The Cherenkov Telescope Array and its Science

Paris-Saclay ISAPP school
April 1, 2022

Werner Hofmann
MPI for Nuclear Physics
Heidelberg

for the CTA Consortium

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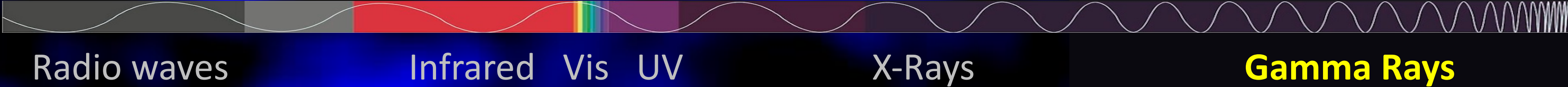
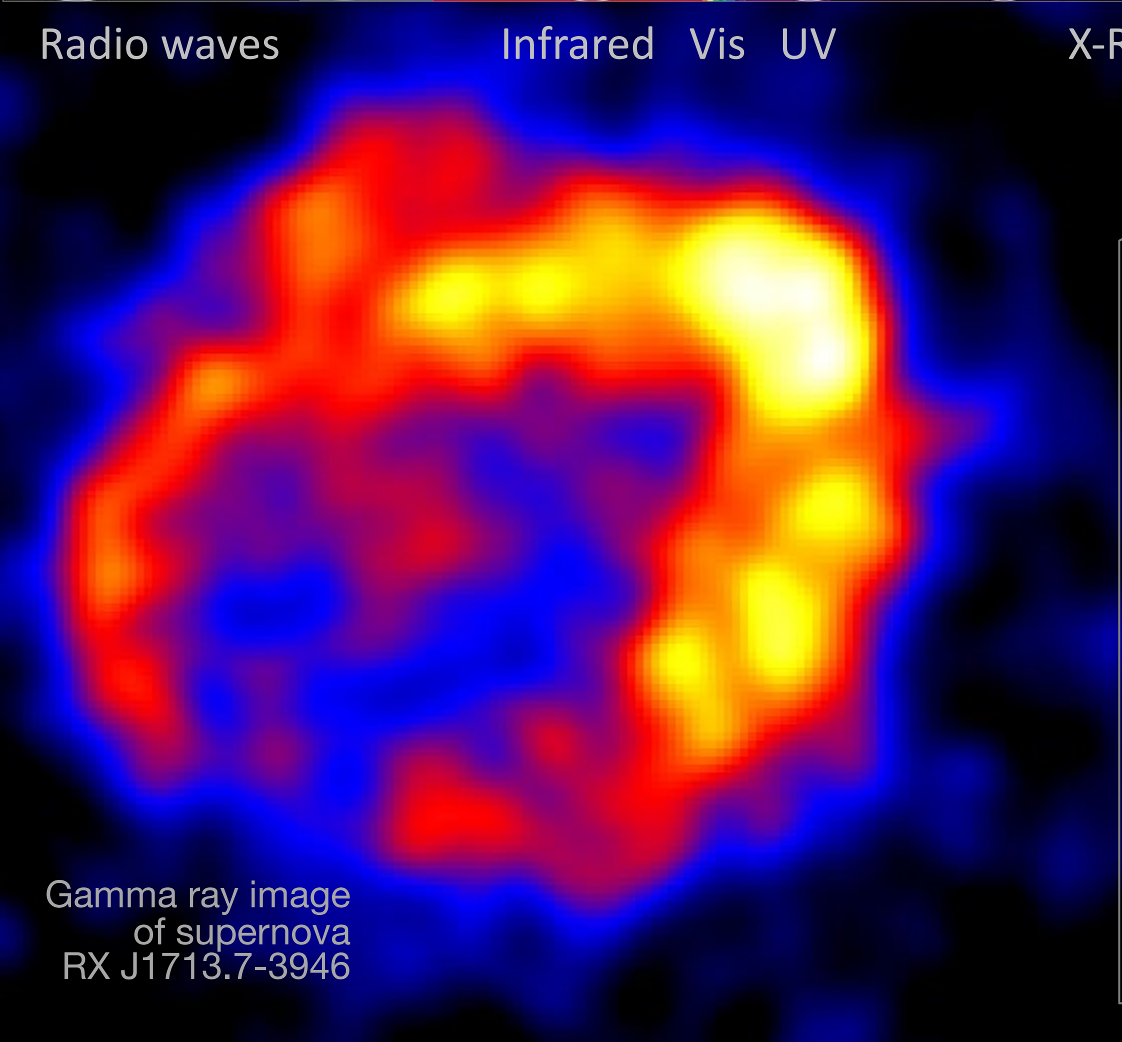
- Gamma-ray astronomy
- Motivation for CTA
- CTA concept & array design
- CTA technology, status
- CTA performance
- CTA Key Science Projects

