CTA : toward deep insight into the very high energy Universe

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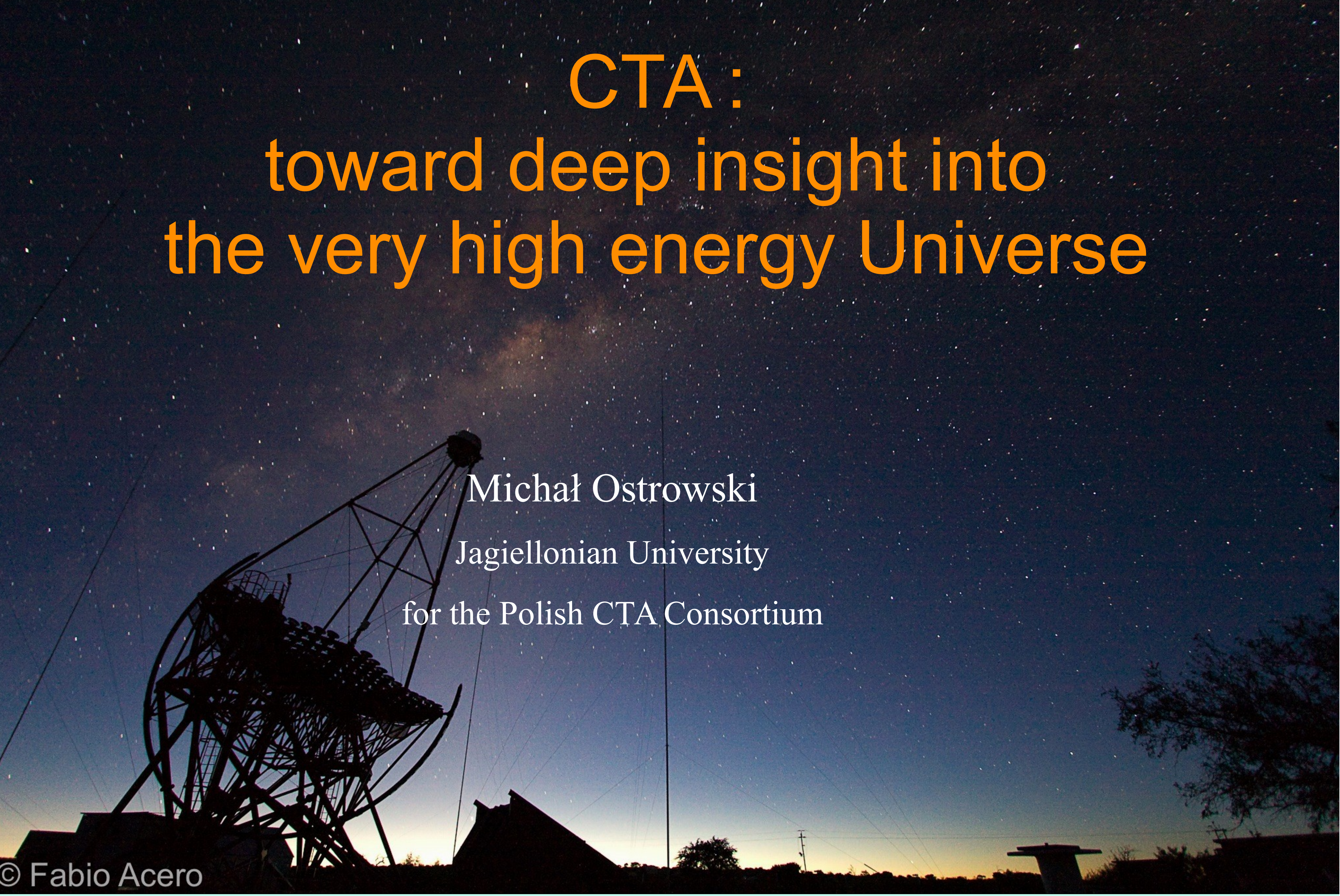
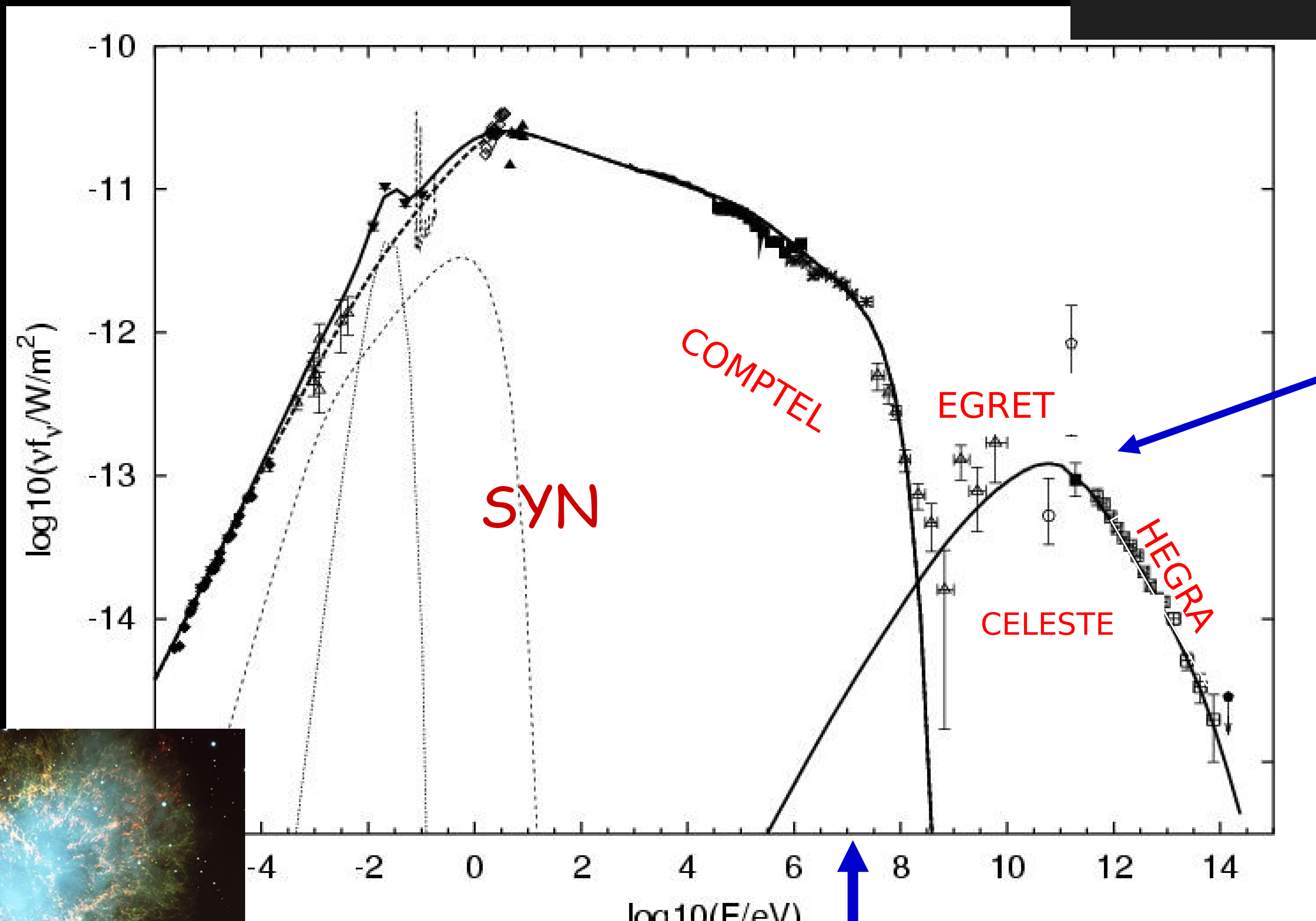
for the Polish CTA Consortium



I acknowledge receiving slides and figures kindly provided by Werner Hofmann, Mathieu de Naurois and my other HESS and CTA colleagues

Chandra animation

Crab nebula spectrum

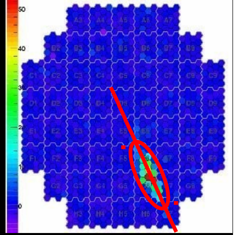


IC: syn, opt, IR, micro, CMB

$E_e \sim 10^{15}$ eV

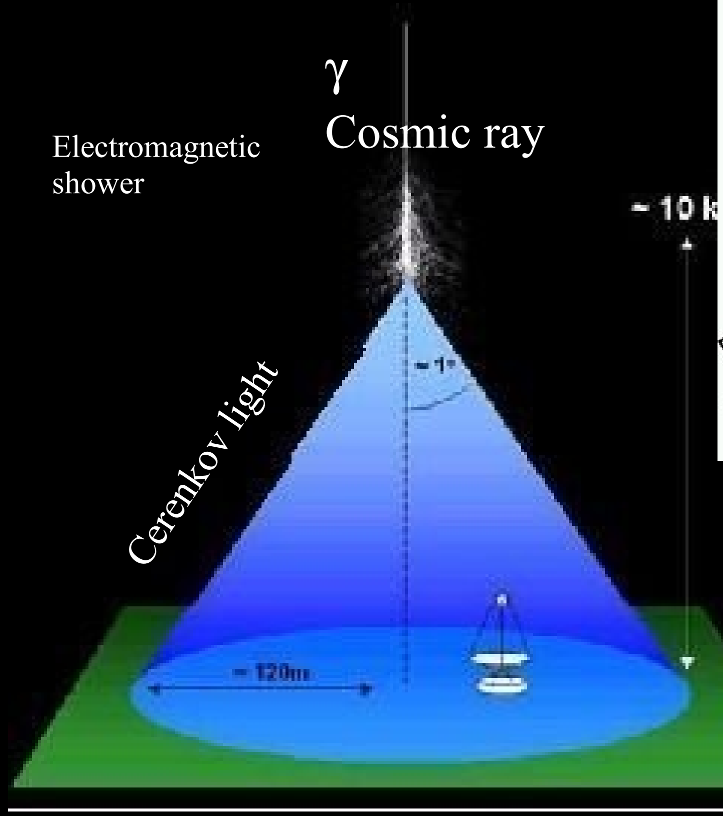
B=160 μG

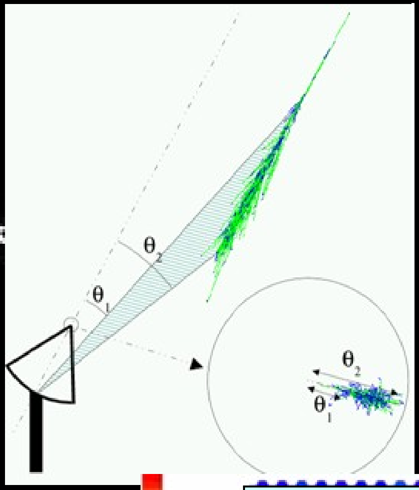
Atmospheric Cherenkov Telescopes

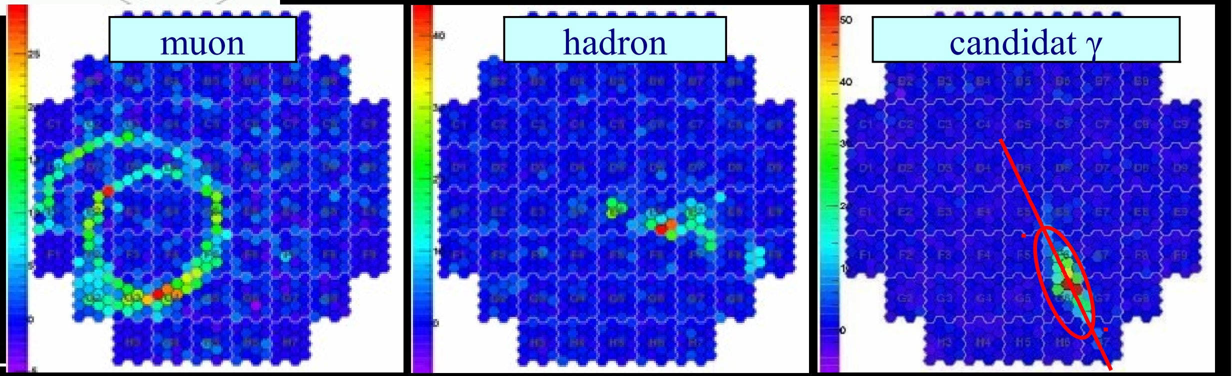


- ❑ Cherenkov light-pool ~ 120 m
- ❑ Image the shower on a fast camera (ΔT ~ 2 ns)
- ❑ Large effective area ~10^5 m^2 even with modest reflector

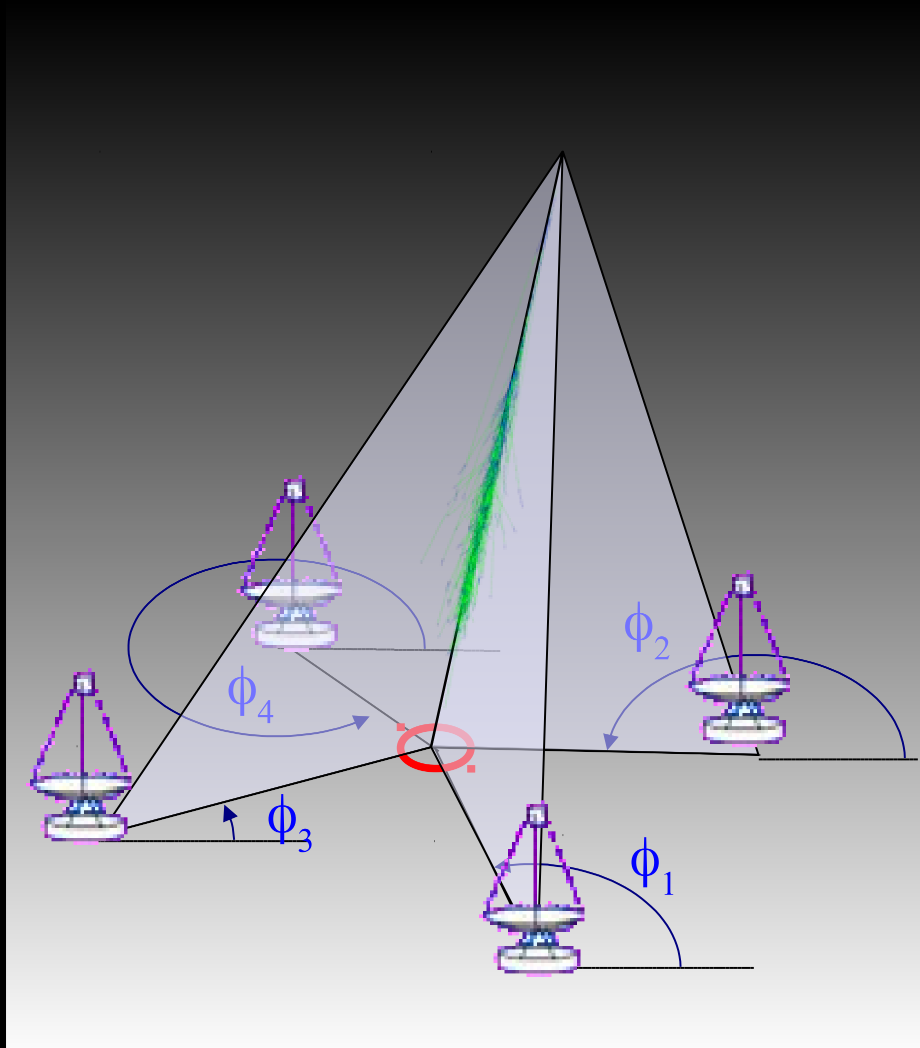
- ❑ Key parameter : speed (< 10 ns)
- ❑ Image shape used in discrimination

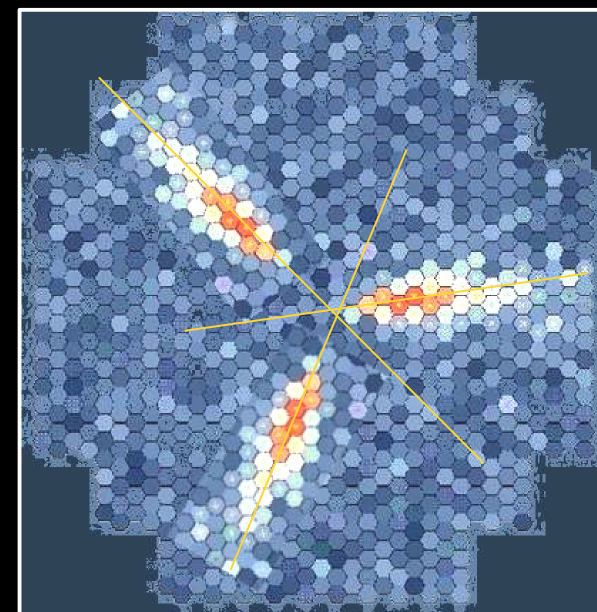






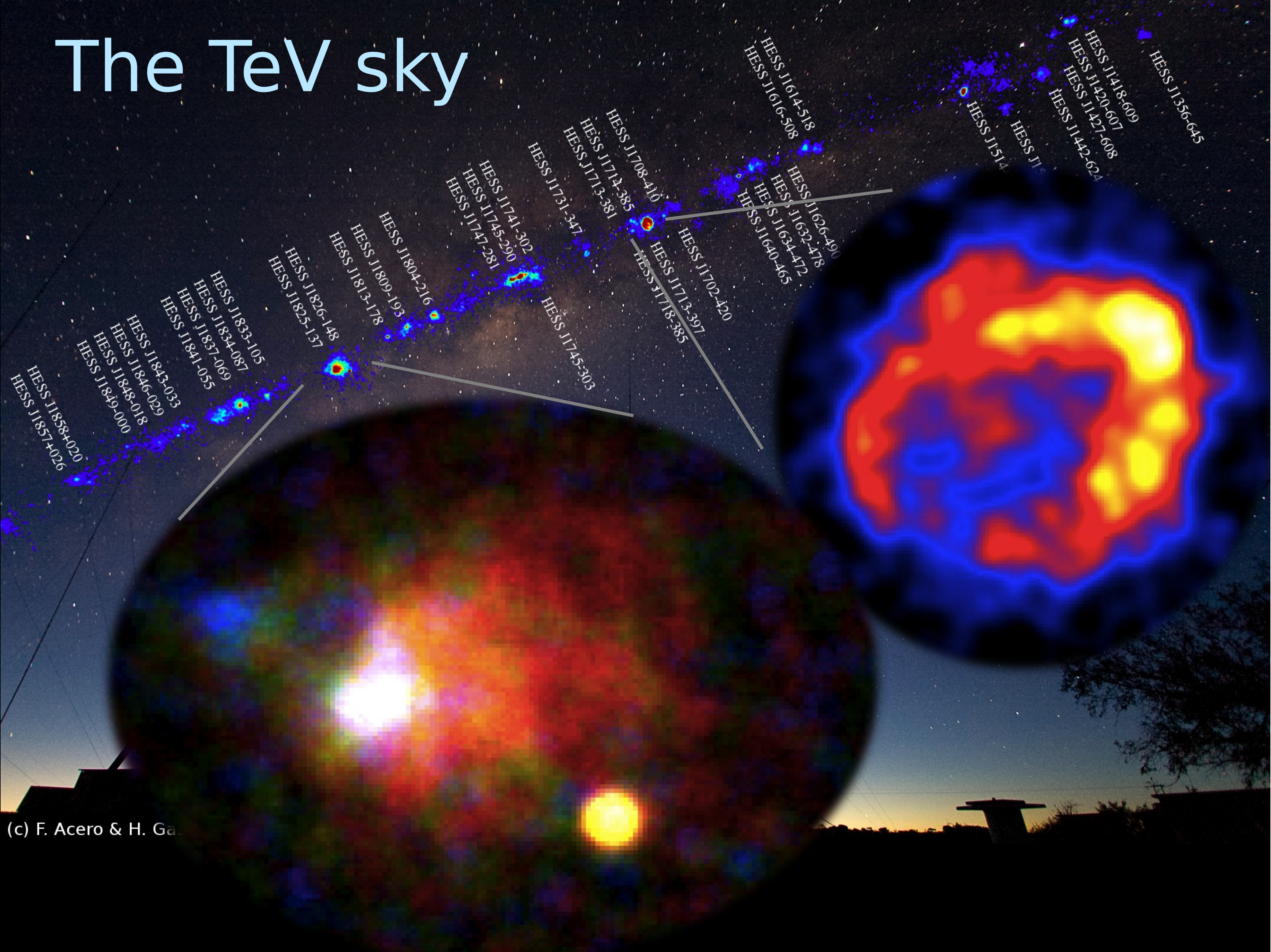
Stereoscopy



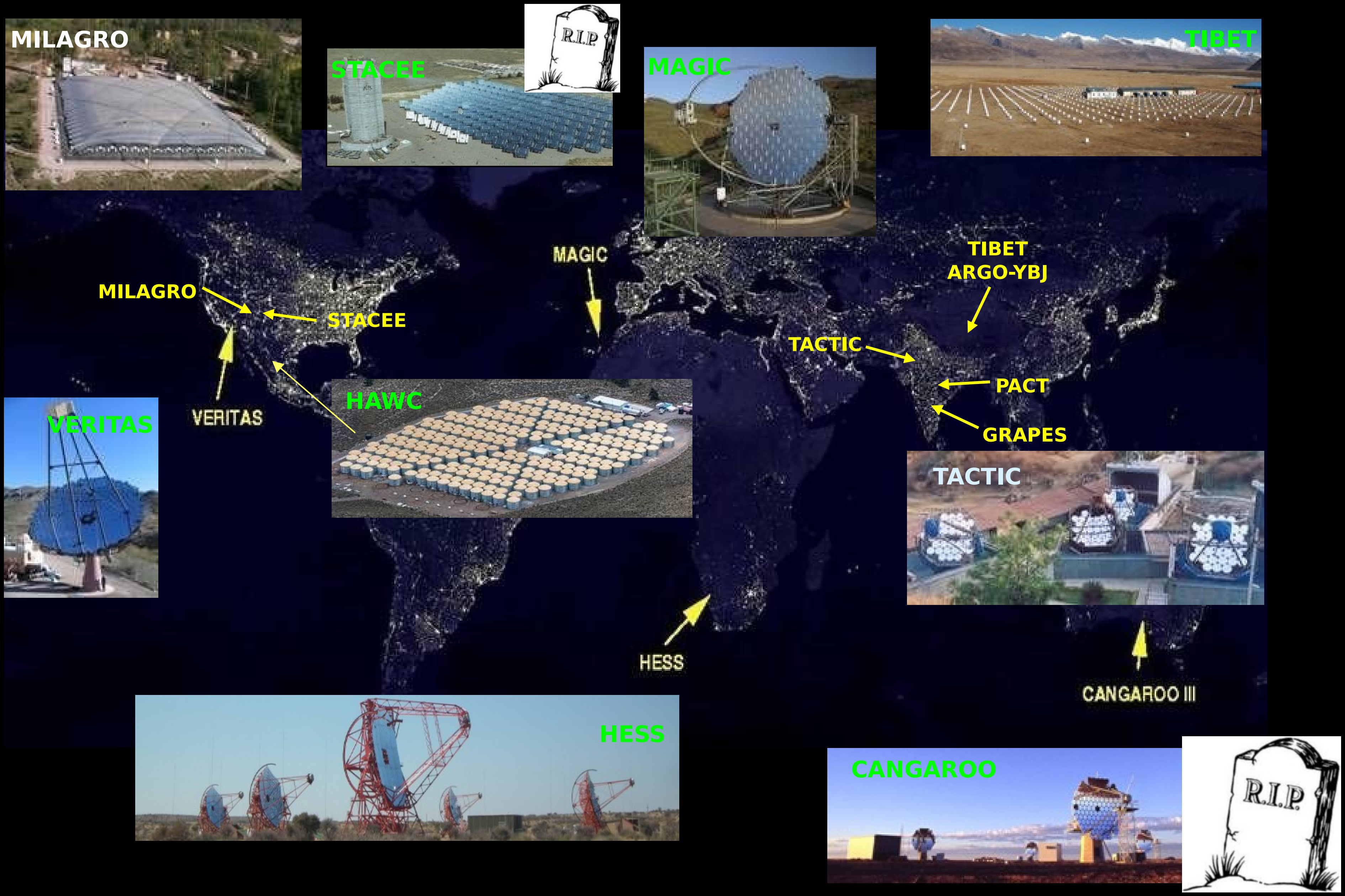


Superimposed images of 3 telescopes

- Stereoscopic observation of the same showers allow a much easier, almost geometric reconstruction

