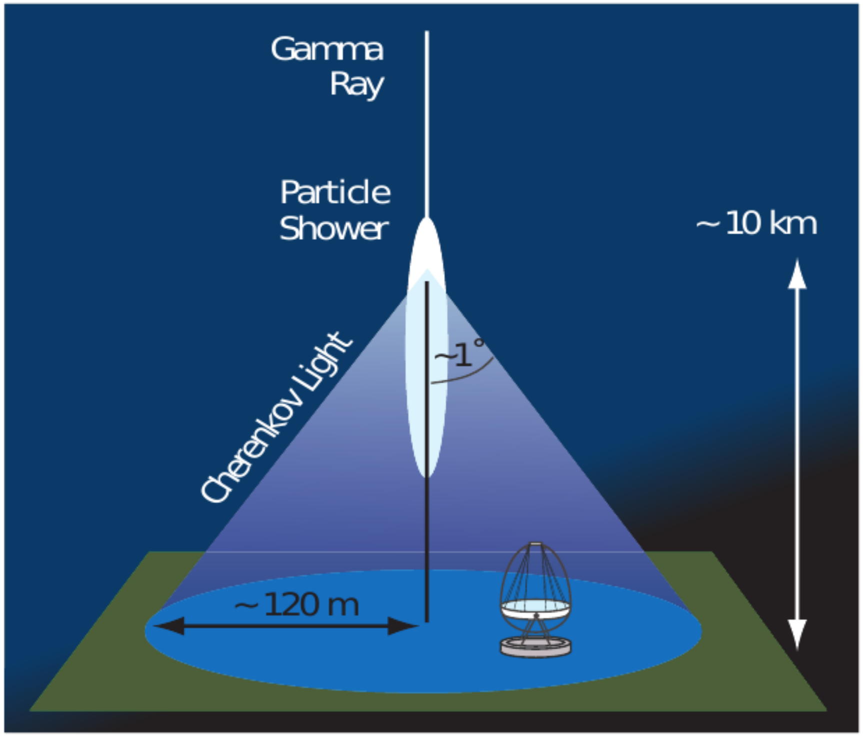
Very high energy photons from GRB and other possibly unknown sources: very low rate.

- Very big detection surface because of low statistics -> earth bound
- Pointing accuracy
- Some energy accuracy
- Wide FoV to be able to make scans
- Fast reaction on GRB alert

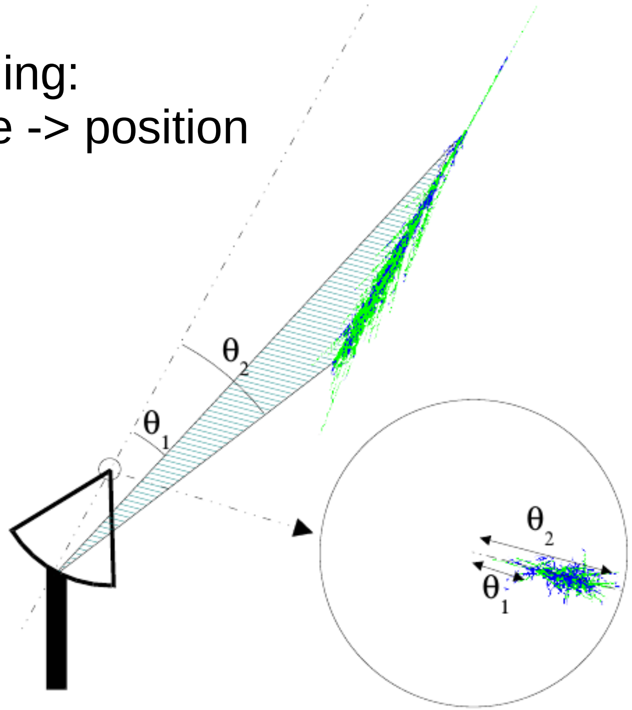
-> Imaging Atmospheric Cherenkov Telescope IACT

IACT and CTA concept

Cherenkov Telescope



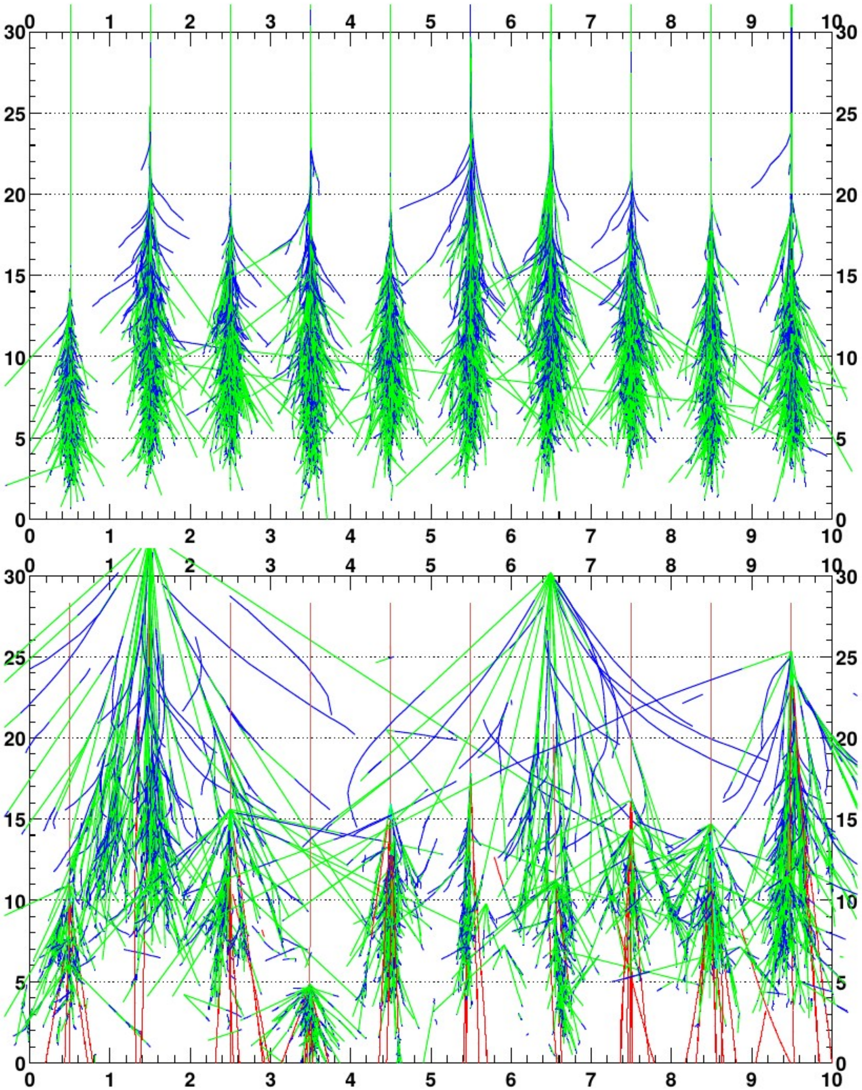
Imaging:
angle -> position



Extensive Air shower:

- Cosmic particle -> particle shower -> Cherenkov light
- "Pancake of particles": diameter 250m, thickness 1 m, 3ns
- Need telescope with large focal plane camera -> high FoV

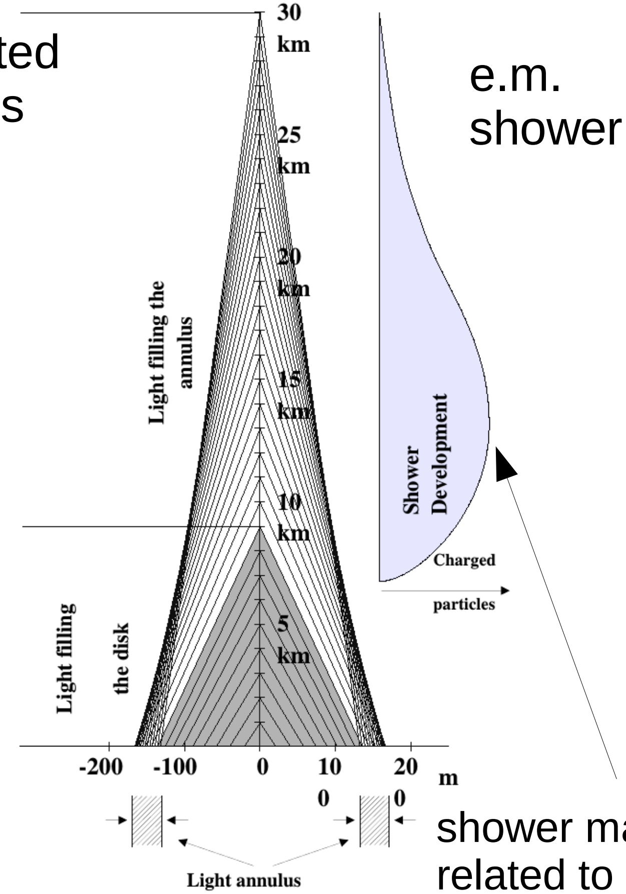
Cherenkov Telescope



10 Simulated air showers

Photons

Hadrons



e.m. shower

shower max related to E

Shower ends at E_c=83 MeV

M. de Naurois, D. Mazin
arXiv:1511.00463v1

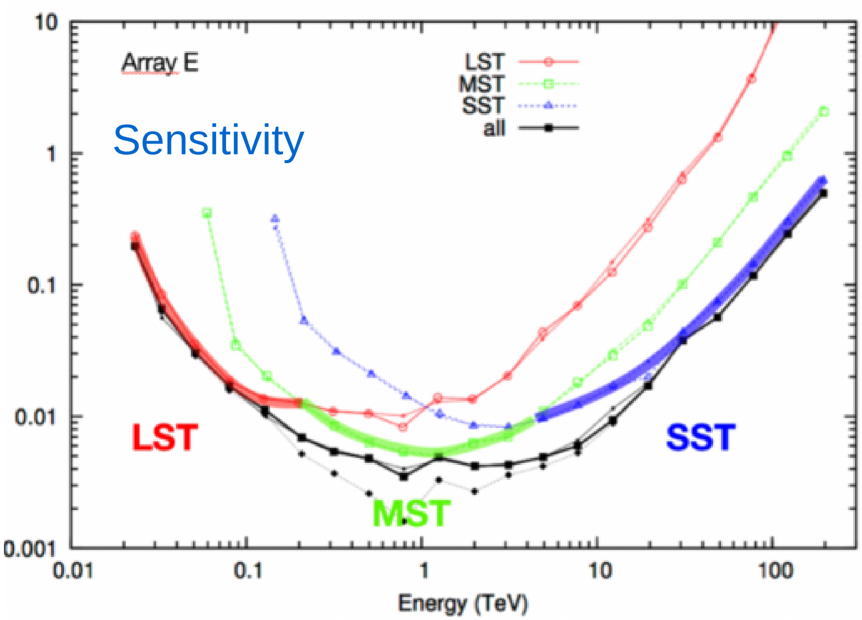
Cherenkov Telescope Array

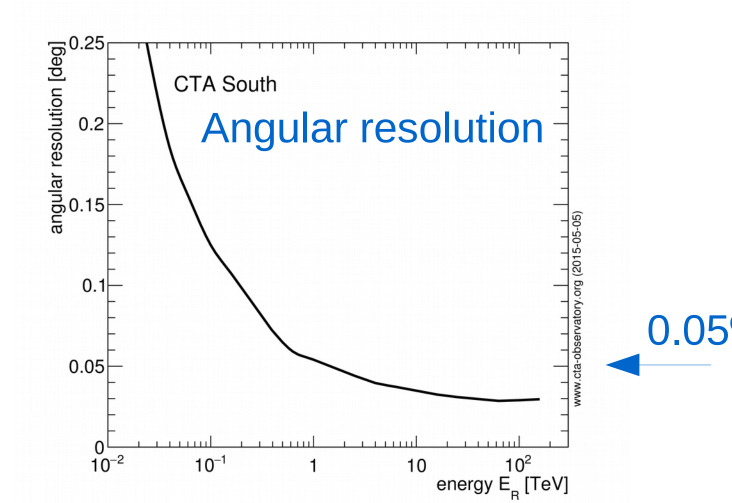
Requirements:

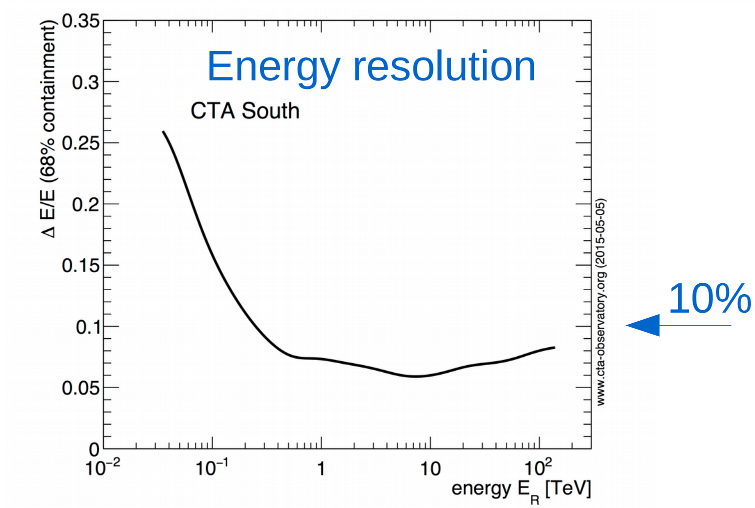
- Pointing accuracy, Energy resolution -> use relatively simple telescopes
- Big detection surface -> use array of telescopes
- Sensitive from 20 GeV to 300 TeV:
  - Low energy -> low light -> large telescope; high rate -> few telescopes
  - High energy -> lots of light -> cheap telescope; low rate -> many telescope.
- Wide FoV to be able to make scans -> big cameras
- Fast reaction on GRB alert -> fast repositioning

