cherenkov telescope array

Cherenkov Telescope Array

Ueli Straumann, 24. November 2017, Winterthur

Content

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

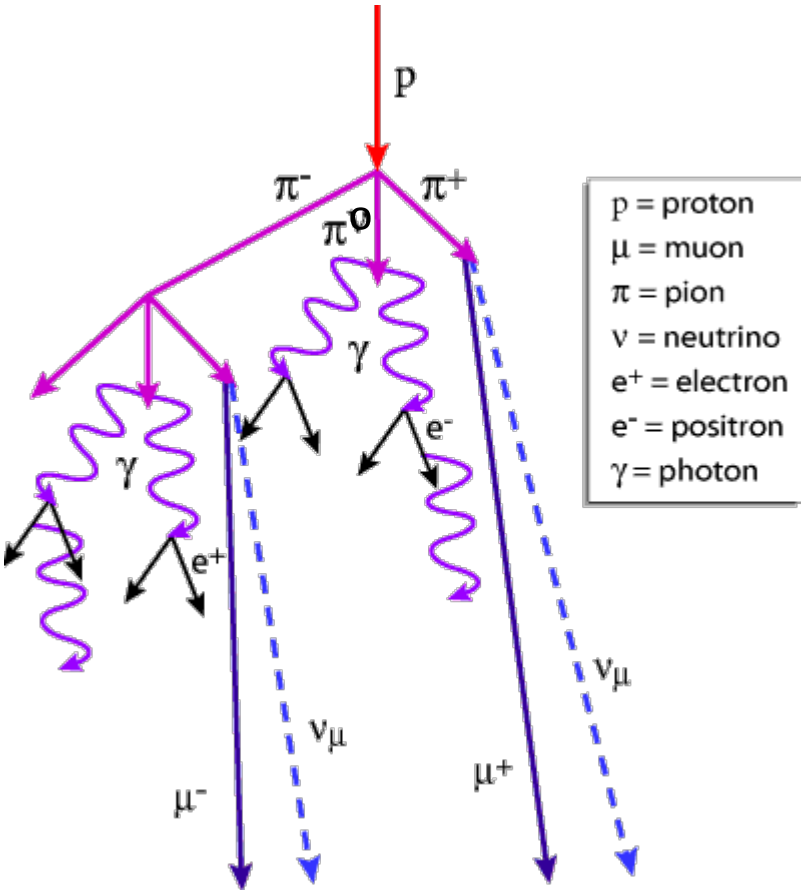
Cosmic Rays and Gamma Rays

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: two options:

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

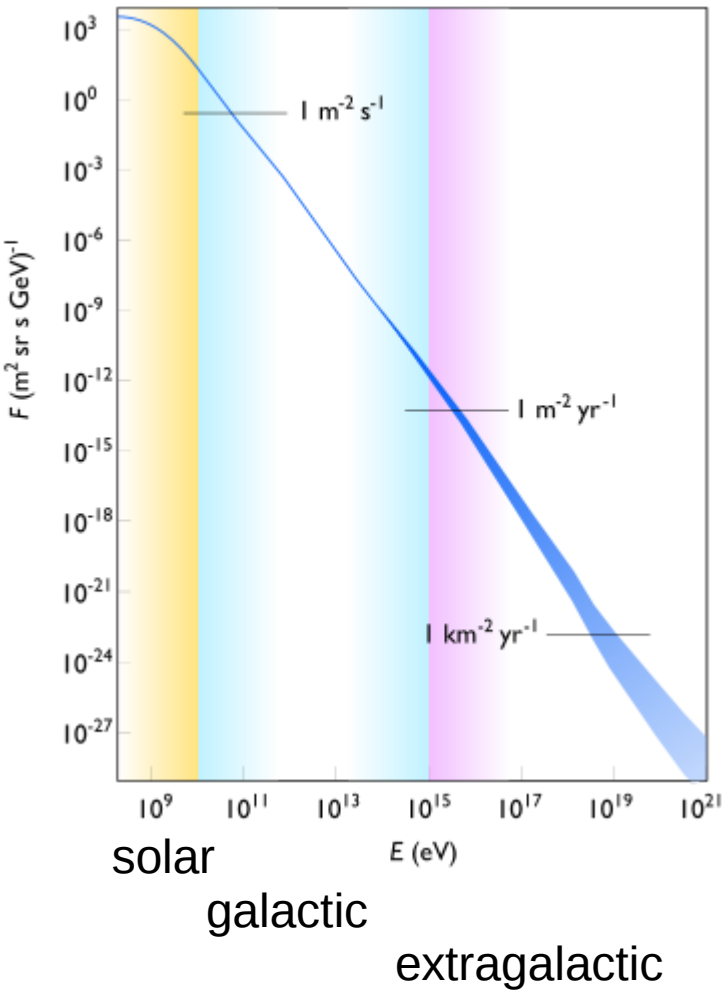


Cosmic Rays

- 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

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



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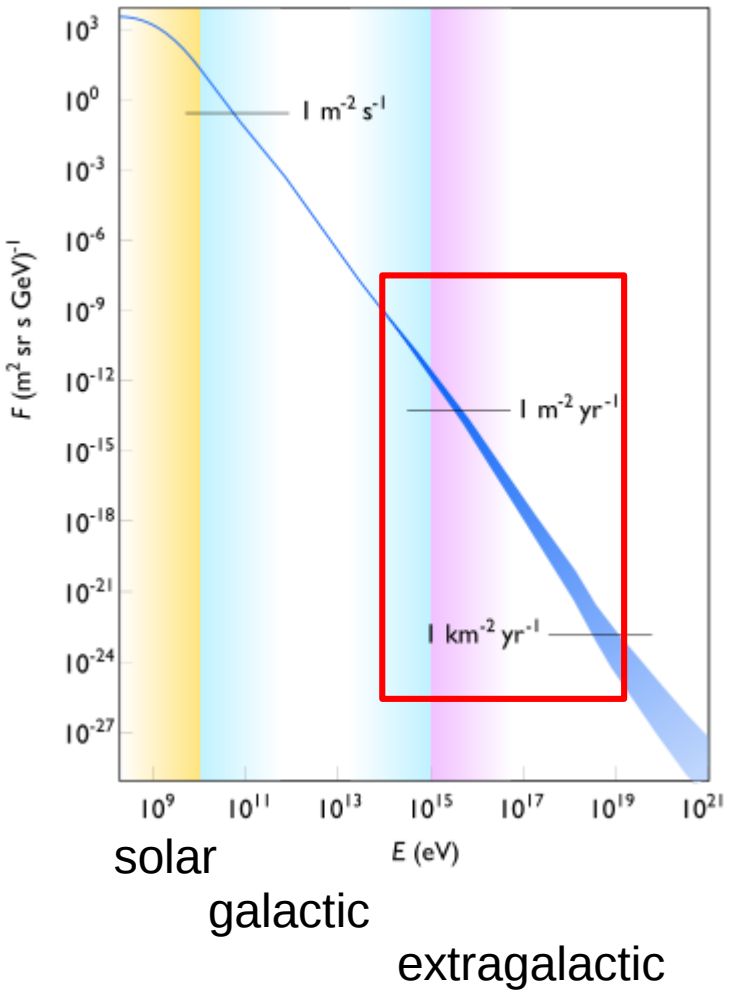
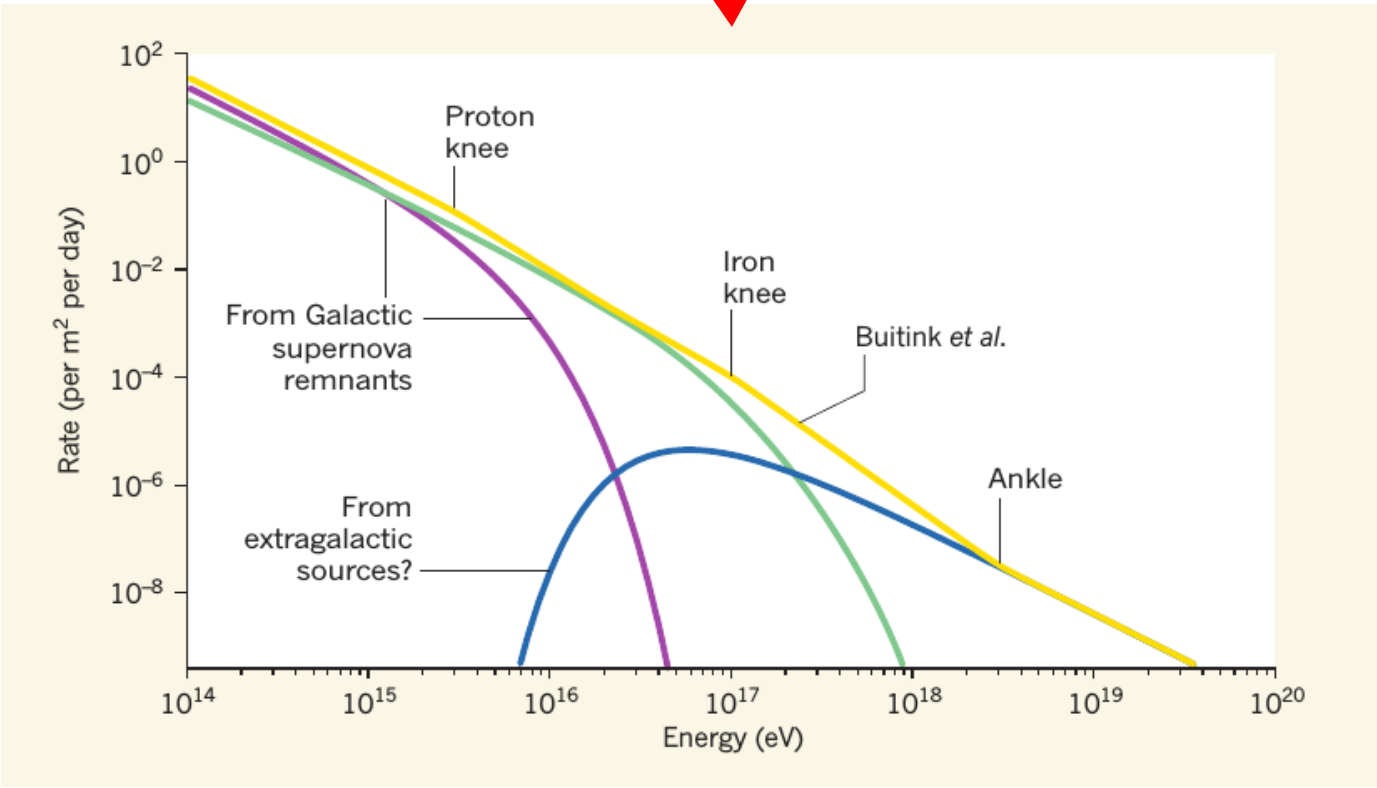


Cosmic Rays

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 5×10^{18} eV (extragalactic, protons?)



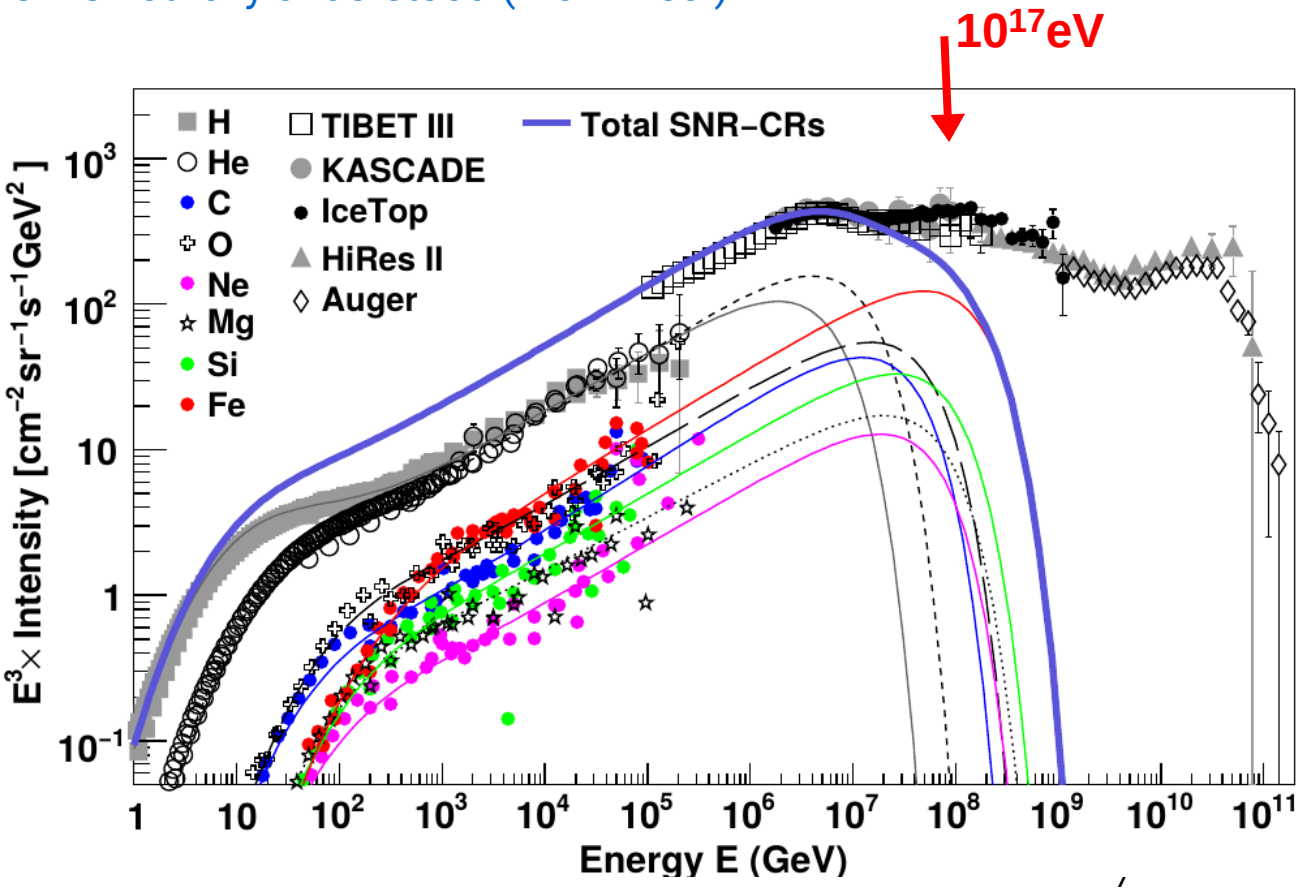
Nature, 531 (2016)