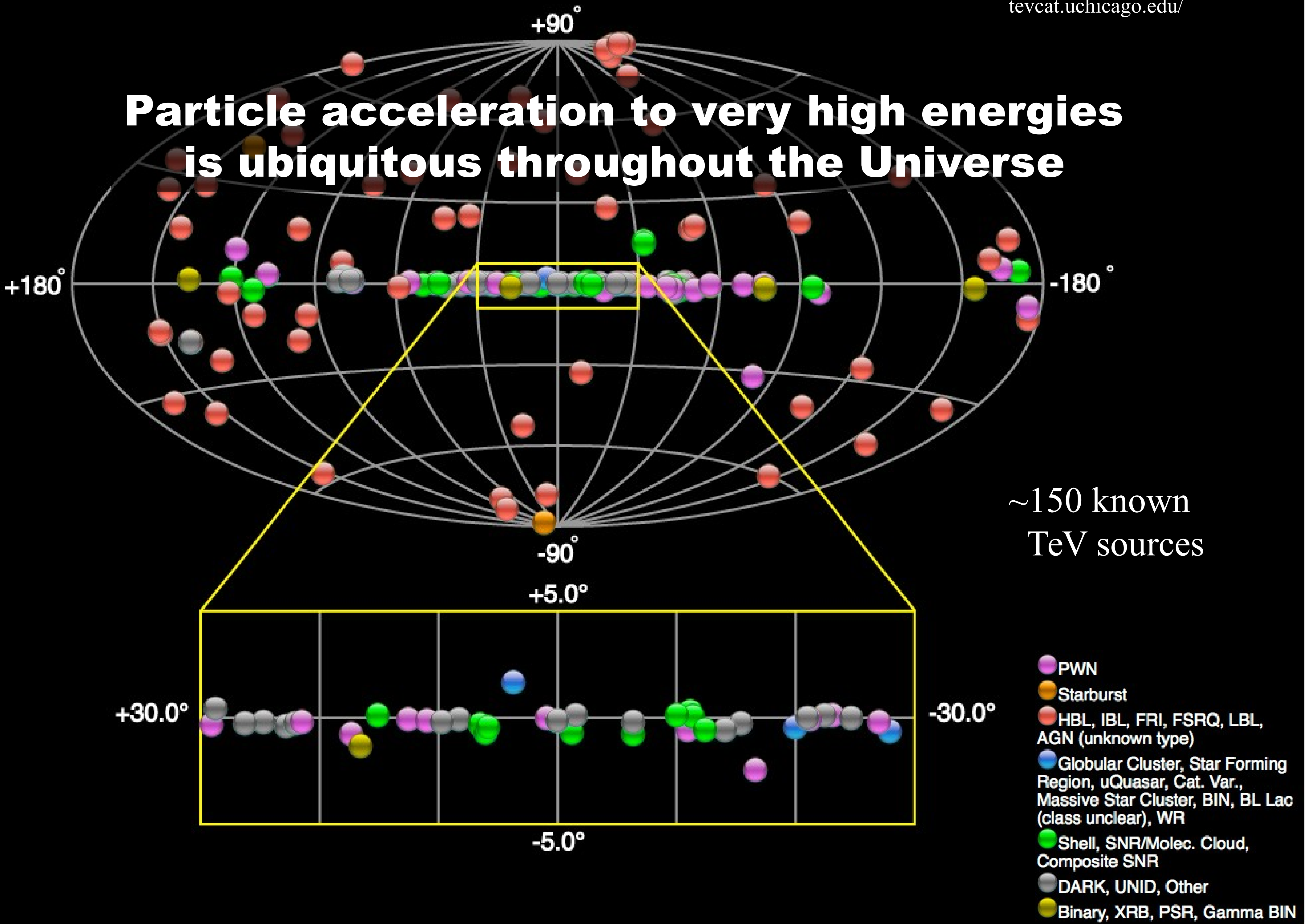

The TeV sky
HESS J1356-645
HESS J1418-609
HESS J1420-607
HESS J1427-608
HESS J1442-624
HESS J1614-518
HESS J1616-508
HESS J1626-490
HESS J1632-478
HESS J1634-472
HESS J1640-465
HESS J1708-410
HESS J1714-385
HESS J1713-381
HESS J1731-347
HESS J1702-420
HESS J1713-397
HESS J1718-385
HESS J1741-302
HESS J1745-290
HESS J1747-281
HESS J1745-303
HESS J1804-216
HESS J1809-193
HESS J1813-178
HESS J1826-148
HESS J1825-137
HESS J1833-105
HESS J1834-087
HESS J1837-069
HESS J1841-055
HESS J1843-033
HESS J1846-029
HESS J1848-018
HESS J1849-000
HESS J1858+020
HESS J1857+026
(c) F. Acero & H.

VHE γ-ray world

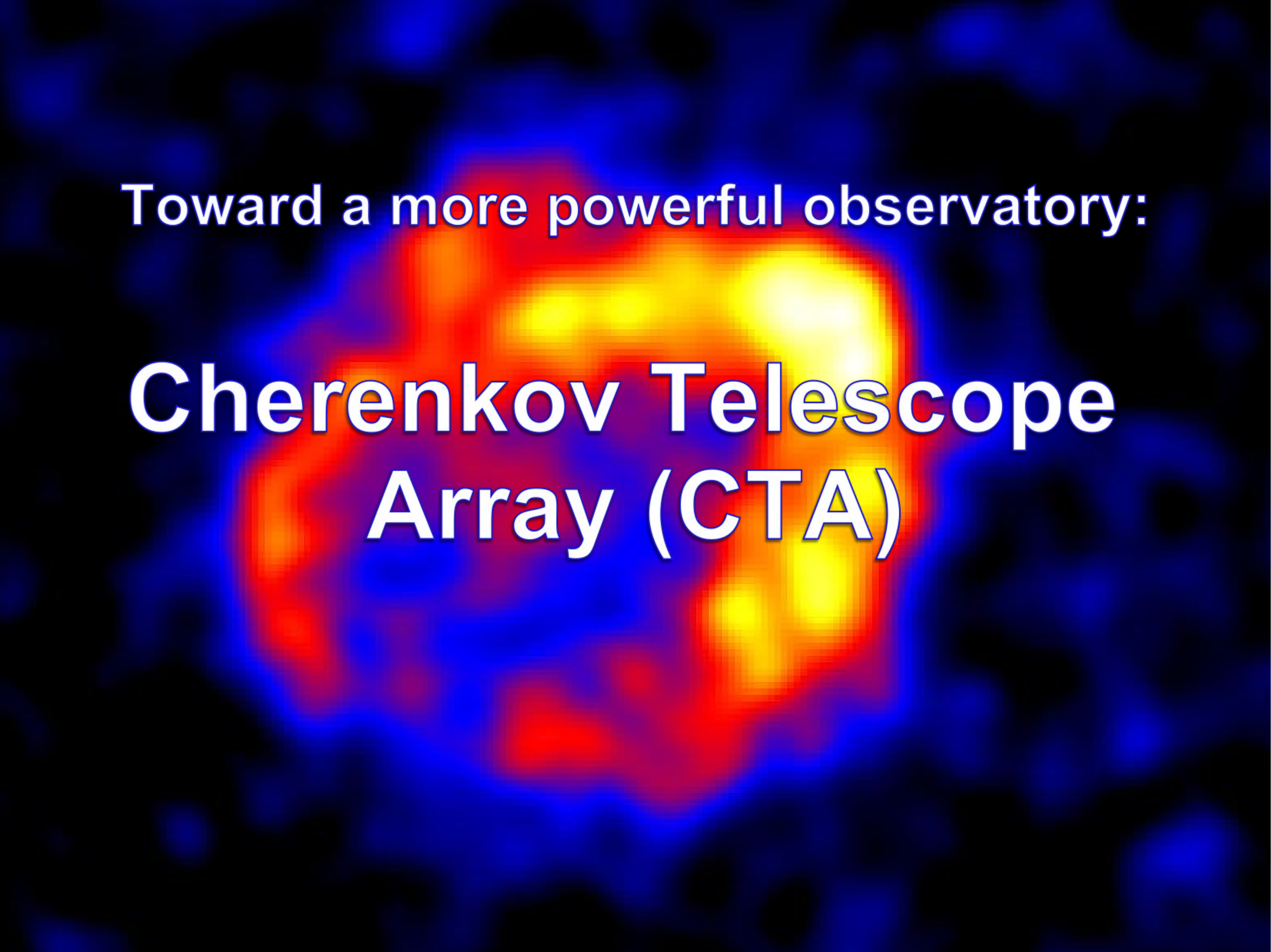


Particle acceleration to very high energies is ubiquitous throughout the Universe

tevcat.uchicago.edu/



~150 known TeV sources



Toward a more powerful observatory:

Cherenkov Telescope Array (CTA)


cta
cherenkov telescope array

Theme 1: Cosmic Particle Acceleration

- How and where are particles accelerated?
- How do they propagate?
- What is their impact on the environment?

Theme 2: Probing Extreme Environments

- Processes close to neutron stars and black holes?
- Processes in relativistic jets, winds and explosions?
- Exploring cosmic voids

Theme 3: Physics Frontiers – beyond the SM

- What is the nature of Dark Matter? How is it distributed?
- Is the speed of light a constant for high energy photons?
- Do axion-like particles exist?

Requirements & drivers

10 x Sensitivity
and collection area
(nearly every topic)

Good energy
resolution of ~10%
(lines, cutoffs)

Large field of view of 8^{o}
(surveys, extended
sources, flares)

Rapid slewing
(20 s)
to catch flares

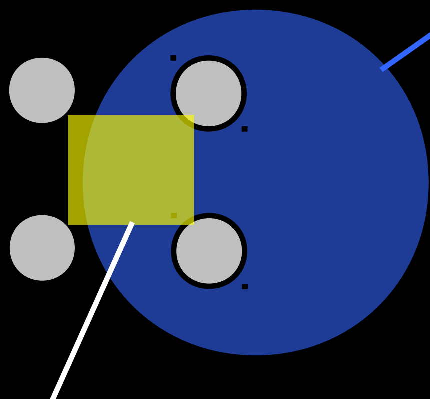
Improved angular
resolution of few ’
(source
morphology)

Energy coverage
down to 20 GeV
(AGN, cosmology)

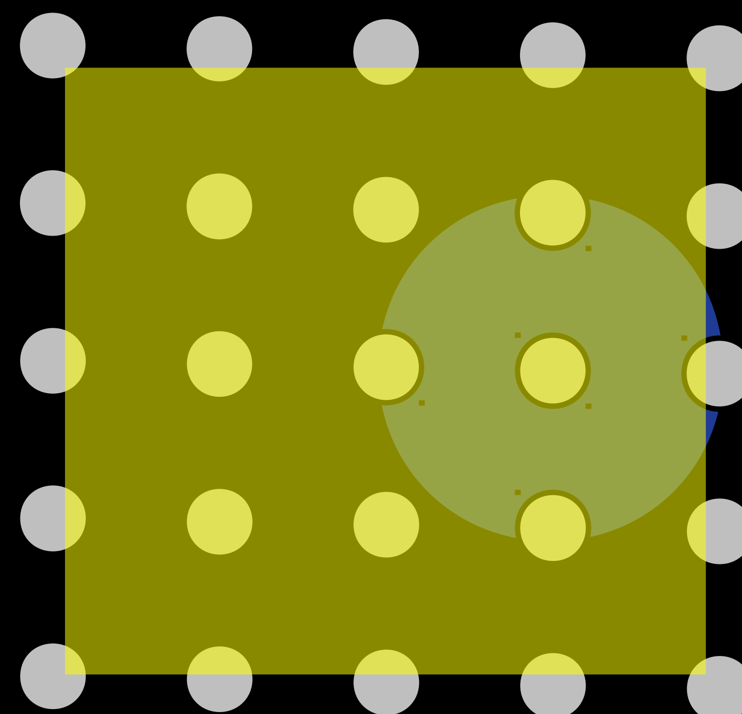
Energy coverage
up to 300 TeV
(Pevatrons)

From current arrays to CTA

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



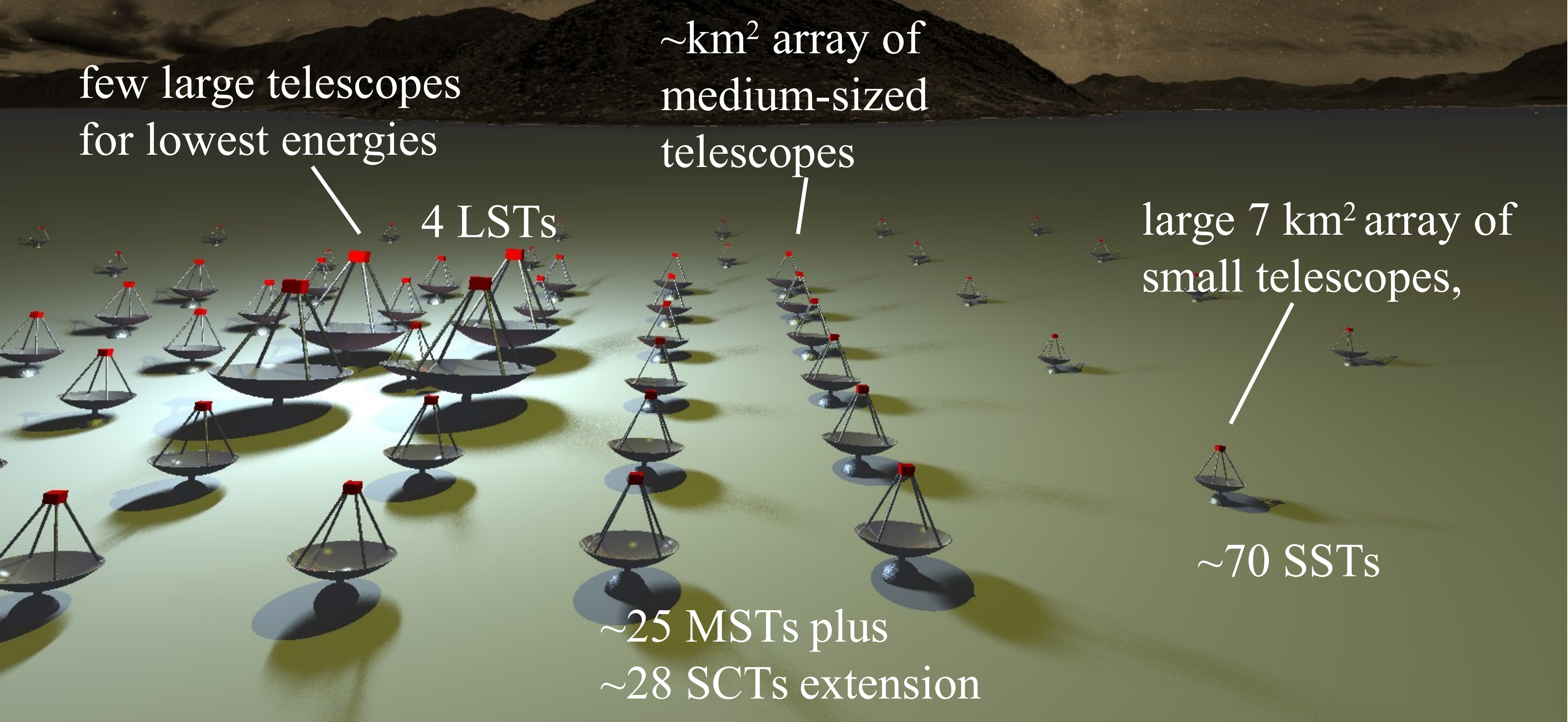
Sweet spot for
best triggering
and reconstruction:
most showers miss it!



large detection area
more images per shower
lower trigger threshold

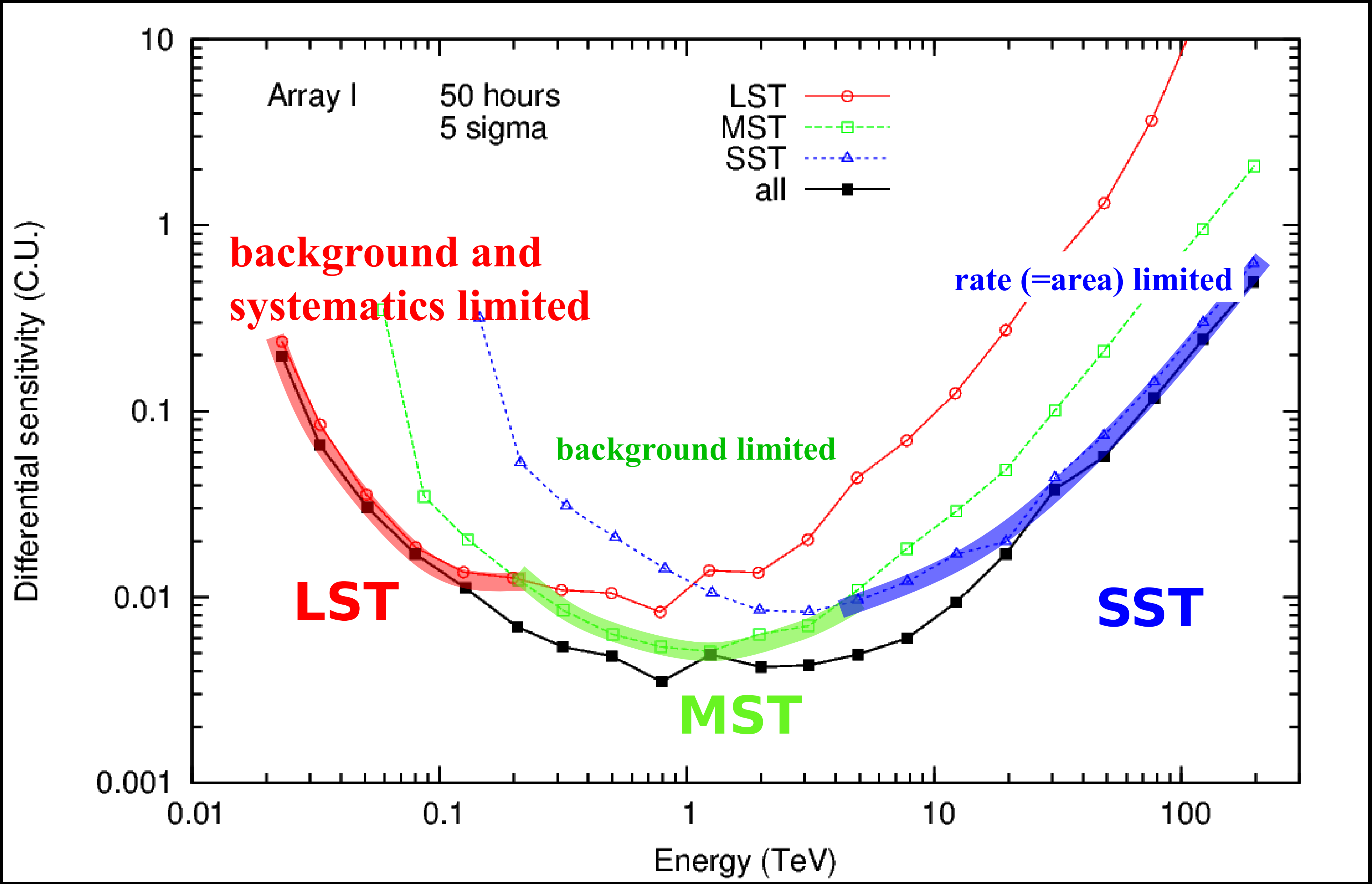
Science-optimization under budget constraints:

- Low-energy γ high γ-ray rate, low light yield
  ➜ require small ground area, large mirror area
- High-energy γ low γ-rate, high light yield
  ➜ require large ground area, small mirror area