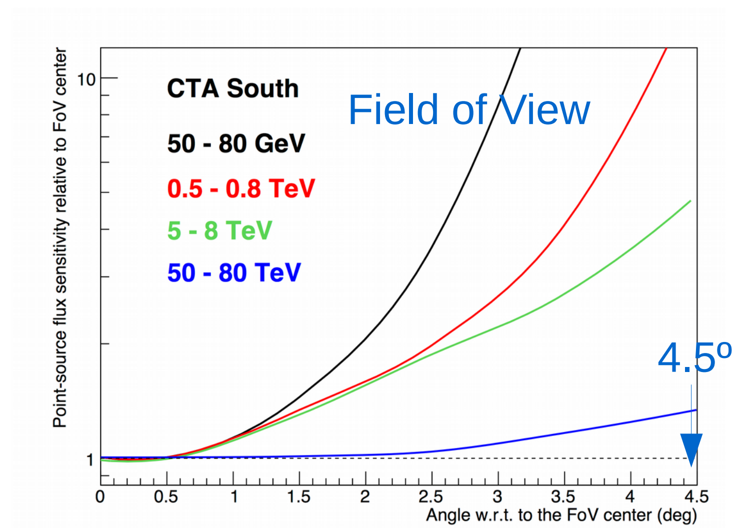
CTA uses three types of telescopes in South (North) Array:
4 (4) Large (LST), 25 (15) Medium (MST), 70 Small (SST)