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

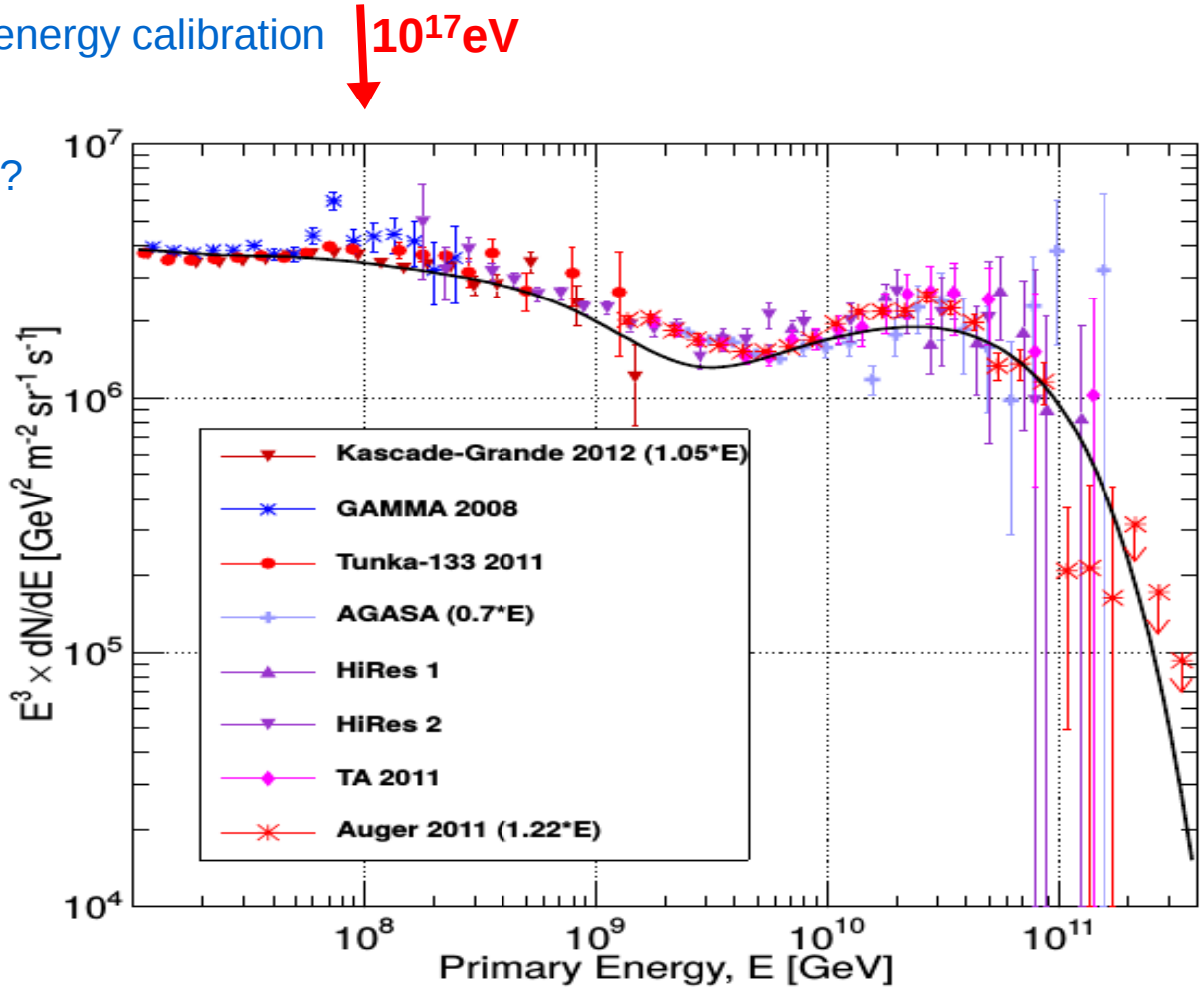


S. Thoudam et al., arXiv:1605.03111v2

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?



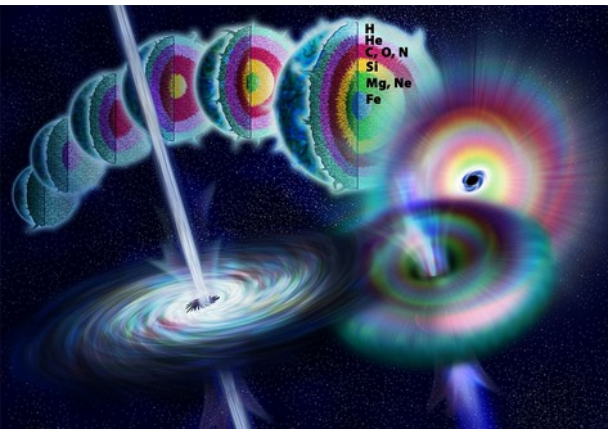
Gaisser et al.,
arXiv:1303.3565v1

Cosmic Rays: above knee

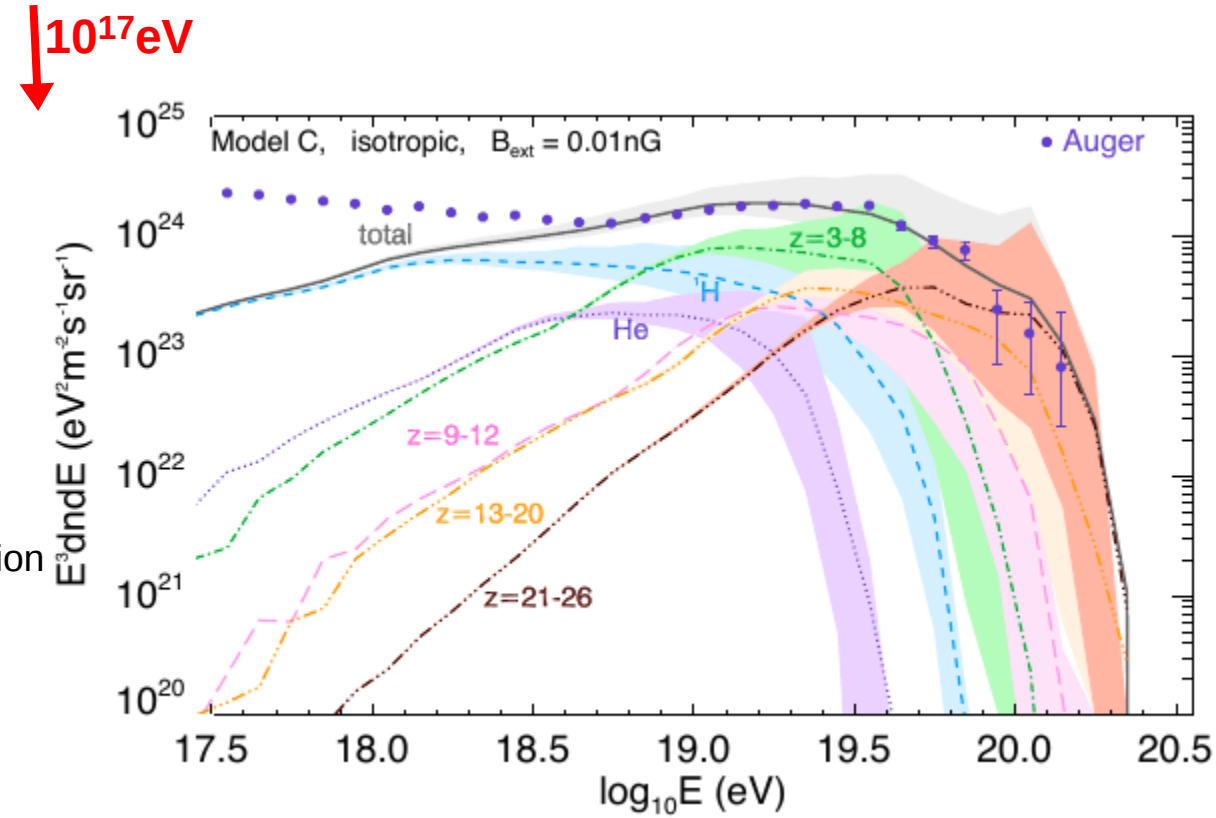
Gamma Ray Bursts?

- 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).

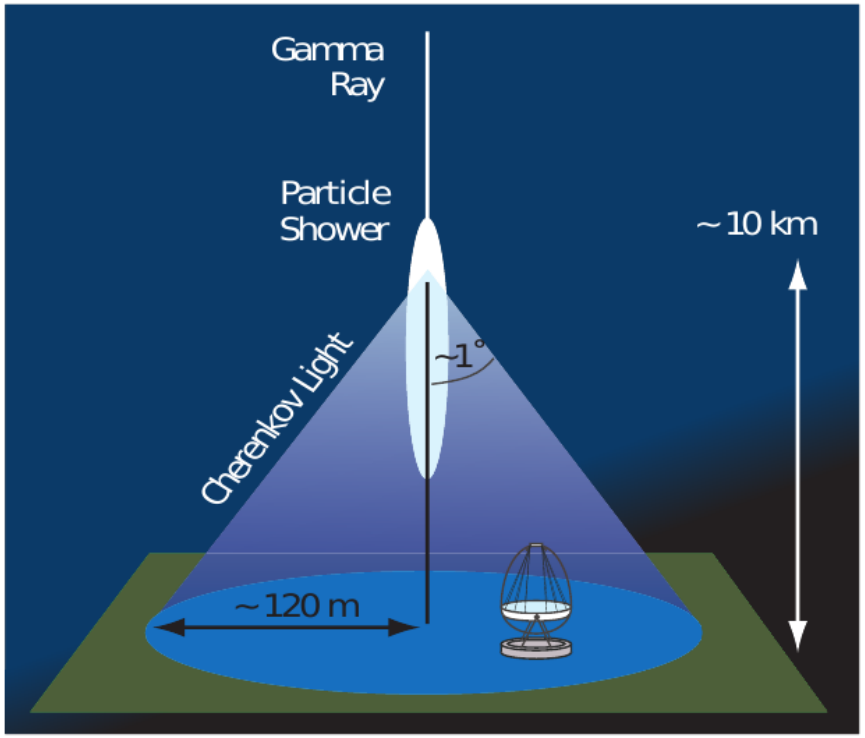
Very high energy photons from GRB and other possibly unknown sources: all have very low rate => Requirements for Detectors:

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

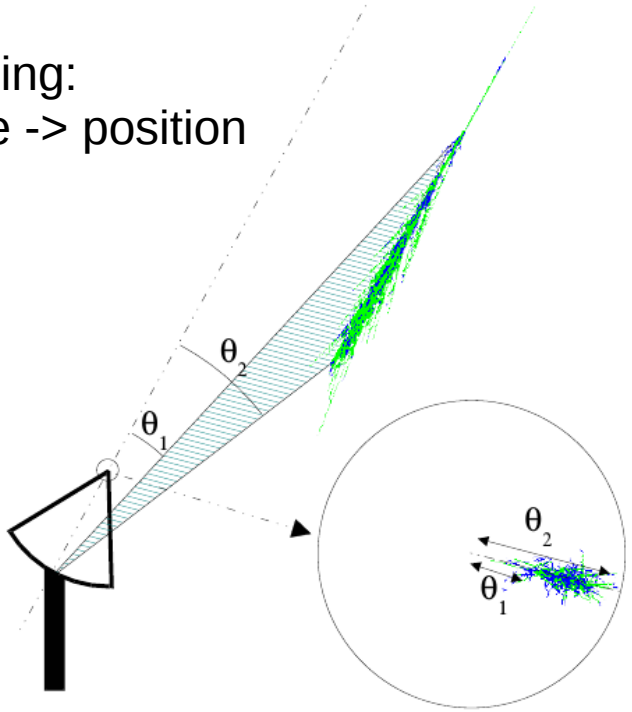
-> Imaging Atmospheric Cherenkov Telescope IACT

IACT and CTA concept

Cherenkov Telescope



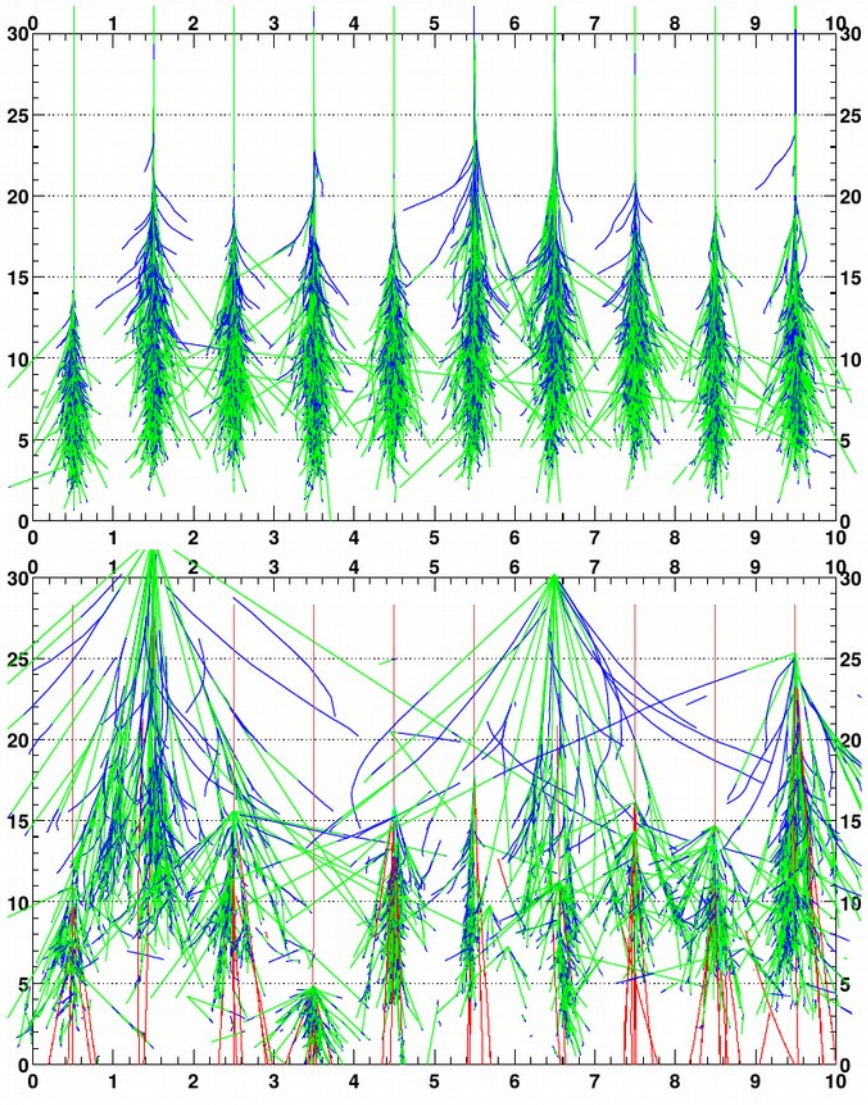
Imaging:
angle -> position



Atmosphere used as a calorimeter.