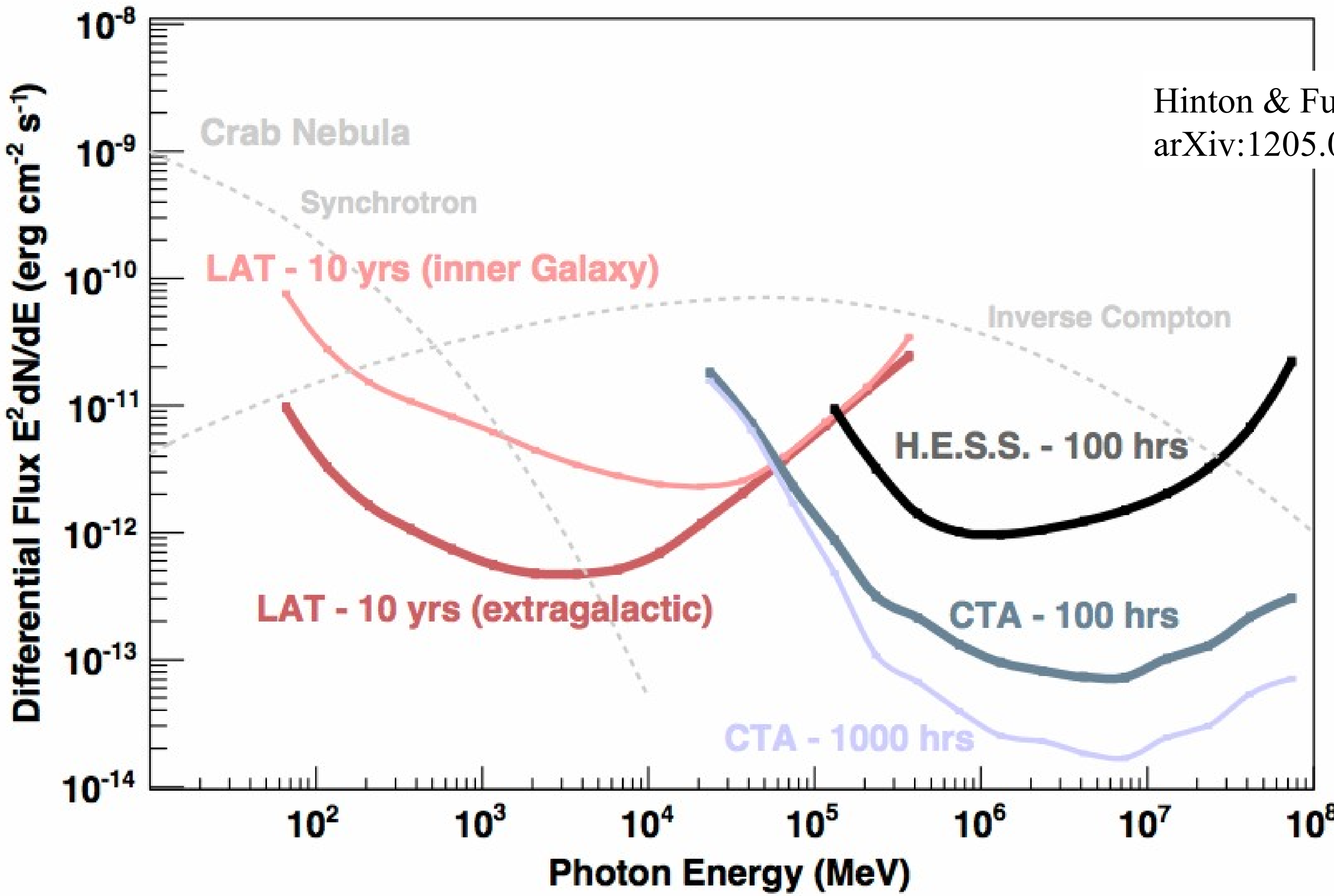


Sensitivity (in units of Crab flux)

for detection in each 0.2-decade energy band

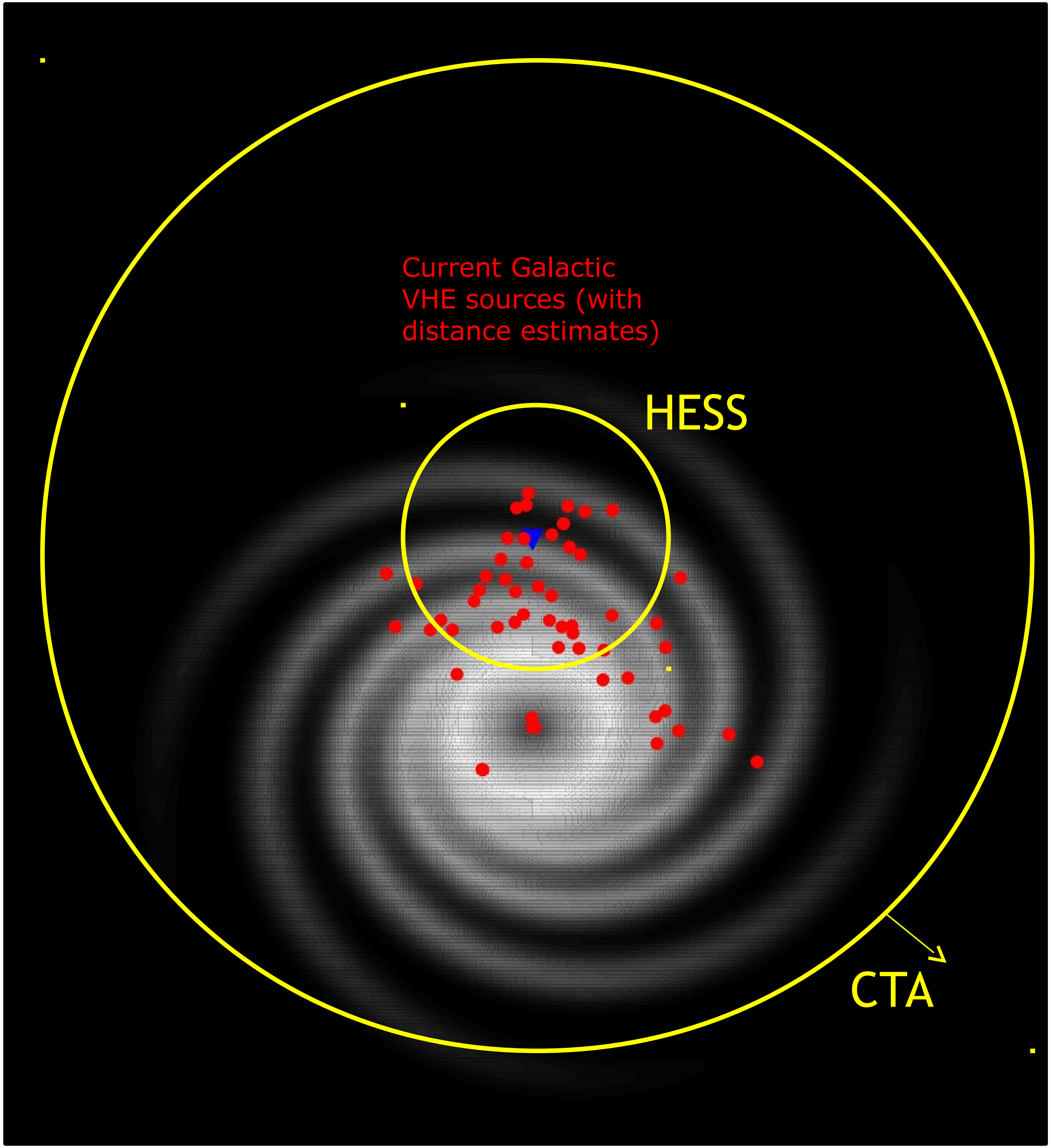


differential flux sensitivity



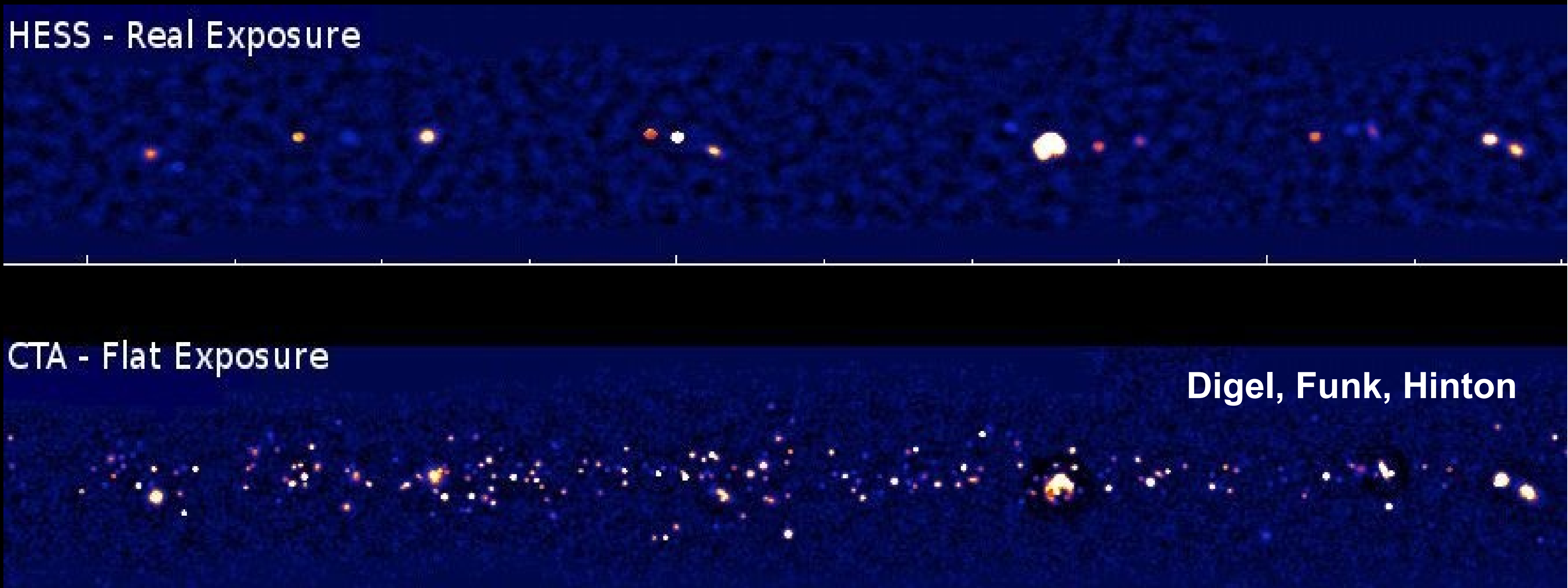
Hinton & Funk
arXiv:1205.0832

CTA Reach

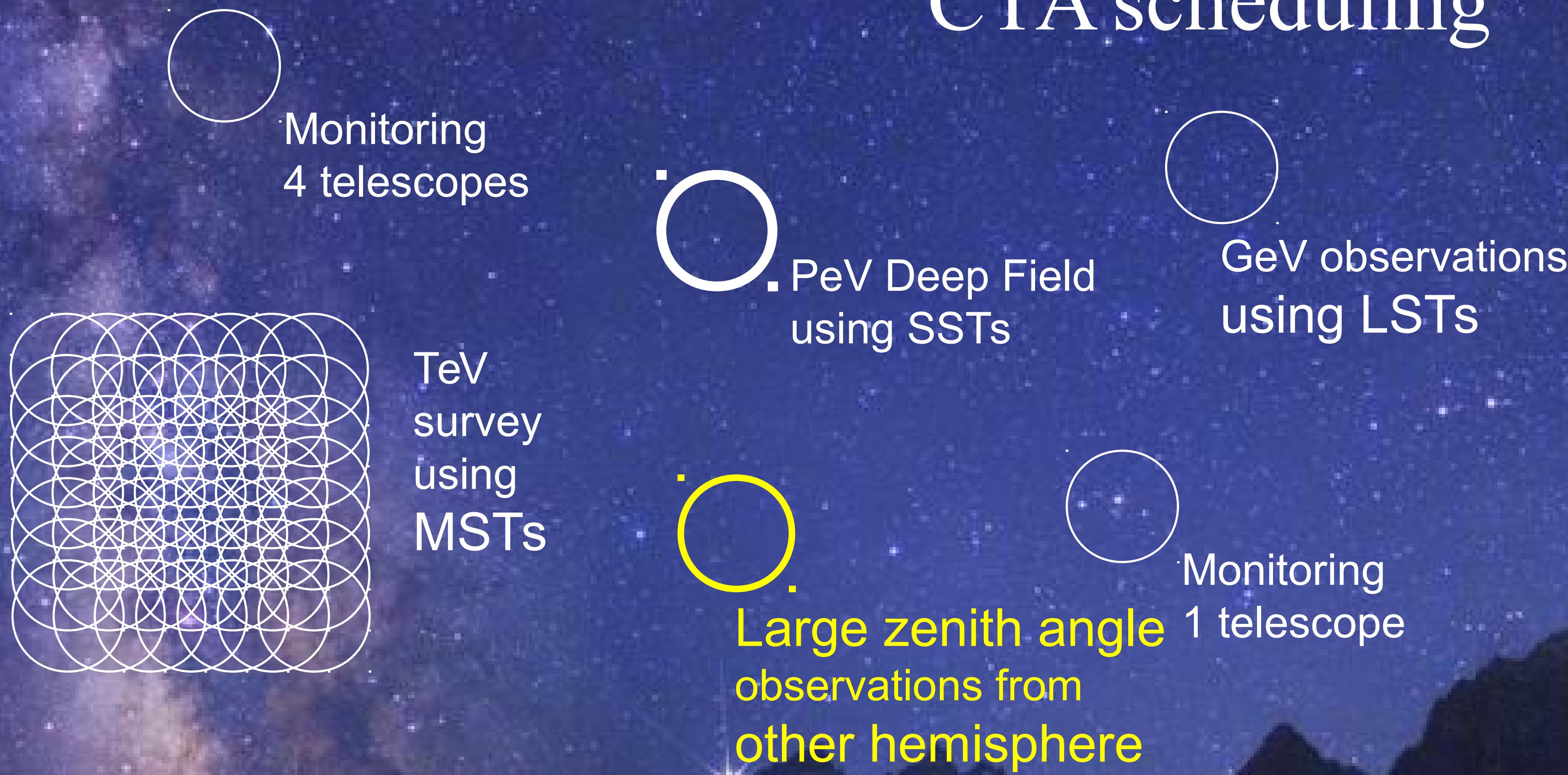


Current Galactic
VHE sources (with
distance estimates)
HESS
CTA

Deep TeV Vision



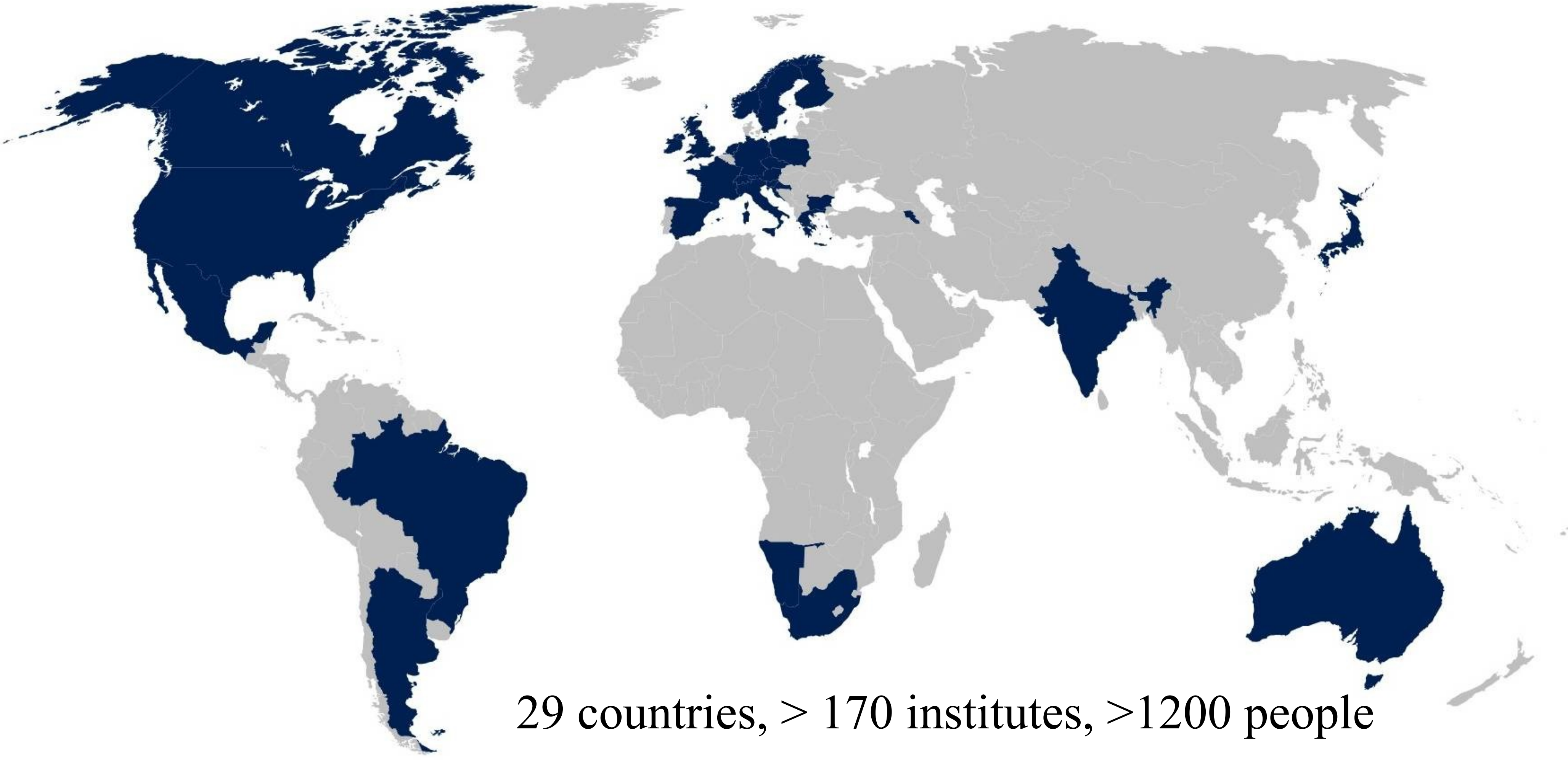
CTA scheduling



- CTA North and South through single portal, AO, identical tools
- Queue mode scheduler taking into account actual sky conditions, sub-arrays & conditions requested in proposal, priorities, TOOs

CTA 2015

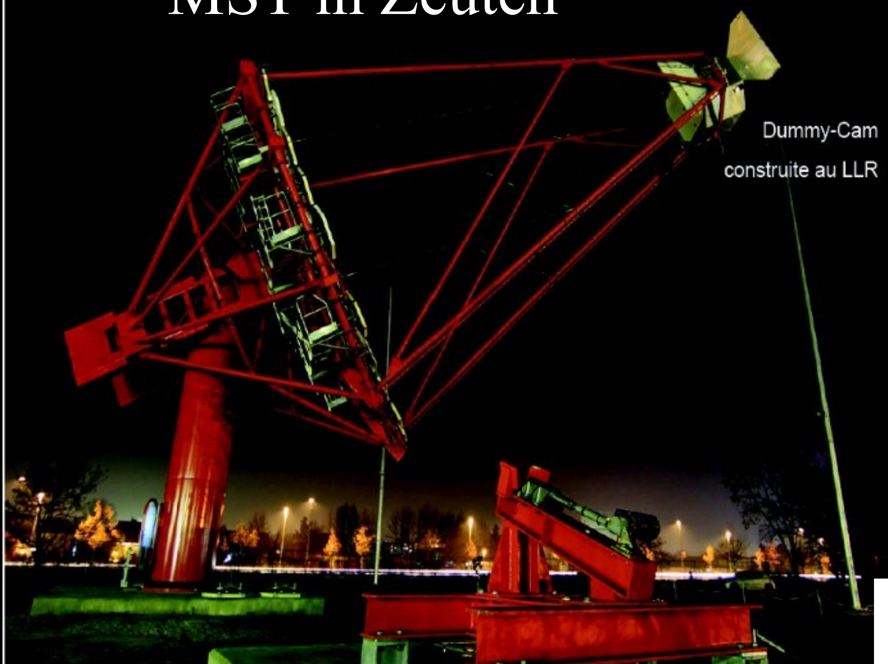
4 - 8 May 2015 - Turku, Finland



+ Chile & Ukraina = 31 countries at 6 continents

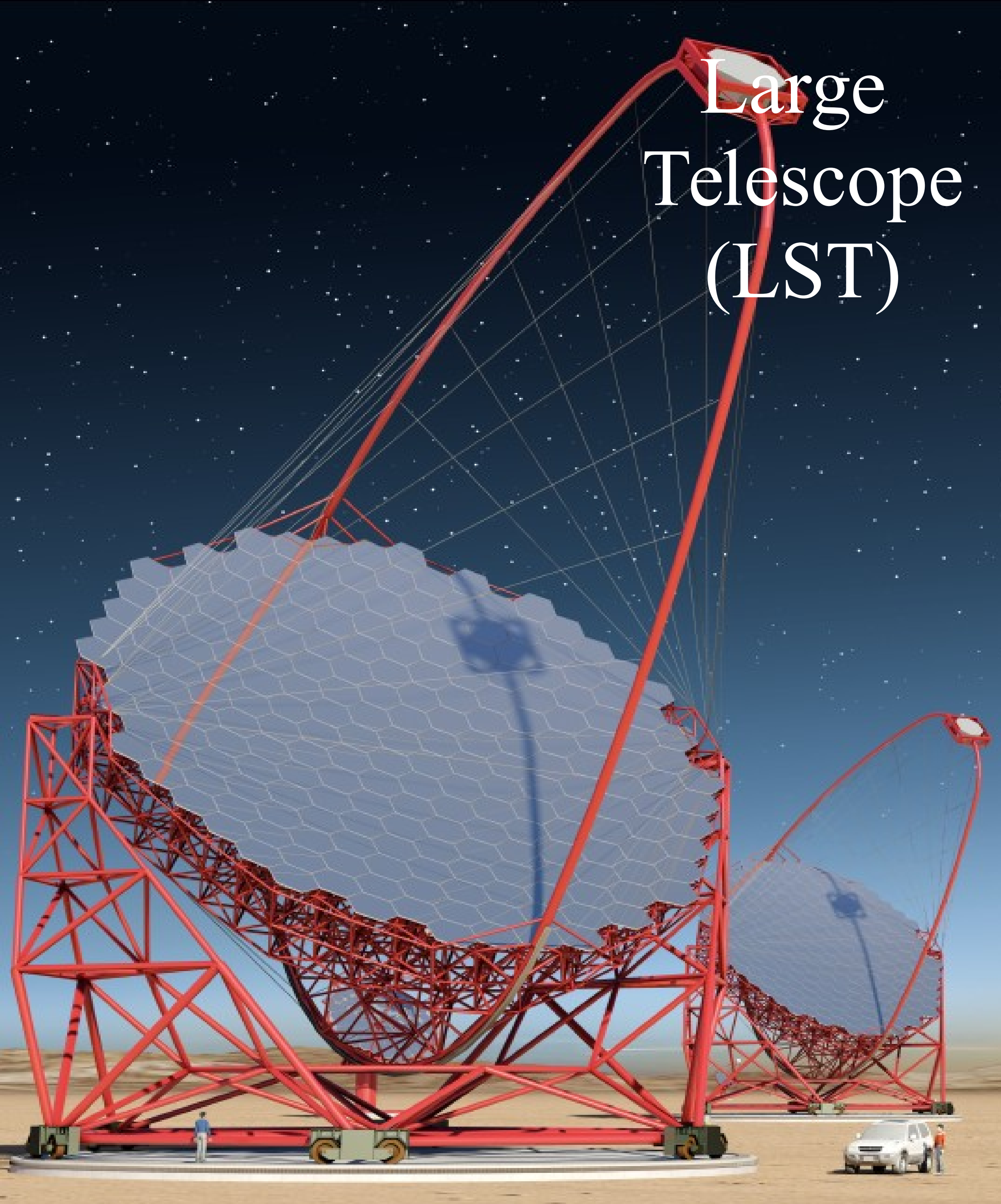
Prototyping

MST in Zeuten



GATE

Large Telescope (LST)



23 m diameter
389 m² dish area
28 m focal length
1.5 m mirror facets

4.5° field of view
0.1° pixels
Camera ∅ over 2 m

Carbon-fibre structure
for 20 s positioning

Active mirror control

4 LSTs on South site
4 LSTs on North site
Prototype = 1st telescope

Medium-Sized 12 m Telescope

optimized for the 100 GeV to ~10 TeV range

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 - Zeuten
MST prototype
operational

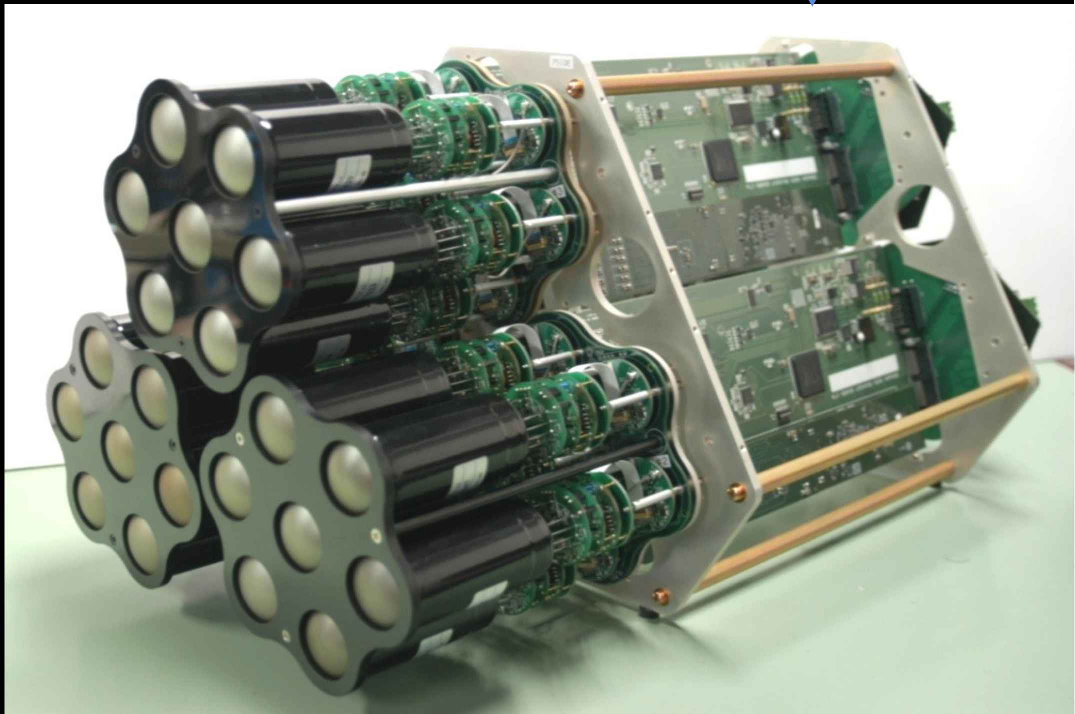
photomultiplier cameras for MST

Recording signal waveform for “interesting” (triggered) images

Options:

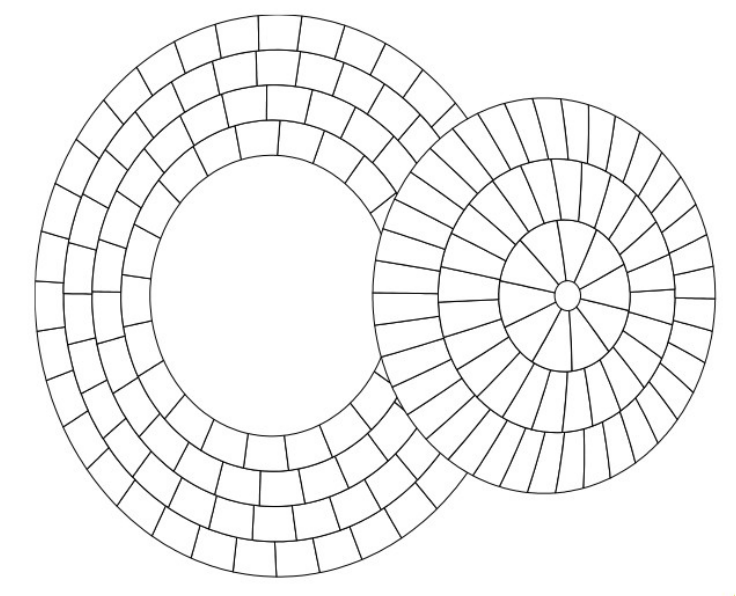
- NectarCam (Pixel cluster prototypes operational)
- DragonCam (Pixel cluster prototypes operational)

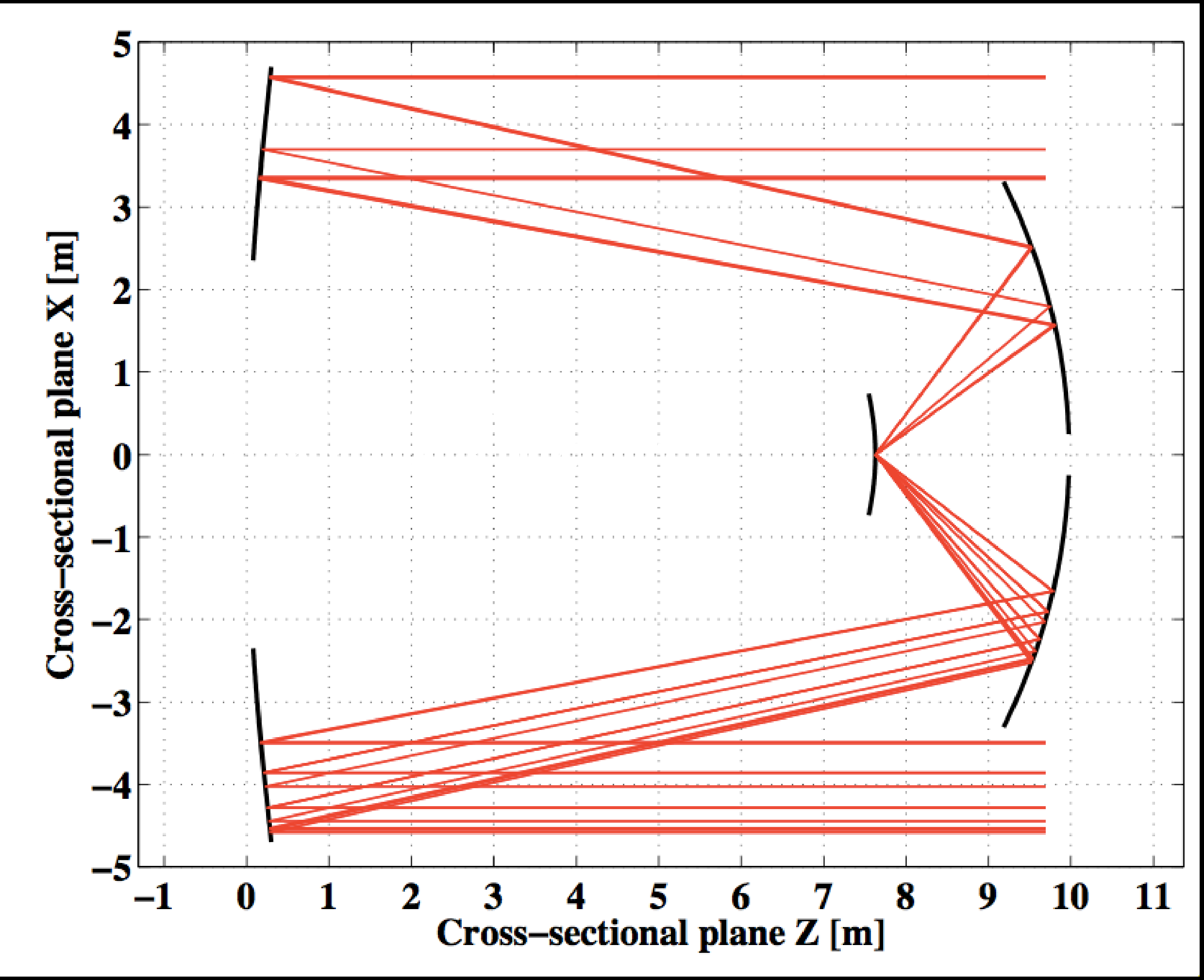
- Flashcam (144 pixel prototype operational)




HESS II Camera
2048 pixels
On-board electronics
2.5 m ∅

Interesting new developments: Dual-mirror telescopes





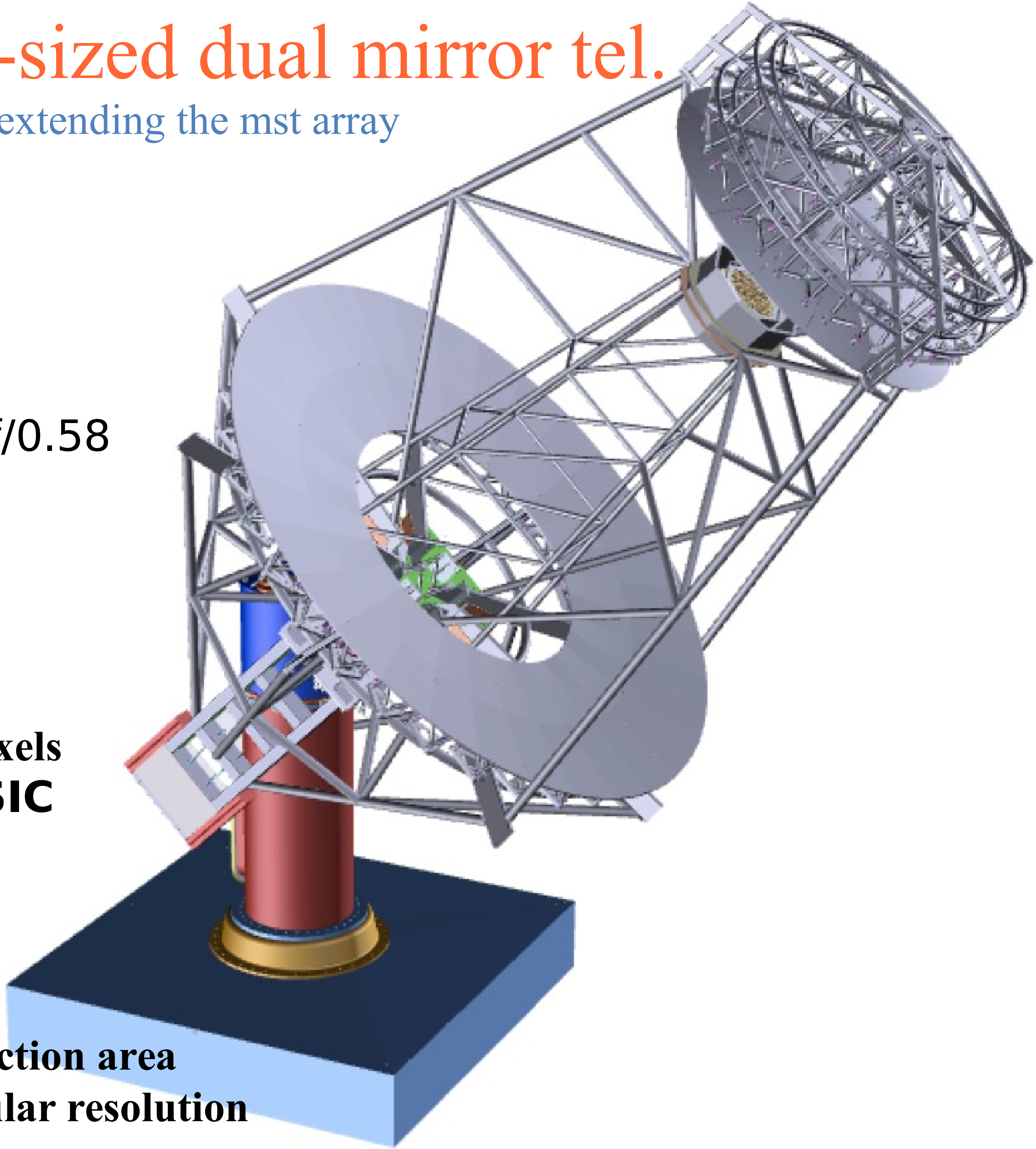
- Reduced plate scale
- Reduced psf
- Uniform psf across f.o.v.

➜ Cost-effective small telescopes with compact sensors (SST-2M)

➜ Higher-performance telescopes with small pixels (SCT)

Medium-sized dual mirror tel.

extending the mst array



9.7 m primary
5.4 m secondary
5.6 m focal length, f/0.58
40 m^2 eff. coll. area
PSF better than 4.5’
across 8° fov

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

Extend South array
by adding 24 SCTs

➜ increased γ-ray collection area
➜ improved γ-ray angular resolution

Small telescopes

Several options under prototyping

Single-mirror telescope with Silicon camera (prototype under constr.)

Dual-mirror telescopes

ASTRI telescope structure (prototype under constr.)

GATE telescope structure (prototype under constr.)

with camera options

ASTRI (Silicon, S&H ASIC) (prototype under constr.)

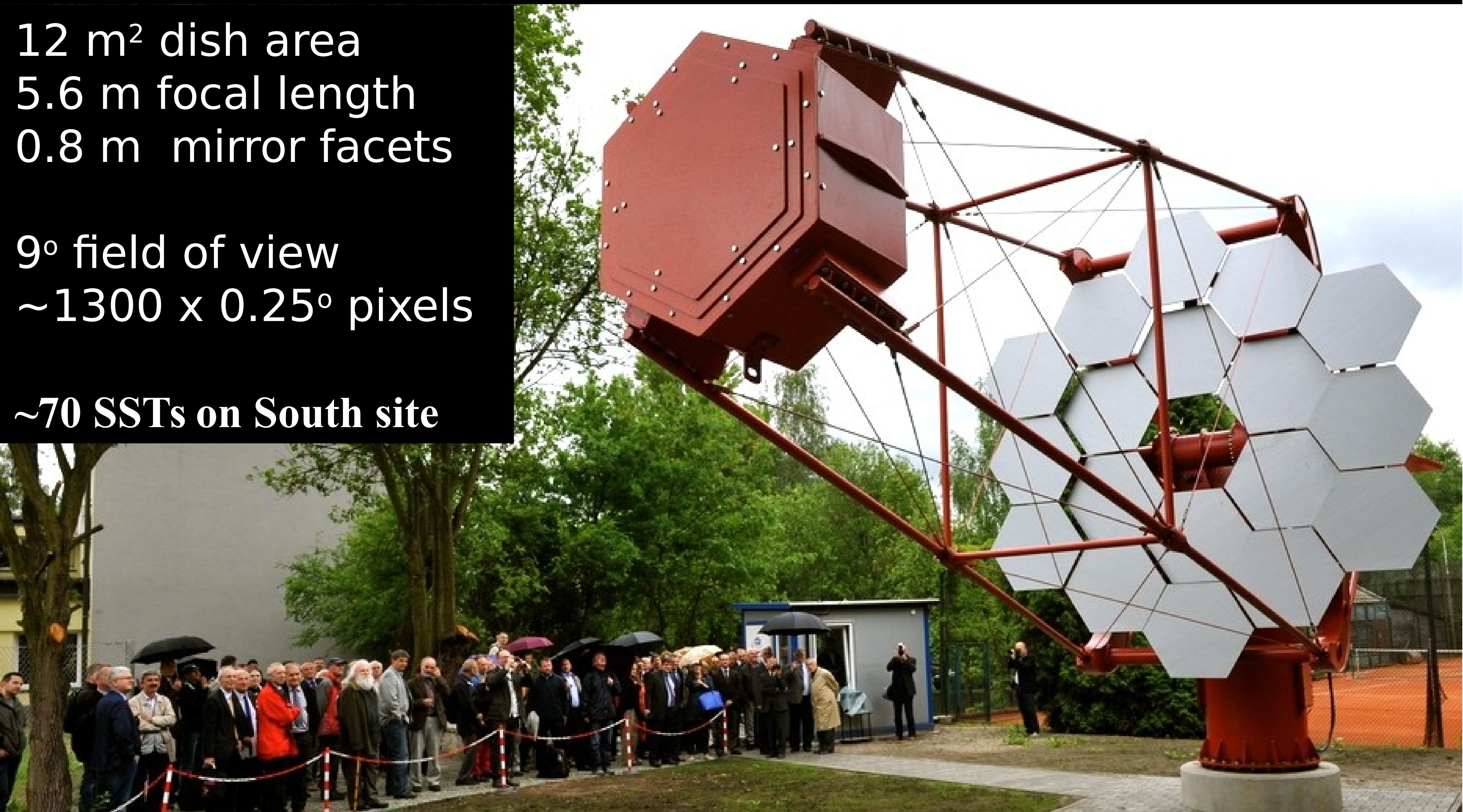
CHEC (Silicon or MAPMT, Pipeline ASIC) (prototype under constr.)

SST-1M structure prototype opening
INP, Cracow (June 2nd, 2014)

12 m² dish area
5.6 m focal length
0.8 m mirror facets

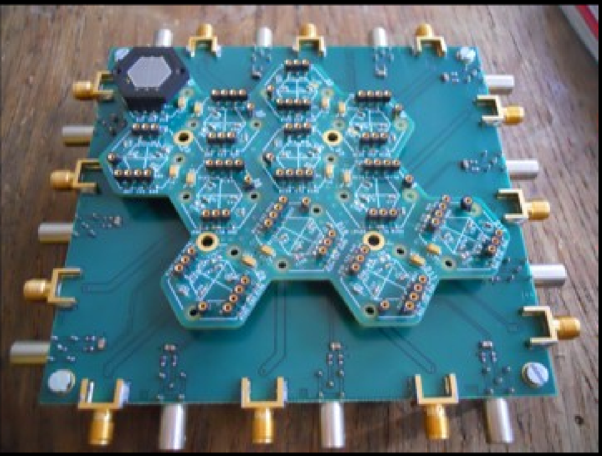
9° field of view
~1300 x 0.25° pixels

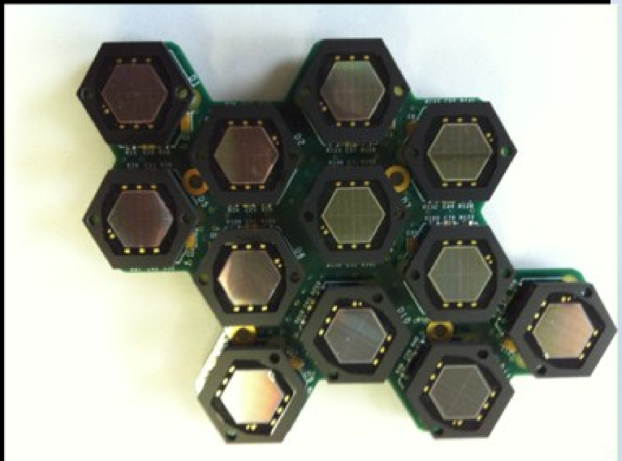
~70 SSTs on South site

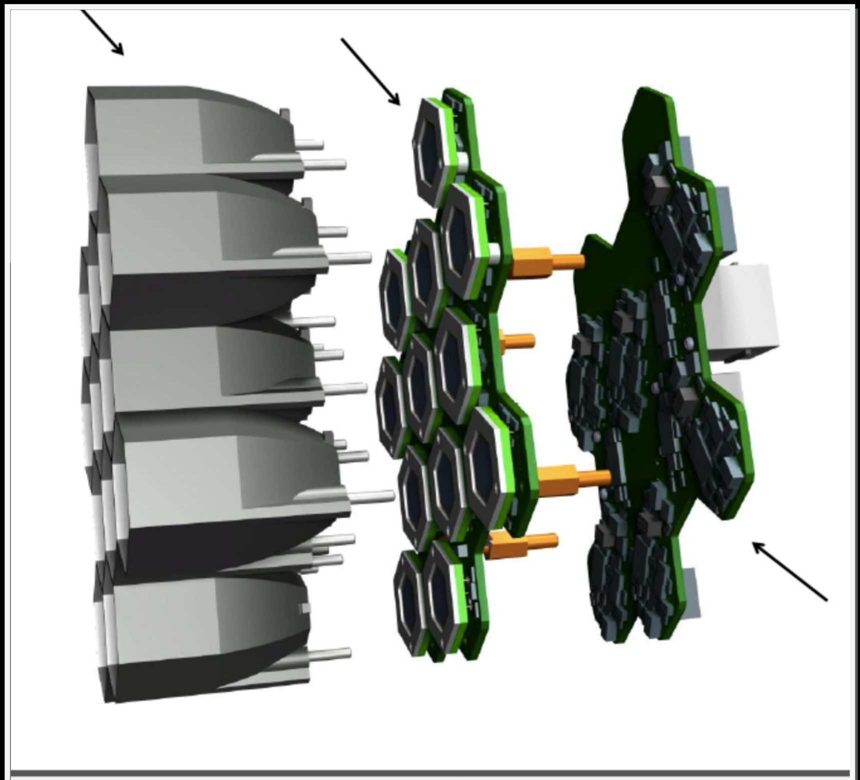


Single-mirror prototype

Silicon PMT camera with digital electronics



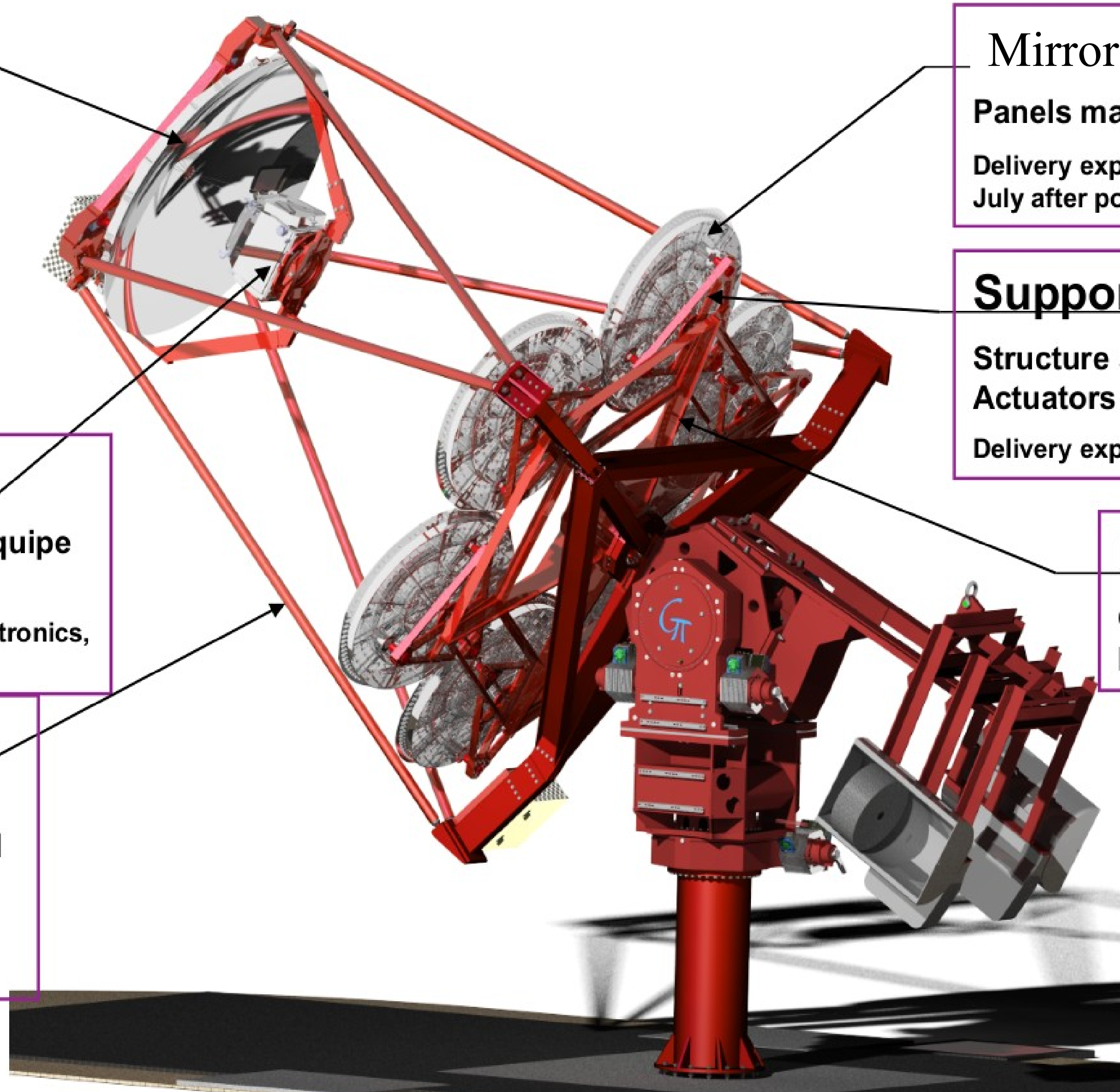




Double mirror Schwartshild Couder telescope
SST-2M (Sept.2014)

Italy: ASTRI

GATE



Mirror M2

Call of tender published week 26 of 2014

Industrialization & tools due at the end of July 2014.