Interrupt any time with questions



Gamma Rays

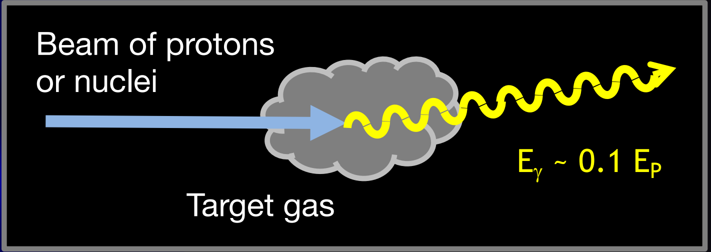
TeV ($10^{12 \pm 2}$ eV) domain

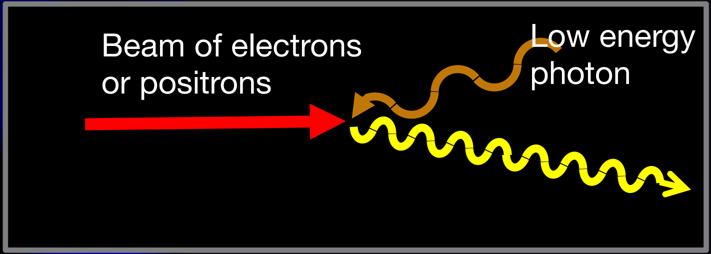


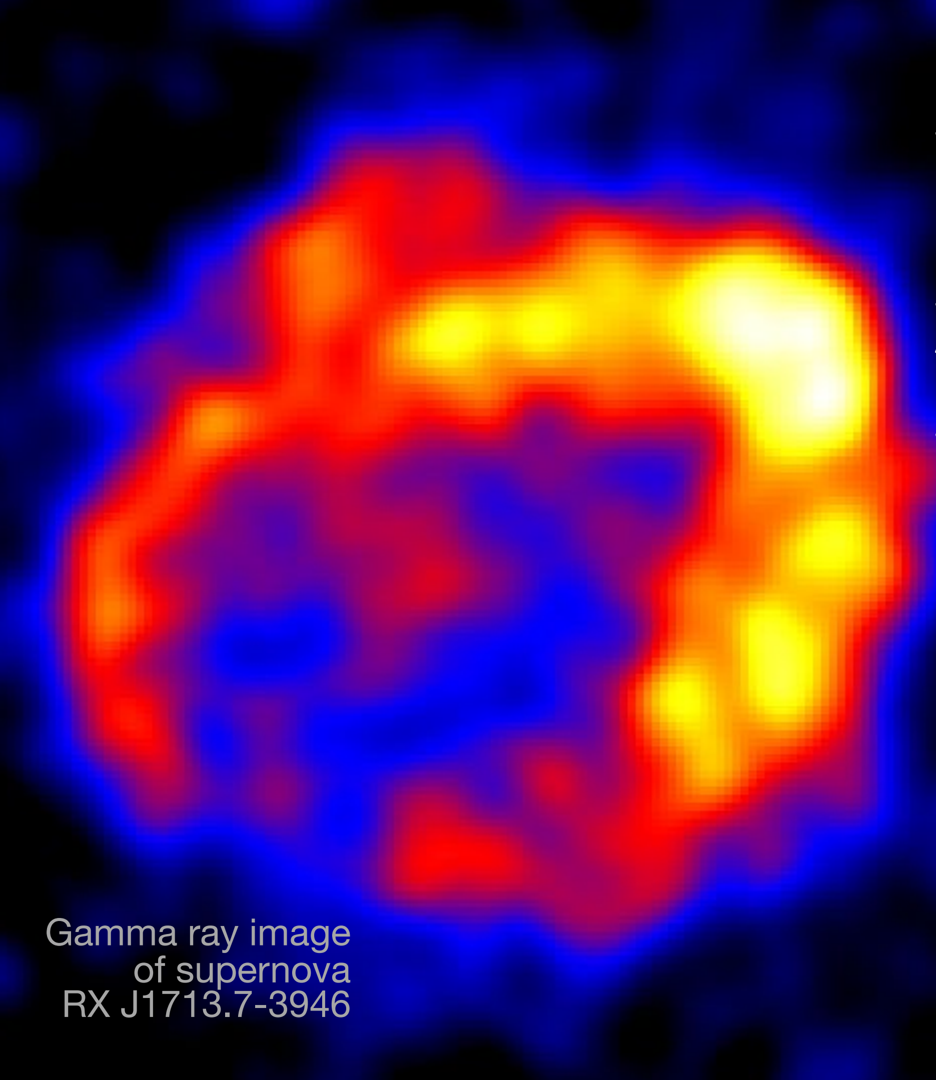
Gamma ray image of supernova RX J1713.7-3946

Gamma rays

- are produced by non-thermal mechanisms
- trace high-energy particles
- locate cosmic particle accelerators

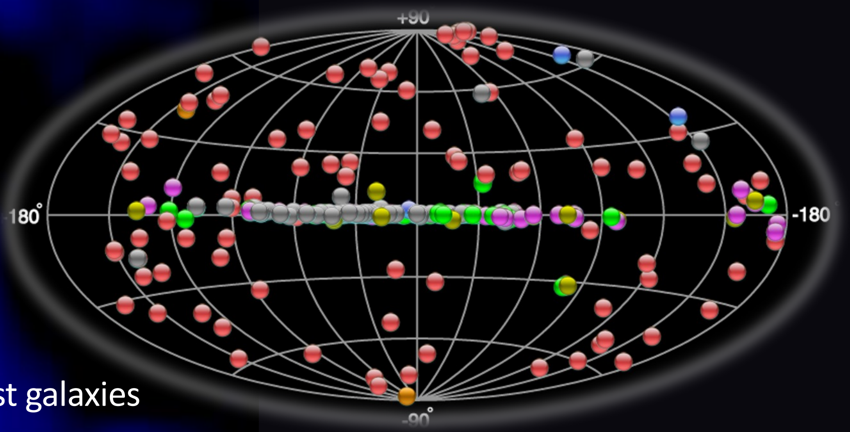






Gamma ray image
of supernova
RX J1713.7-3946

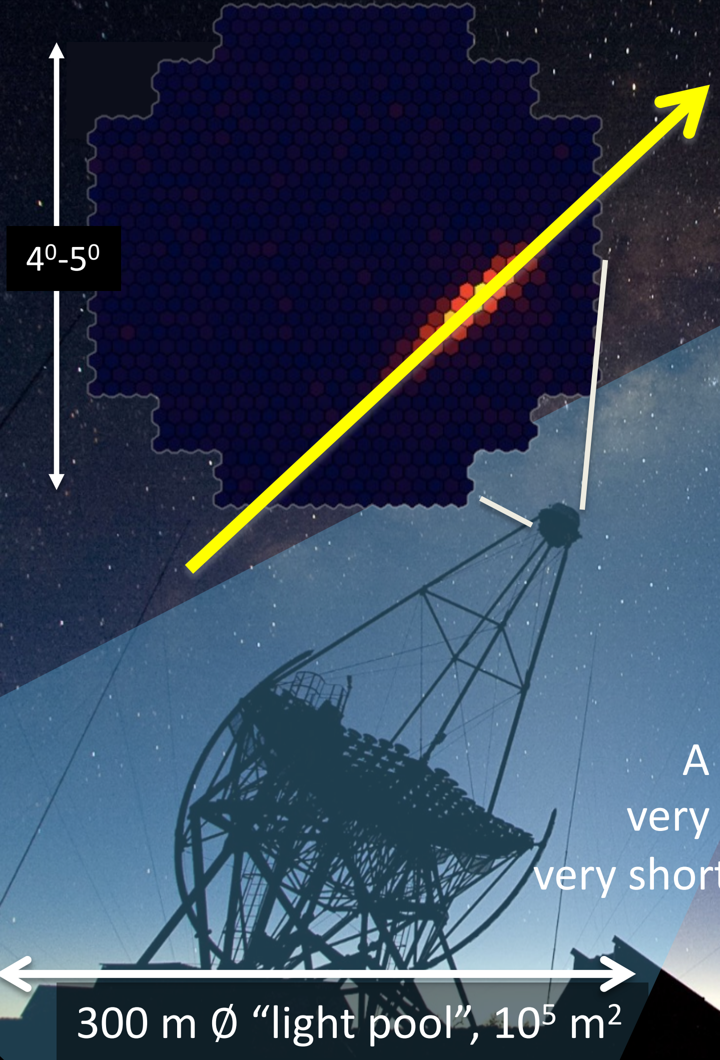
SNR
PWN
Binaries
Novae
SFR
AGN
GRBs
Starburst galaxies
…



http://tevcat.uchicago.edu/

- TeV particle acceleration everywhere in the cosmos
- Over 200 detected sources
- 3 orders of magnitude in gamma-ray flux
- Sky maps with 5’ resolution
- Energy spectra over 3 decades in energy
- Light curves on all scales from minutes to years