Presently active telescopes:
MAGIC(LaPalma, 2), HESS(Namibia, 5), VERITAS(US, 4)

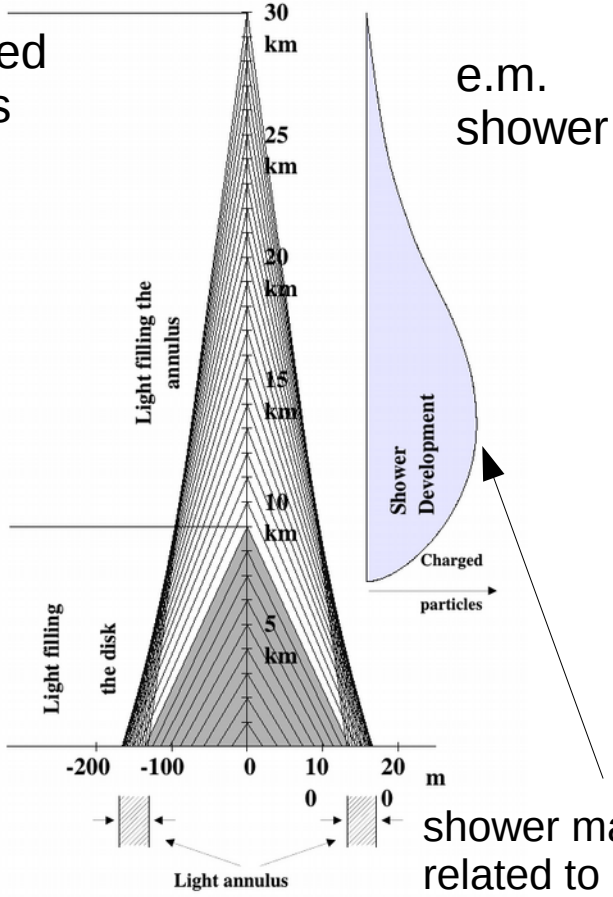
Cherenkov Telescope



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:

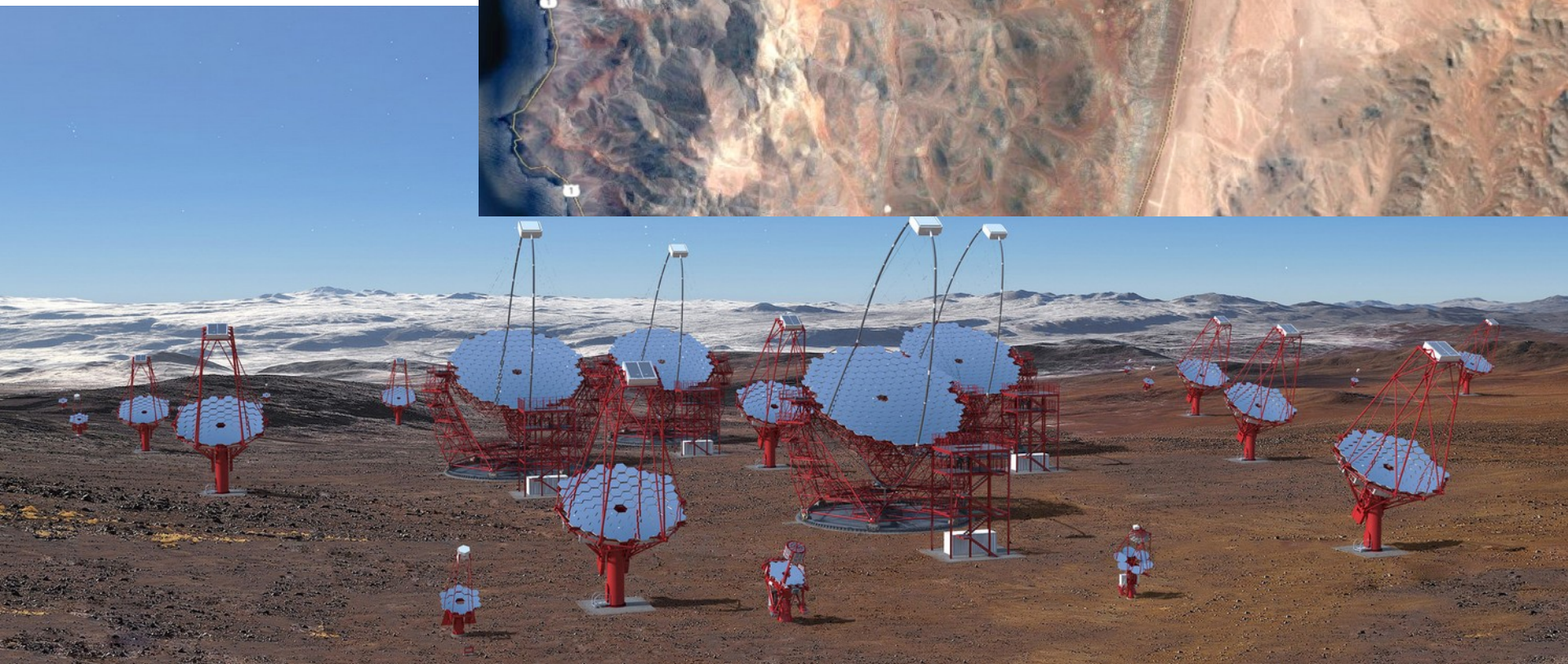
- Pointing accuracy, Energy resolution -> use relatively simple telescopes
- Big detection surface -> use array of telescopes
- Sensitive from 20 GeV to 300 TeV:
  - Low energy -> low light -> large telescope; high rate -> few telescopes
  - High energy -> lots of light -> cheap telescope; low rate -> 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)