Realization due for October 2014

CHEC

Caméra fournie par l'équipe CHEC

Interfaces (mechanics, electronics, power, cooling) studied

MTS

(bottom dish, tubes, top dish)

Call of tender expected during July 2014

Need of adjustment after final FEA simulations

Mirror M1

Panels machined

Delivery expected at the end of July after polishing and coating

Support M1

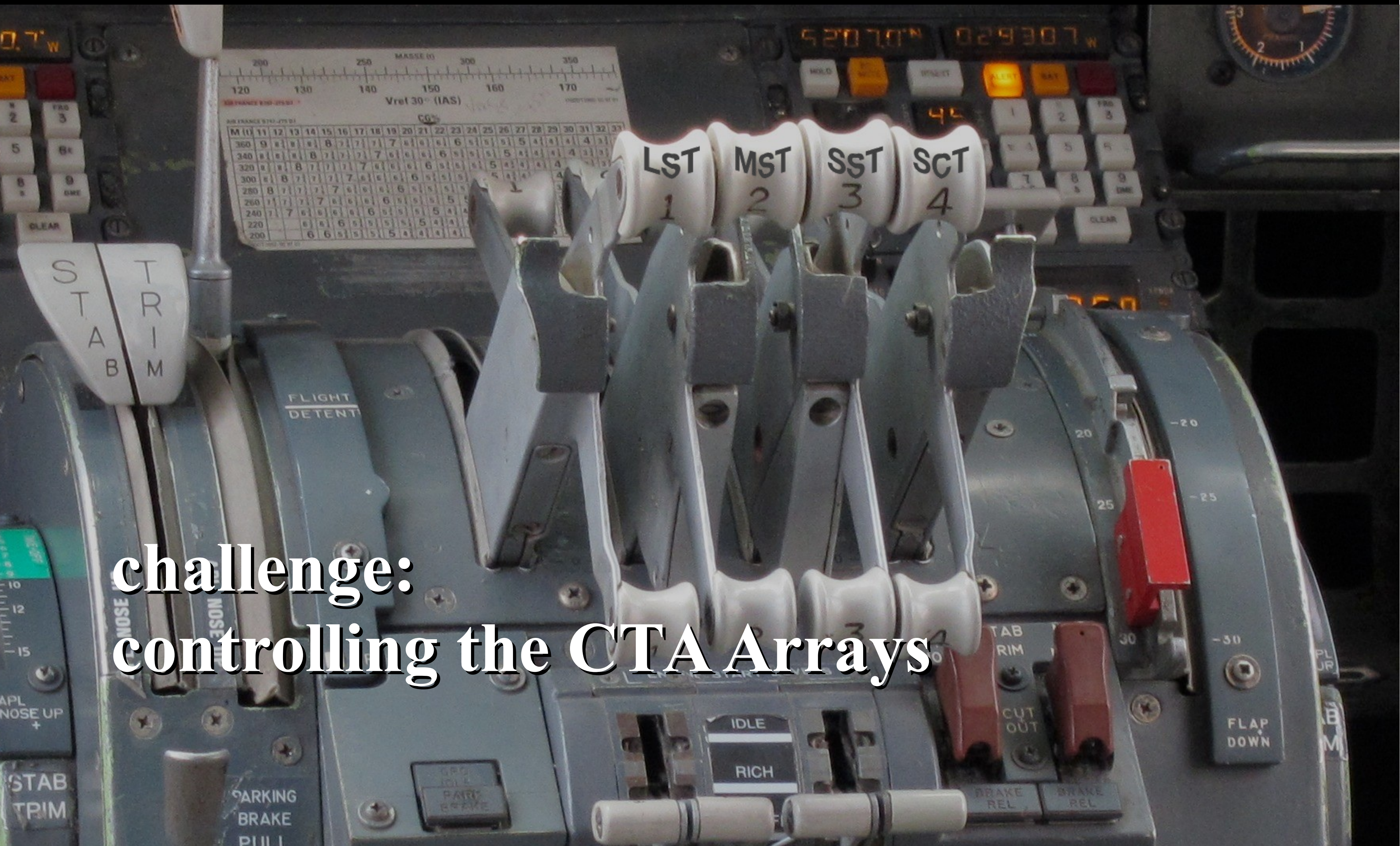
Structure studied, Actuators on progress

Delivery expected for October

Dish M1

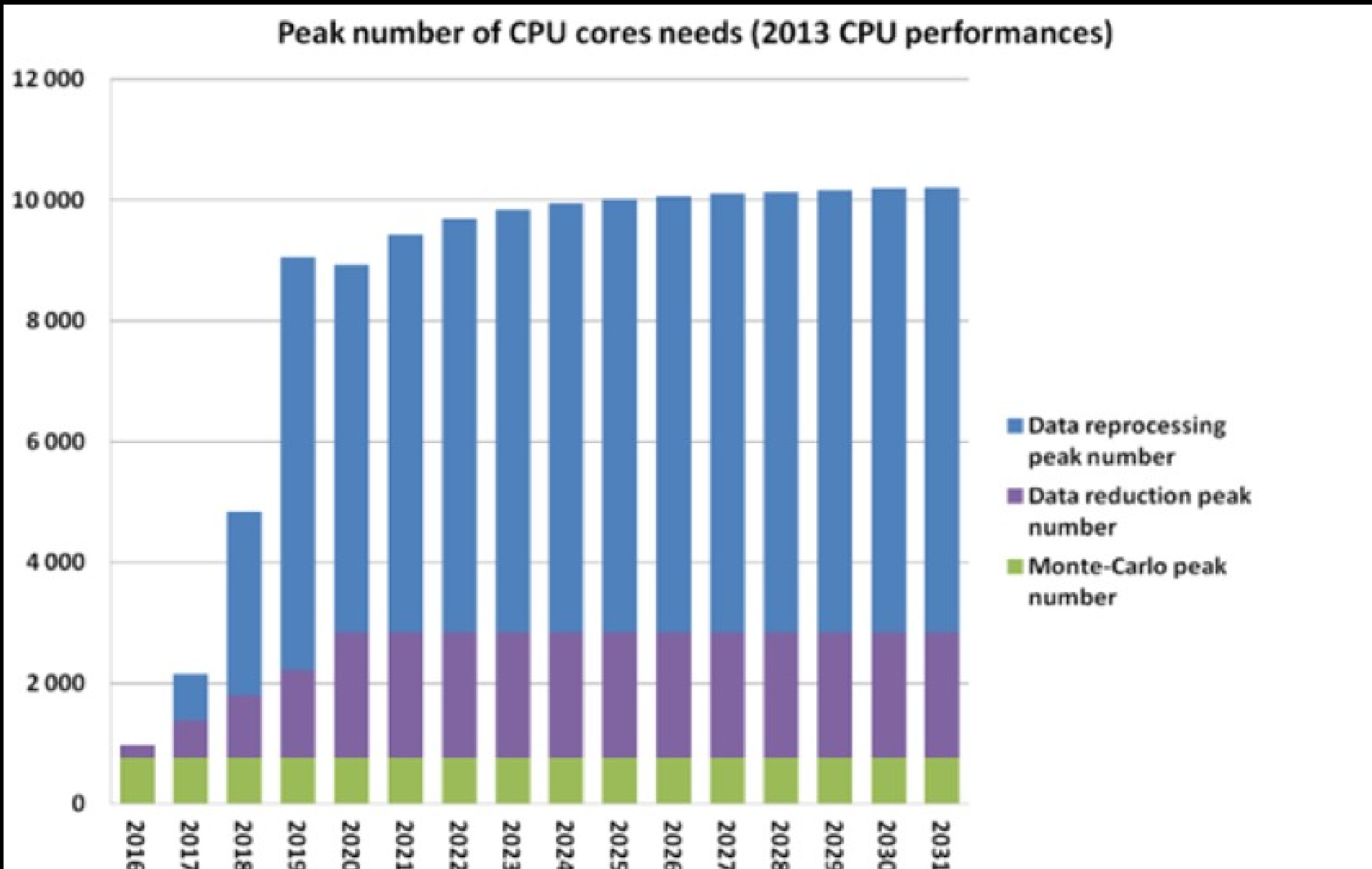
Call of tender with MTS

GATE

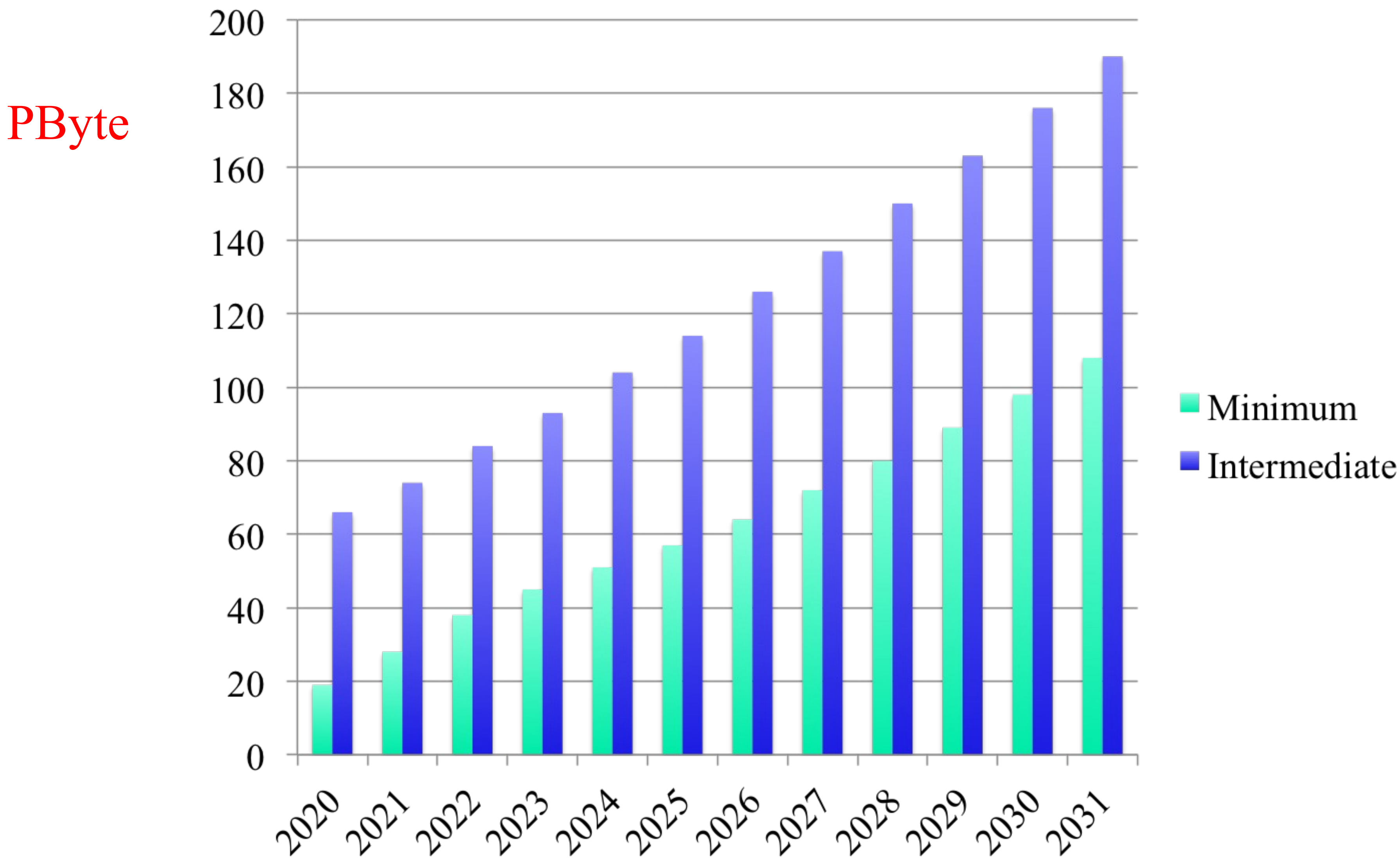

LST
MST
SST
SCT
1
2
3
4
STAB TRIM
FLIGHT DETENT
IDLE
RICH
CUT OUT
FLAP DOWN
BRAKE REL
PARKING BRAKE
STAB TRIM
challenge:
controlling the CTA Arrays

challenge:
handling CTa data

processing needs

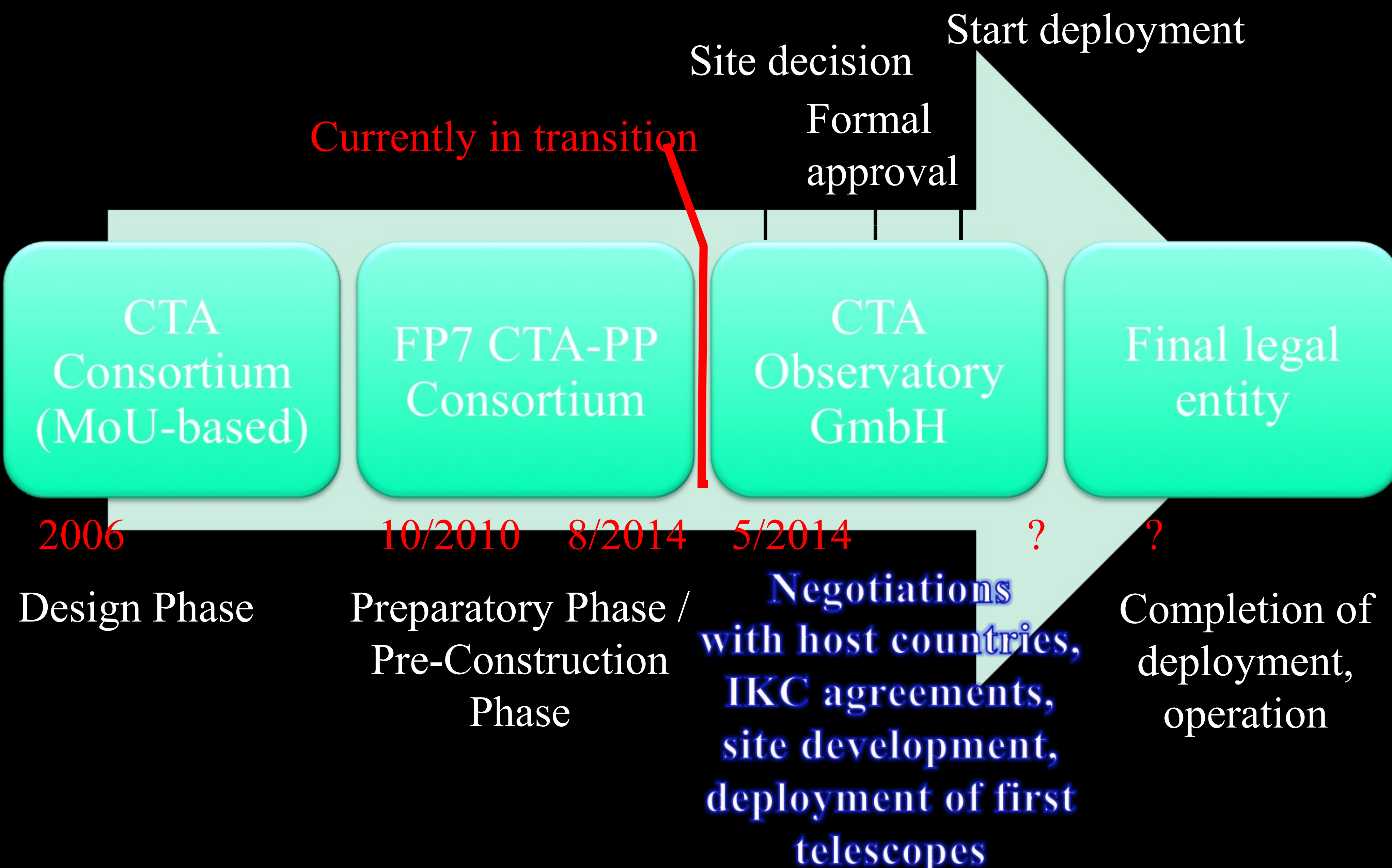


storage capacity



time line

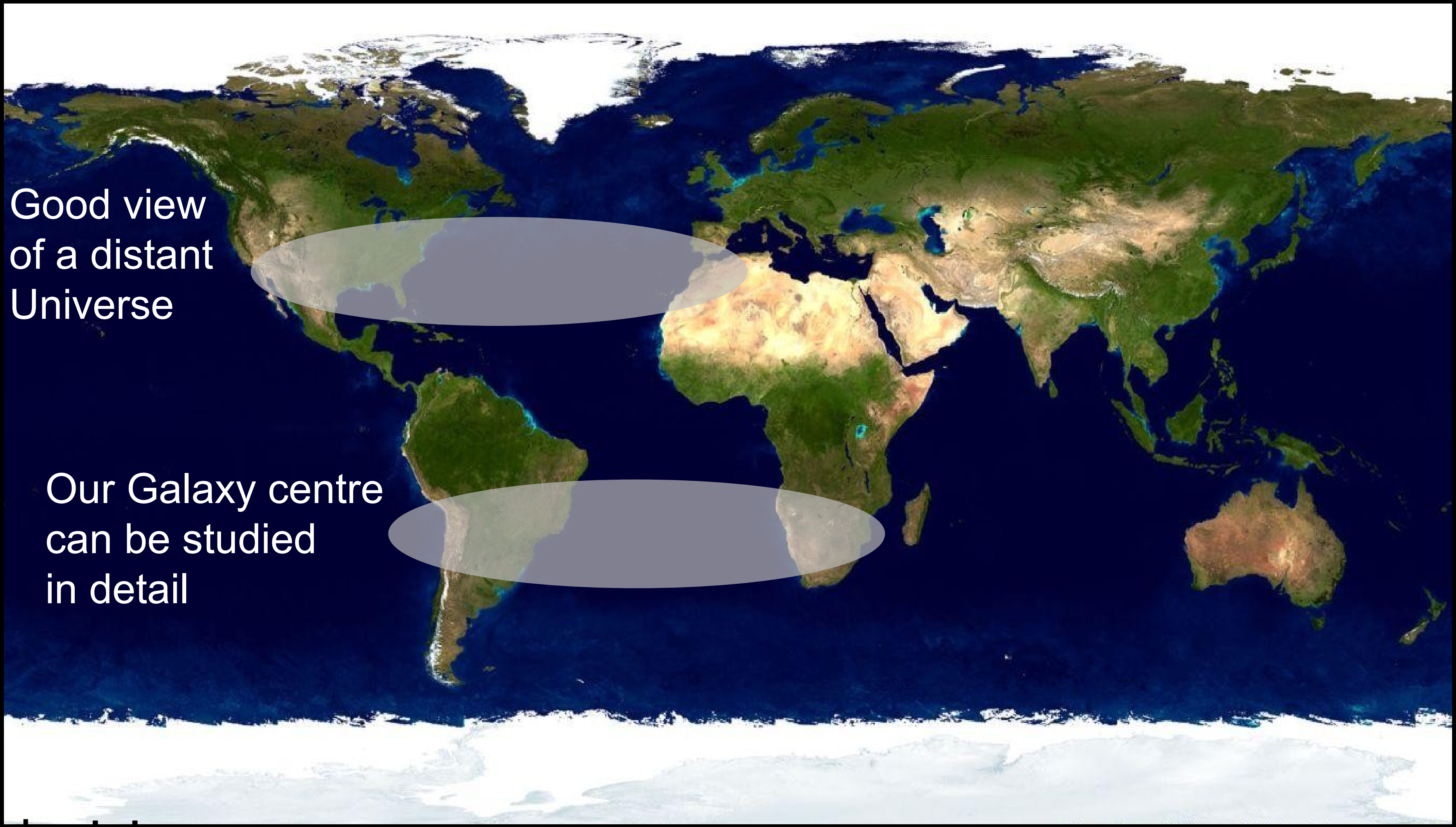
CTA Observatory



Global observatory with 2 sites:

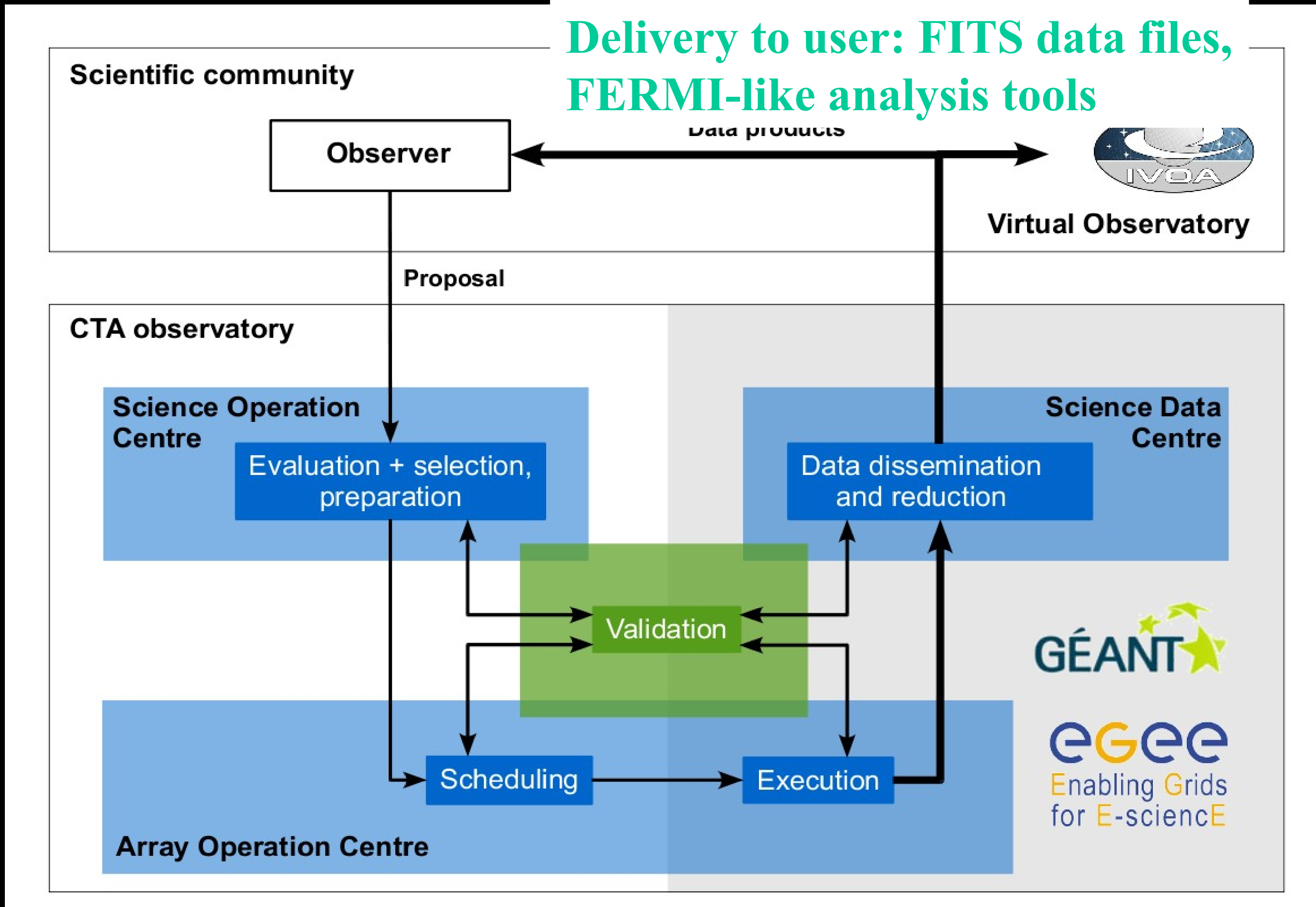
on Southern and Northern hemispheres

Chile or Namibia
Mexico or Canary Islands



For the first time in this field: Open access

Delivery to user: FITS data files, FERMI-like analysis tools



Astérics

Astronomy ESFRI & Research Infrastructure Cluster

WP2: Dissemination, Engagement and Citizen Science (DECS)
WP3: OBELICS (OBservatory E-environments LInked by common ChallengeS)
WP4: DADI (Data Access, Discovery and Interoperability)
WP5: CLEOPATRA: Connecting Locations of ESFRI Observatories and Partners in Astronomy for Timing and Real-time Alerts

CTA: ~32%, ~5 M€

H2020 INFRADEV-3 APPLICATION

Addressing bottlenecks identified by ESFRI

“Site preparation/site infrastructure to address the specific challenge of characterising and surveying remote sites in the southern hemisphere, designing and implementing site infrastructure, defining appropriate long term agreements with host country, and preparing for construction to begin.”