Cherenkov Telescope Array





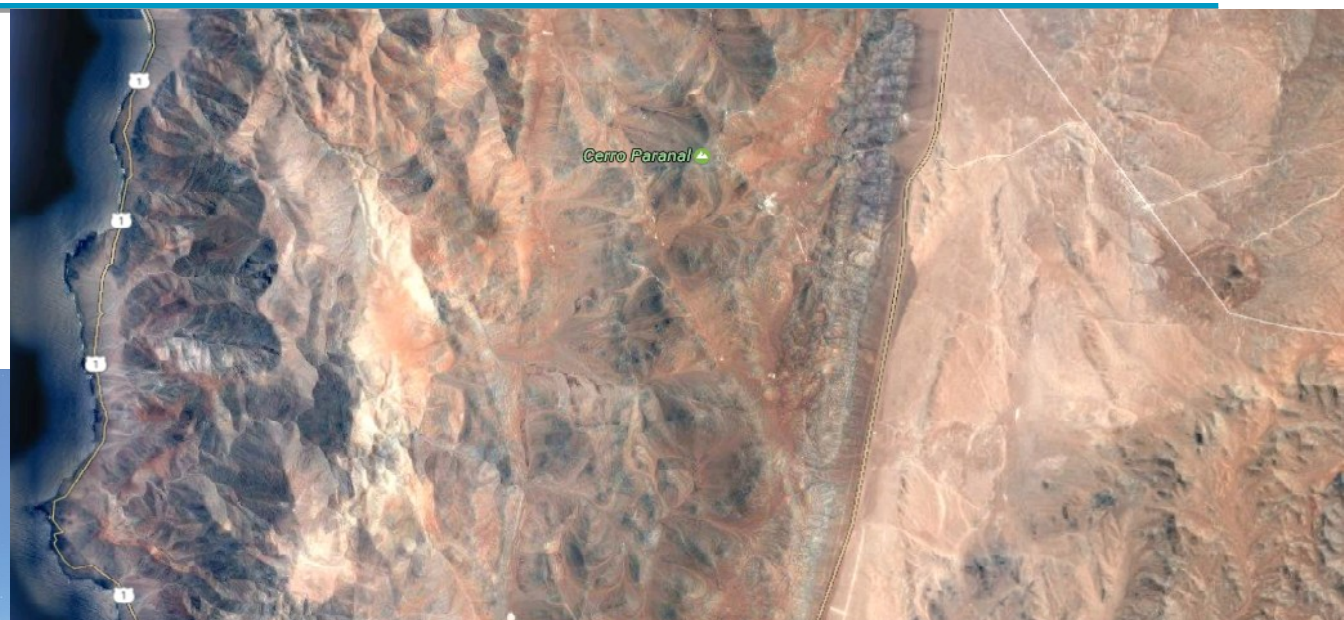


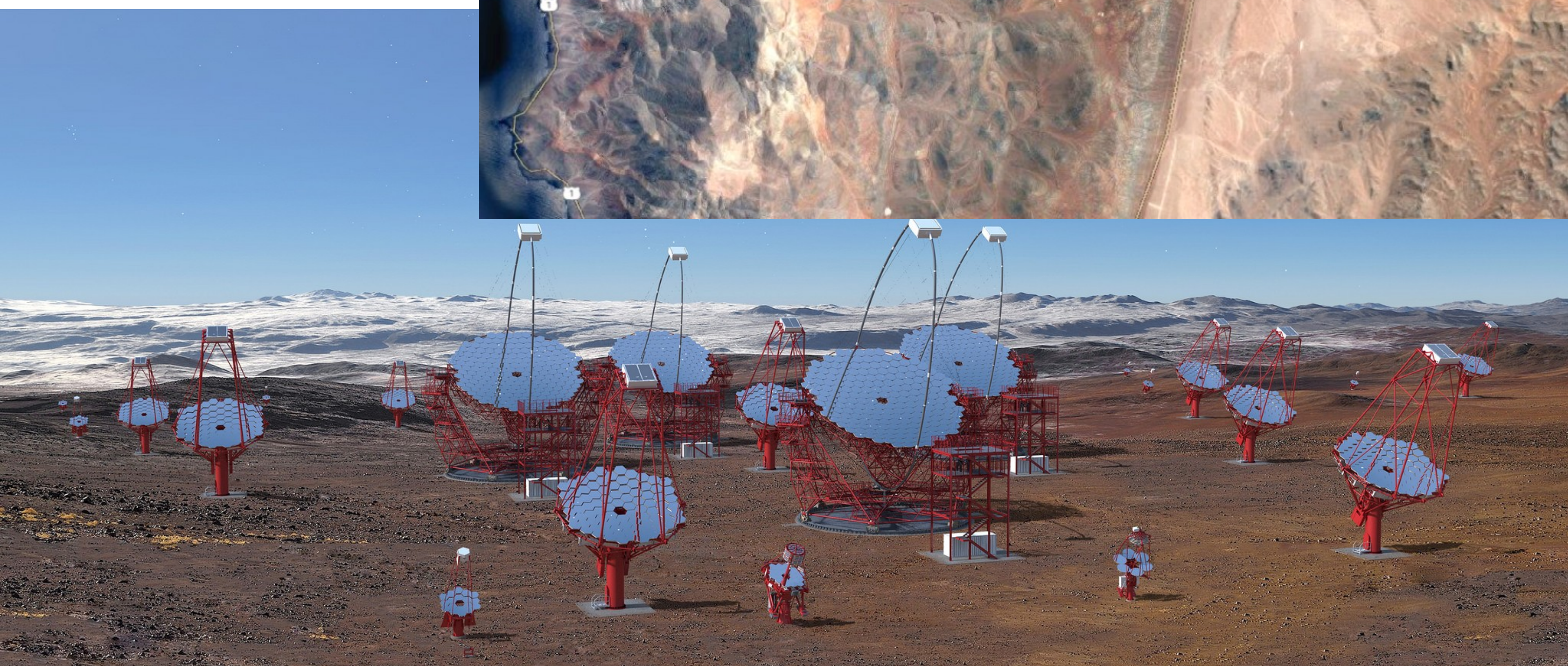


CTA project details

South Site

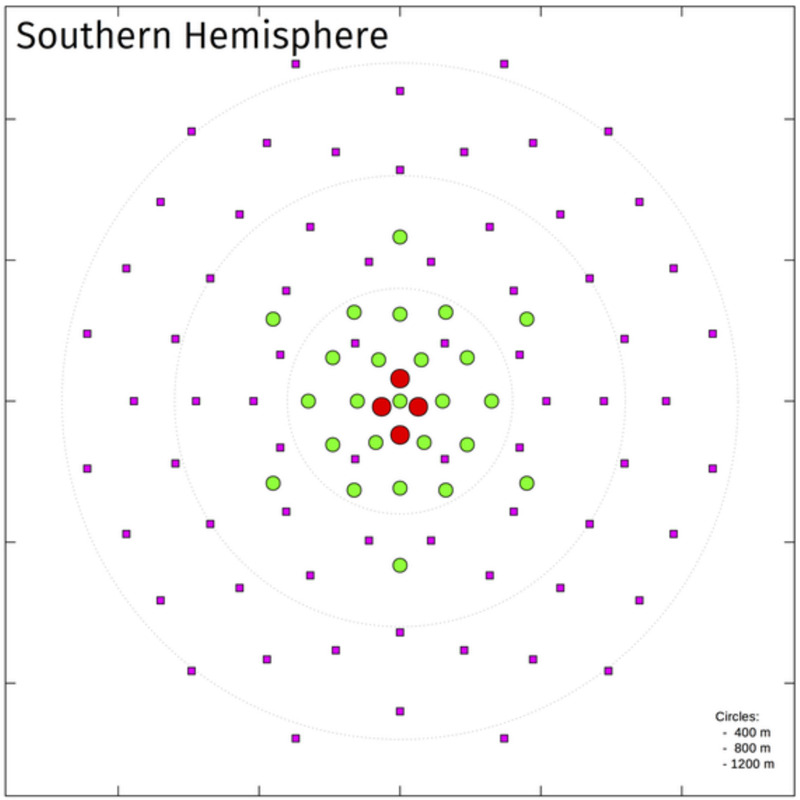
Atacama desert,
ESO site, Chile



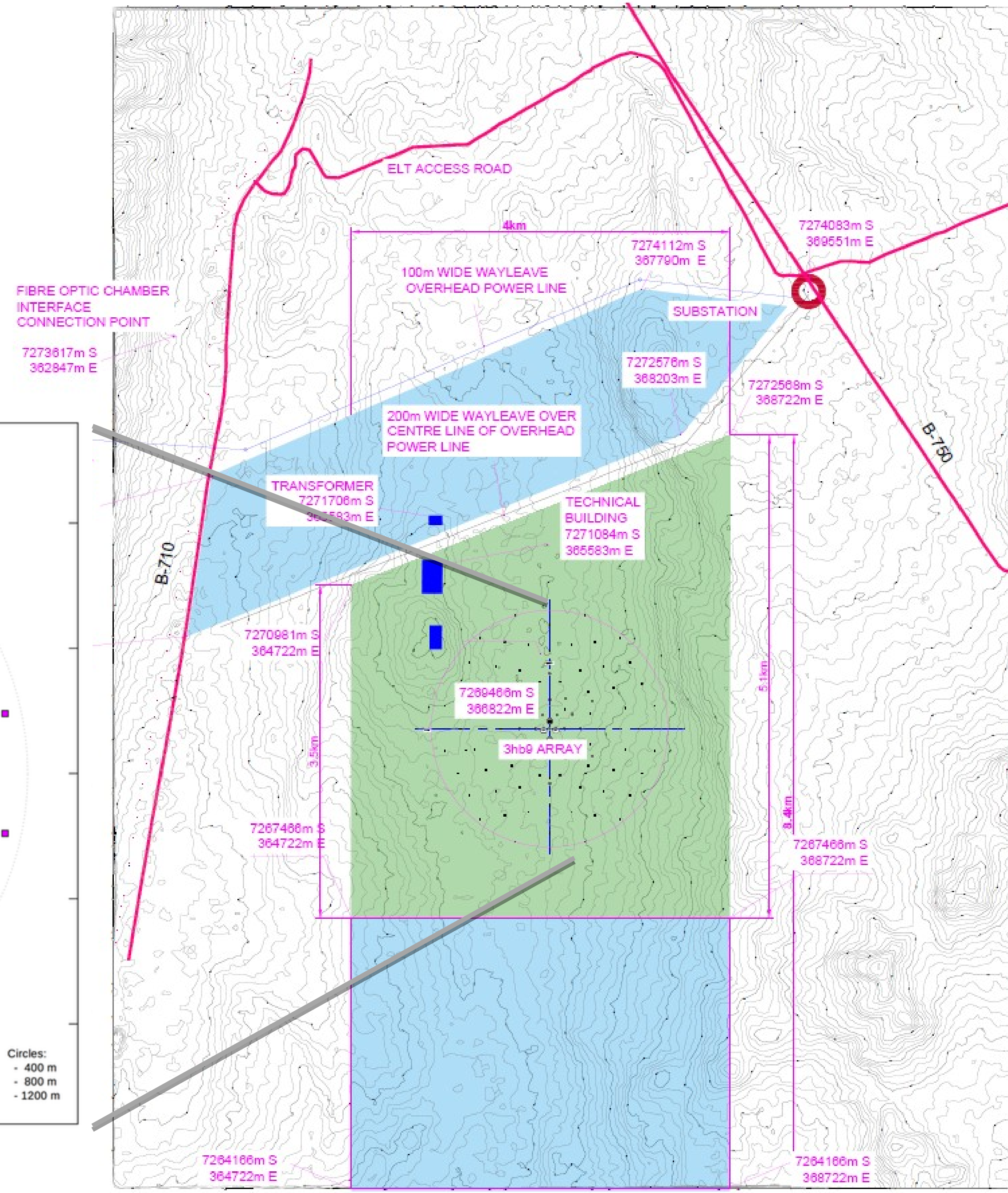


South Layout

4 LST
25 MST
70 SST



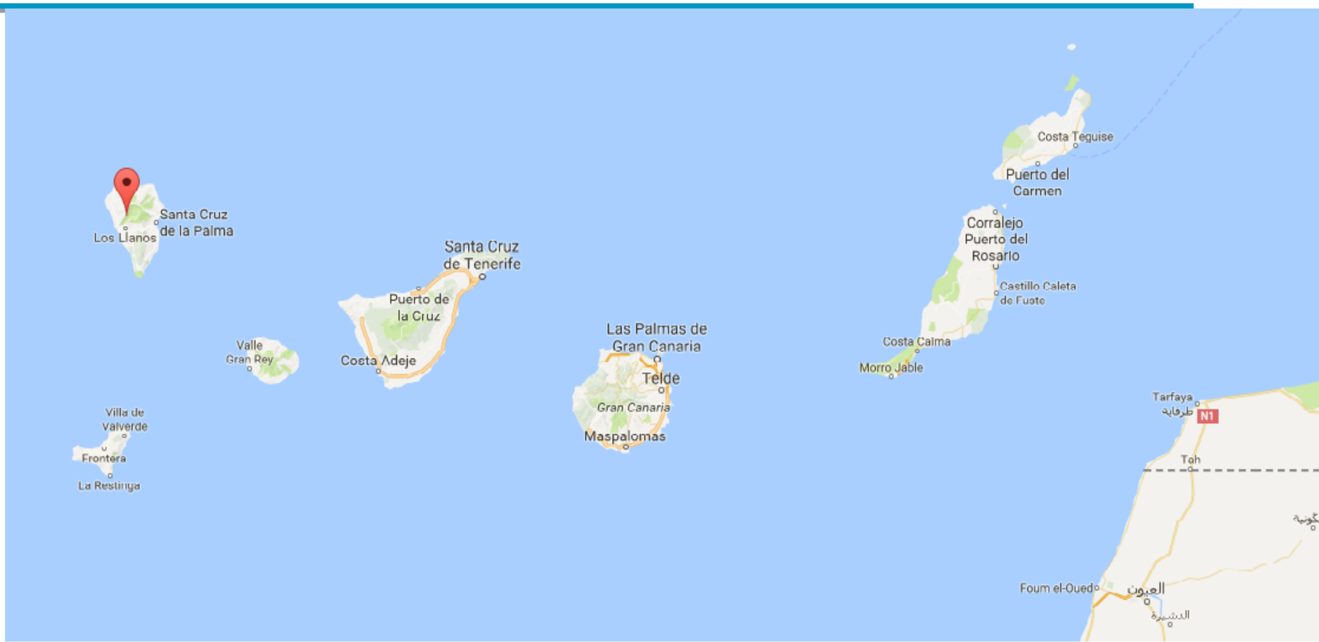
4 LSTs, 25 MSTs, 70 SSTs



Sites & Site Infrastructure

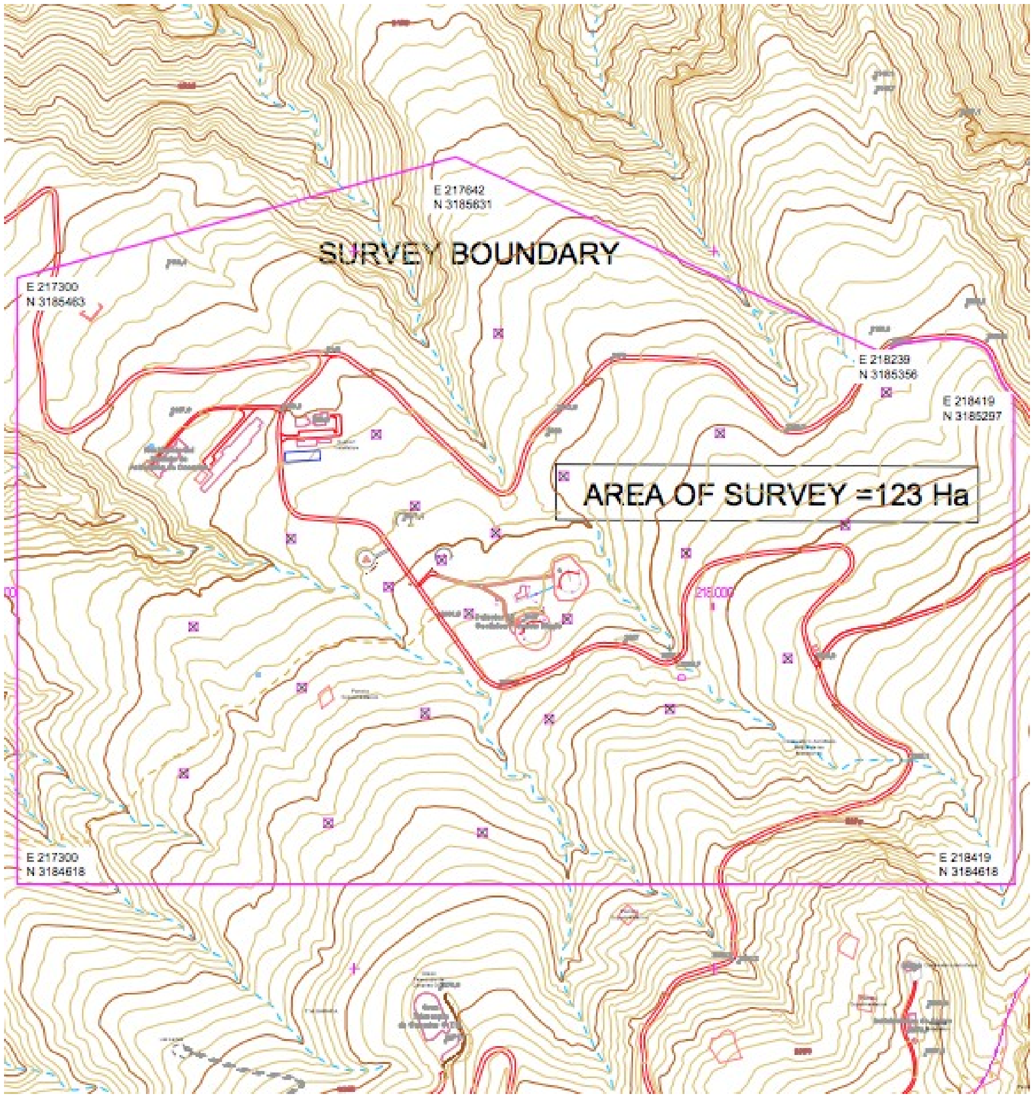
North Site

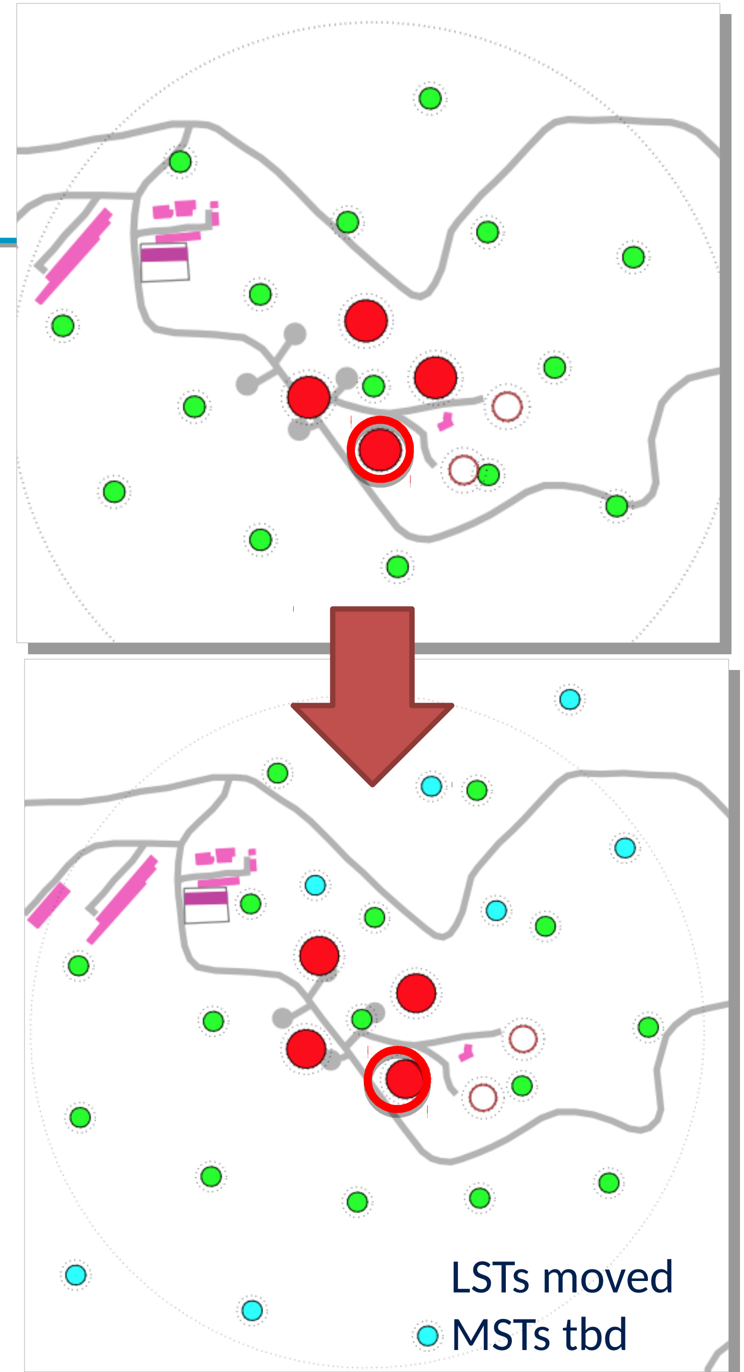
La Palma,
Canary Islands,
IAC site



North Layout

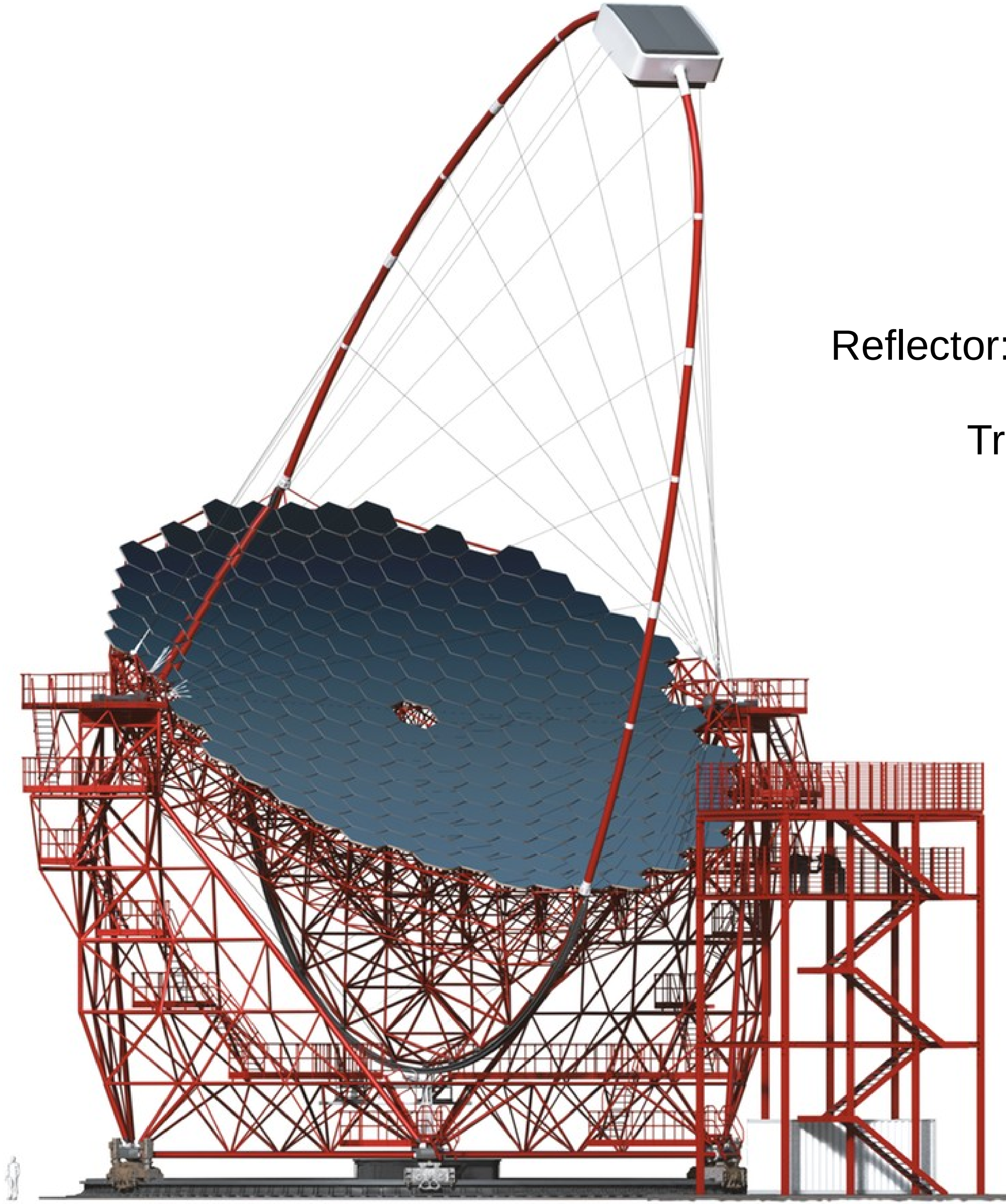
4 LST
15 MST





November 2016
Foundation Construction of LST 1

Sites & Site Infrastructure



LST cta

Reflector: parabolic, Diameter=23m, f=28m
Point Spread Function: 0.05º
Tracking accuracy online: 20 arcsec

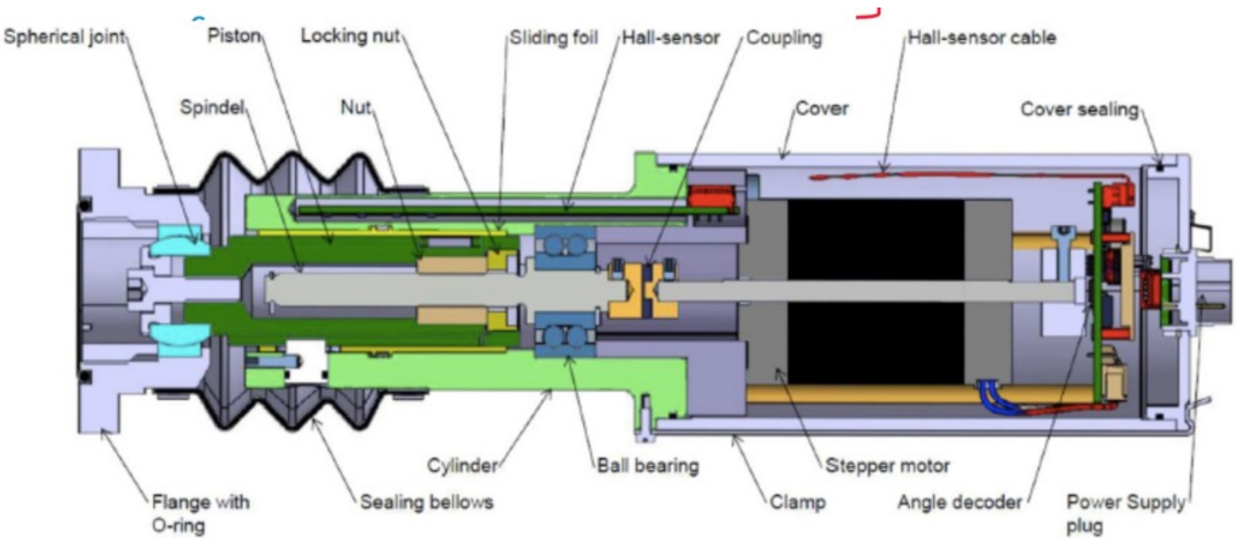
Weight moving parts 103 tons
Repositioning time 20sec.