CTA project details

South Site

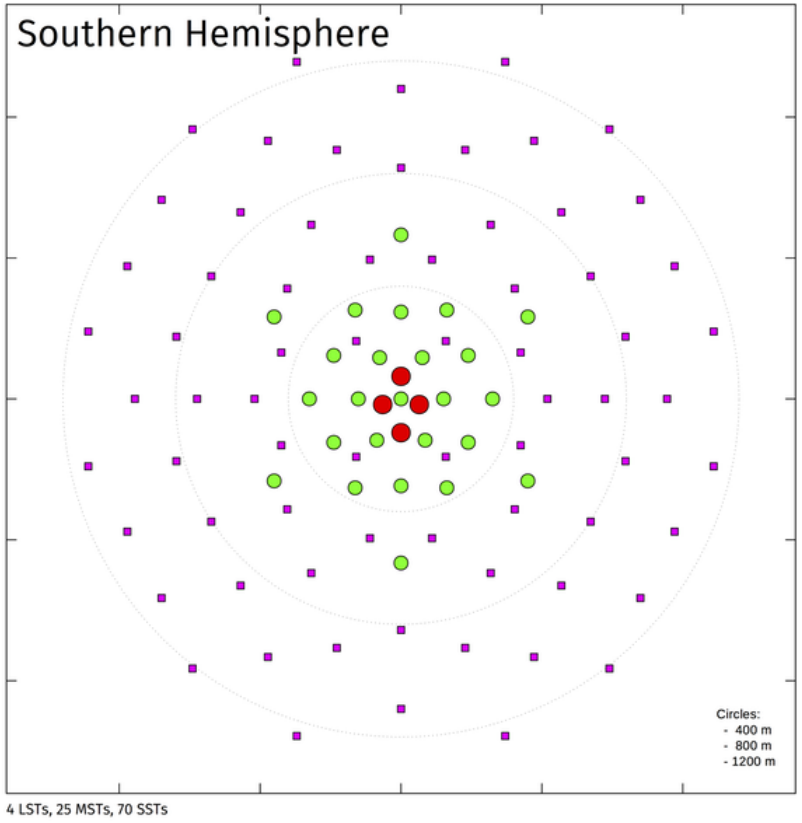
Atacama desert,
ESO site, Chile

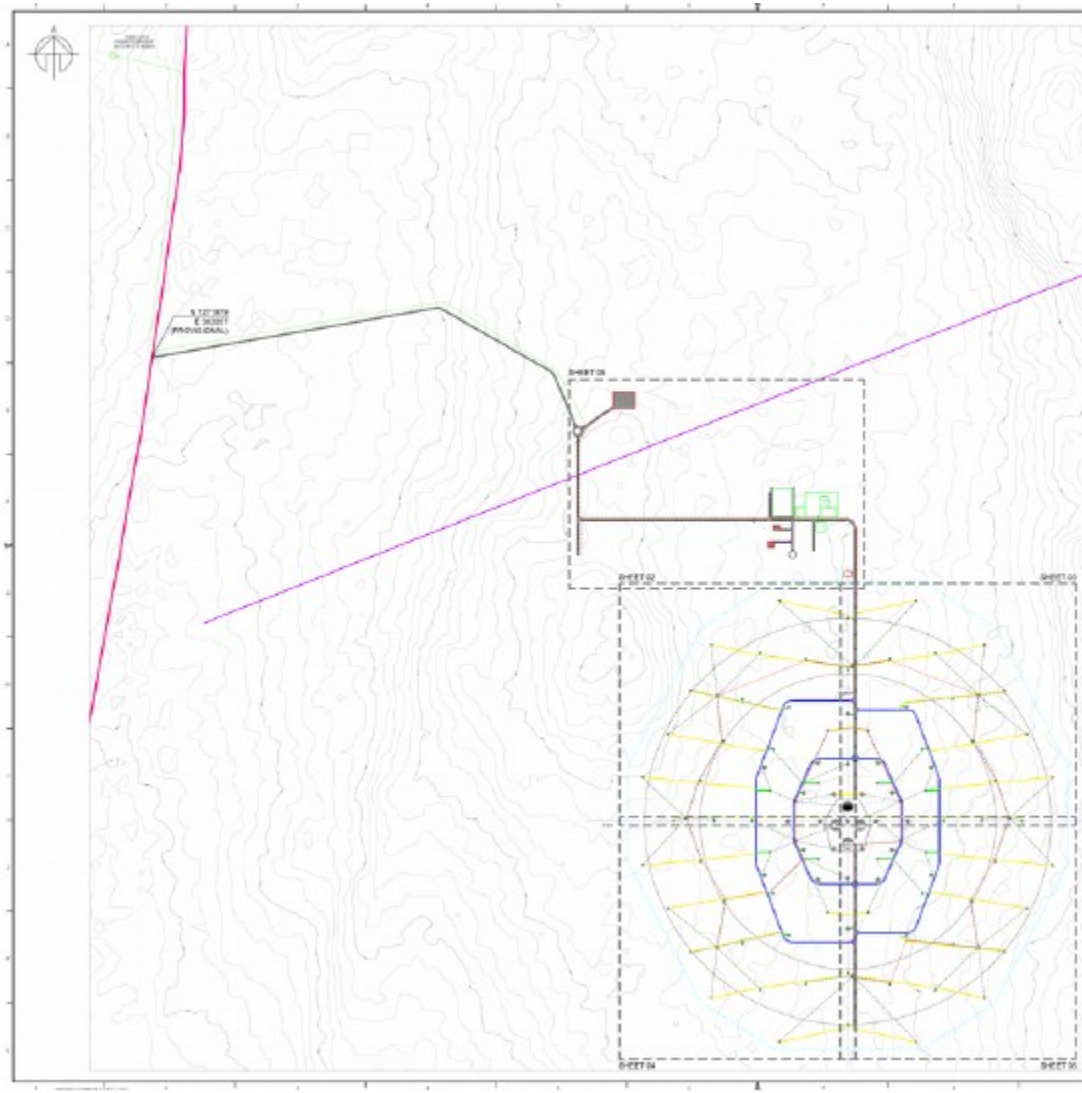



Infrastructure South
Geotechnical Study, May 2017
sondeal

South Layout

4 LST
25 MST
70 SST

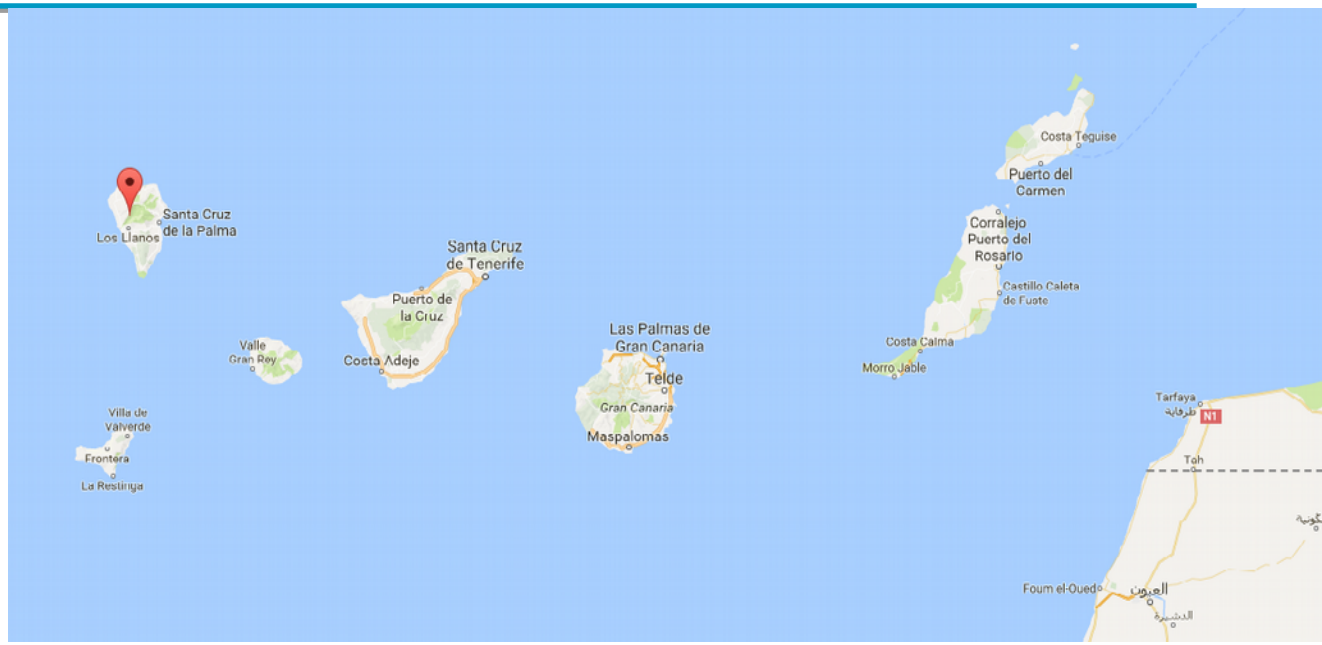


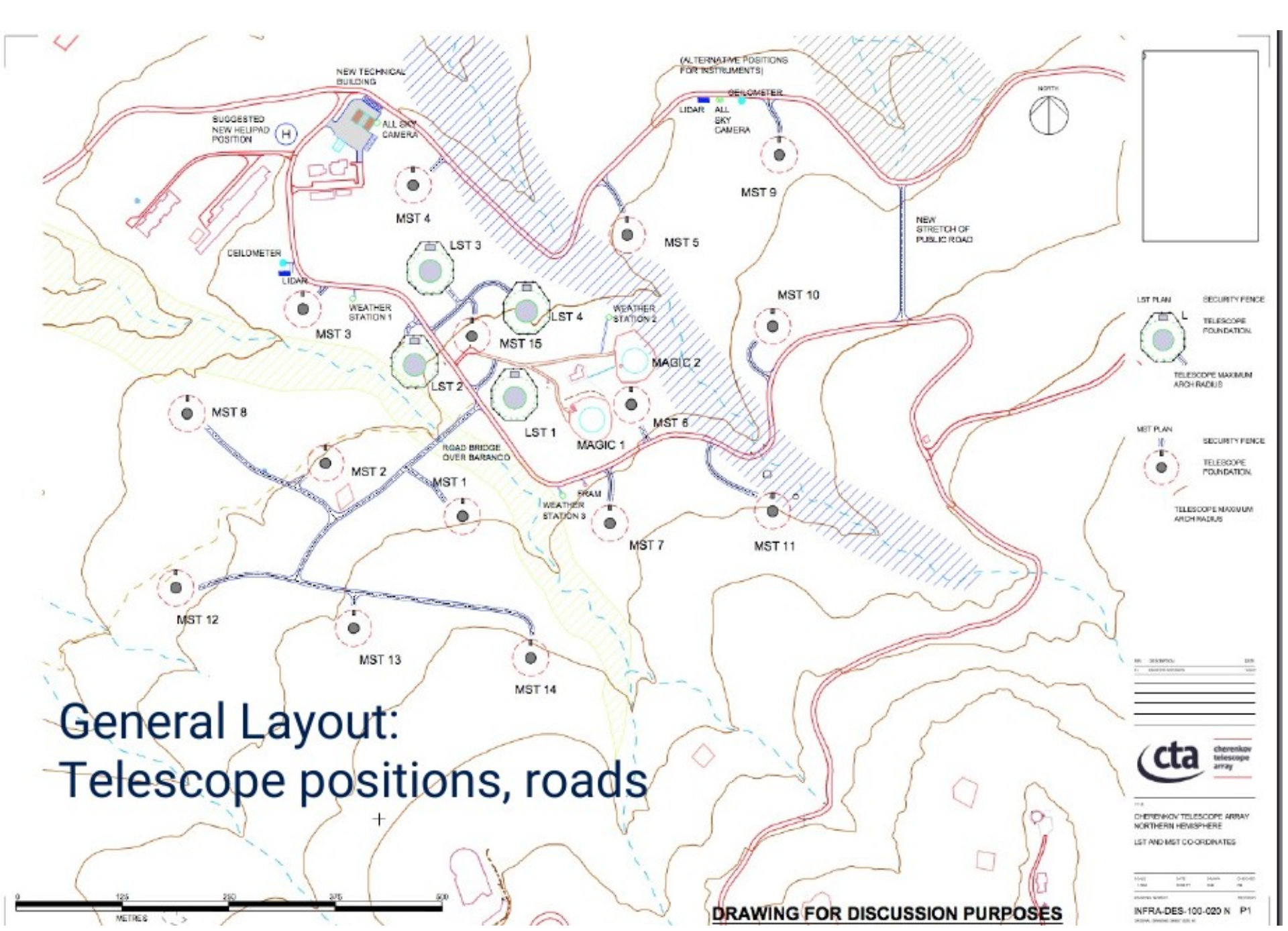


Sites & Site Infrastructure

North Site

La Palma,
Canary Islands,
IAC site

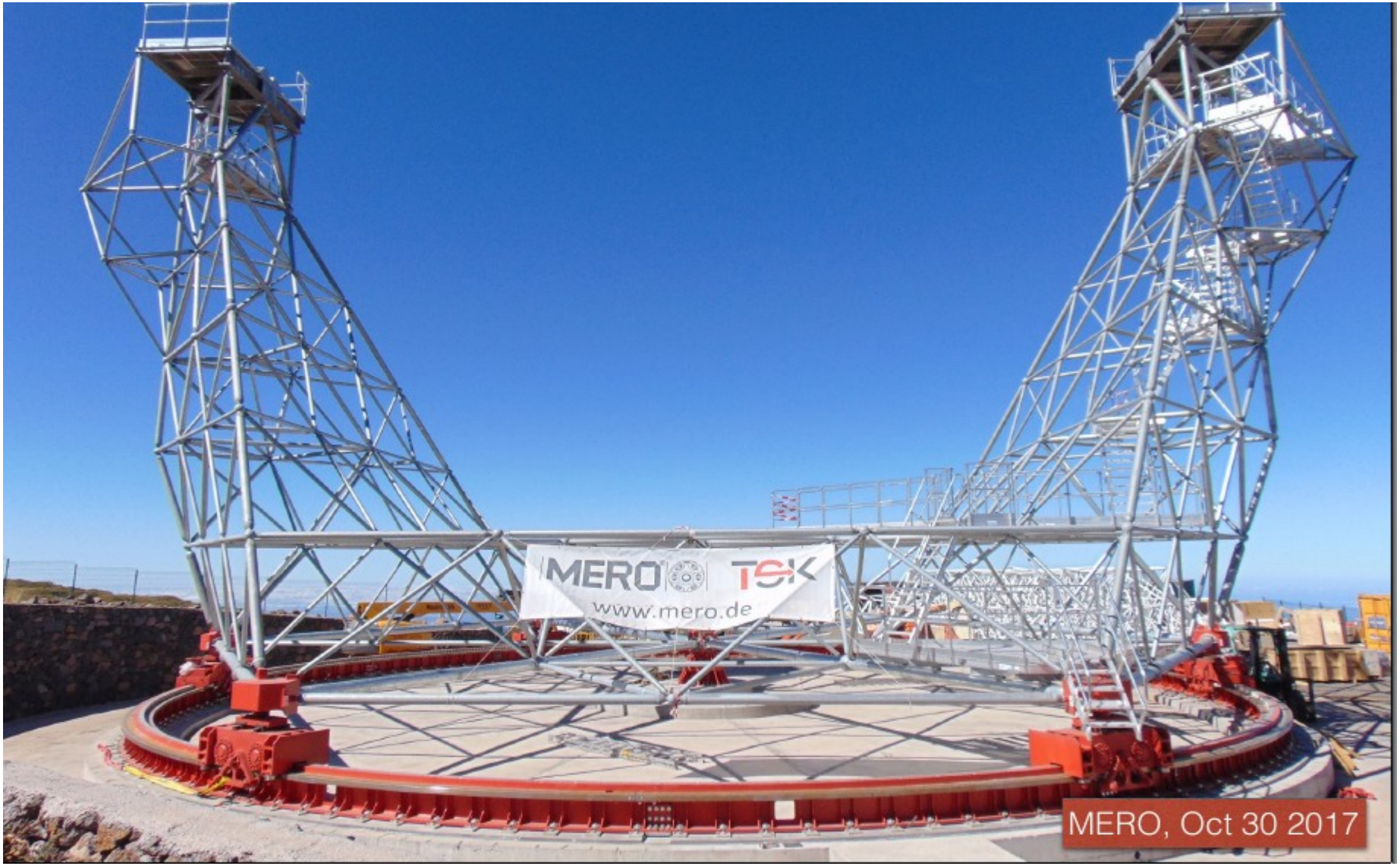




General Layout: Telescope positions, roads

LST1 prototype: 20. July 2017

LST1 prototype: 30. Oct. 2017

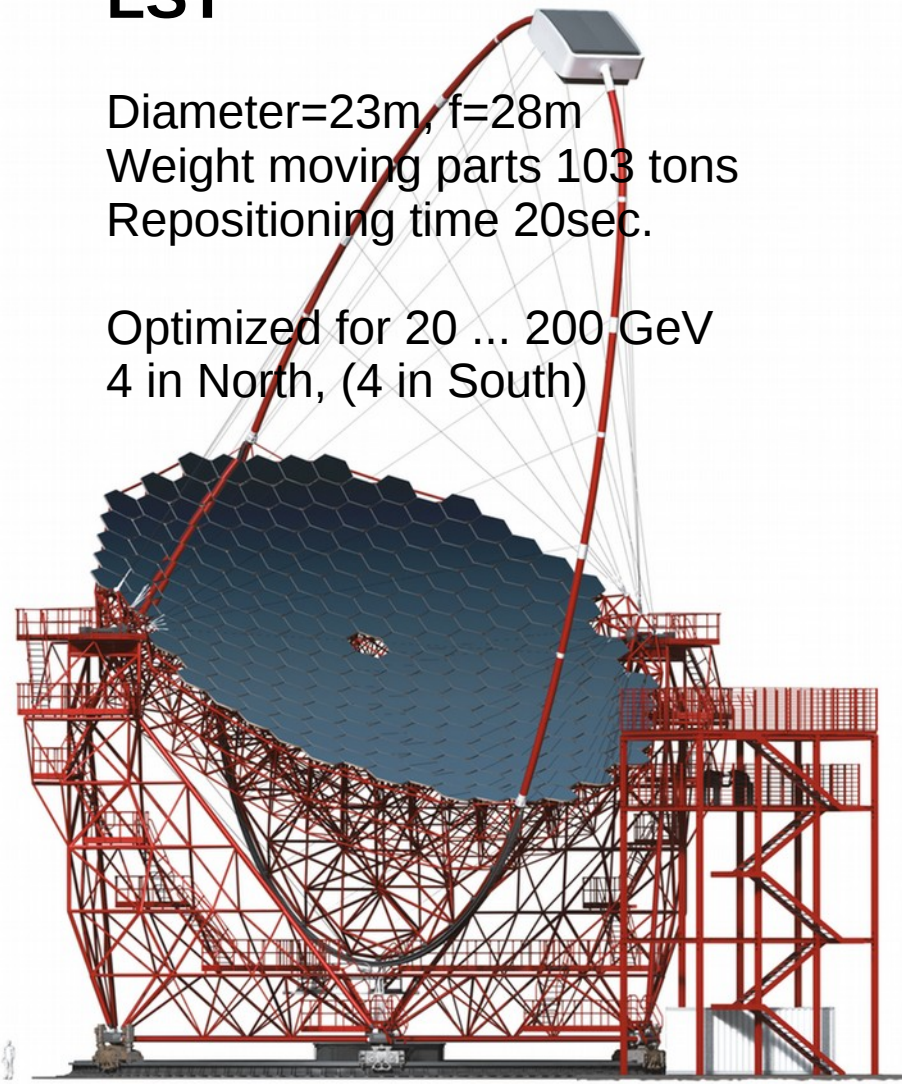


Telescopes to be installed in CTA North

LST

Diameter=23m, f=28m
Weight moving parts 103 tons
Repositioning time 20sec.