Application submitted by CTAO GmbH

WPs

WP1: Management

WP2: Infrastructure design and planning

WP3: Infrastructure deployment (no bricks!)

WP4: Legal agreements

WP5: Infrastructure for outreach and host country relations

H2020 INFRADEV-3 APPLICATION

Favorably reviewed, score 13.5 or 15 (passing score 10)

Currently preparing grant agreement

30 months, aim to start July 1

Polish project at the ESFRI roadmap to study universe in TeV gamma rays

Main contributions:

Polish CTA Consortium

11+1 intitutions
~ 70 people
~3 MEuro till now

5 + 2 universities:
Jagiellonian University
Warsaw
AGH
Lodz
N. Copernicus University
Zielona Góra
Białystok (?)

3 institutes of PAS + NCBJ:
N. Copernicus Astr. Center
Space Research Centre
Institute of Nuclear Physics
NCBJ

A computing centre:
CYFRONET AGH

A **small Cherenkov telescope** SST-1M prototype opening in INP Krakow (collaboration with University of Geneva)

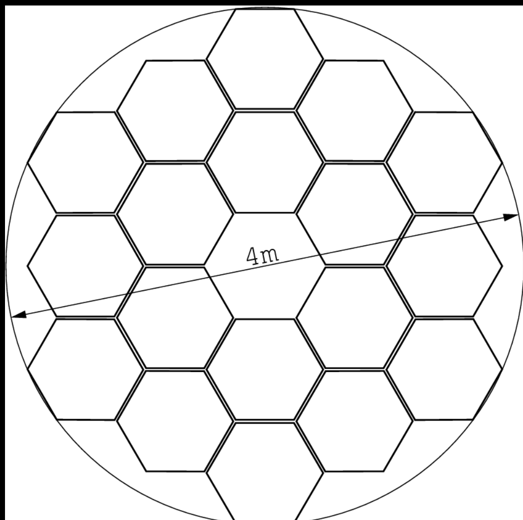
Digital camera with SiPMTs "DigiCam"

Mirrors based on composites

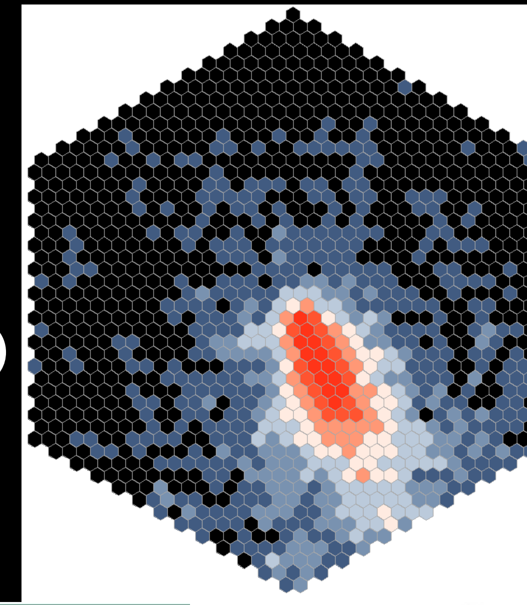
CTA Science Gateway in CYFRONET

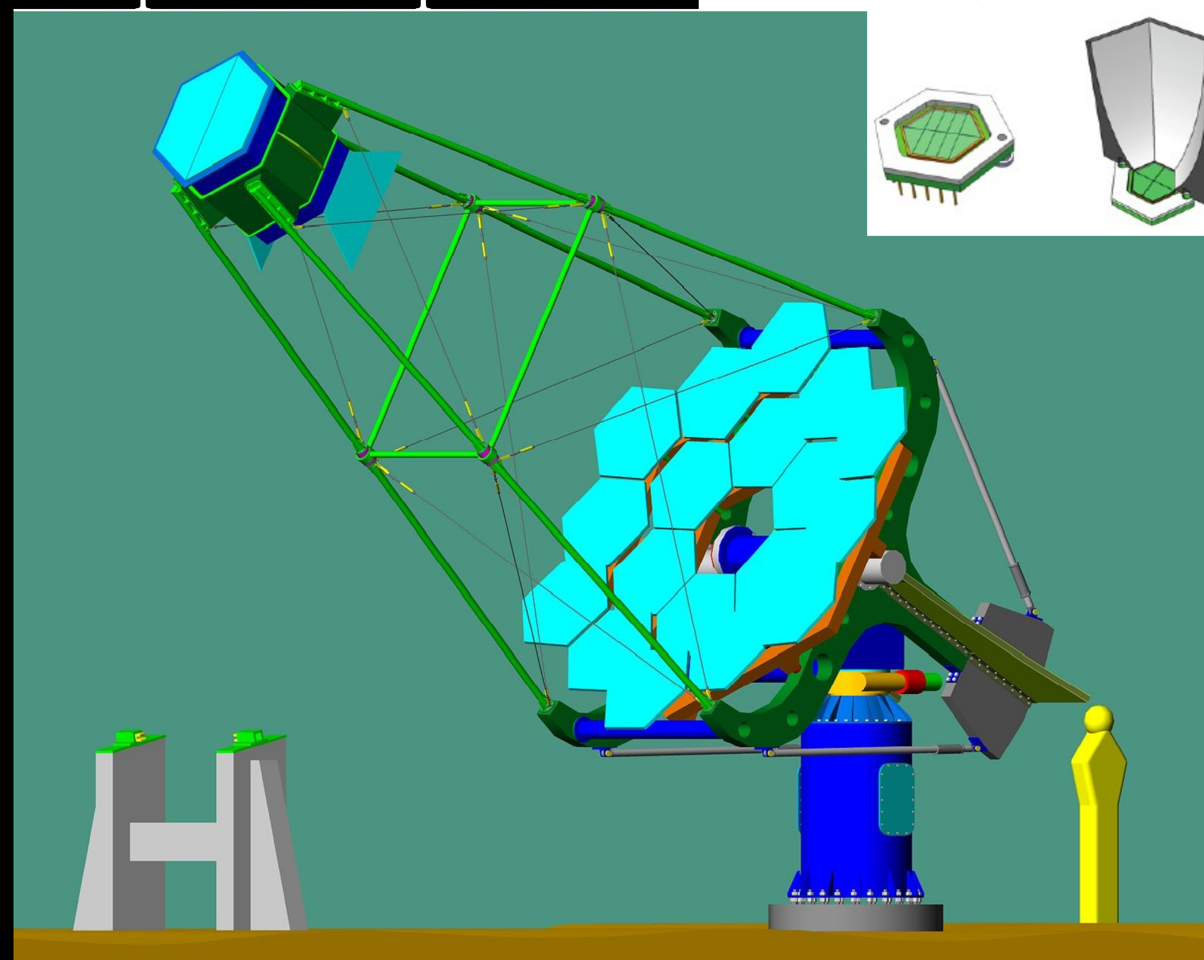
CTA data centre in Poland ?

SST-1M: single-mirror Small Size Telescope



- 1296 pixels (0.25deg)
- 9.1 deg FoV
- hexagonal silicon photomultipliers

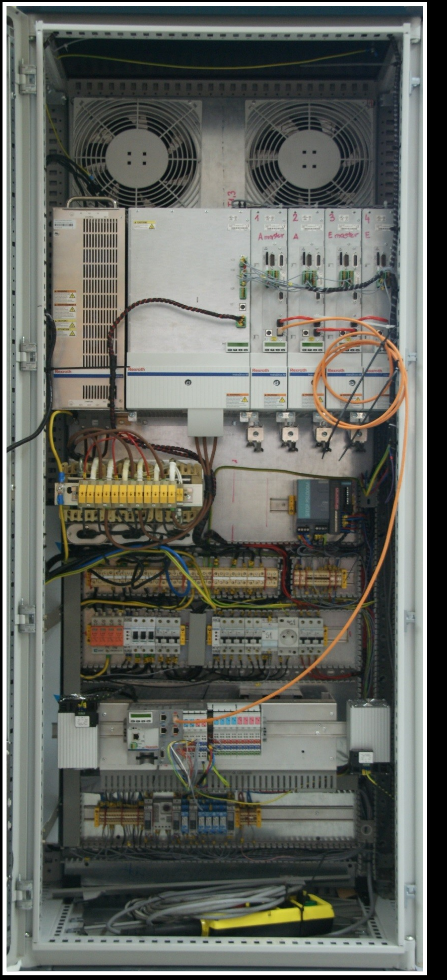




focal length 5,6 m

- dish diameter 4 m
- 18 spherical mirrors (78 cm flat-to-flat, f=5.6m)

SST-1M: prototype mechanical structure designed and built at IFJ PAN



UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

AGH
University of Science and Technology

Centrum Badań Kosmicznych
Space Research Centre

Nicolaus Copernicus Astronomical Center

Universität Zürich

Institute of Nuclear Physics
Polish Academy of Science (PAN)

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ISDC

JAGIELLONIAN UNIVERSITY IN KRAKOW

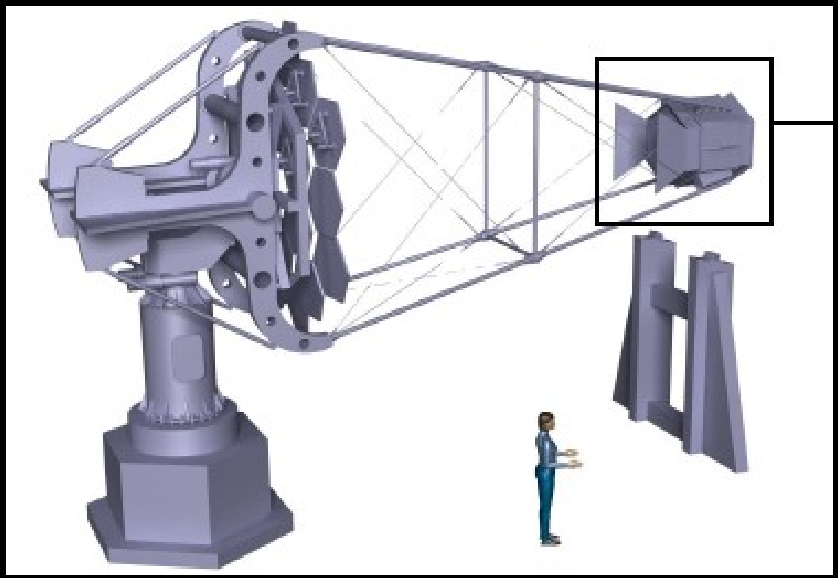
The DigiCam

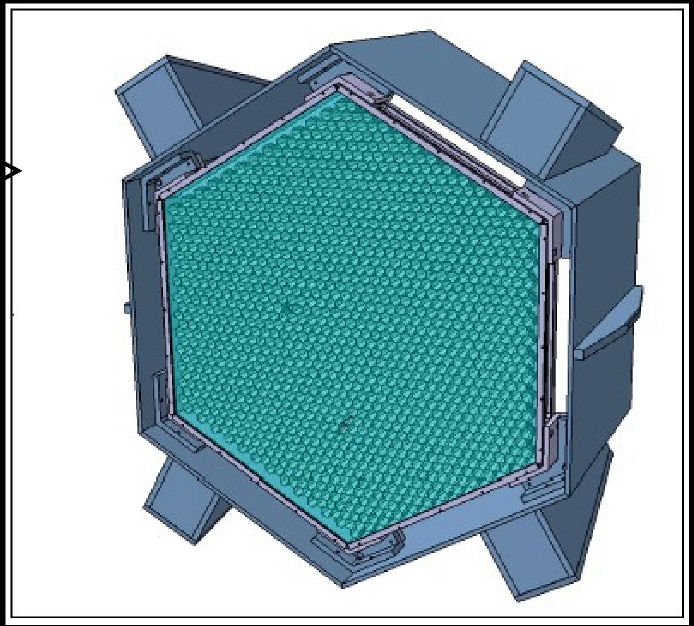
Digital camera dedicated for
the SST-1M telescope

From: Krzysztof Zietara JU

DigiCam camera features

- 1296 pixels PDP based on silicon fotomultipliers (SiPM)
- Signal acquisition implemented using 250MSPS/12bit ADC's
- Fully digital trigger path with reconfigurable algorithms and signal preprocessing
- Serial architecture based on mulitgigabit links (trigger and adc readout)
- Reduced number of cables and connectors
- Compact selfcontained and lightweight – perfect for SST-1M telescope





DigiCam camera architecture

Photon Detector Plane
(PDP, lightweight)

Crate-based acquisition and readout electronics
(behind PDP)

Si PMT's

Preamplifier
Slow control
HV

Analog transmission via CATx (typ. ≤1.5 m)

CAN BUS Slow control

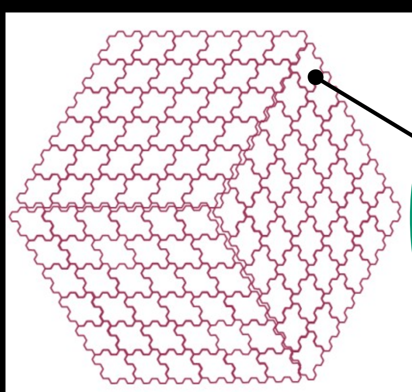
250 MS/s
12 bit
FADC

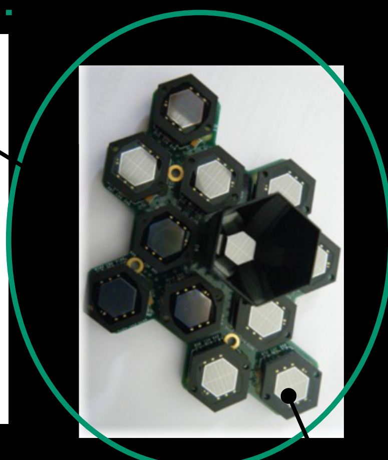
Ring buffer
Preprocessed trigger
(data reduction)
Slow control

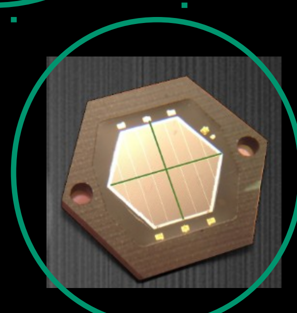
multi Gbit serial links

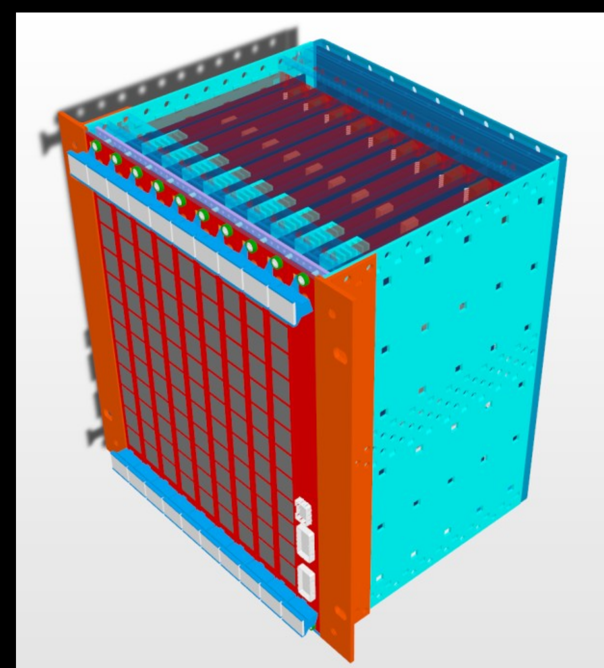
Main trigger
&
readout

10Gbit Ethernet





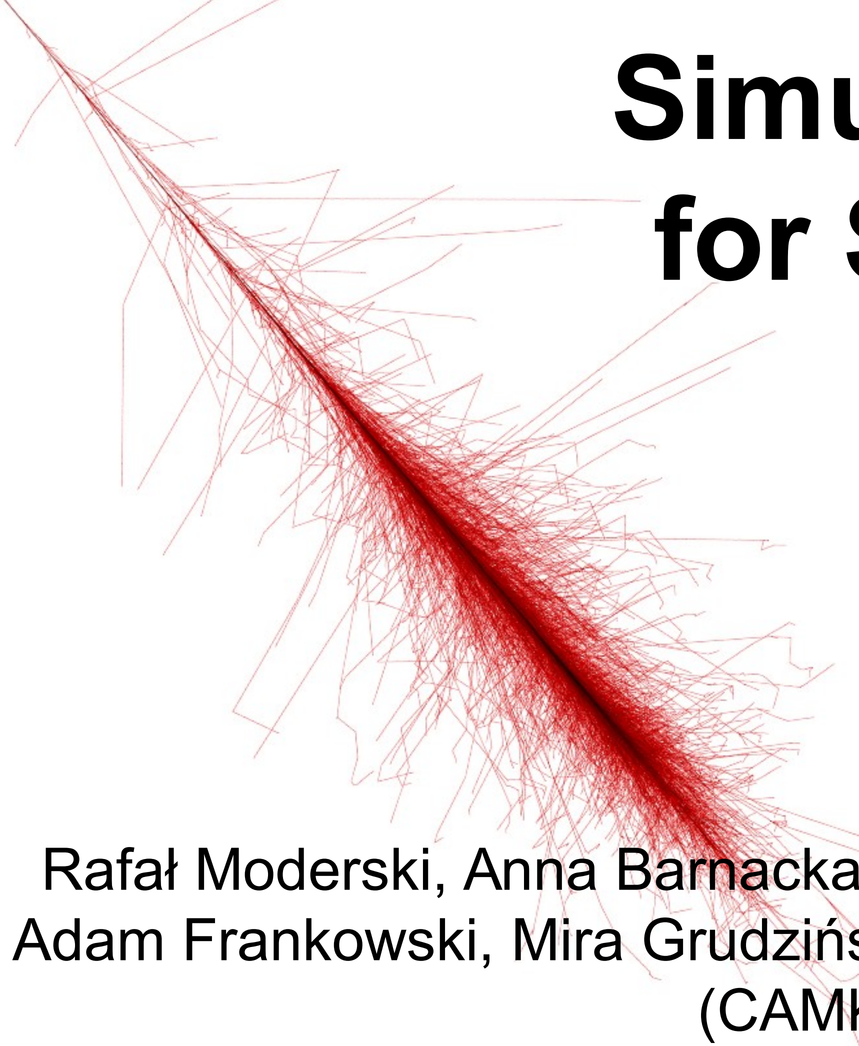


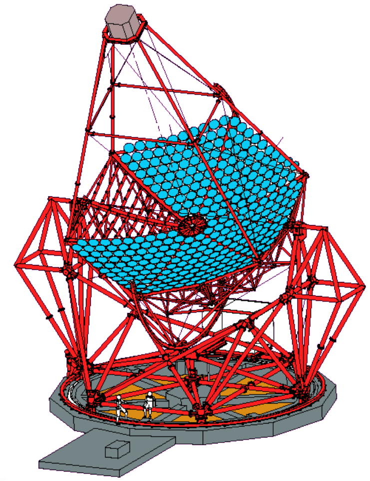


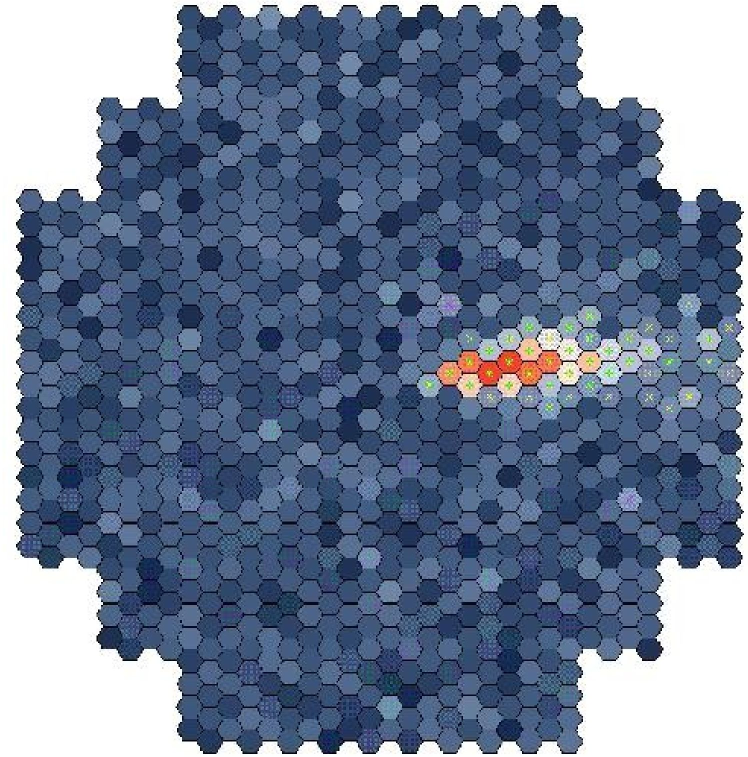
3 μ-Crates holding 27 FADC cards (48 channels each) and 3 trigger cards

PDP composed of 108 mechanical units, each holdong 12 pixels (12 SiPMT's)

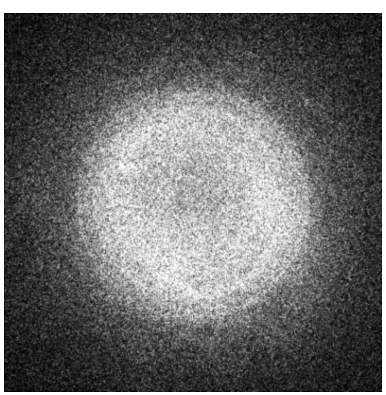
Simulations for SST-1M

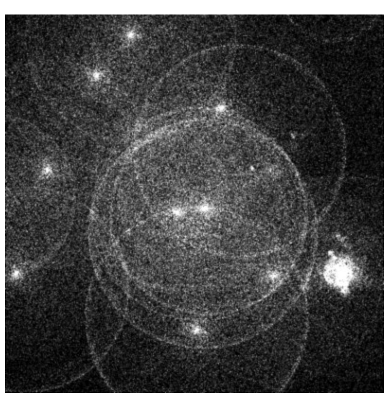


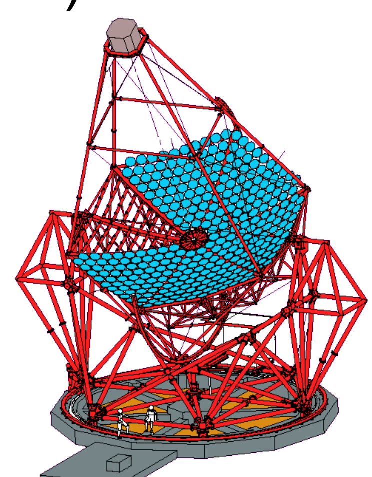




Rafał Moderski, Anna Barnacka, Leszek Bogacz, Martyna Chruślińska, Adam Frankowski, Mira Grudzińska, Mateusz Janiak, Piotr Rozwadowski
(CAMK, OAUW, UJ)







Numerical simulations - software

- air shower simulations for gammas, protons, electrons and muons

CORSIKA

http://www-ik.fzk.de/~corsika/

- most time consuming, 95% data volume, storage for several months for possible reprocessing