1855 Pixels of PMT with FoV 0.1º
FoV total 4.5º

Optimized for 20 ... 200 GeV

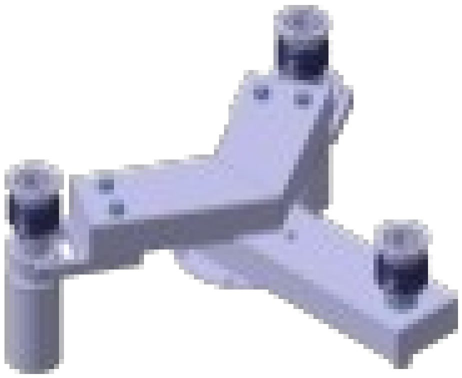
Mirror actuators

Mirror segments need to be adjusted individually
2 Actuators, one fixed point per segment.   Zurich design



To be used for LST, also for MST, SST-1M

mirror segment mounting flansh for SST-1M



MST cta

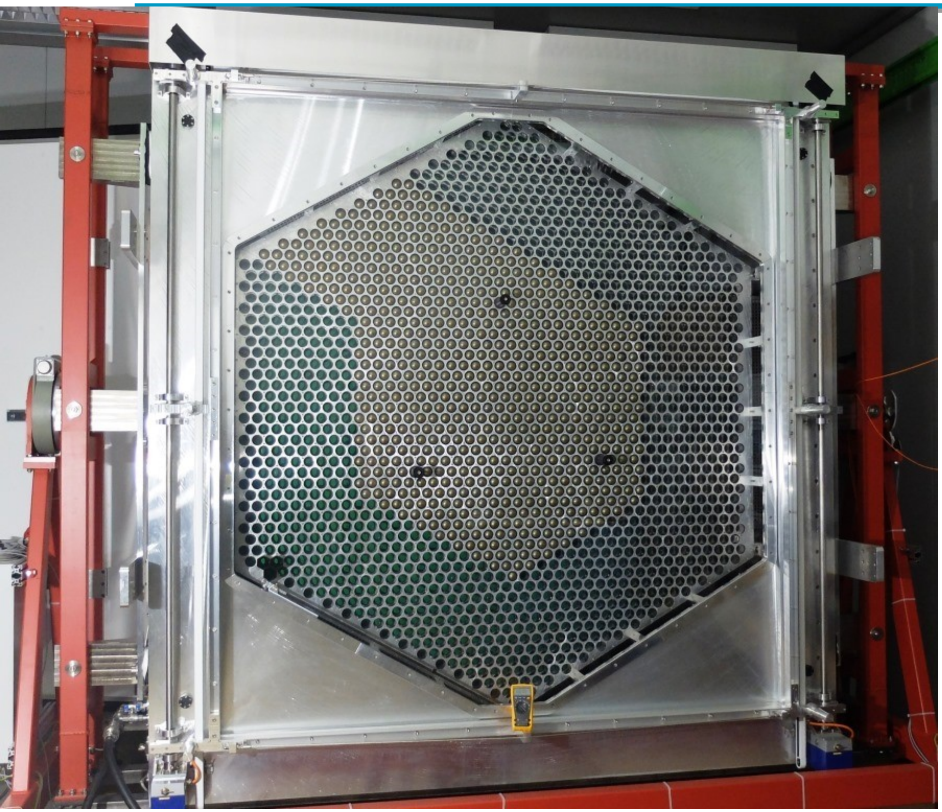
Reflector: spherical, Diameter=12m, f=19.2m
Point Spread Function: 0.18º
Tracking precision: 0.1º
Pointing precision 7 arcsec

Repositioning time 90sec.

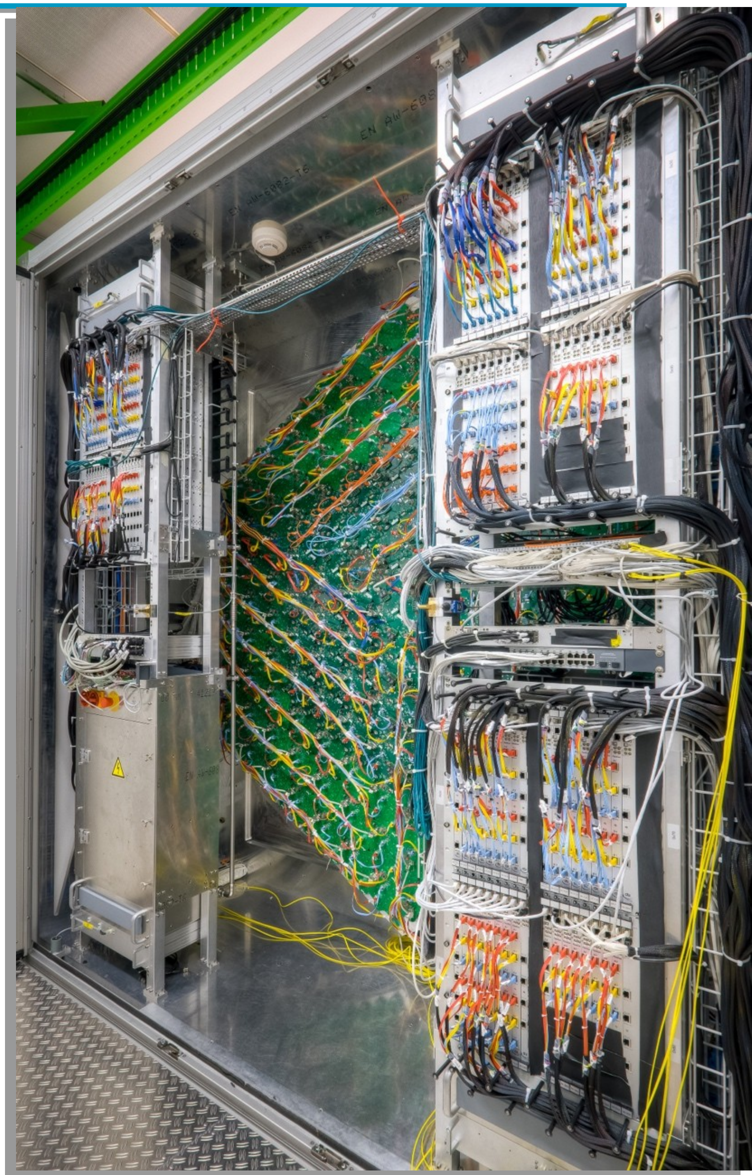
1700 Pixels of PMT with FoV 0.18º
FoV total 7º

Number foreseen 15 (N), 25 (S)
Optimized for 100 GeV ... 10 TeV

MST Camera: 2 options. only FlashCam shown here.



- Fully digital readout, 250 MS/s ADC
- digital trigger on same data
- Protoype 24/7 operation for several months
- >30 kEvents/sec readout without no dead time,
- slow control, trigger, timing interfaces work
- parts of electronics / mechanics designed at UZH



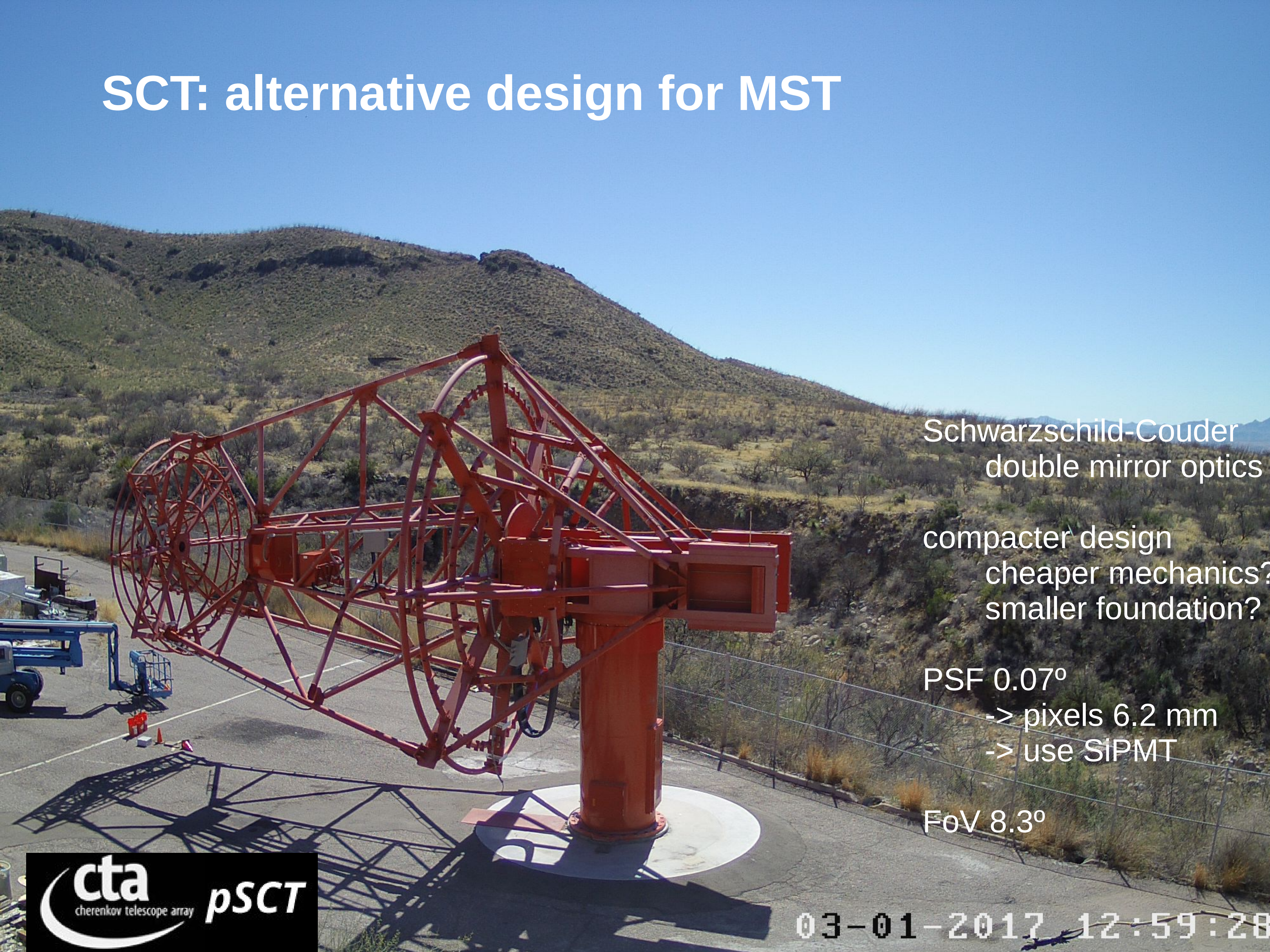
SCT: alternative design for MST

Schwarzschild-Couder
  double mirror optics

compacter design
  cheaper mechanics?
  smaller foundation?

PSF 0.07º
  -> pixels 6.2 mm
  -> use SiPMT

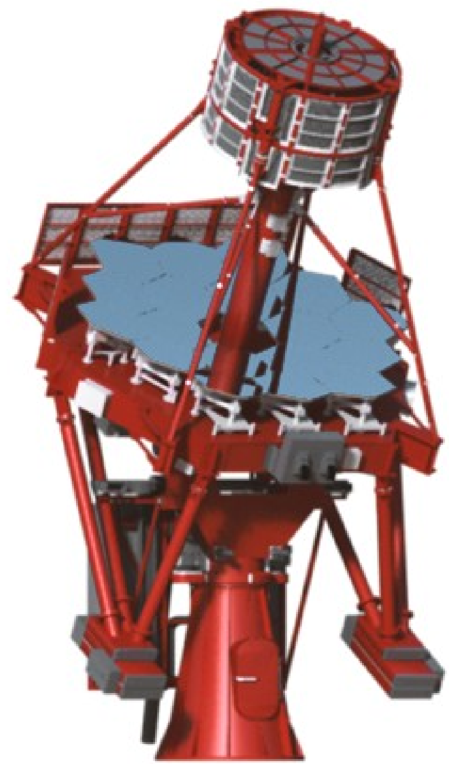
FoV 8.3º



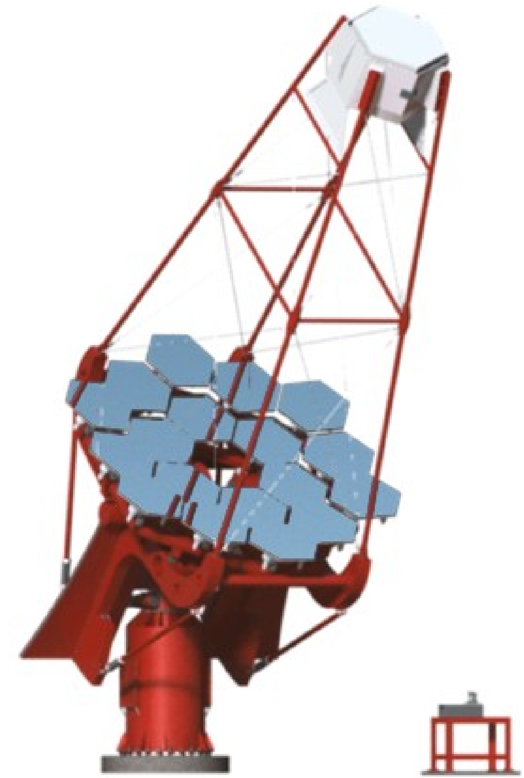
SST Telescopes

- 70 SSTs planned for South, 3 TeV ... 300 TeV, 6 m²
- large showers, lots of light, low statics -> large area needed
- Main challenge: Reliability!
- Three options: very nice -- how to choose?