Optimized for 20 ... 200 GeV
4 in North, (4 in South)



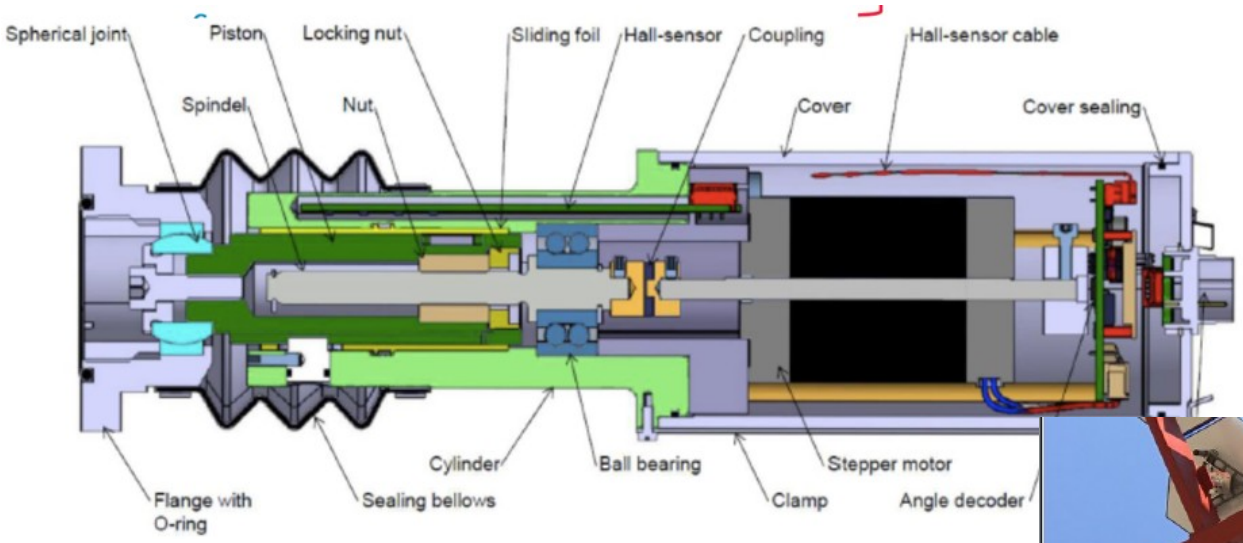
MST

Diameter=12m, f=19.2m

Optimized for 100 GeV .. 10 TeV
15 in North, (25 in South)

Mirror actuators (Uni ZH)

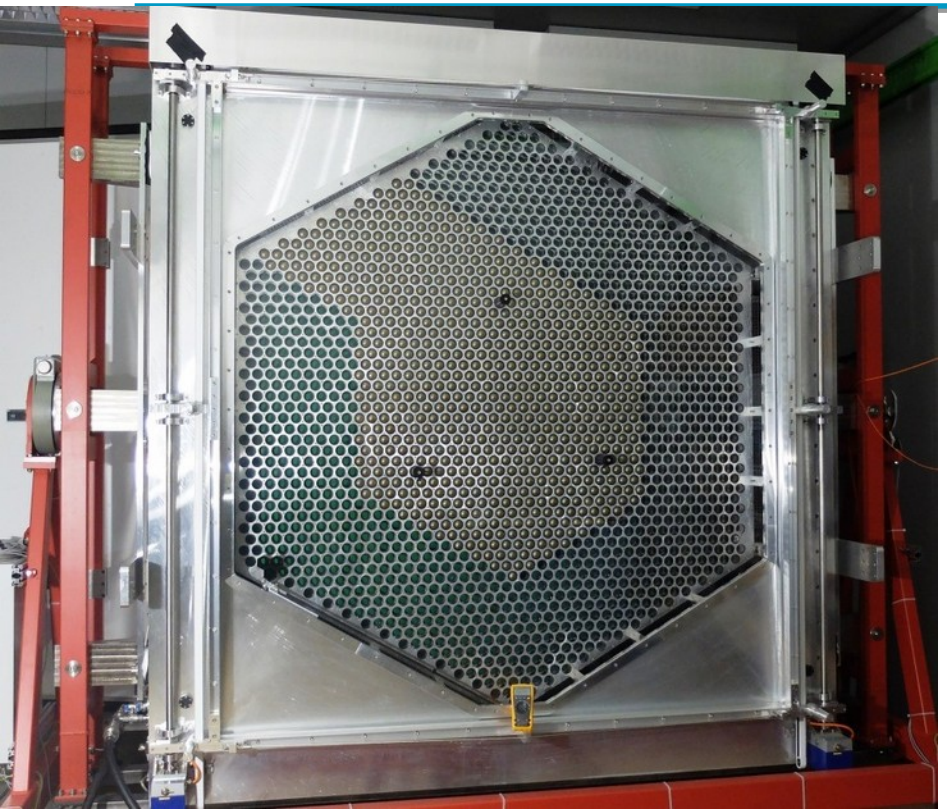
Mirror segments need to be dynamically adjusted individually
2 Actuators, one fixed point per segment.

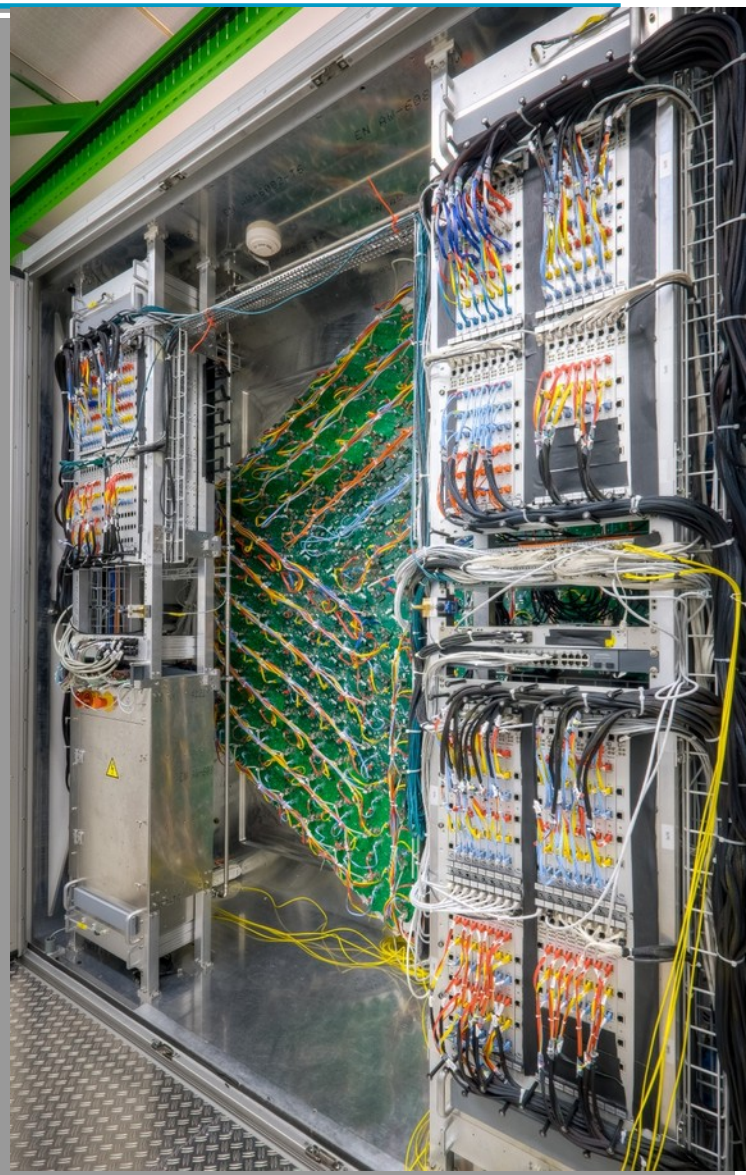


Actuators mounted on MST prototype

To be used for LST, also for MST, SST-1M
Started from ETH Magic actuators,
→ complete redesign,
optimized for reliability and price.
longterm tests since >6 years.

MST Camera: 2 options. only FlashCam shown here.

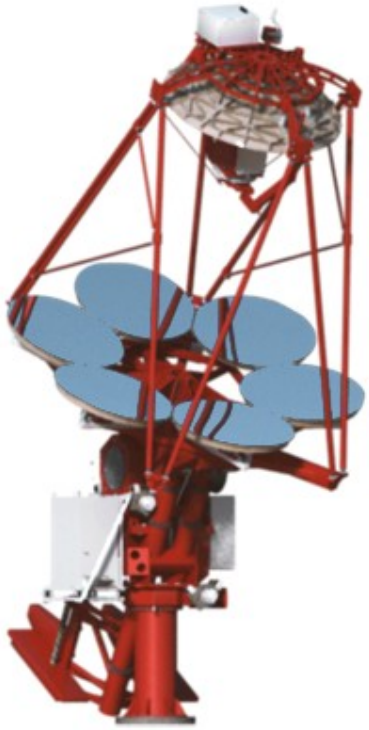




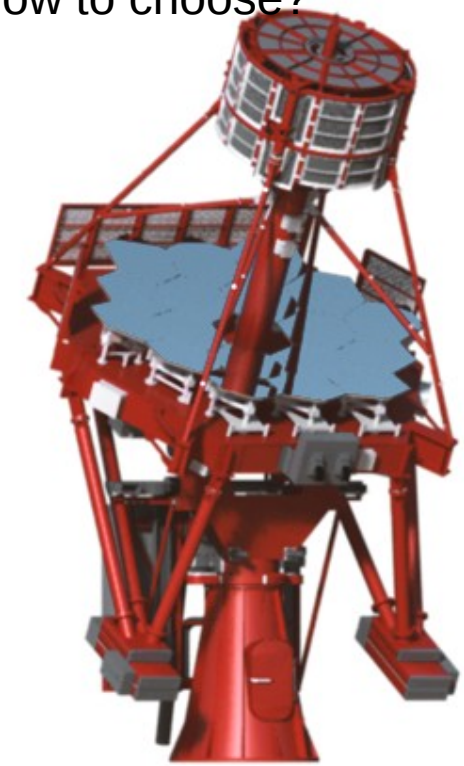
- Fully digital readout, 250 MS/s ADC
- digital trigger on same data
- Protoype 24/7 operation for several months
- >30 kEvents/sec readout without no dead time,
- slow control, trigger, timing interfaces work
- parts of electronics / mechanics designed at UZH