CHERENKOV TELESCOPES



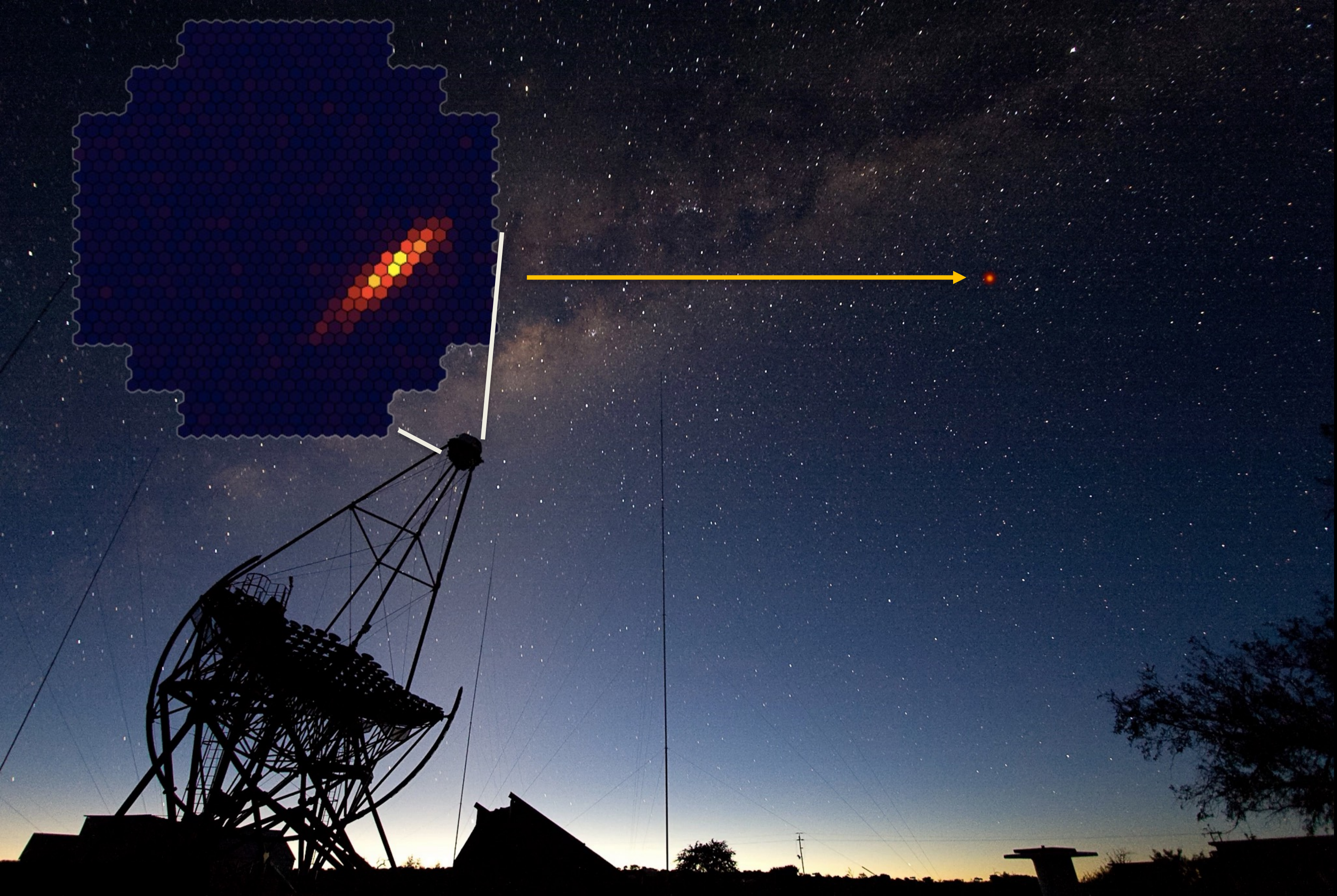
Multiple telescopes provide stereoscopic views of the cascade

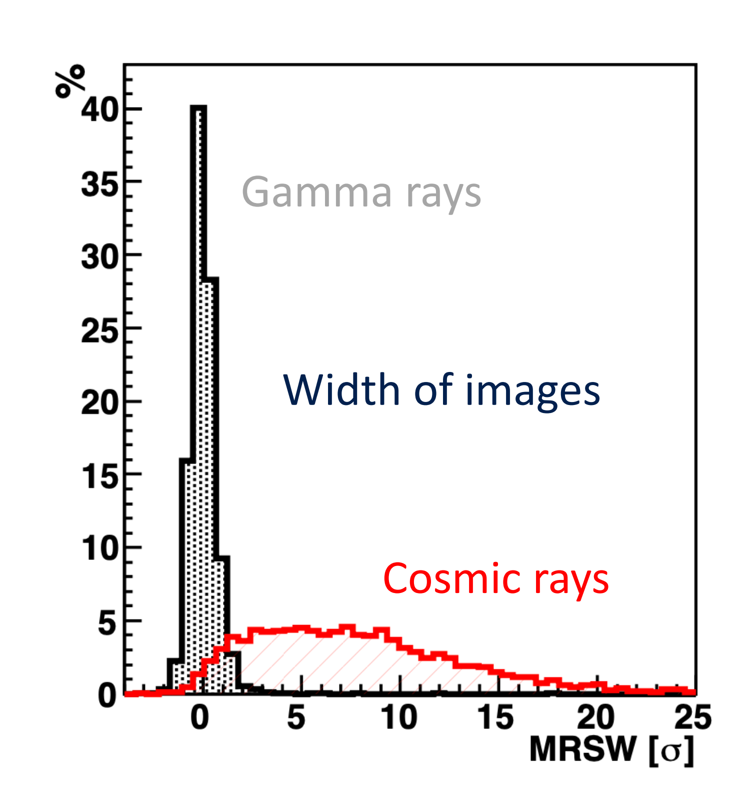
Telescopes

- must point at the source
- need clear & dark nights (1000-1500 h/y)