SST-2M GCT

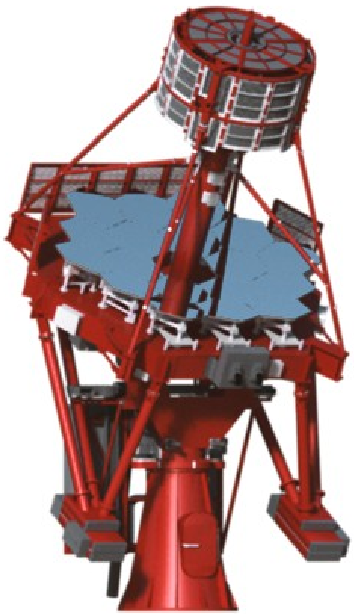


SST-2M ASTRI

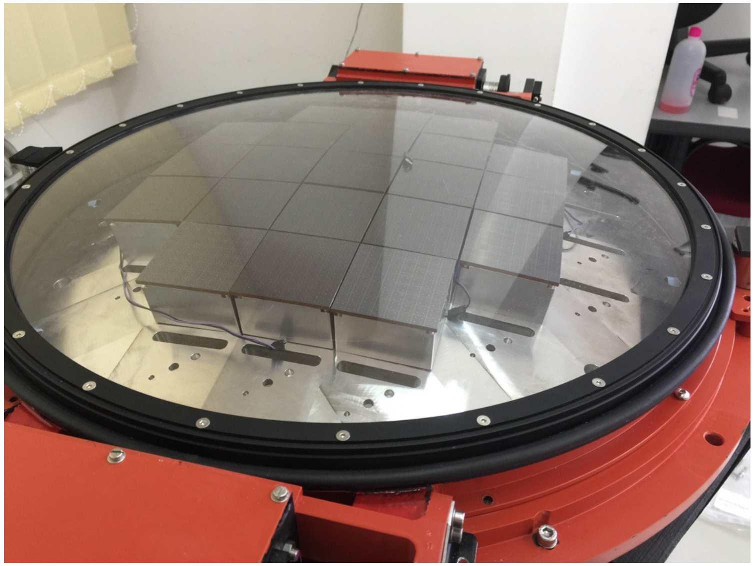


SST-1M

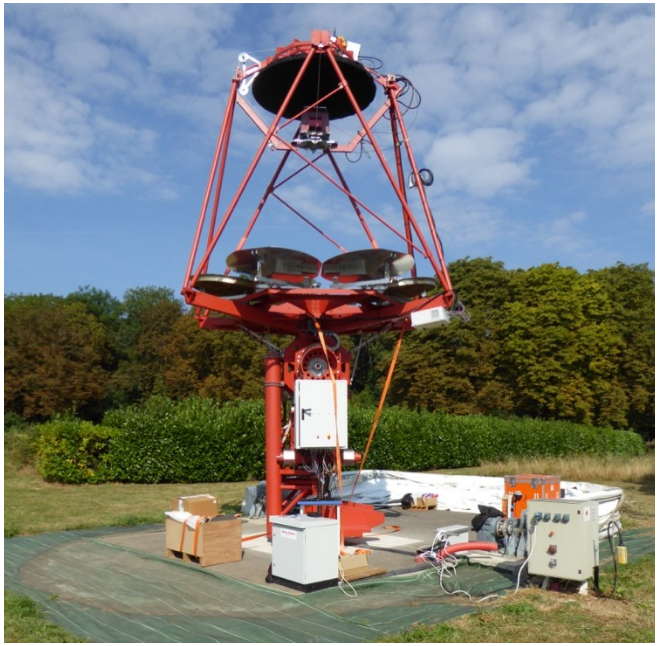
ASTRI Prototype in Sicily

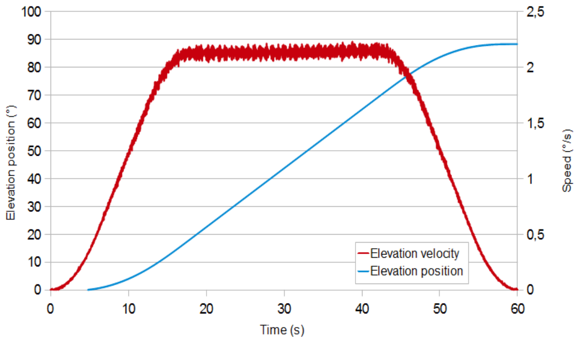


- 1984 pixels, size 6.1 mm, SiPMT
-



SST-2M-GCT:

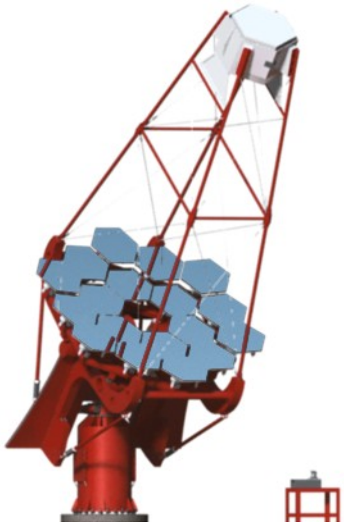




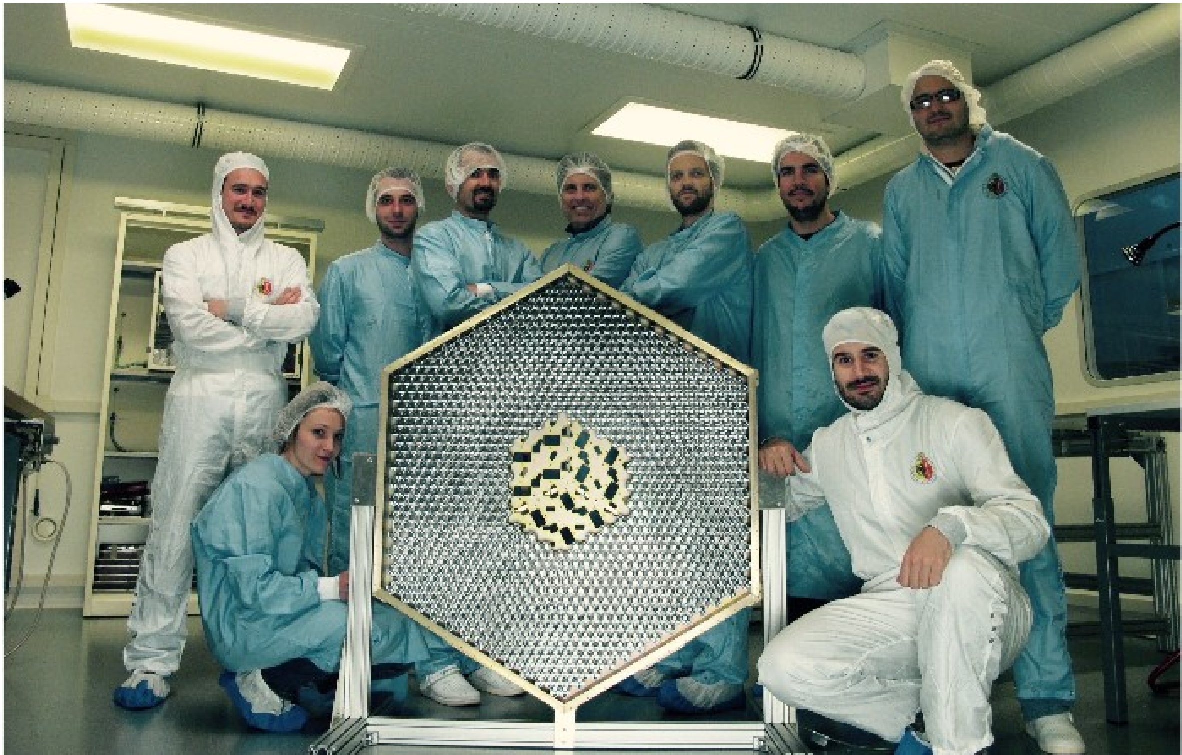
Azimuth and elevation maximum velocities: the telescope can reach to any point in the sky within **60s**.

Protoype in Meudon, Paris
Camera protoype with MC-PMT
New version planned with SiPMT

SST-1M



- Davies Cotton single mirror telescope
- focal length 5.6 m
- FoV 9.1º
- PSF 0.08º
- 1296 pixels of 6mm, SiPMT readout
- Camera built by UniGe
- Protoype structure
  in Poland