SST Telescopes

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



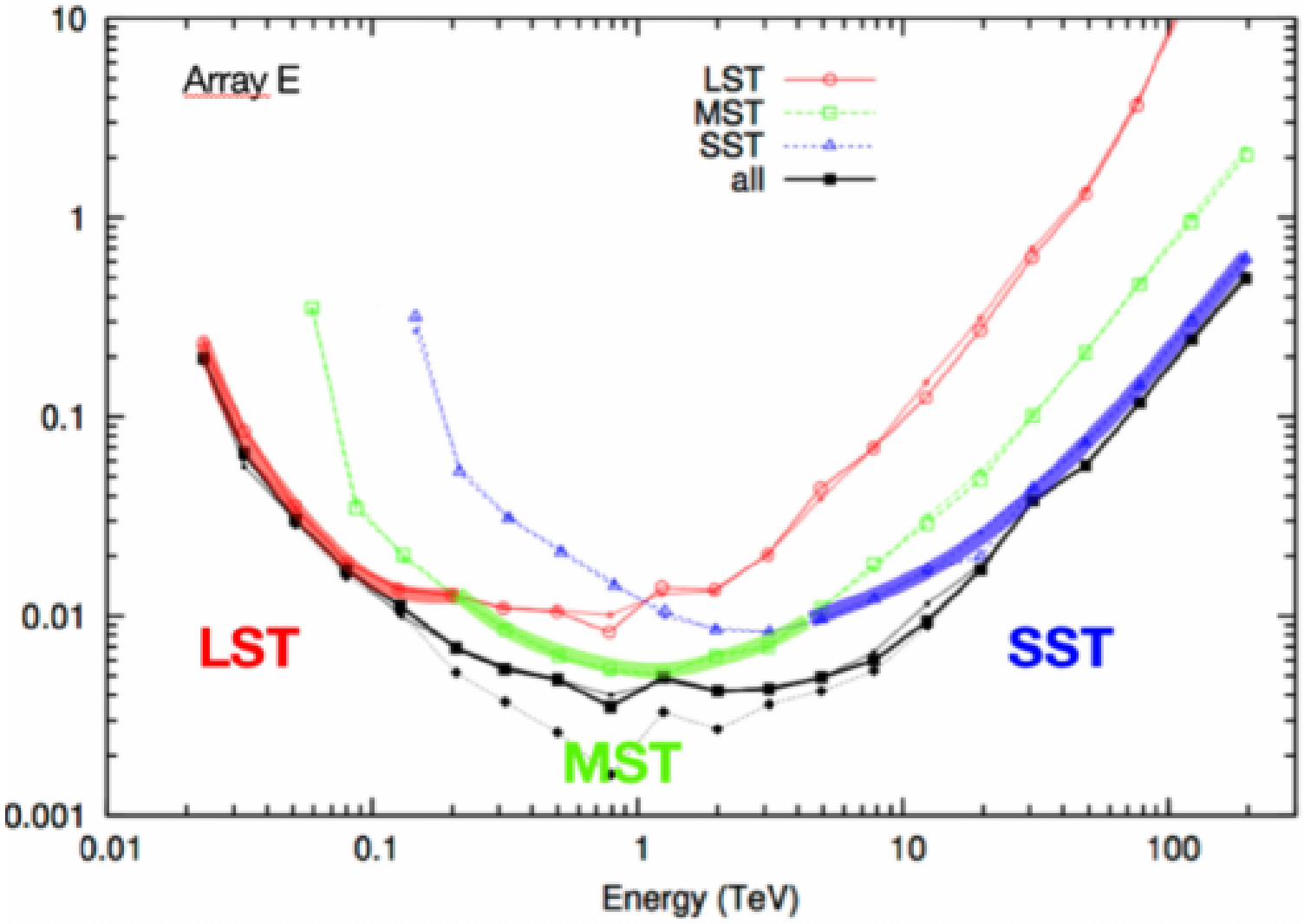
SST-2M GCT



SST-2M ASTRI

SST-1M

Flux sensitivity x E^2

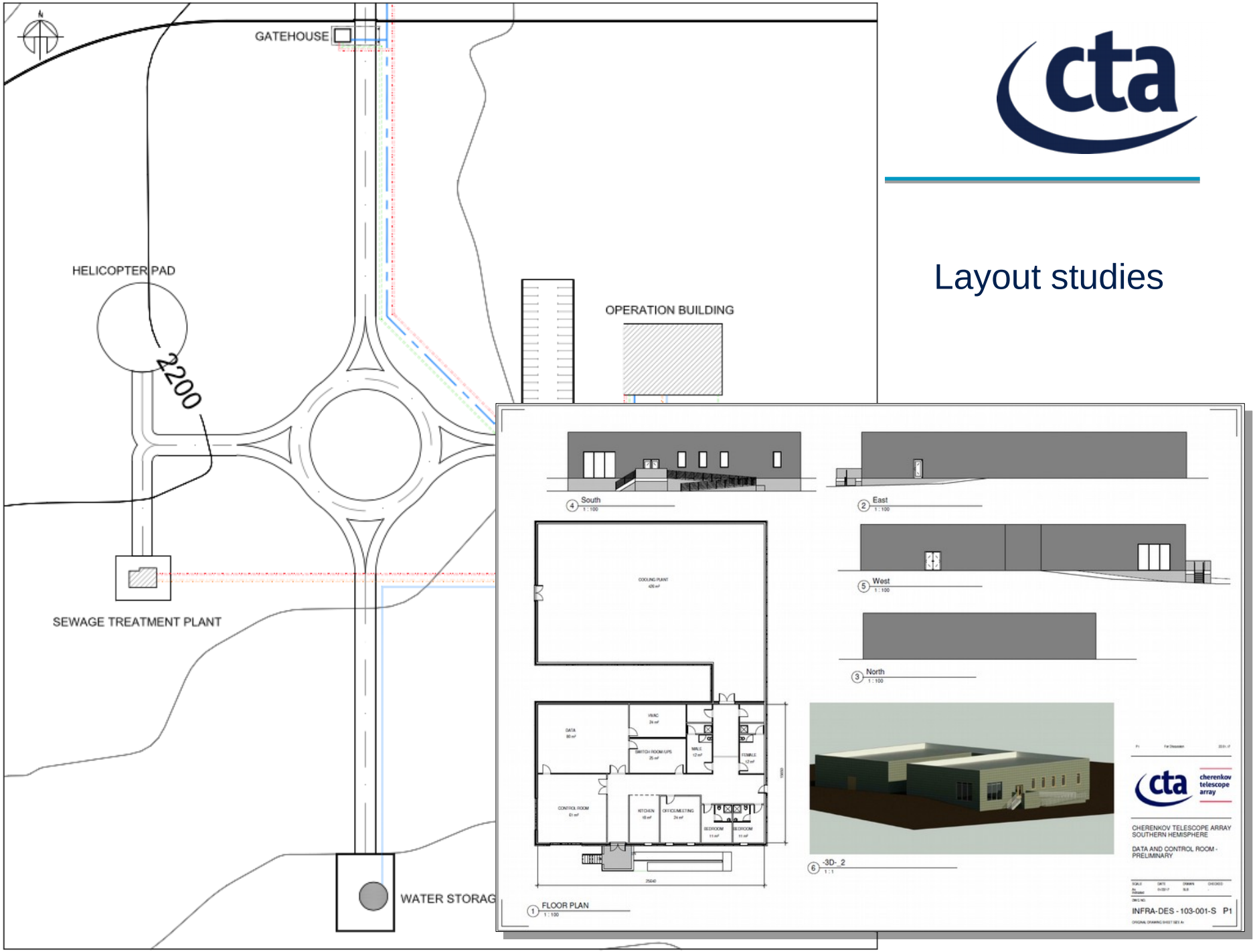


More infrastructure

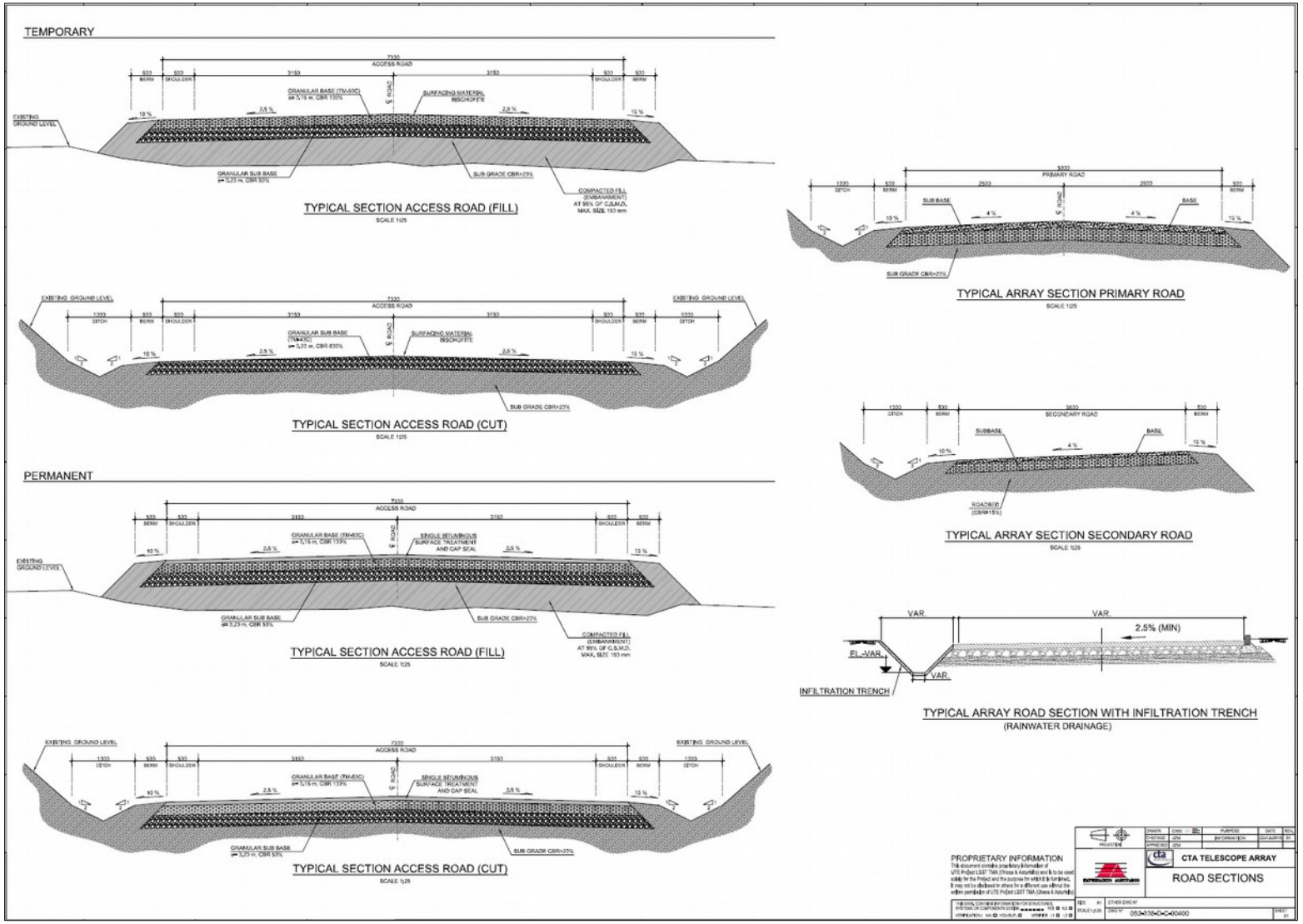
- Buildings
- Roads
- Foundations
- Power
- Datanetwork
- Software
- Computers