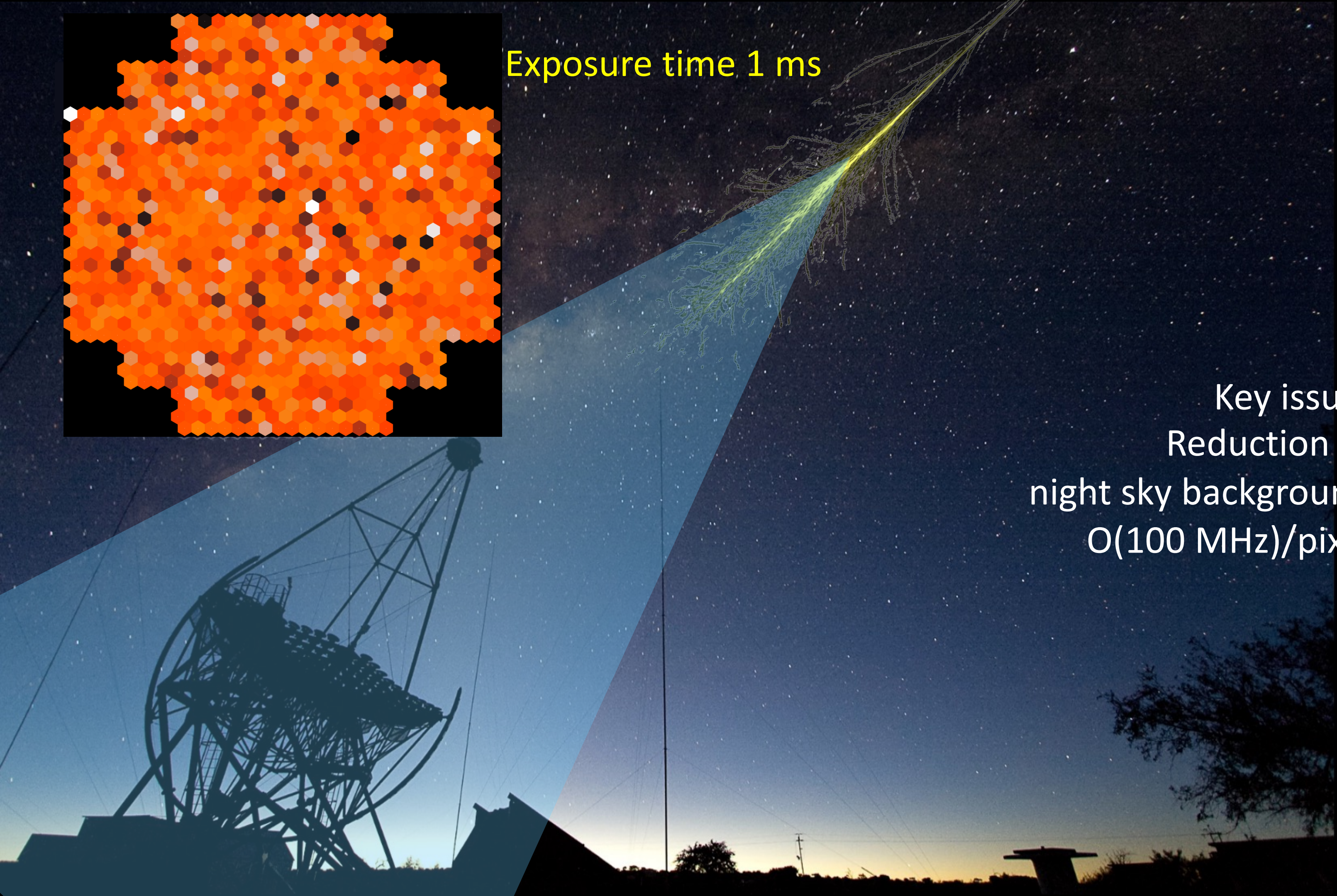
CHERENKOV TELESCOPES

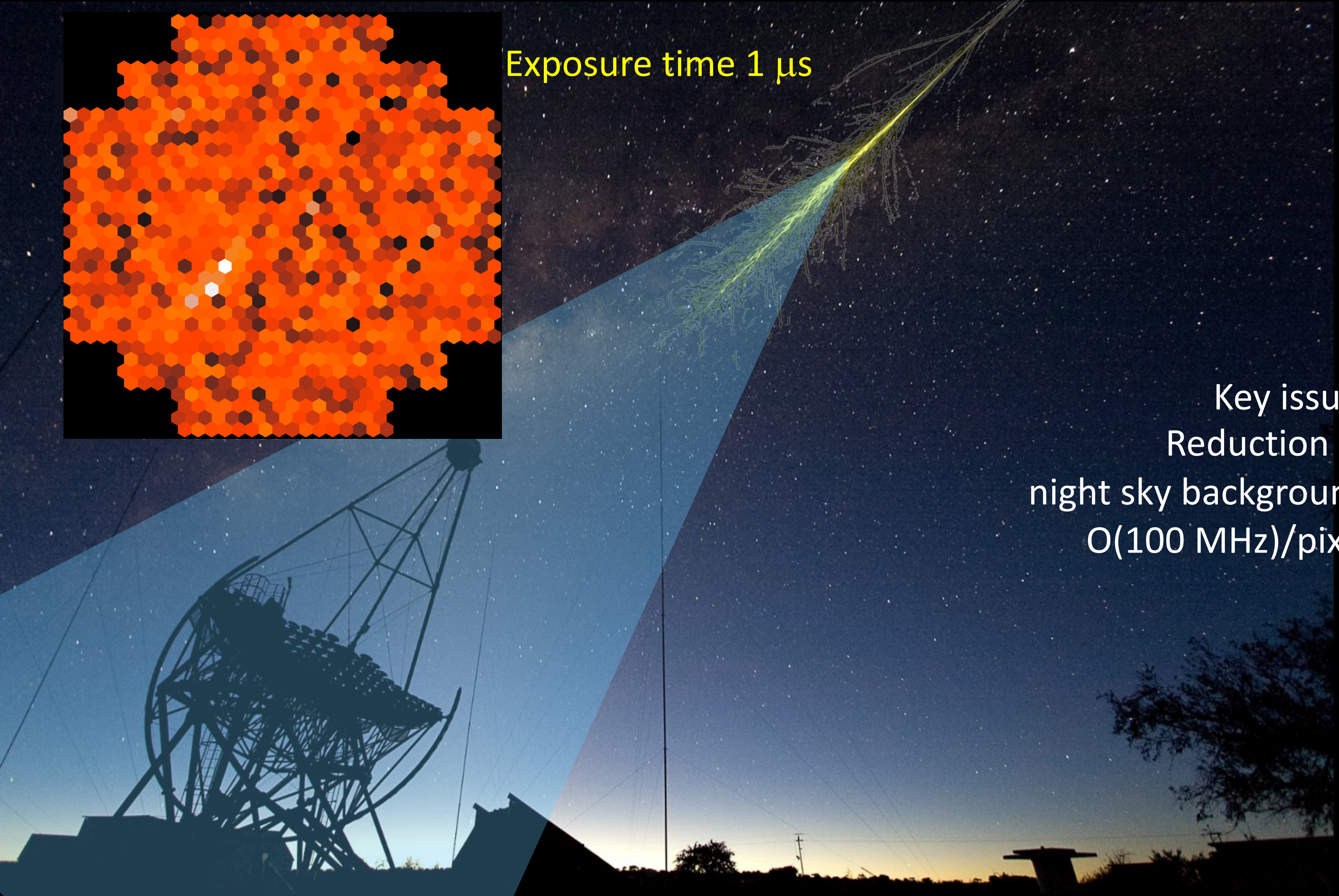
A bit like a meteor track, but
very faint (few photons per m^2)
very short-lived (some 10^{-9} seconds)