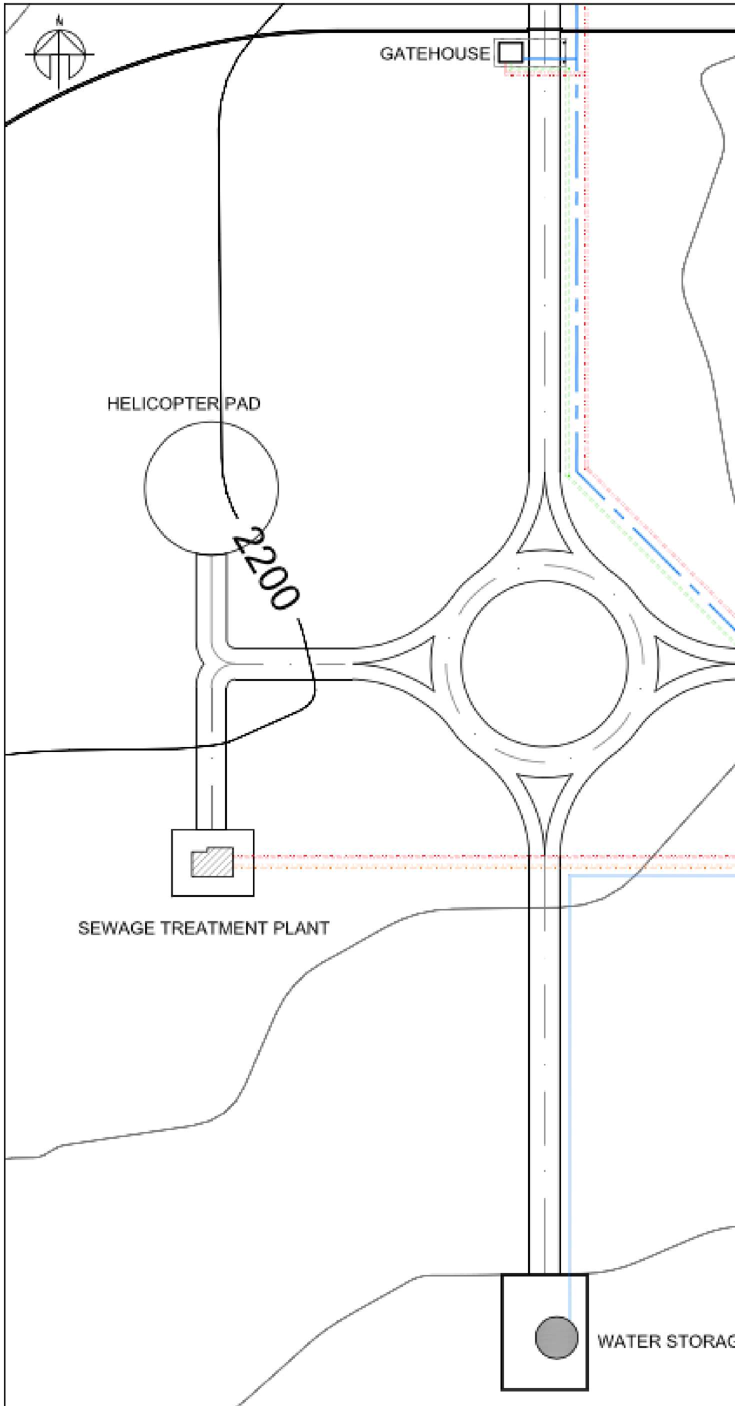


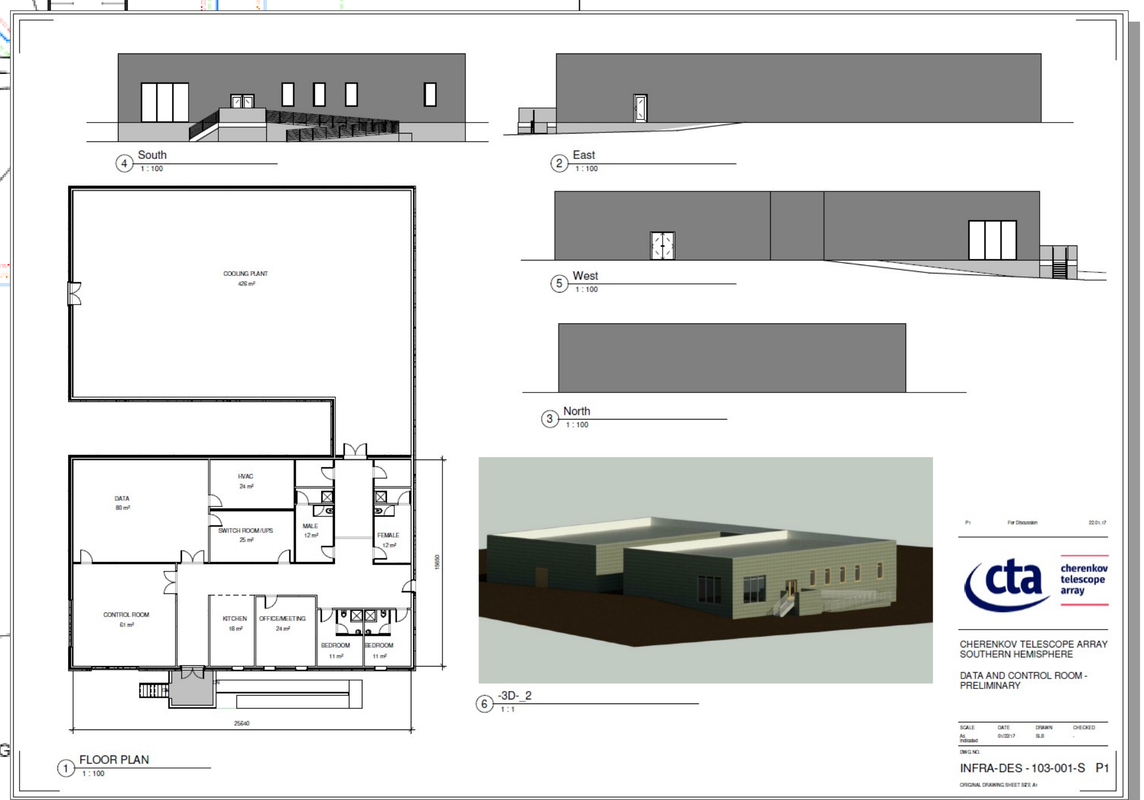
More infrastructure

- Buildings
- Roads
- Foundations
- Power
- Datanetwork
- Software
- Computers

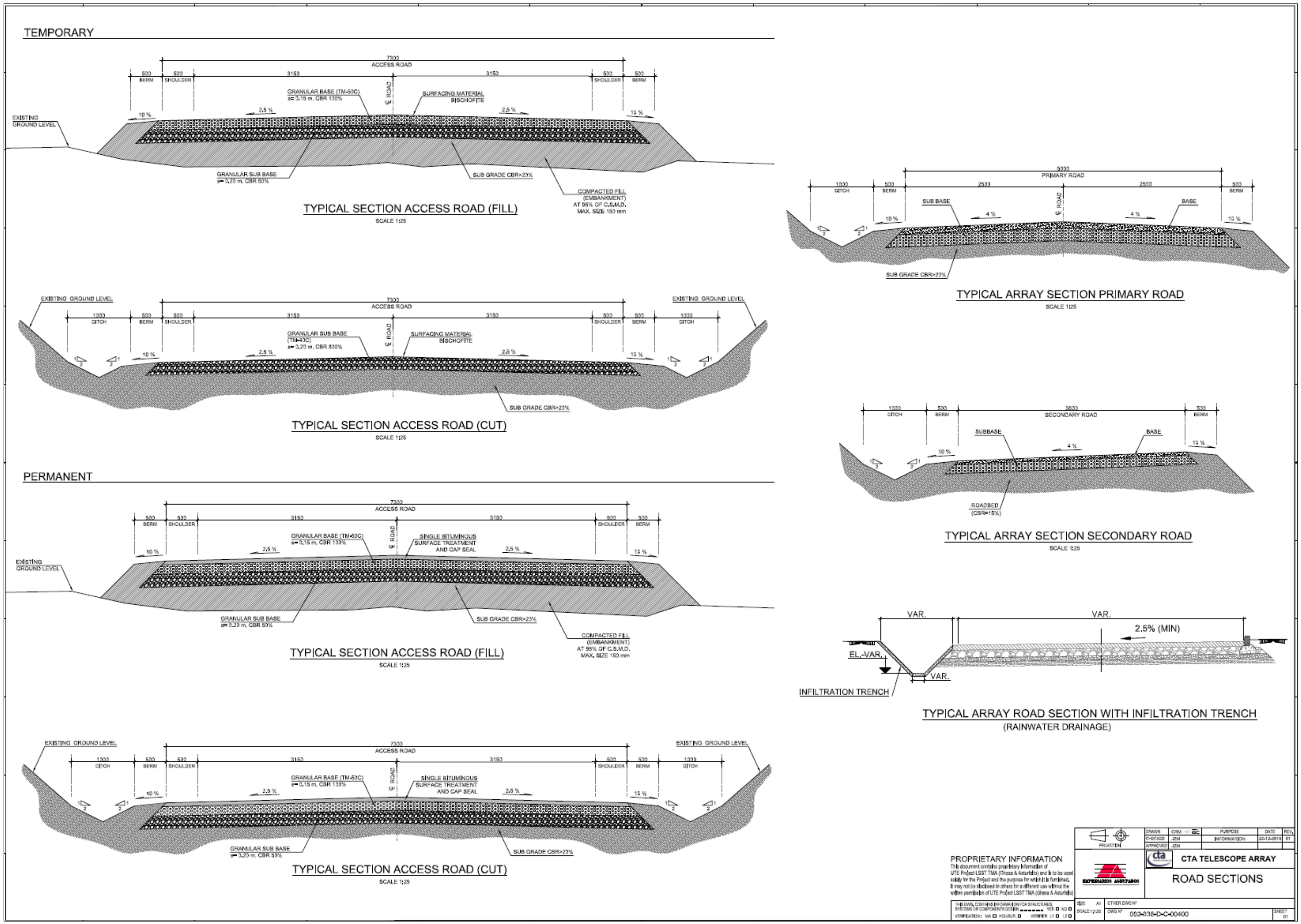
Interfaces - Interfaces - Interfaces

Layout studies

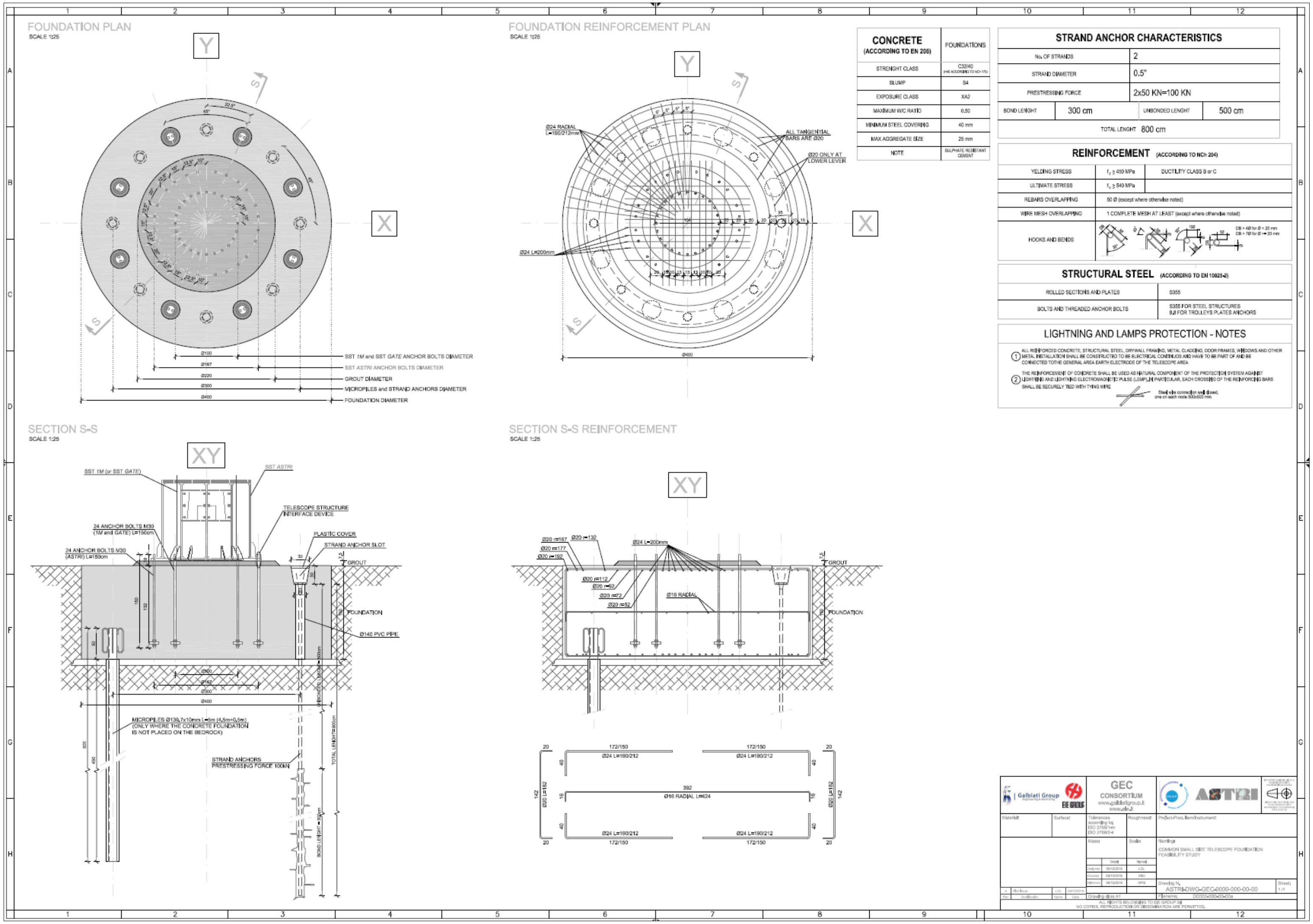




Roads


TEMPORARY
TYPICAL SECTION ACCESS ROAD (FILL)
TYPICAL SECTION ACCESS ROAD (CUT)
PERMANENT
TYPICAL SECTION ACCESS ROAD (FILL)
TYPICAL SECTION ACCESS ROAD (CUT)
TYPICAL ARRAY SECTION PRIMARY ROAD
TYPICAL ARRAY SECTION SECONDARY ROAD
VAR.
VAR.
2.5% (MIN)
EL.-VAR.
VAR.
INFILTRATION TRENCH
TYPICAL ARRAY ROAD SECTION WITH INFILTRATION TRENCH
(RAINWATER DRAINAGE)
PROPRIETARY INFORMATION
CTA TELESCOPE ARRAY
ROAD SECTIONS

Universal SST Foundation



CONCRETE (ACCORDING TO EN 206)	FOUNDATIONS
STRENGHT CLASS	C32/40 (H40 ACCORDING TO NCh 170)
SLUMP	S4
EXPOSURE CLASS	XA2
MAXIMUM W/C RATIO	0,50
MINIMUM STEEL COVERING	40 mm
MAX AGGREGATE SIZE	25 mm
NOTE	SULPHATE RESISTANT CEMENT

STRAND ANCHOR CHARACTERISTICS			
No. OF STRANDS	2		
STRAND DIAMETER	0.5"		
PRESTRESSING FORCE	2x50 KN=100 KN		
BOND LENGHT	300 cm	UNBONDED LENGHT	500 cm
TOTAL LENGHT	800 cm		

REINFORCEMENT (ACCORDING TO NCh 204)		
YELDING STRESS	$f_y \geq 450$ MPa	DUCTILITY CLASS B or C
ULTIMATE STRESS	$f_u \geq 540$ MPa	
REBARS OVERLAPPING	50 Ø (except where otherwise noted)	
WIRE MESH OVERLAPPING	1 COMPLETE MESH AT LEAST (except where otherwise noted)	
HOOKS AND BENDS	DB > 4Ø for Ø < 20 mm; DB > 7Ø for Ø >= 20 mm	

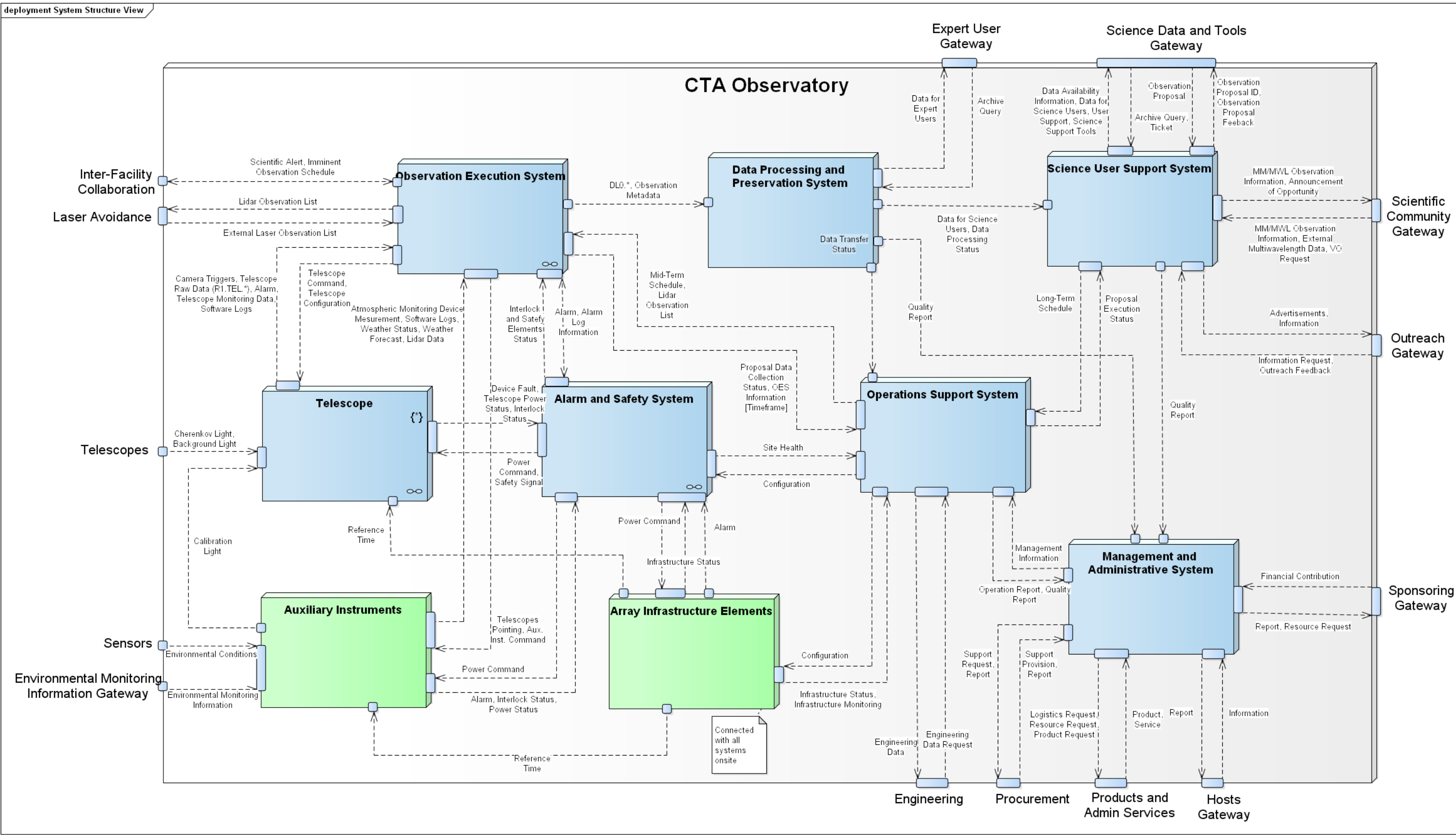
STRUCTURAL STEEL (ACCORDING TO EN 10025-2)	
ROLLED SECTIONS AND PLATES	S355
BOLTS AND THREADED ANCHOR BOLTS	S355 FOR STEEL STRUCTURES 8.8 FOR TROLLEYS PLATES ANCHORS