Interfaces - Interfaces - Interfaces

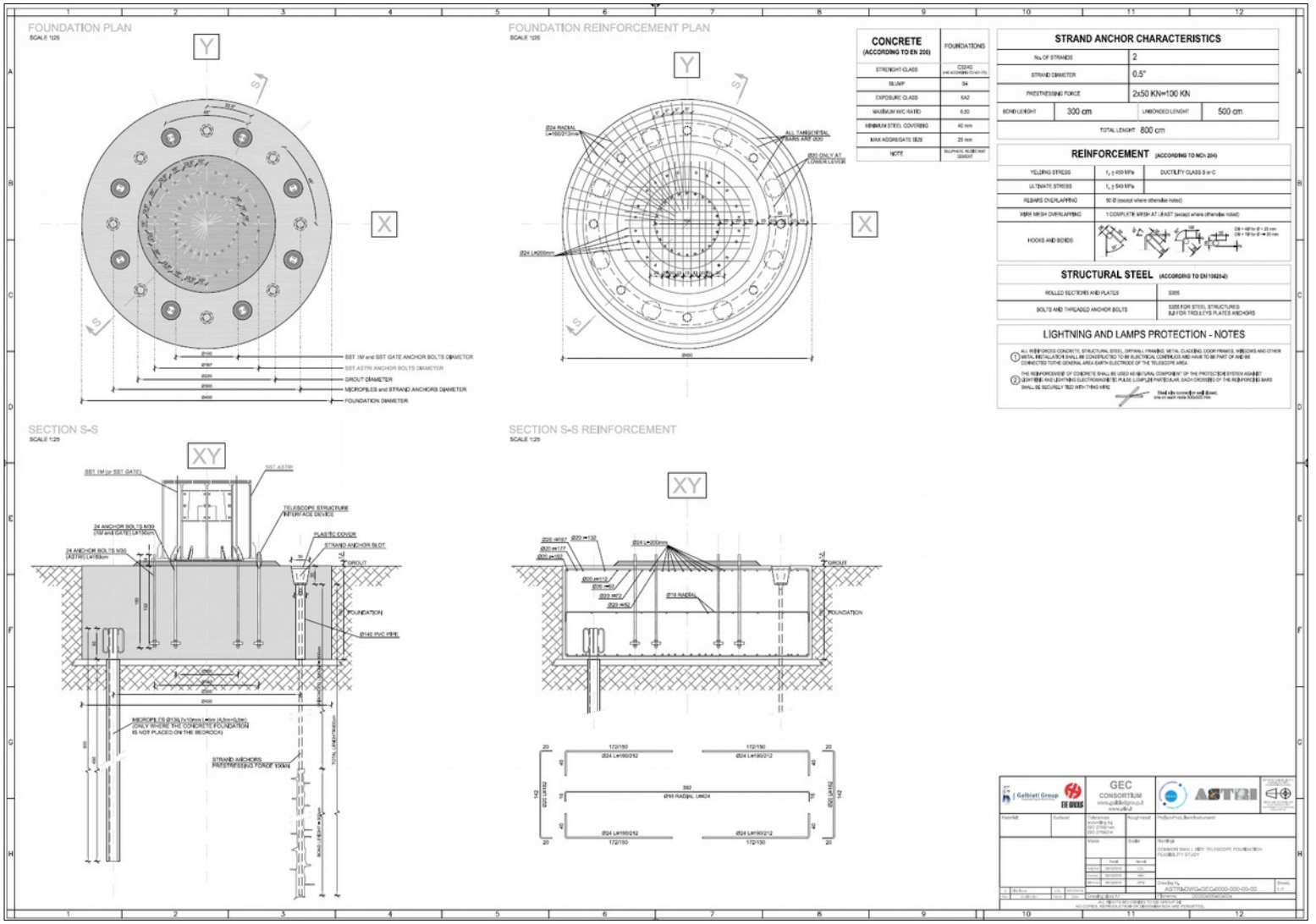
Layout studies



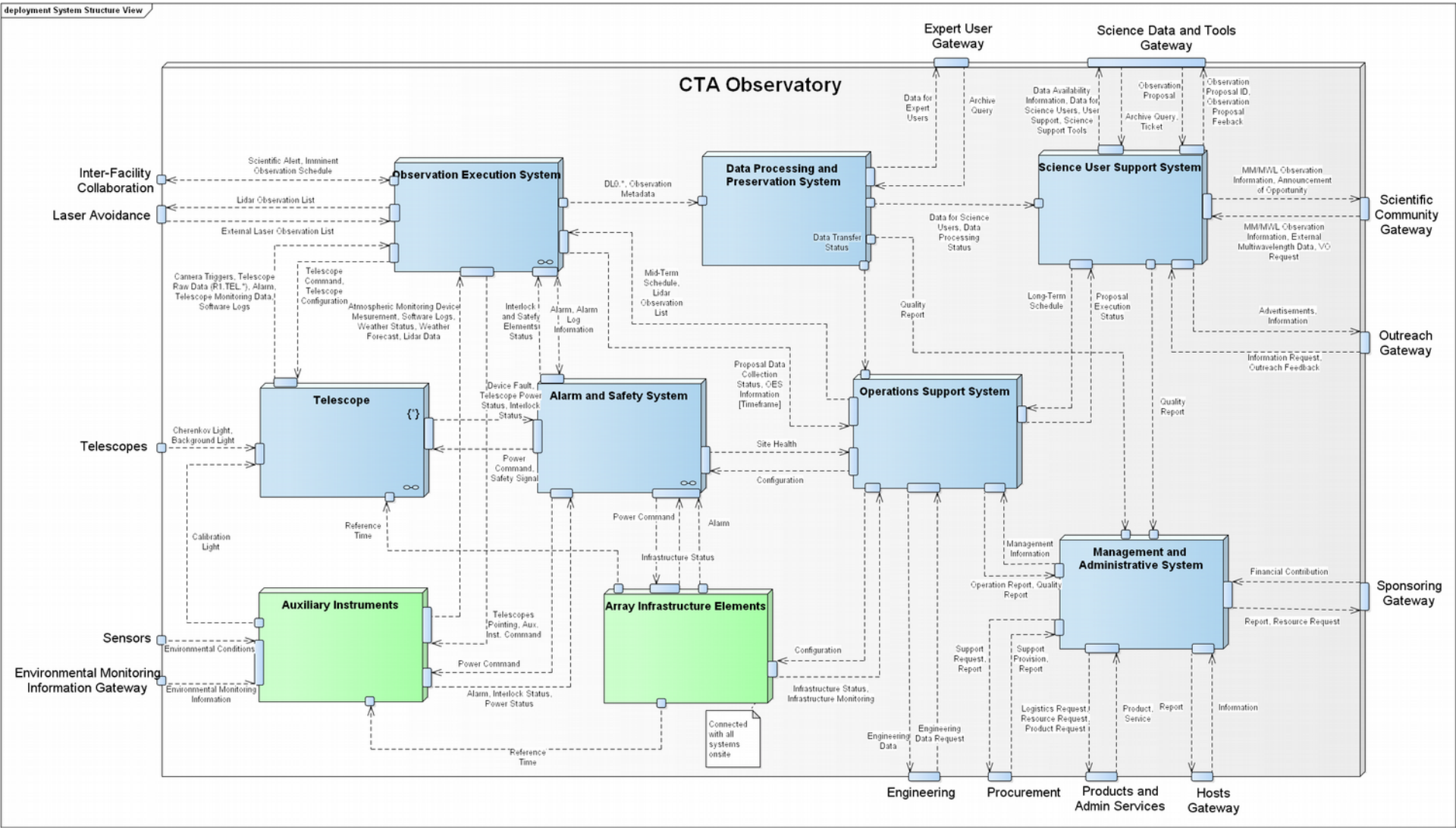
Roads


TEMPORARY
TYPICAL SECTION ACCESS ROAD (FILL)
SCALE 1:25
TYPICAL SECTION ACCESS ROAD (CUT)
SCALE 1:25
PERMANENT
TYPICAL SECTION ACCESS ROAD (FILL)
SCALE 1:25
TYPICAL SECTION ACCESS ROAD (CUT)
SCALE 1:25
TYPICAL ARRAY SECTION PRIMARY ROAD
SCALE 1:25
TYPICAL ARRAY SECTION SECONDARY ROAD
SCALE 1:25
TYPICAL ARRAY ROAD SECTION WITH INFILTRATION TRENCH
(RAINWATER DRAINAGE)
INFILTRATION TRENCH
PROPRIETARY INFORMATION
CTA TELESCOPE ARRAY
ROAD SECTIONS

Universal SST Foundation



CTA Software Architecture

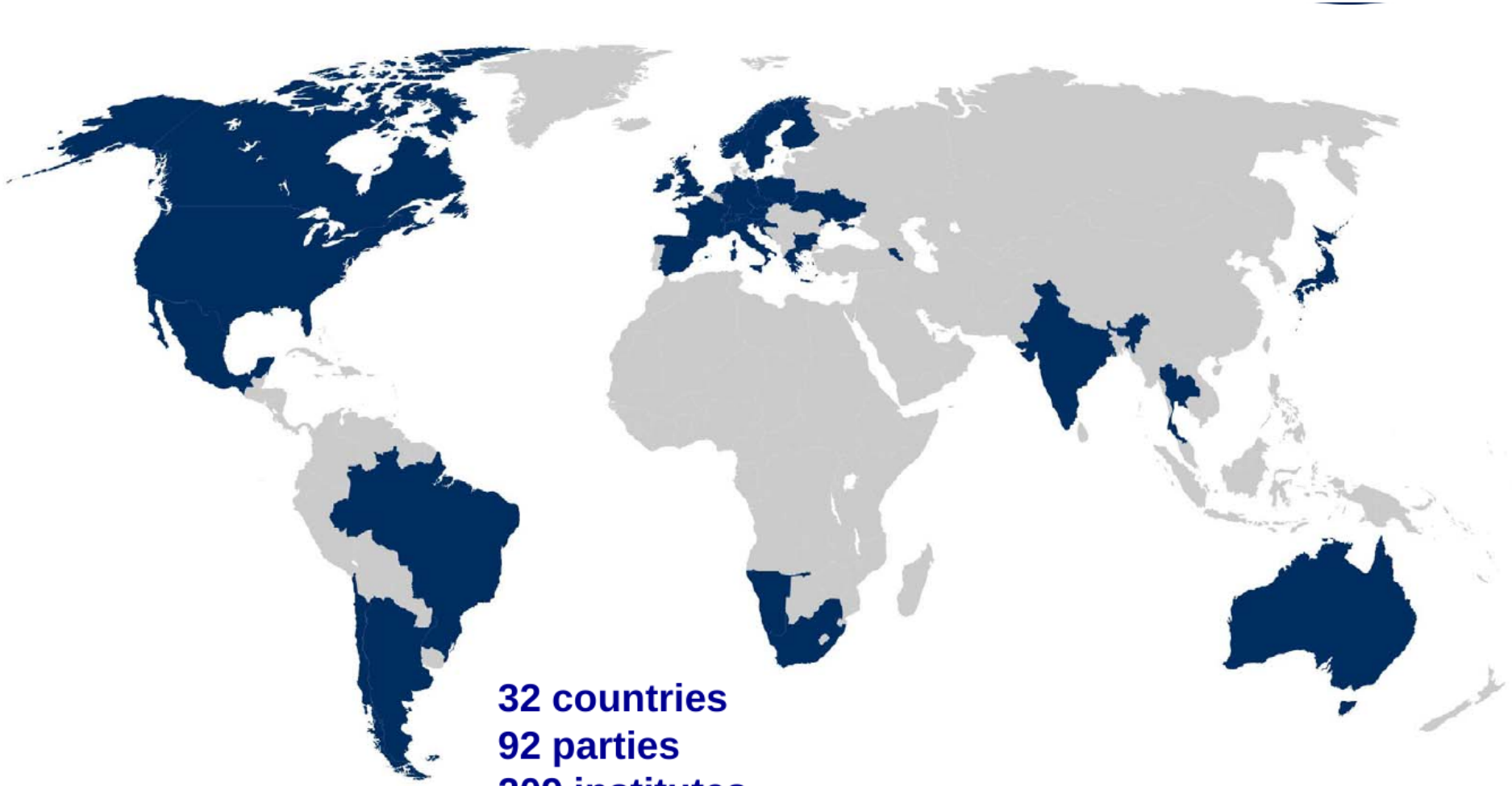


North Computing & Network

- 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

Government

CTA Consortium, growing since 2006



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

CTAO GmbH

- 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 (11 countries)
  - Australia (AAL)
  - Austria (University of Innsbruck)
  - France (CRNS, CEA),
  - Germany (DESY. MPG),
  - Italy (INAF, INFN),
  - Japan (Uni Tokio),
  - Czech Republic,
  - Slovenia (U Nova Gorice)
  - 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)

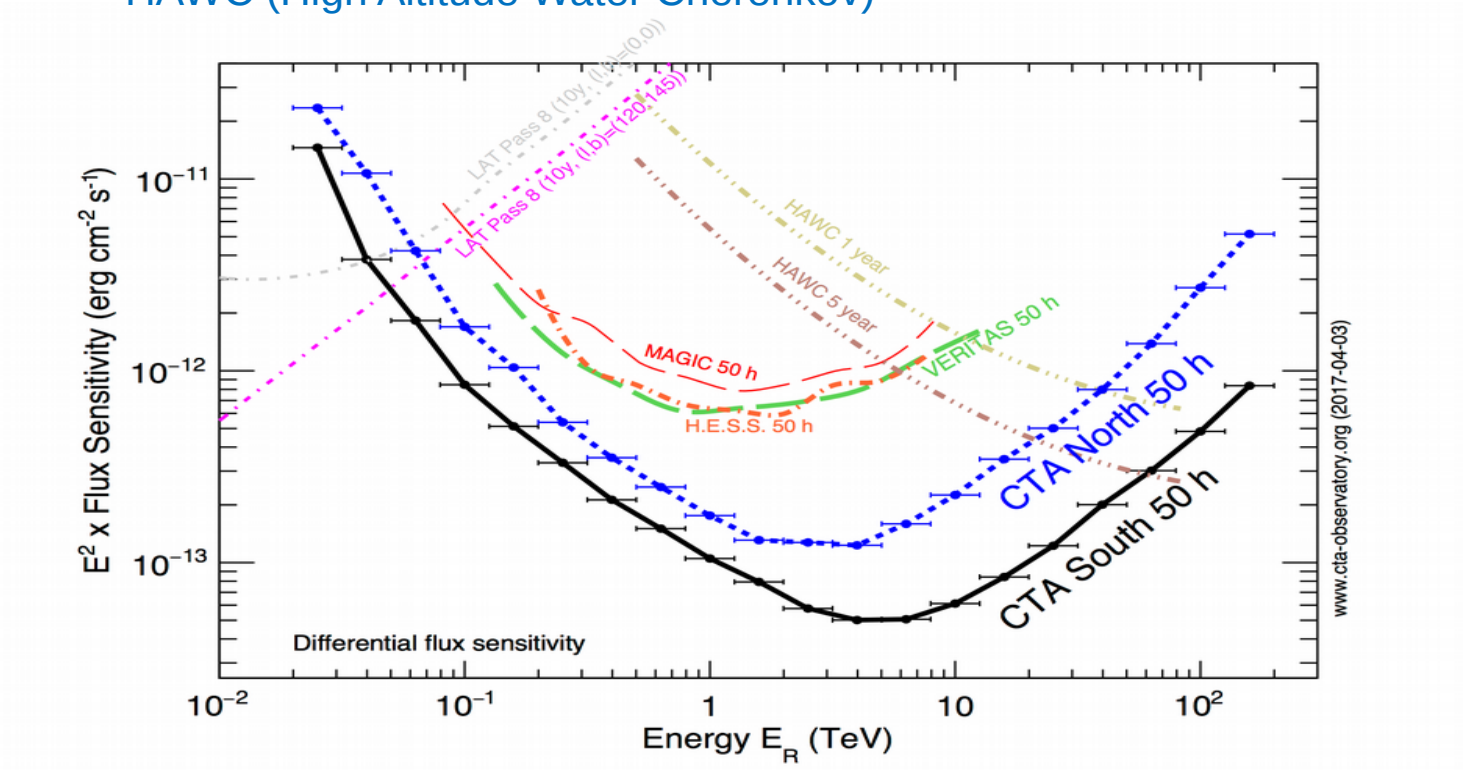
Resources, final legal entity

- Total investment for construction: about 300 MEuro + 100 MEuro person power
- This includes infrastructure at observation sites and at European centres
  - Streets, power, data net, service buildings, computer centres, calbration and service facilities
- “Threshold scenario”: Construction may only start, once 250 MEuro are promised.
  - We are very close (90% available).
- 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 will be CTAO - ERIC. Main seat in Italy = hosting country.
  - draft statutes available, plan to submit proposal to EU by end of 2018.

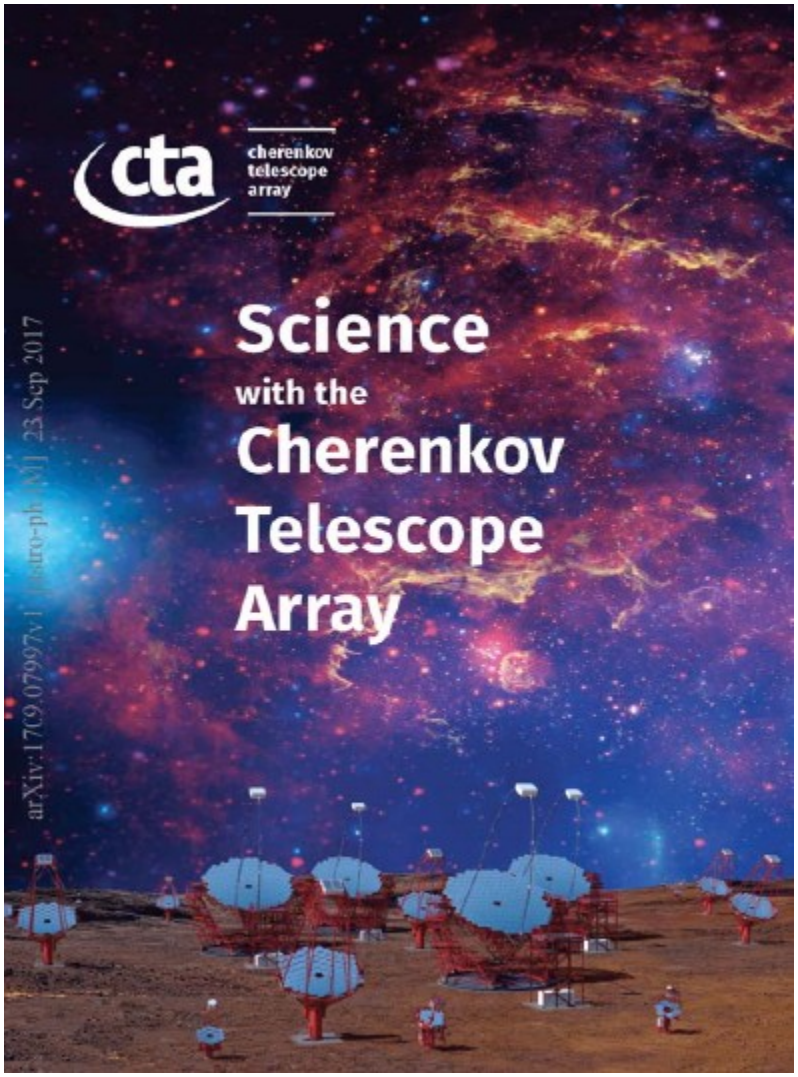
Physics perspectives

Sensitivity: comparison

- 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)