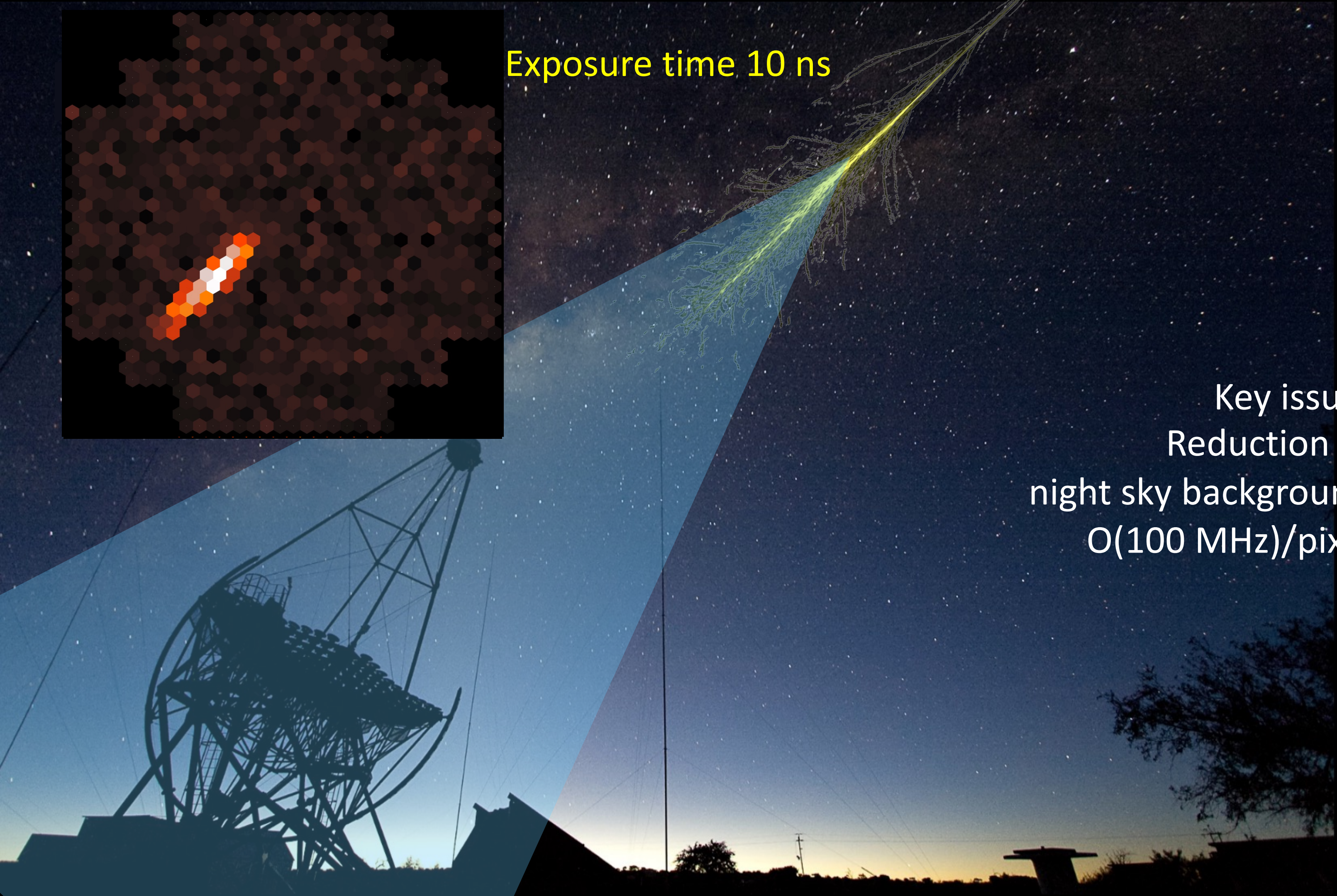




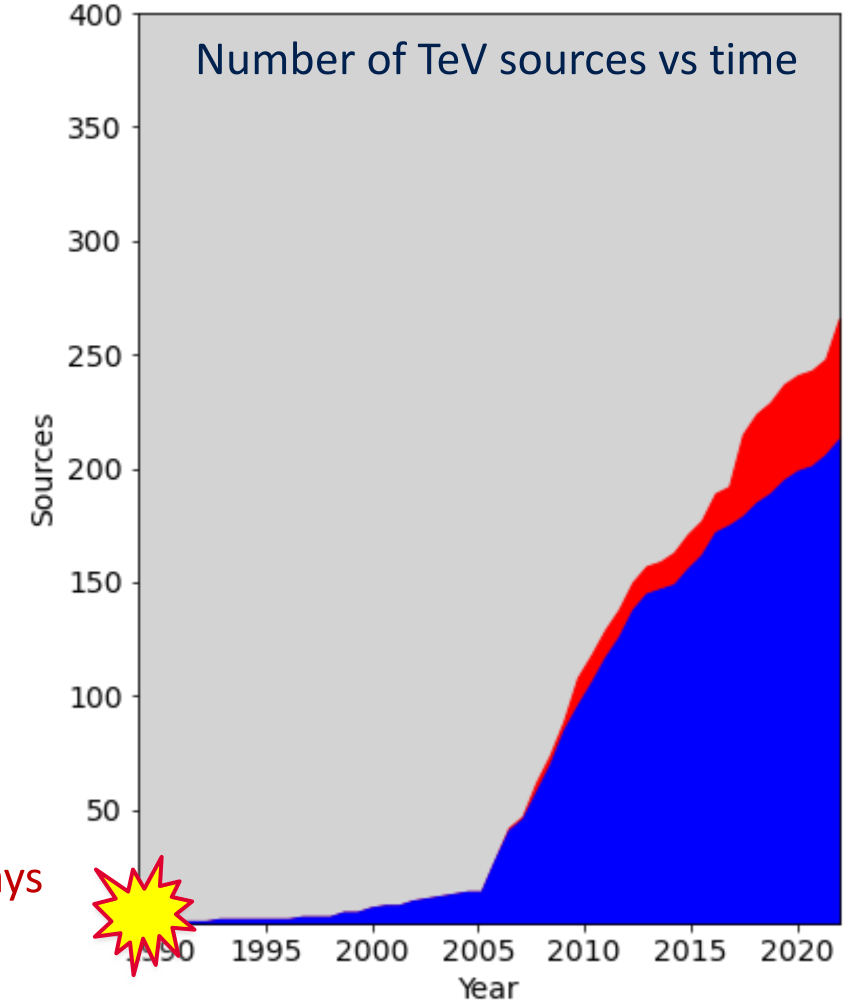
Key issue:
Cosmic ray veto
via image shape


Exposure time 1 ms
Key issue:
Reduction of
night sky background
O(100 MHz)/pixel


Exposure time 1 μs
Key issue:
Reduction of
night sky background
O(100 MHz)/pixel


Exposure time 10 ns
Key issue:
Reduction of
night sky background
O(100 MHz)/pixel

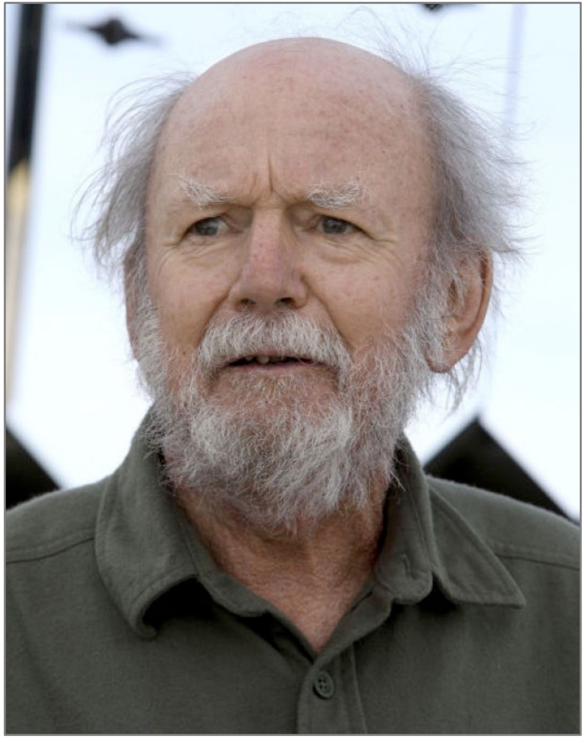