LIGHTNING AND LAMPS PROTECTION - NOTES

1. ALL REINFORCED CONCRETE, STRUCTURAL STEEL, DRYWALL FRAMING, METAL CLADDING, DOOR FRAMES, WINDOWS AND OTHER METAL INSTALLATION SHALL BE CONSTRUCTED TO BE ELECTRICAL CONTINUOS AND HAVE TO BE PART OF AND BE CONNECTED TOTHE GENERAL AREA EARTH ELECTRODE OF THE TELESCOPE AREA
2. THE REINFORCEMENT OF CONCRETE SHALL BE USED AS NATURAL COMPONENT OF THE PROTECTION SYSTEM AGAINST LIGHTNING AND LIGHTNING ELECTROMAGNETIC PULSE (LEMP). IN PARTICULAR, EACH CROSSING OF THE REINFORCING BARS SHALL BE SECURELY TIED WITH TYING WIRE

Steel wire connection well closed, one on each node 500x500 mm

CTA Software Architecture

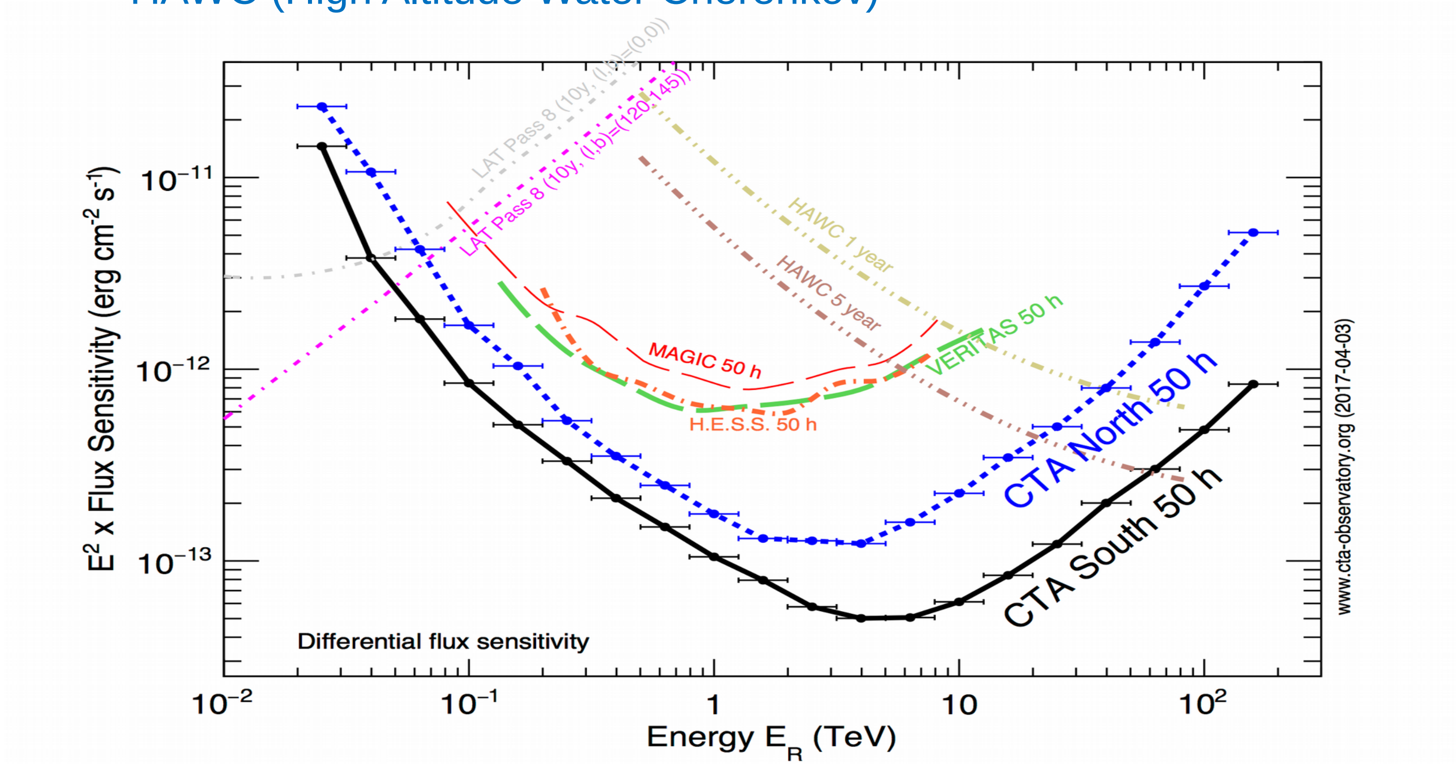


North Computing & Network

- Final specifications agreed for the full northern computing & network system
  - 1500 processor cores
  - 2 PB disk space
  - Switches: 4 x 10 Gb Ethernet to each LST, 2 x 10 Gb to each MST
  - Located in 40 ft contained with air cond., UPS
- Procurement documentation in preparation

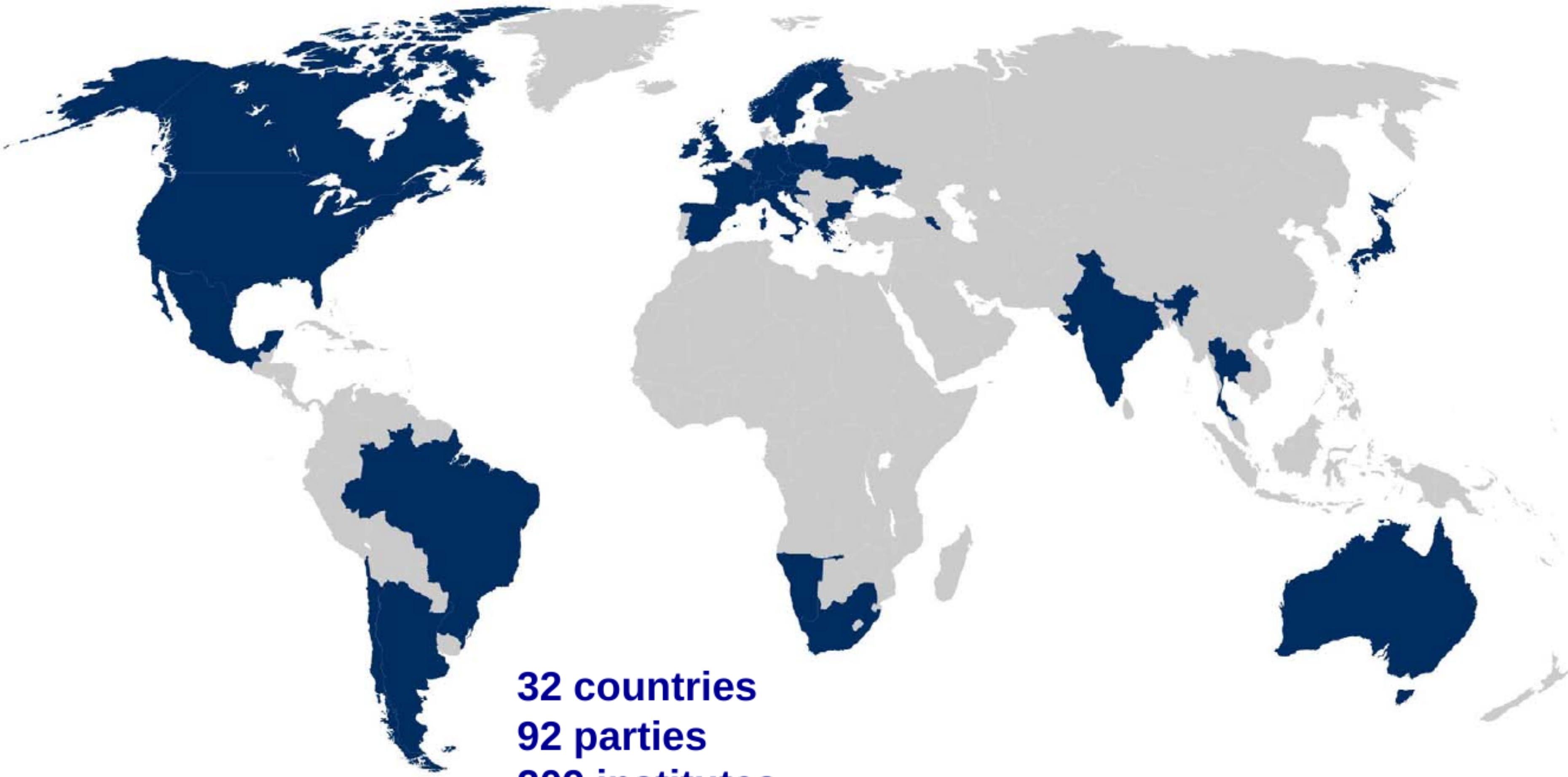
Sensitivity

- Overall system sensitivity (5 sigma discovery limit reached in 50 h)
- Comparing to existing detectors
  - LAT on Fermi satellite
  - Magic on La Palma (2 IACT)
  - H.E.S.S. in Namibia (5 IACT)
  - VERITAS in US (4 IACT)
  - HAWC (High Altitude Water Cherenkov)



Government

CTA Consortium, growing since 2006



32 countries
92 parties
209 institutes
1346 members (456 FTE)

CTAO GmbH and more politics

- The countries which intend to significantly contribute financially for construction and operation founded a limited liability company, called CTAO GmbH in 2014.
- Present shareholders with formal voting rights:
  - Austria (University of Innsbruck)
  - France (CRNS, CEA),
  - Germany (DESY. MPG),
  - Italy (INAF, INFN),
  - Japan (Uni Tokio),
  - Czech Republic,
  - Spain,
  - Switzerland (University of Zurich),
  - UK (STFC).
- Associate members:
  - The Netherlands,
  - South Africa,

Council of CTAO GmbH

- The council is the main governing body of CTAO gGmbH.
- It consists of shareholder representatives, each country may have up to two shareholders.
- Counil has set up 3 committees with external experts who support CTAO:
  - Scientific and technical advisory committee (STAC)
  - In-kind contribution review committee (IKRC)
  - Administrative and financial advisory committee (AFC)
- Council decided on sites:
  - Headquarters in Bologna (being setup now), thus Italy = host country
  - Science Data Management Centre in Berlin-Zeuthen
  - North site in La Palma (IAC, Canary Islands)
  - South site in Atacama desert (ESO site, Chile)

Resources

- Total investment for construction: about 300 MEuro + 100 MEuro person power
- This includes infrastructure at observation sites and at European centres of about 60 MEuro
  - Streets, power, data net, service buildings, computer centres, calbration and service facilities
- Many parts are supposed to be delivered "in-kind" by the shareholders
  - Good idea, but produces a lot of legal overhead, not finished yet. Use ESS (European Spallation Source) as a template.
- Final legal entity to be defined yet. Main seat in Italy = hosting country.
- Operation costs estimated to be 16 MEuro per year (incl. personnel).
- Swiss financial contribution: 2%.
- Swiss intellectual contributions to construction:
  - SST-1M design and prototypes (Uni GE)
  - Data acquisition software (Uni GE)
  - Active mirror control (Uni Zuerich
  - FlashCam mechanics and part of electronics (Uni Zuerich)

Physics perspectives

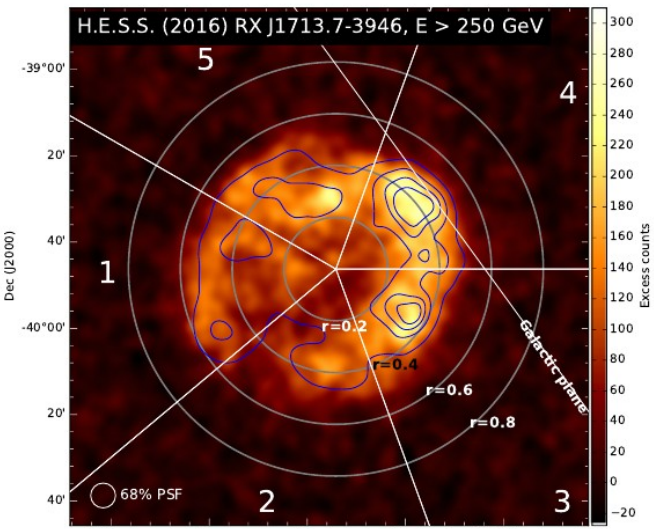
Present plan: Observation time will be split into

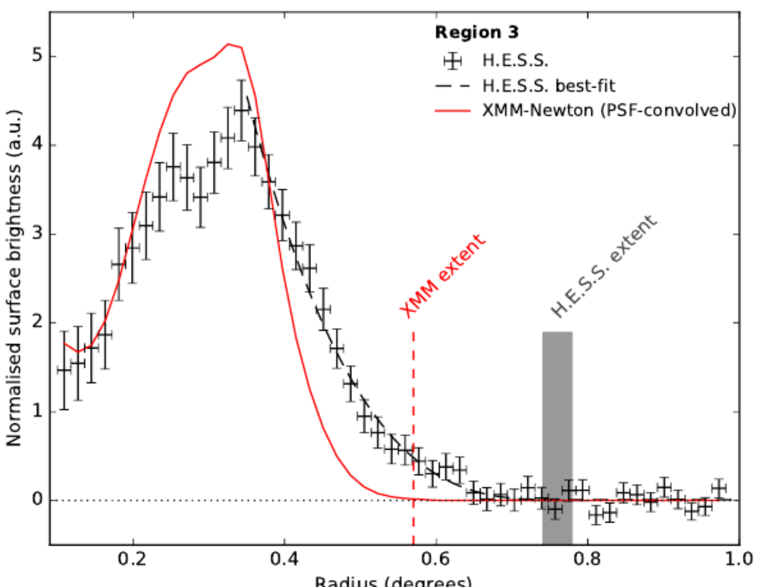
60% based on proposals to observe specific regions, everybody can hand in.