- telescope response calculations

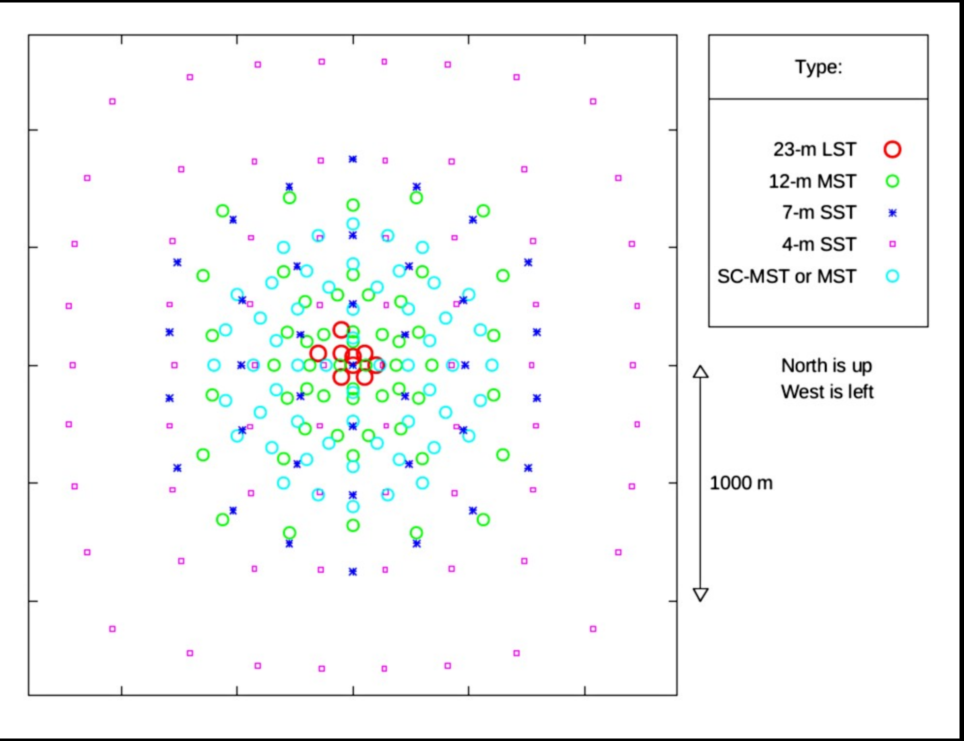
sim_telarray

Bernloehr et al. Astropart. Phys. (2008,2013)

- several configurations, storage for 1-2 years (but small volume ~30TB) for user analysis

- ~10^{10} events need to be simulated and processed - ~200k jobs of 50k events, ~8 mln HS06 hours (70% air showers simulations), >500TB of storage
- **EGEE/EGI** grid infrastructure chosen (**vo.cta.in2p3.fr** – 21 EGI grid sites in 7 countries, several thousands CPU cores and >650TB dedicated storage)

Production-2



229 telescope positions

7 different telescope types (LST, 2 MST, 4 SST) with updated parameters and sometimes several different trigger schemes

3 different candidate sites at altitudes between 1600 and 3600 m

traces of pulses in all pixels stored

3.7×10^{10} events generated, total storage max **1.86PB**

Telescope separation – dedicated study of optimal telescope separation

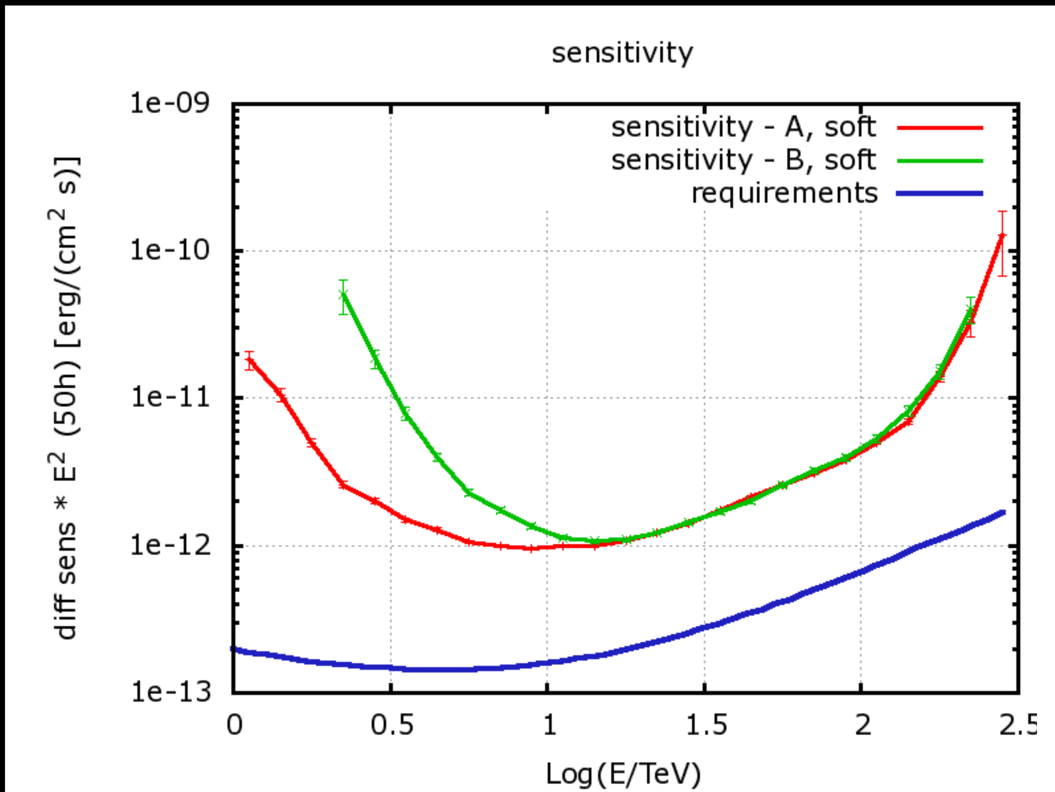


Fig. 1. SMART5 sensitivity based on the Prod-2 data for two different telescope separation: ~250m (confA) and ~370m (confB).

- dedicated simulations for 5 telescopes at different separations of 150m, 200m, 250m, 300m, 350m
  - 2.3e6 gamma events, 18.1e6 proton events
  - different filters (only 540nm presented here)

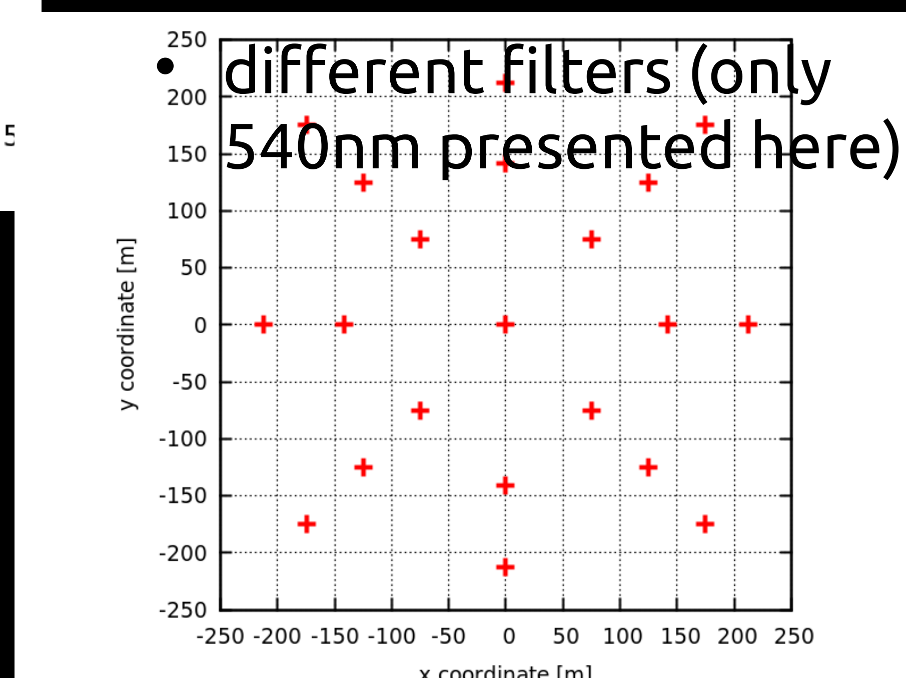


Fig. 2. Locations of the telescopes used in the simulations.

SHADOWING (TELESCOPE TRANSMISSION)

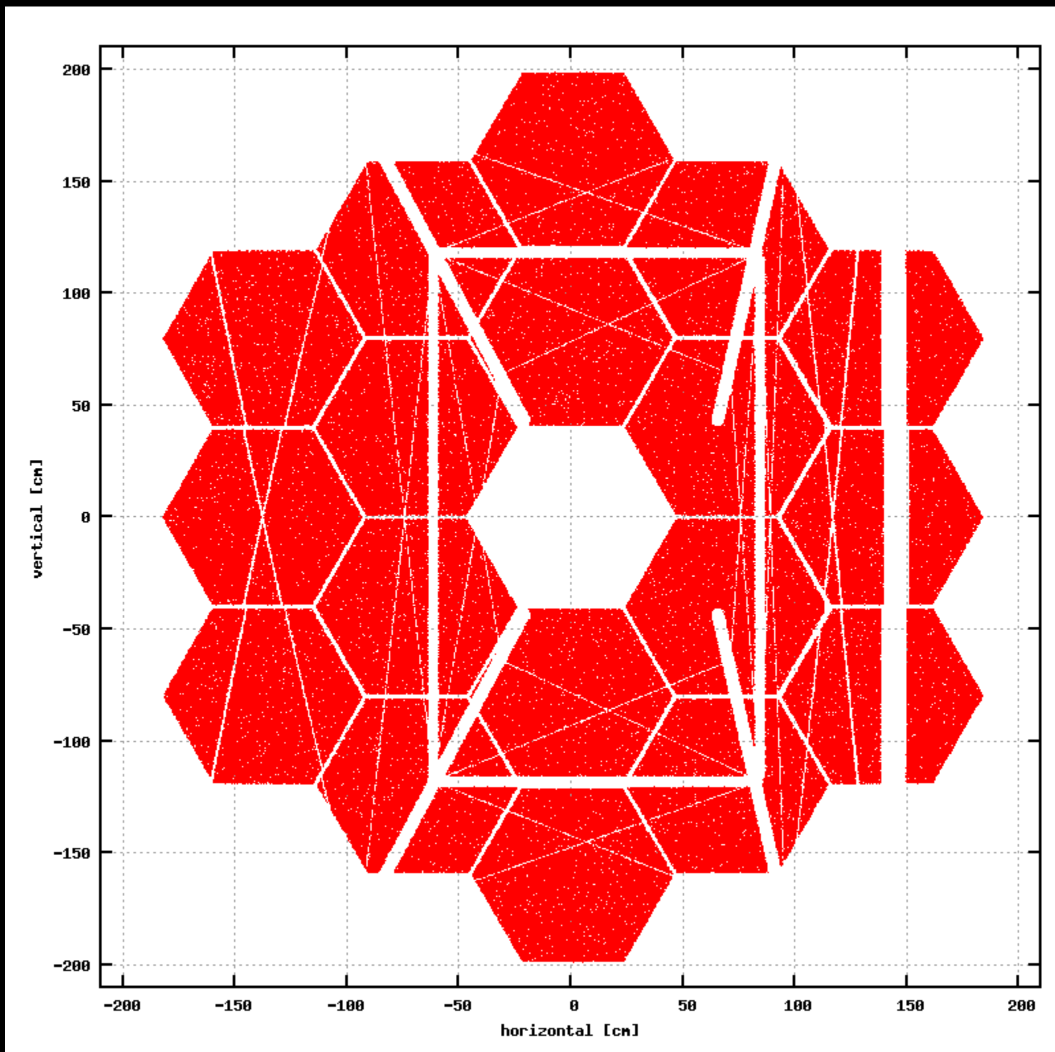


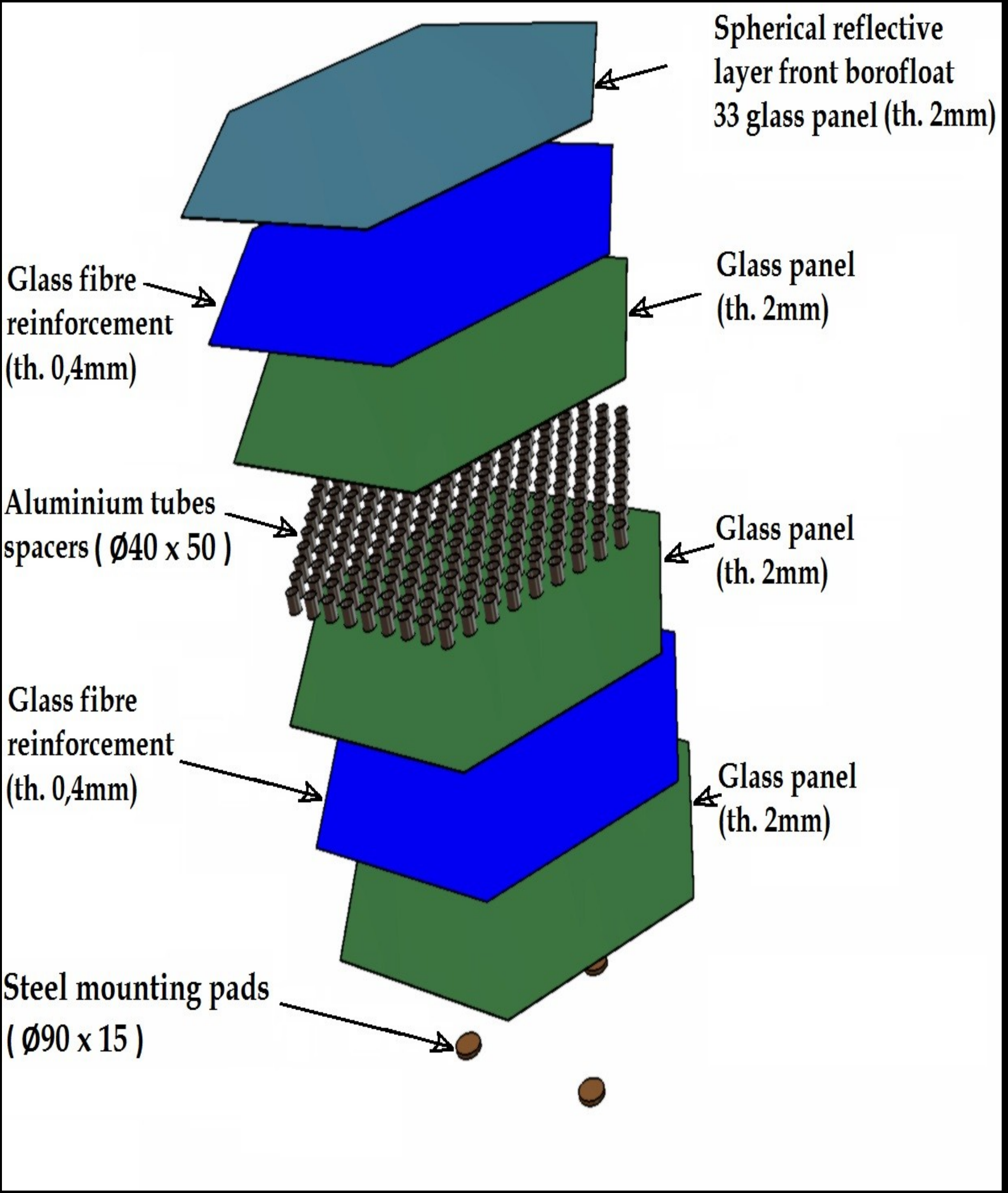
Fig. 1. Masts only shadowing at 2 deg off axis.

- The SST-1M mirror consists of 18 hexagonal facets of 78 cm dimension (flat-to-flat).
  - 9.48 m^2 total surface area
  - becomes
  - 7.54 m^2 effective area (total telescope transmission coefficient of 0.8 applied).

coating	average reflectance 300-550nm	effective area [m^2]
Al+SiO_2	0.91	6.86
Al+SiO_2+HfO_2	0.95	7.16
dielectric 550	0.97	7.31

Open-structure composite mirrors for Medium-Size Telescope

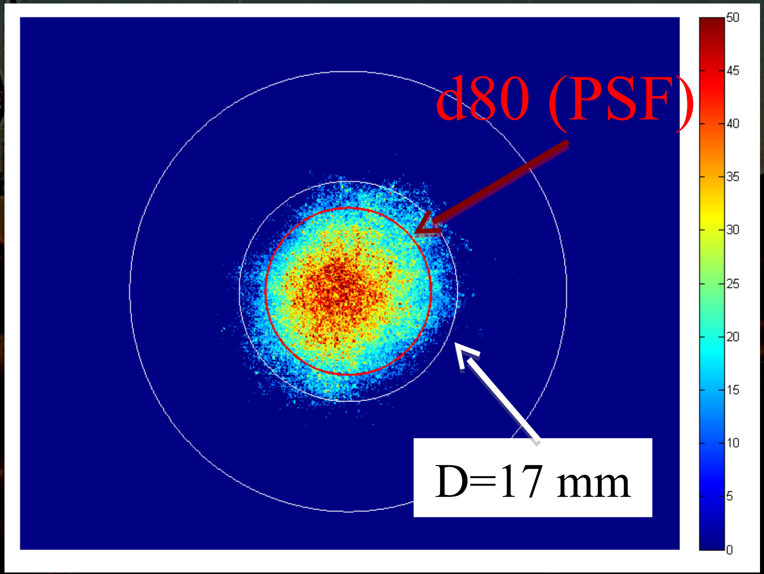
- a novel approach to cold-slumping technology for mirror production developed at IFJ PAN
- made of glass and aluminium
- open structure prohibits water to be trapped inside, improves ventilation and thermal stability
- designed for open-air operations: durable and resistant to atmospheric conditions



MST mirror prototypes

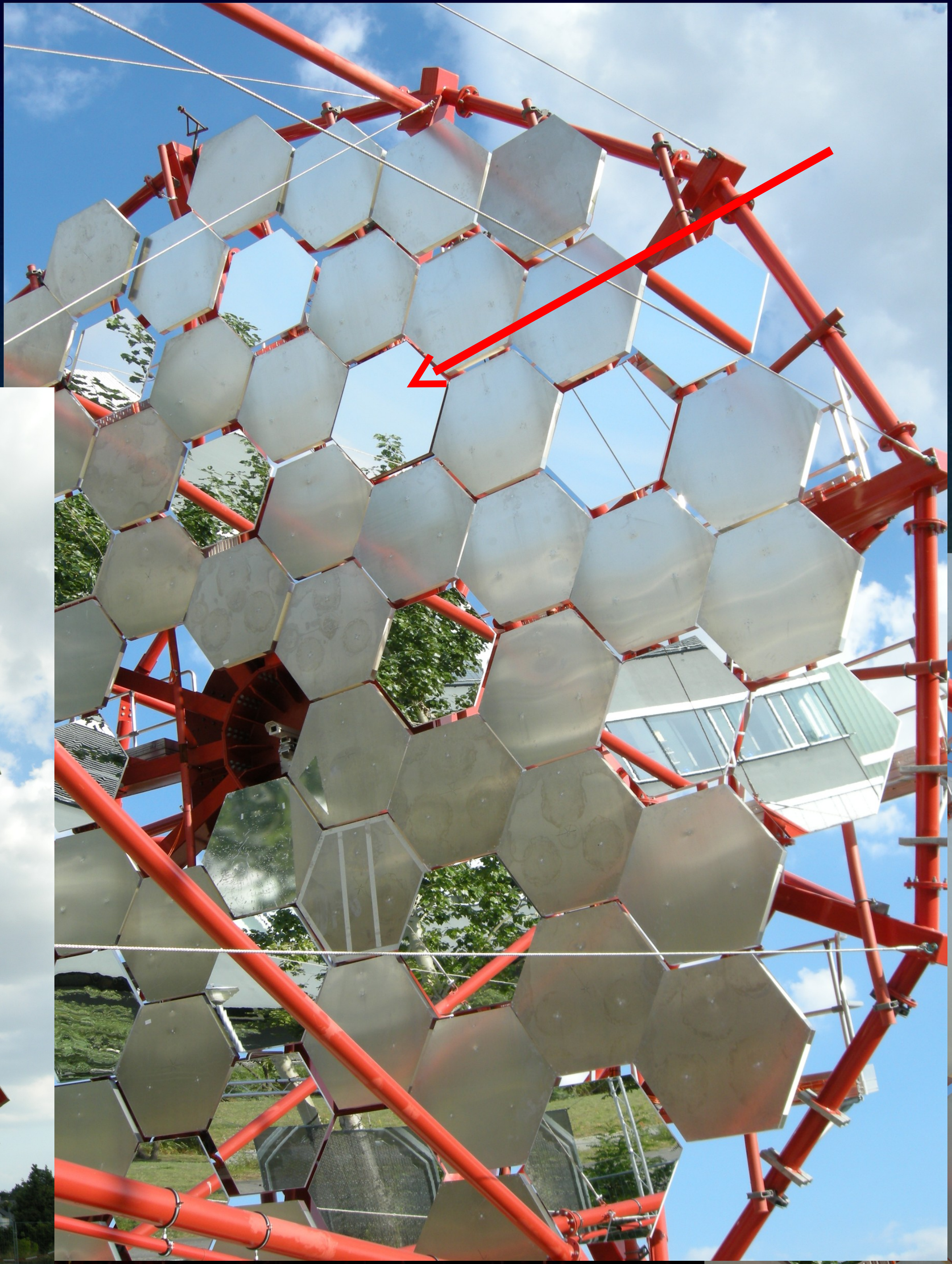


- several full-size (1,2 m face-to-face) prototype mirrors produced so far
- radius of curvature R ~ 32,14 m
- excellent optical characteristics (PSF)
- resistant to environmental conditions
- 4 mirror facets installed on the MST prototype in Berlin