A BIT OF HISTORY – HOW IT ALL STARTED



1989:
Discovery of TeV gamma rays from the Crab Nebula

A BIT OF HISTORY:
GROUND-BASED GAMMA RAY ASTRONOMY 1989

Whipple Telescope 1968



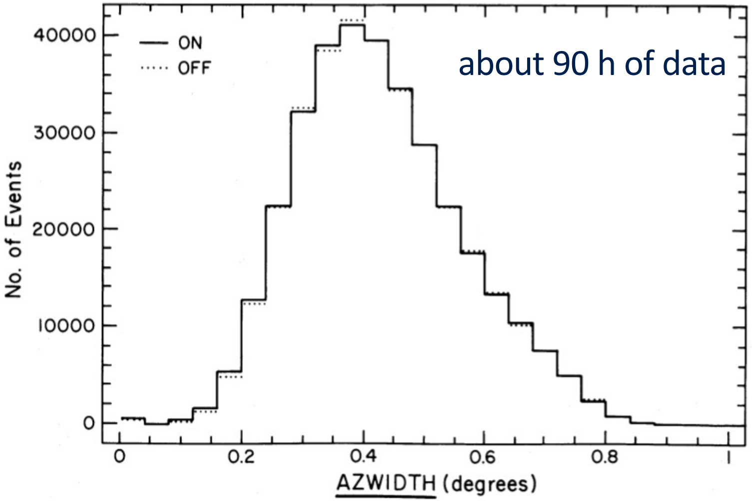
Trevor Weekes

A BIT OF HISTORY: GROUND-BASED GAMMA RAY ASTRONOMY 1989

Whipple Telescope 1968

T. Weekes et al., ApJ 342 (1989) 379

"Observation of TeV Gamma Rays from the Crab Nebula using the Atmospheric Cerenkov Imaging Technique"