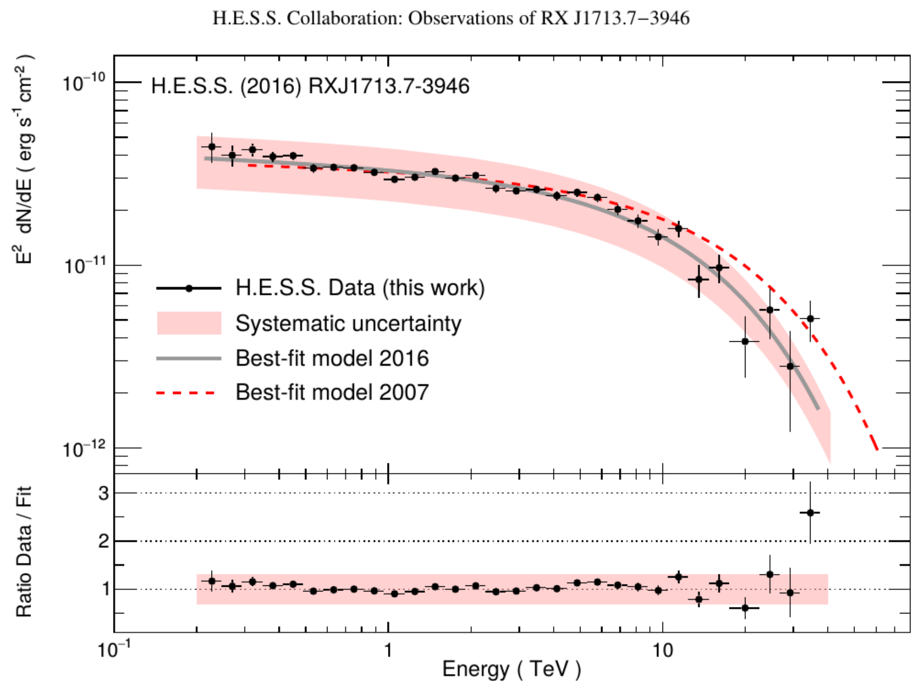
40% key science projects (organized by consortium):

- Indirect search for dark matter constituents (centre of Galaxy, satellite galax.)
- More insight in cosmic rays accelerations
- Lorentz invariance violations?

Source example







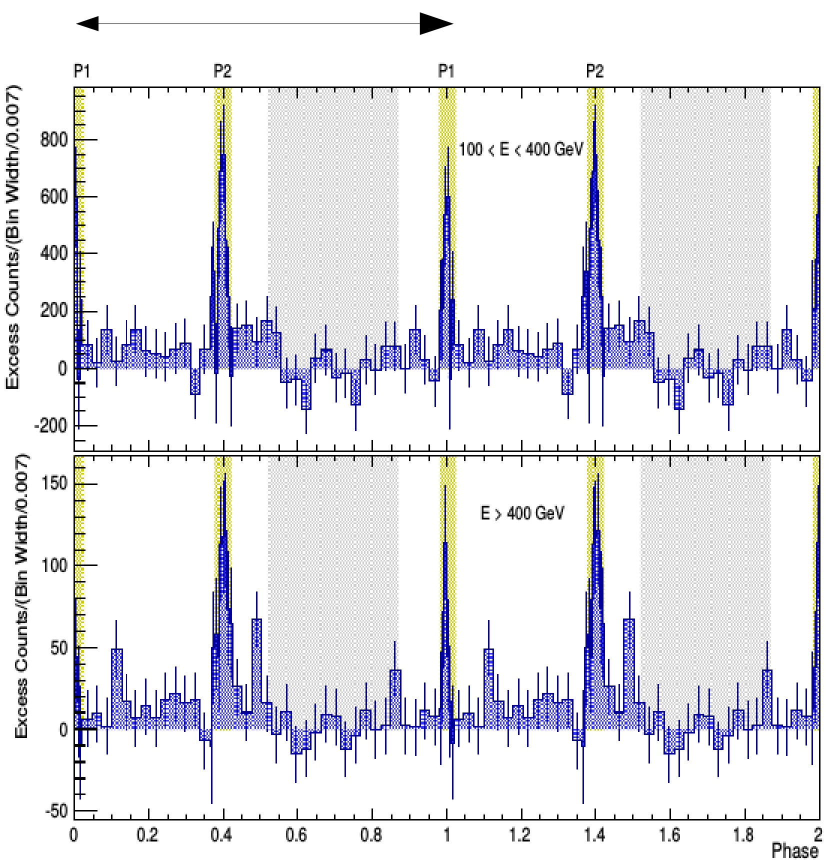
Most brilliant SNR measured so far
Visible source diameter 2 * moon!

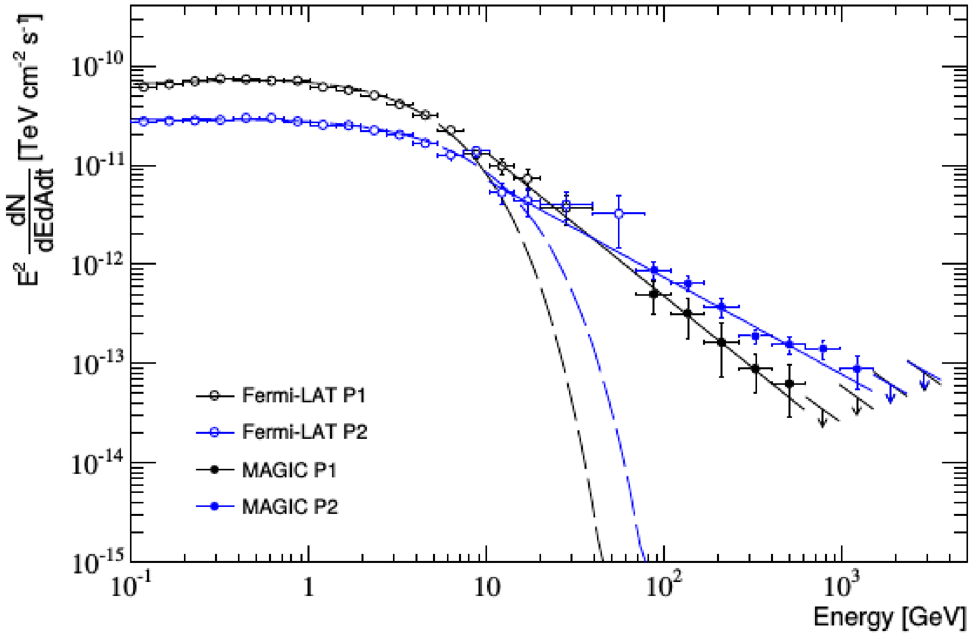
HESS collaboration, arXiv:1609.08671v2

Source example Crab Pulsar

Crab Pulsar is a neutron star, 20km diameter, rotating 30 times a second remnant of Supernova 1054.

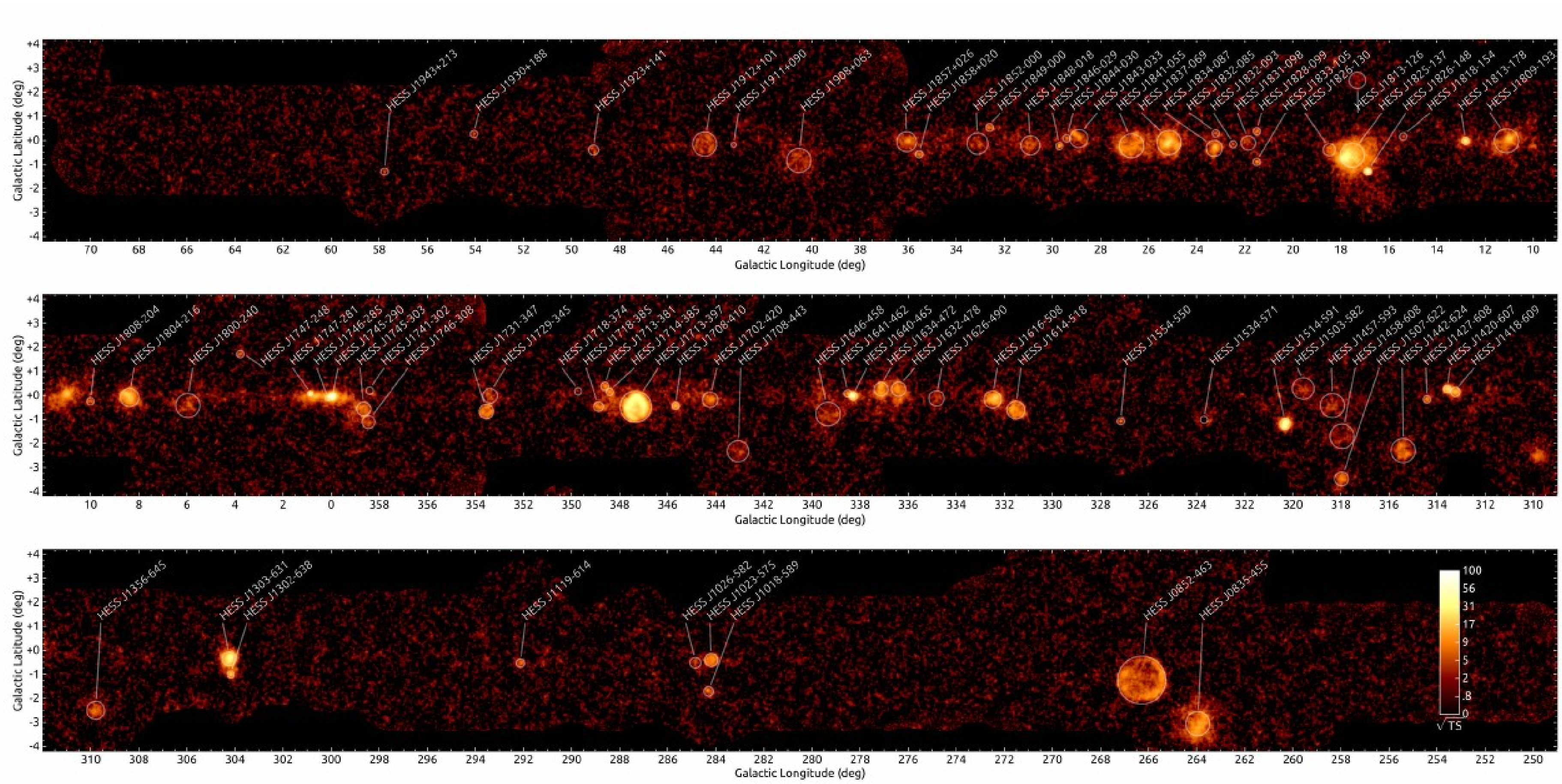
- Two pulses P1 and P2 are observed from radio up to gamma ray
- The pulses are synchronous over all the energy range



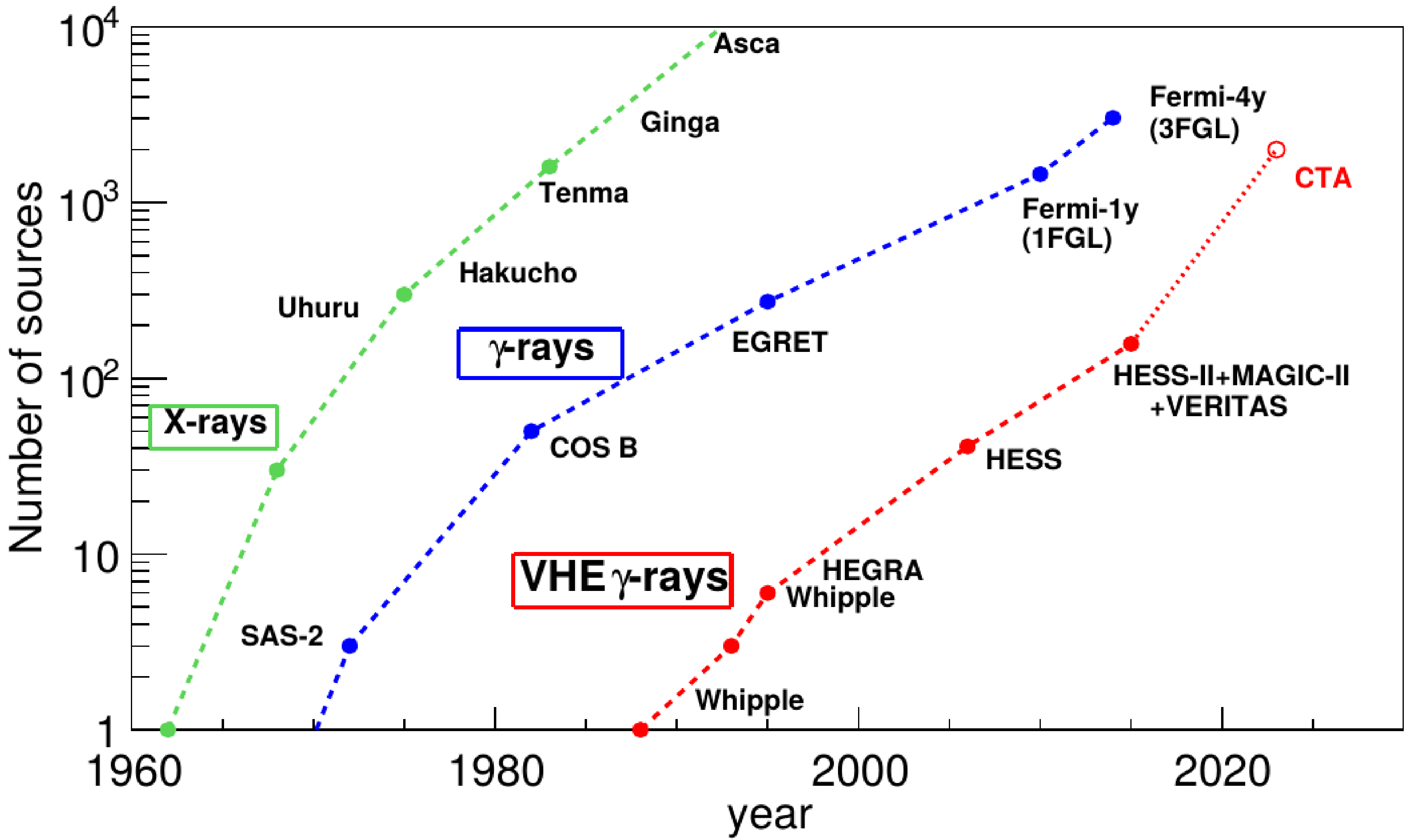


Magic coll. arXiv:1510.07048v1

More Sources in Galactic Disk



More Sources



Summary

- CTA will be 10 times more sensitive -> possibly 1000 sources to discover
- Energy resolution 10% -> spectral features -> dark matter
- Rapid slewing rate allows to watch GRB
- CTA will extend the observable electromagnetic spectrum up to 300 TeV
- 8 degree FoV allows fast surveys and measure extended regions of gamma ray emission
- Good angular resolution to resolve cosmics sources

Technology in good shape,

Physics as fascinating as ever,

Politics needs to do a lot of work.