PSF at 2f:
d80 ~ 10 mm

On the MST prototype…



CTA Science Gateway

The Cyfronet SG Team

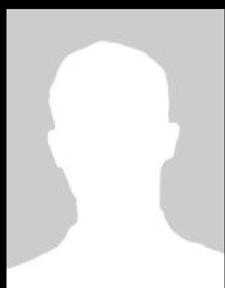
Tomasz Szepieniec

Joanna Kocot

Hubert Siejkowski

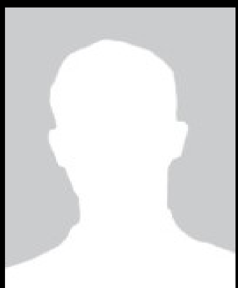
Tomasz Grabarczyk

Daniel Olszowski



Marcin Sałęga

Mariusz Sterzel



Piotr Szwarnóg

Michał Trzeciak

Piotr Wójcik

Production CTA SG (Cyfronet):
http://cta-sg.grid.cyfronet.pl

Demos and tutorials:

http://insilicolab.cyfronet.pl/videos

Contact:
insilicolab@cyfronet.pl

j.kocot@cyfronet.pl
t.szepieniec@cyfronet.pl
h.siejkowski@cyfronet.pl

Search and verification of CTA sites

Coordination of the working group SITE: T. Bulik

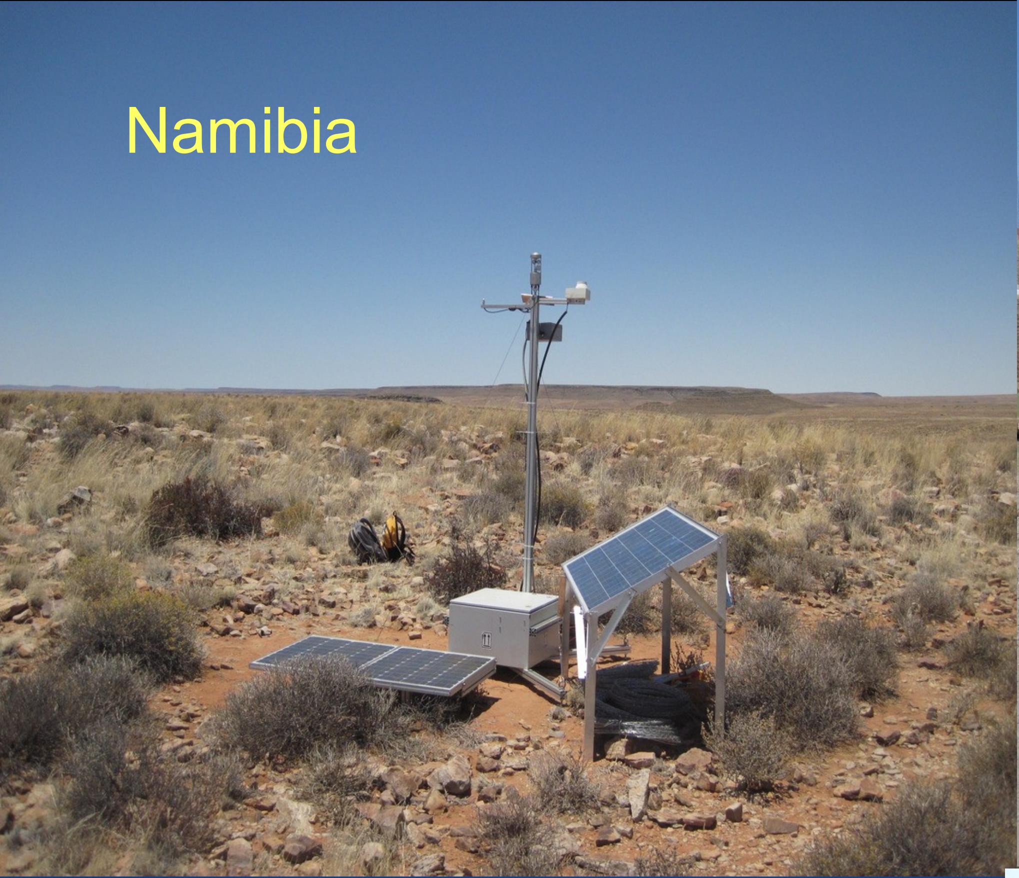
30 people from 12 countries at 5 continents

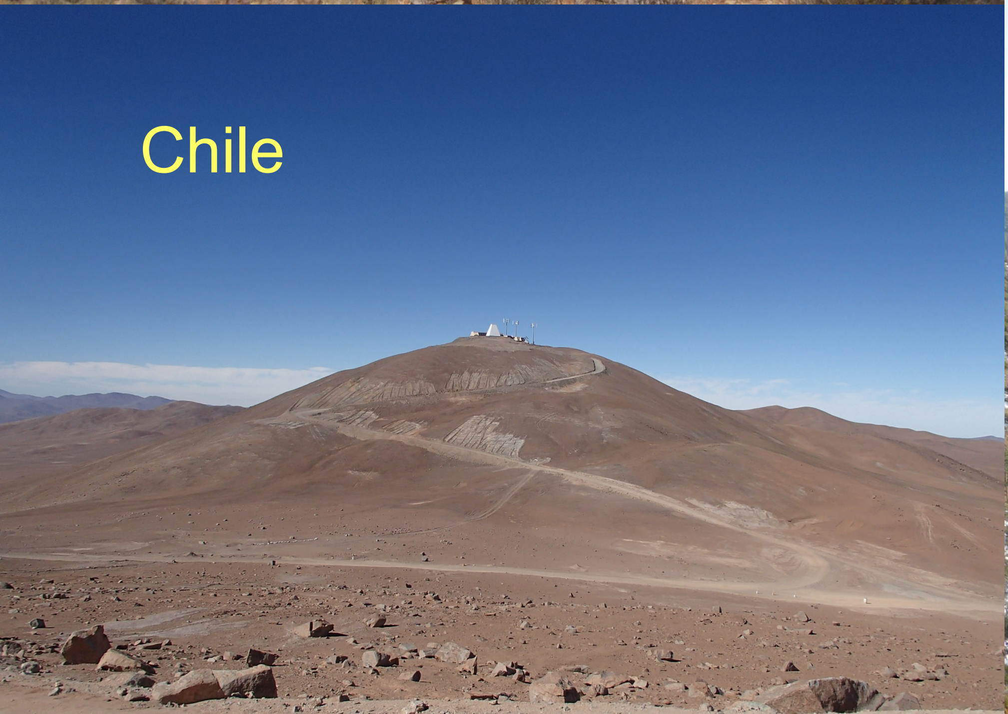
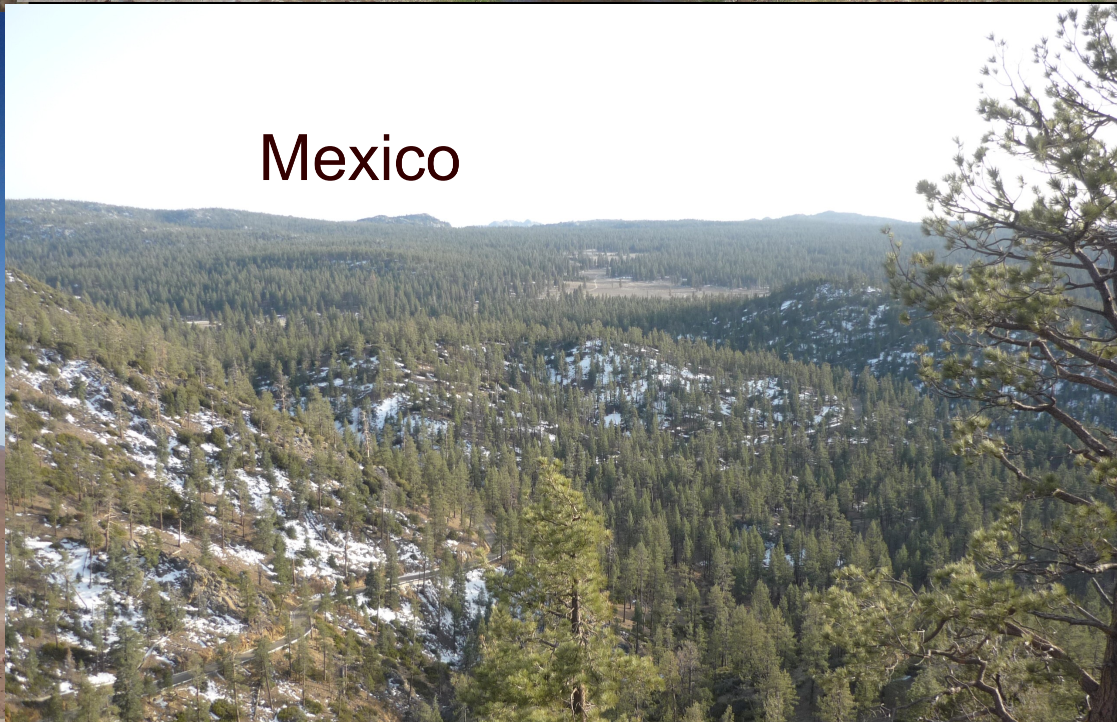
Sites analyzed:

6 at the Southern hemisphere in Argentyna, Chile & Namibia.

7 at the Northern hemisphere in China, India, Spain, US & Mexico

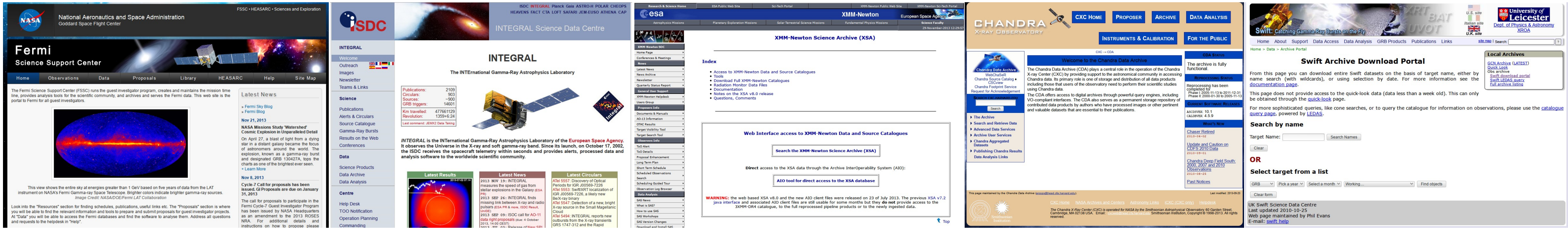
Large effort involved instalation of automatic monitoring stations in all sites.


Namibia

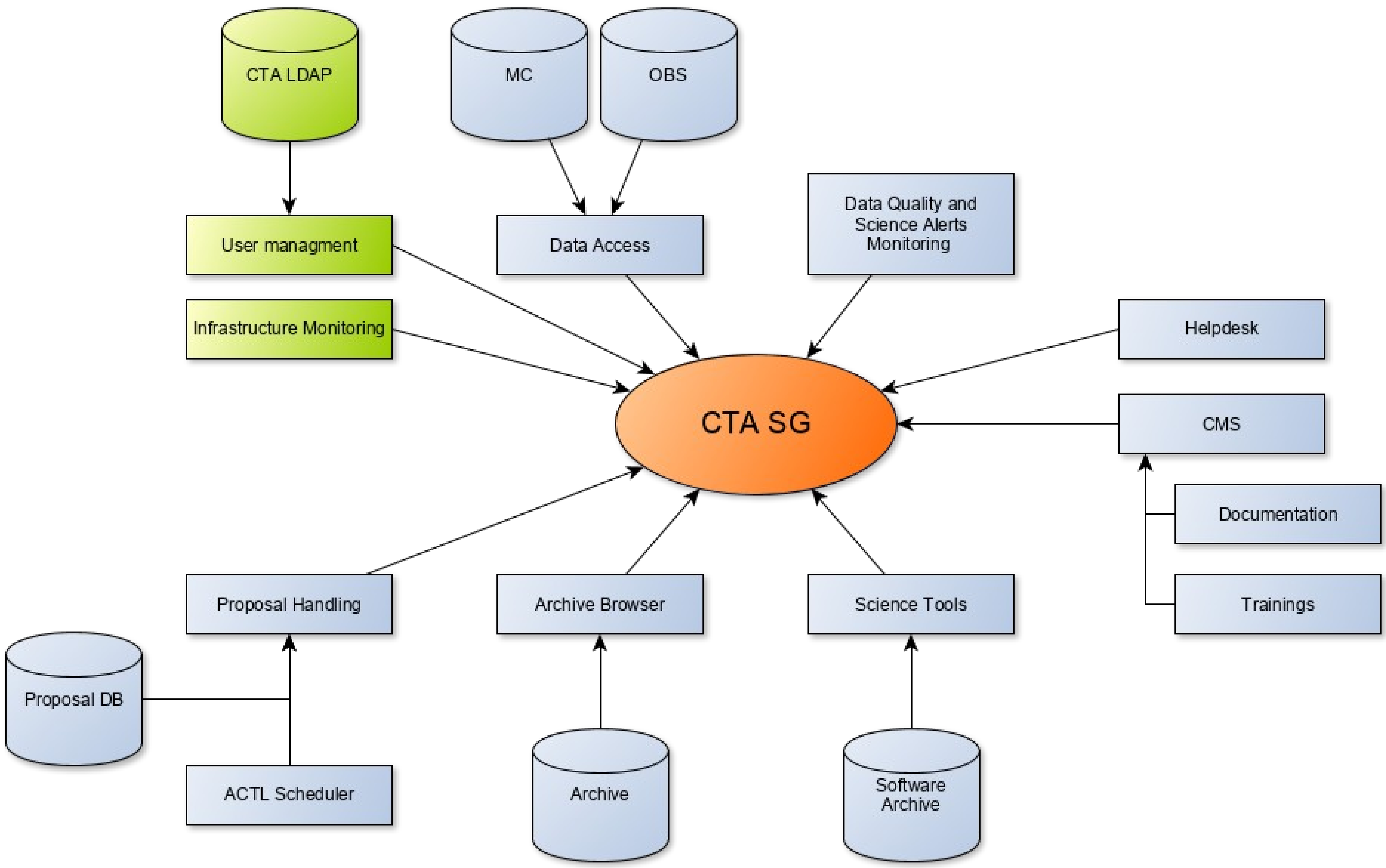
Argentyna

Chile

Mexico

CTA Science Gateway

- Central access point for the CTA users
- Platform integrating CTA tools:
  - Reconstruction, observation analysis
  - Browsing & searching for simulations and observations data
  - Science Tools
  - Others…
- Access for external observers



CTA Science Gateway



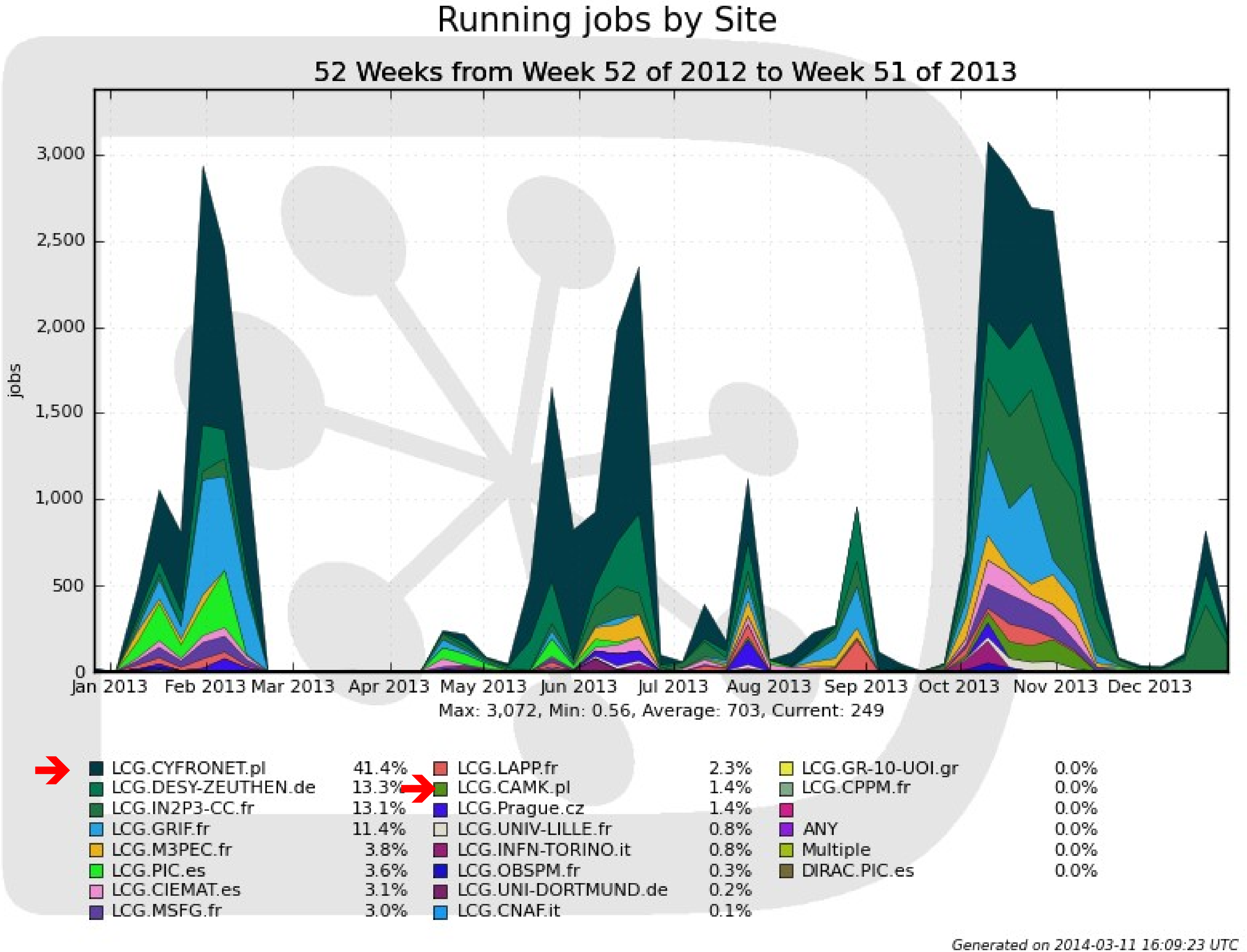
CTA SG – current status

- Address:
- Based on LIFERAY platform
- Login-in: CTA login/password or certificate

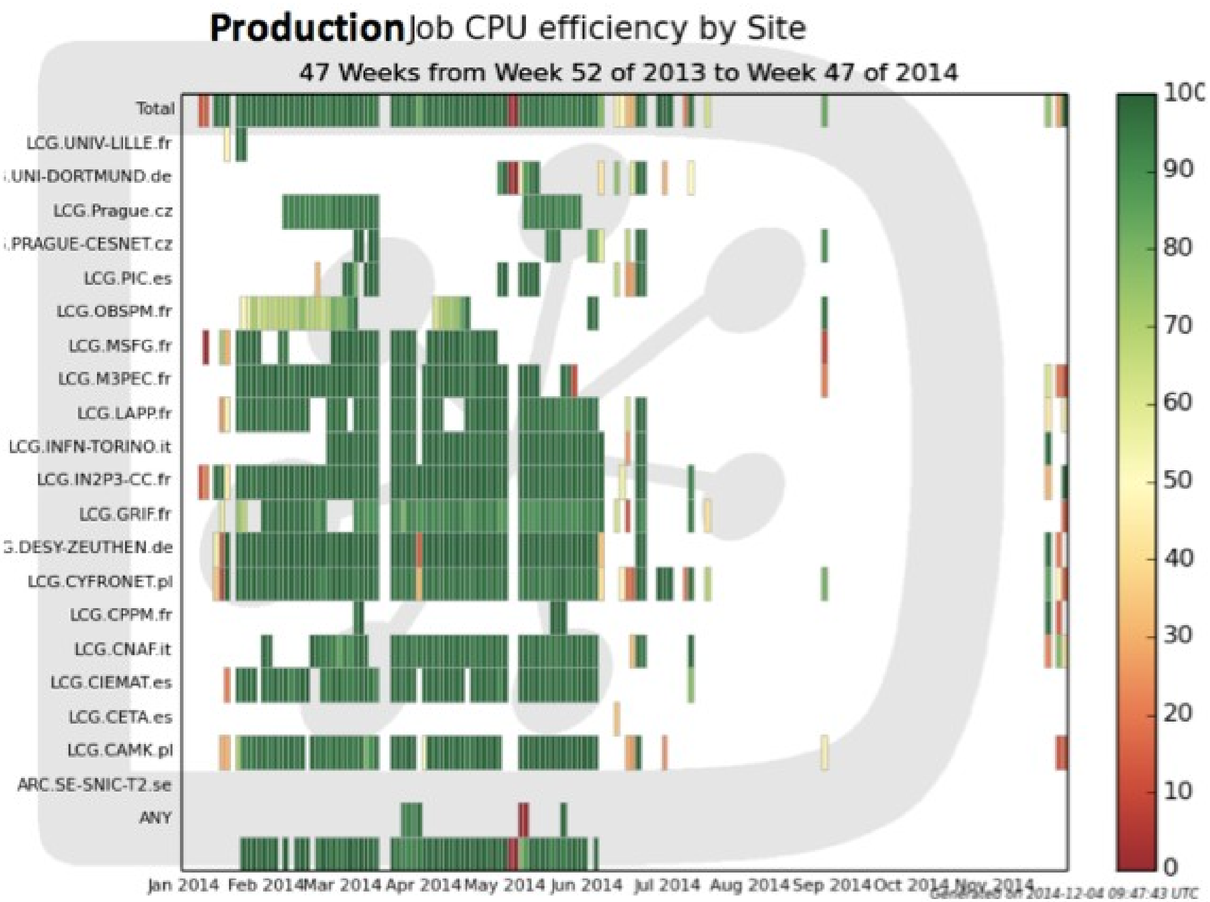
- Features:
  - Browsing of CTA production data
  - Management of computing workflows
  - Access to DIRAC
  - CTA Infrastructure Monitoring
  - Tools:
    - ***sim_telarray*** – CTA array simulation
    - ***read-cta, eventdisplay*** – event reconstruction
    - ***ctools*** – high-level data analysis (light-curves, spectra)

CTA SG – Workflow managment

- Based on in silico LAB framework
- Managing of experiment workflows
- Intuitive interface:
  - Experiment configuration
  - Submitting jobs to GRID (gLite, DIRAC)
  - Results downloading and visualization
  - Sharing data (LFC)
  - Reuse of the results in following exepriments


Running jobs by Site
52 Weeks from Week 52 of 2012 to Week 51 of 2013
jobs
3,000
2,500
2,000
1,500
1,000
500
0
Jan 2013
Feb 2013
Mar 2013
Apr 2013
May 2013
Jun 2013
Jul 2013
Aug 2013
Sep 2013
Oct 2013
Nov 2013
Dec 2013
Max: 3,072, Min: 0.56, Average: 703, Current: 249
LCG.CYFRONET.pl 41.4%
LCG.DESY-ZEUTHEN.de 13.3%
LCG.IN2P3-CC.fr 13.1%
LCG.GRIF.fr 11.4%
LCG.M3PEC.fr 3.8%
LCG.PIC.es 3.6%
LCG.CIEMAT.es 3.1%
LCG.MSFG.fr 3.0%
LCG.LAPP.fr 2.3%
LCG.CAMK.pl 1.4%
LCG.Prague.cz 1.4%
LCG.UNIV-LILLE.fr 0.8%
LCG.INFN-TORINO.it 0.8%
LCG.OBSPM.fr 0.3%
LCG.UNI-DORTMUND.de 0.2%
LCG.CNAF.it 0.1%
LCG.GR-10-UOI.gr 0.0%
LCG.CPPM.fr 0.0%
0.0%
ANY 0.0%
Multiple 0.0%
DIRAC.PIC.es 0.0%
Generated on 2014-03-11 16:09:23 UTC

Computing & Storage



Plans for 2015 in total:
200M CPUh (HS06)
~2 PB

One of the biggest CPU time and storage provider for CTA

Site	Allocated Disk (TB)	Used Disk (TB)
CYFRONET-LCG2	448	220
DESY-ZN	336	272
IN2P3-CC	80 (+110 Tape)	39
IN2P3-LAPP	60	50
GRIF	50	46
INFN-T1	30	-
Total	**1004**	**627**

CTA observatory construction

Current stage: telescope designs essentially complete; advanced prototyping

Passed Preliminary Technical Design Review

Final Technical Design Report and Critical Design Review in ~Q1 2015

Aim for construction approval in mid-2015

5 year construction period

Early operation of partial arrays

Investment cost 150 M€ (2006), escalates to ~200 M€; site infrastr. ~20 M€ (S); updated cost estimate in prep.

Currently establishing CTA Observatory GmbH interim legal entity

Transition to final legal entity in ~2 years

In Poland we have spent ~16 Mzl for CTA (grants). However, there is a problem with current financing of the Polish contribution to CTA construction.

http://www.naukaonline.pl/news/item/1322-projekt-cherenkov-telescope-array-co-z-finansowaniem