Science with CTA



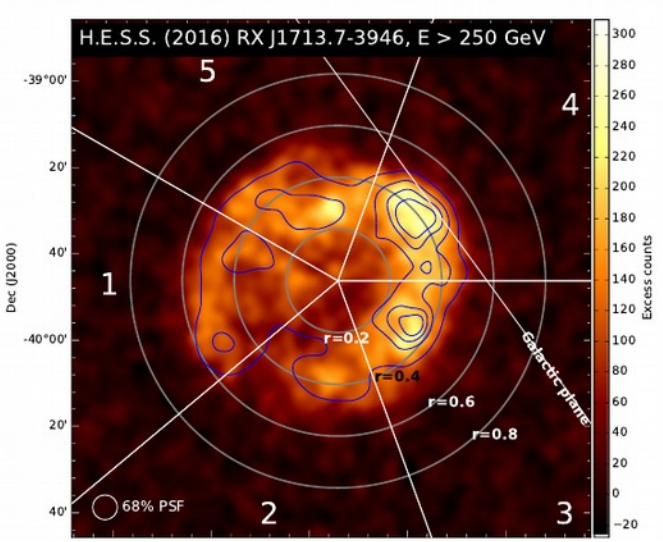
Contents includes

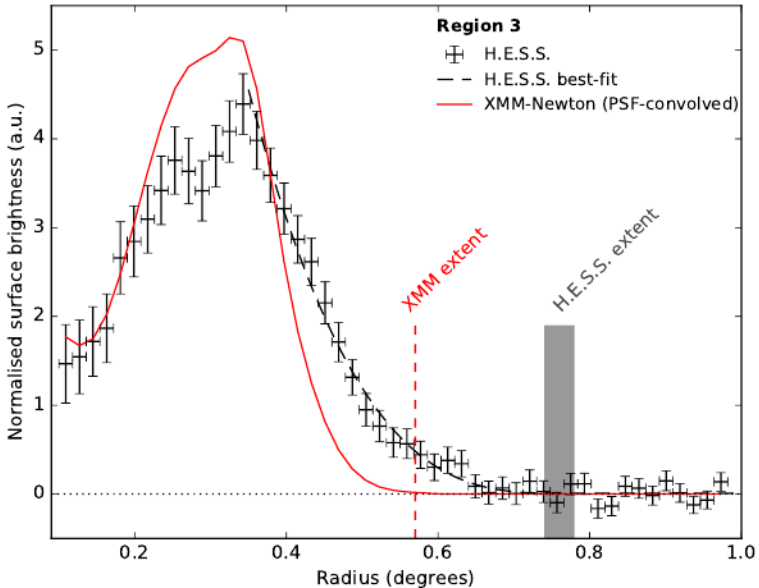
- Dark Matter
- Galactic Centre
- Galactic Plane Survey
- LMC survey
- Extragalactic Survey
- Transients
- Cosmic Ray PeVatrons
- Star Forming Systems
- Active Galactic Nuclei
- Clusters of Galaxies

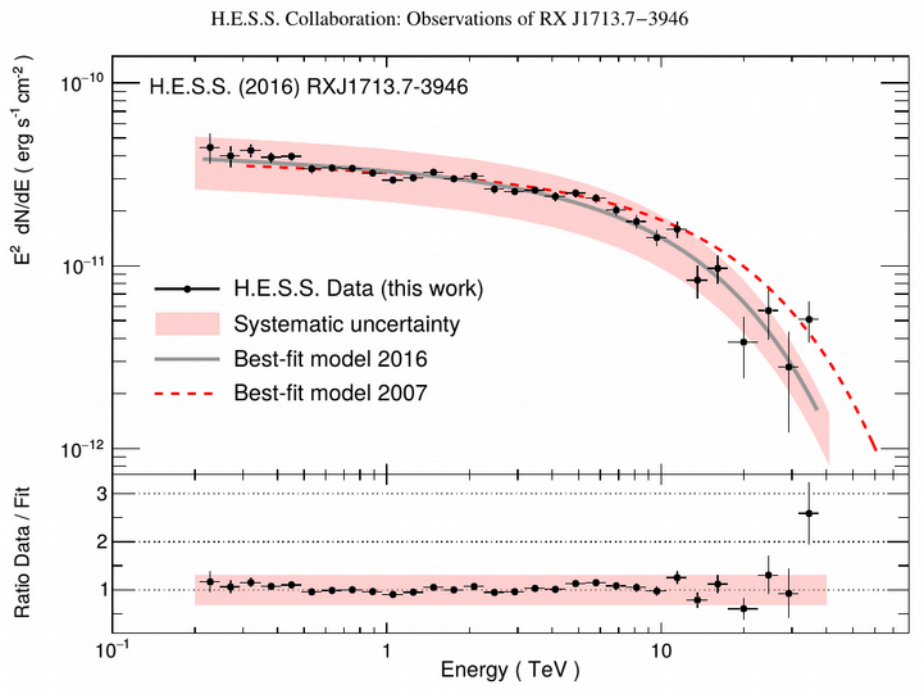
200 pages
arXiv 1709.07997

- CTA will be operated as an open, proposal-driven observatory
- 40% reserved for key science program in the early years

Source example



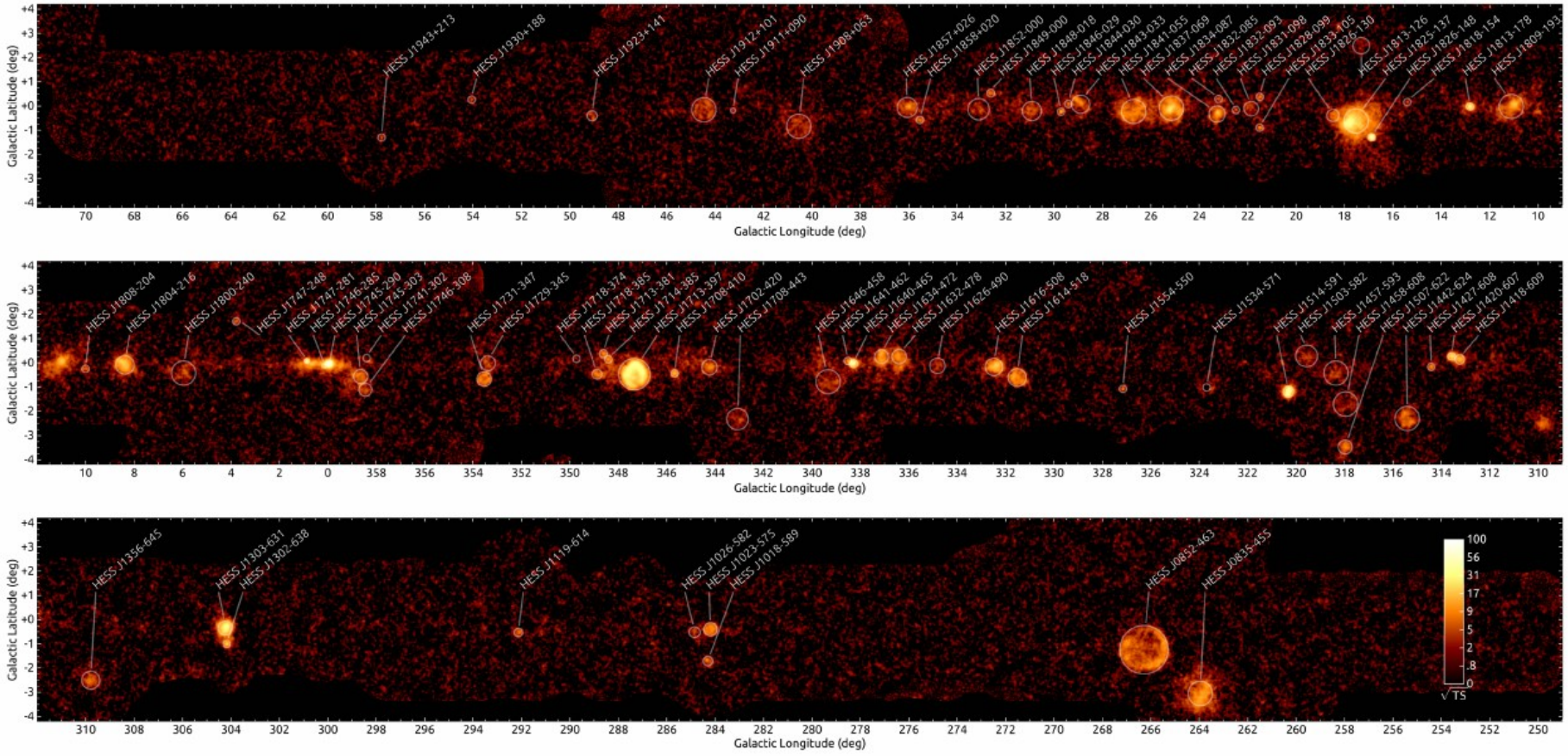




Most brilliant SNR measured so far
Visible source diameter 2 * moon!

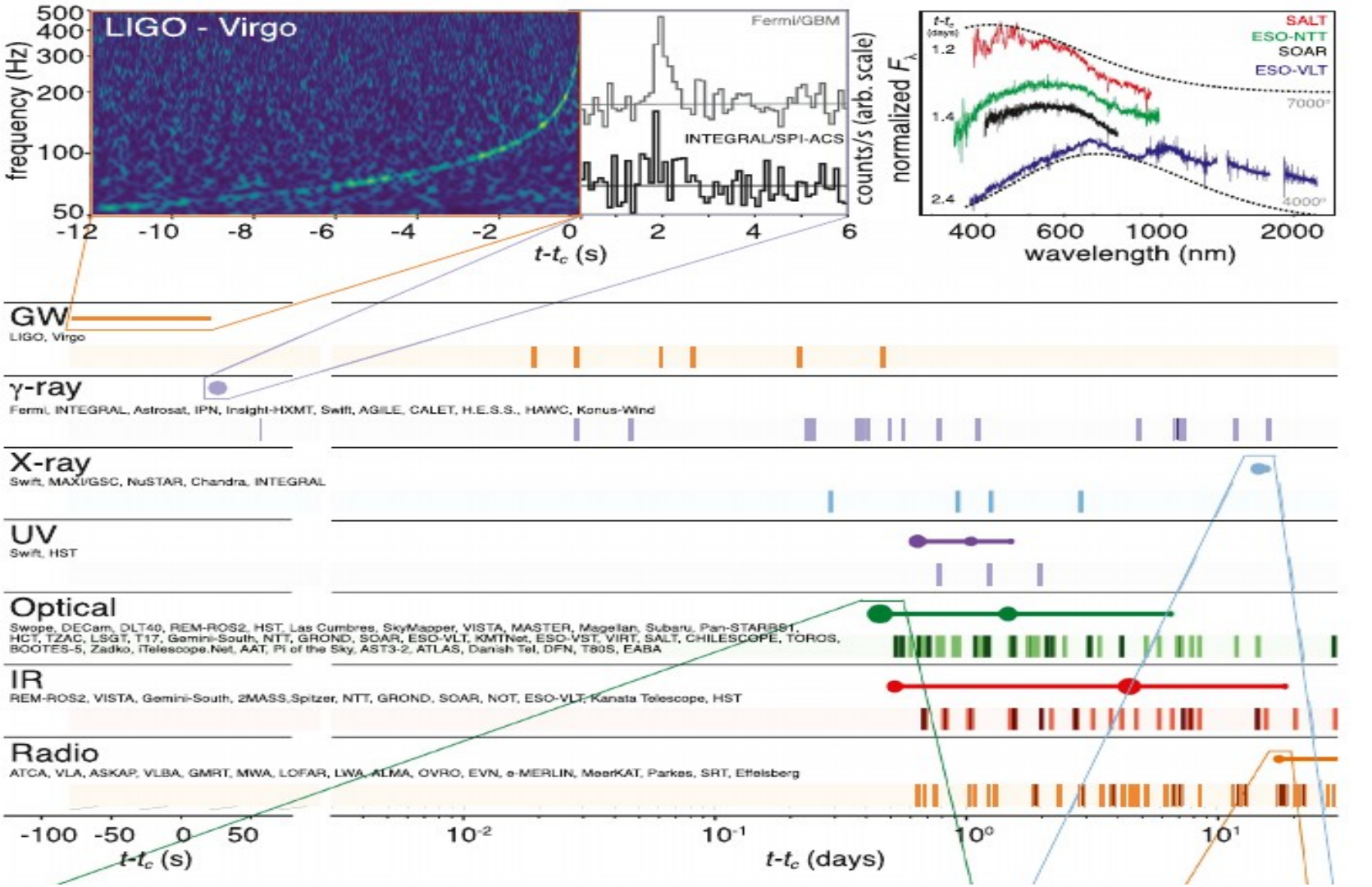
HESS collaboration, arXiv:1609.08671v2

More Sources in Galactic Disk



GW 170817: [arXiv 1710.05833]

BNS merger followed by a sGRB



Summary

- CTA will be 10 times more sensitive -> possibly 1000 sources to discover
- Energy resolution 10% -> spectral features
- 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,
- study cosmic ray acc. mechanism, dark matter annihilation ….

Expect 1 to 2 more years for politics / government

Expect 2 years to prepare infrastructure

First construction phase telescopes on site about 2020

4 more years to finish construction.