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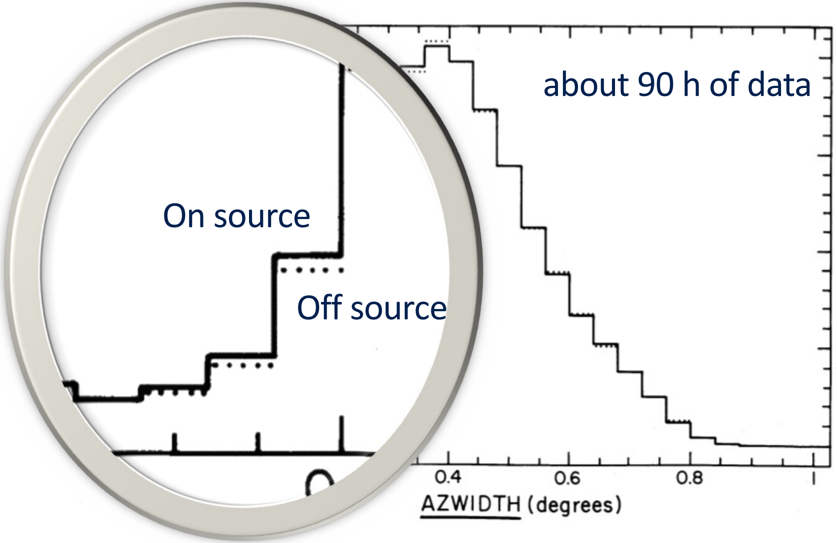
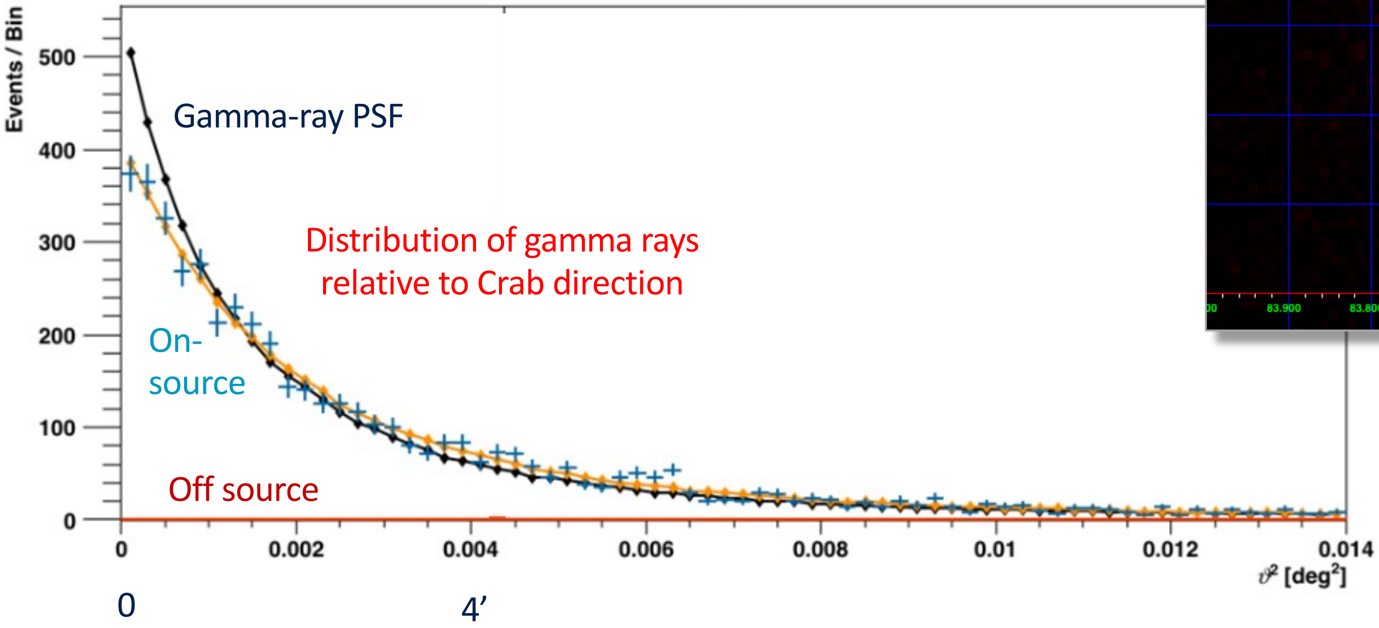
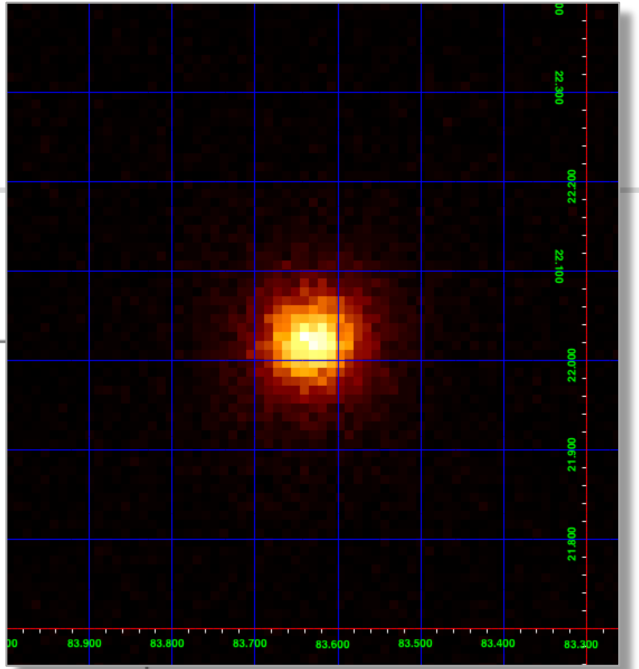


GROUND-BASED GAMMA RAY ASTRONOMY TODAY

H.E.S.S. Coll., Nature Astronomy 4 (2000) 167





Gamma-ray size of Crab Nebula: 52”±3”±8”

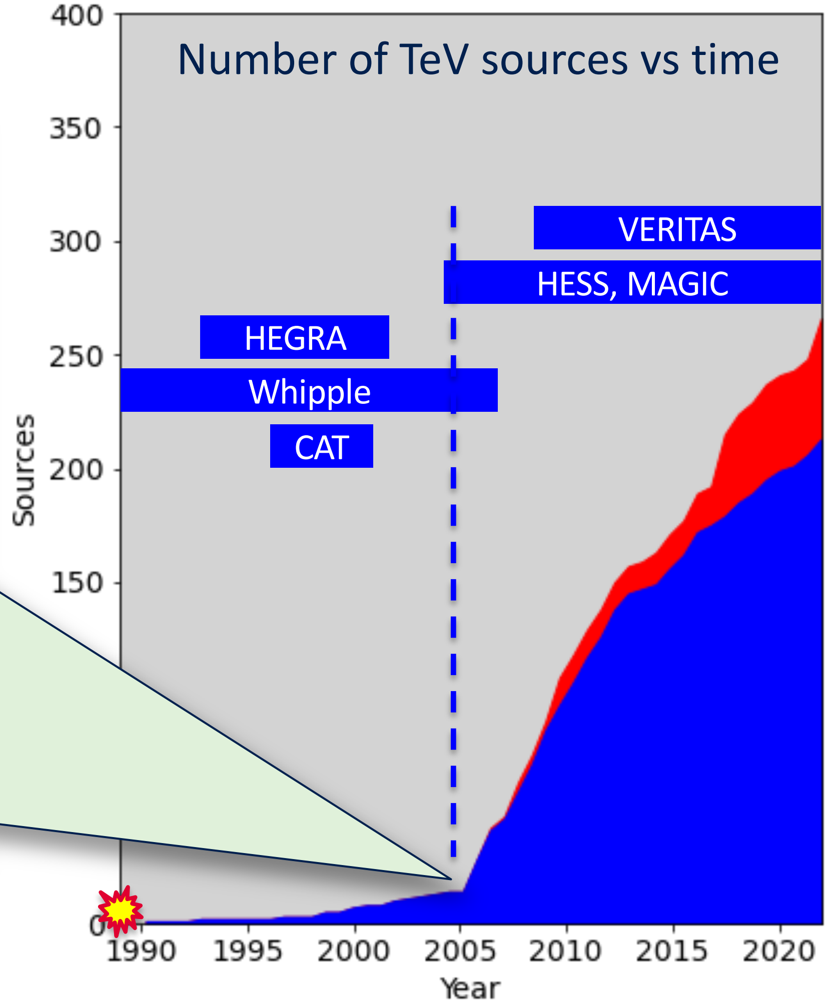
Sweet energy range for Cherenkov telescopes:

TeV domain (~100 GeV to few TeV)

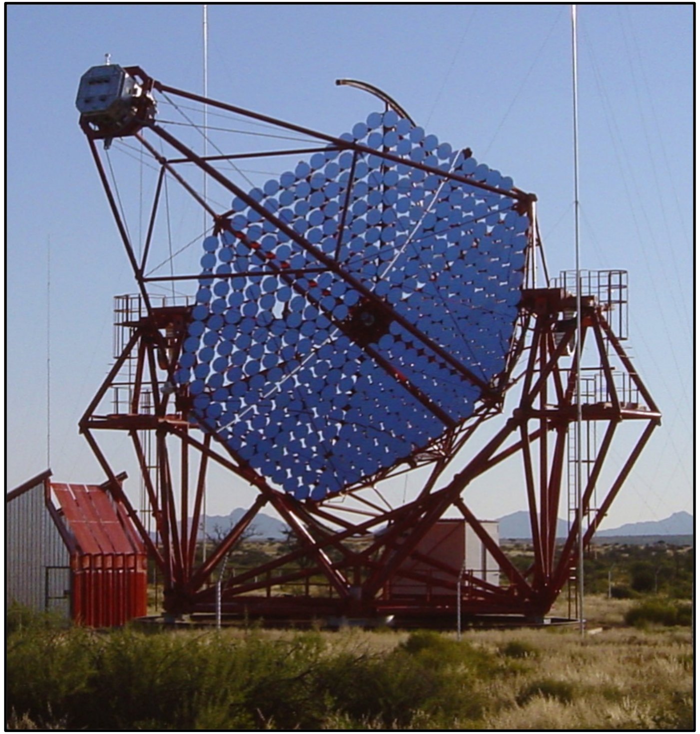
- Well-defined showers allowing efficient gamma-hadron separation
- Decent gamma-ray rates

What came together:

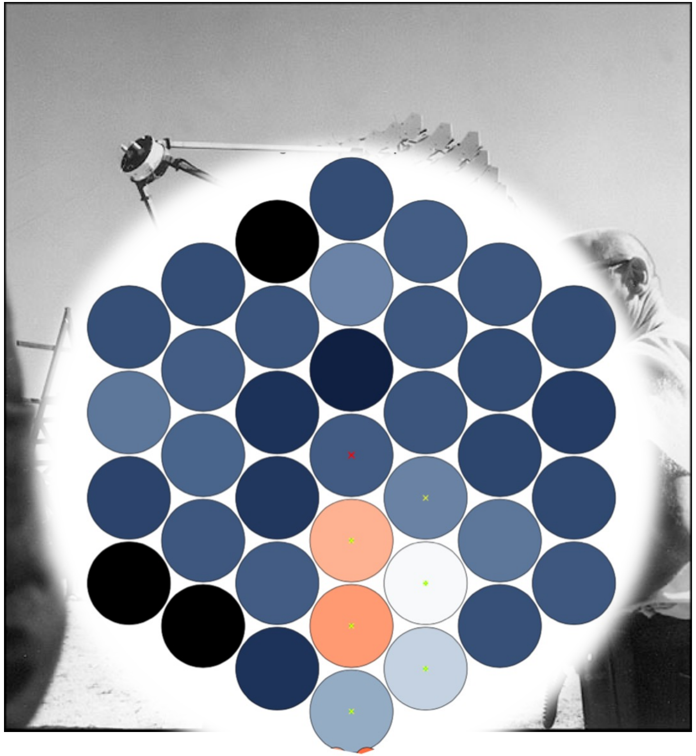
- Right dish size for decent photon statistics of images: 100+ m^2
- Right pixel size to resolve shower features: ~0.2^o or less
- Large field of view, to contain images and extended sources
- Multi-telescope stereoscopic imaging
- Advanced analysis algorithms
- Highly detailed simulations to tune algorithms



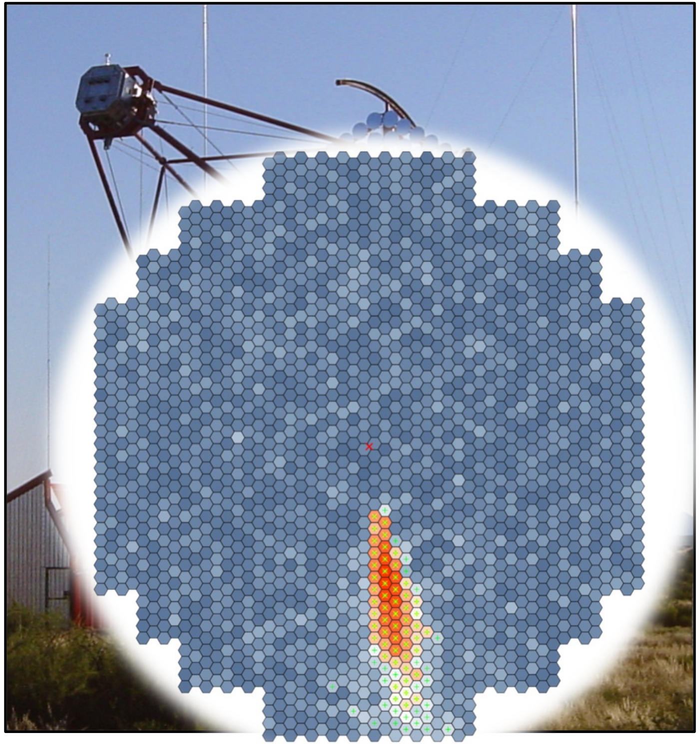
1989 VS TODAY



1989 VS TODAY

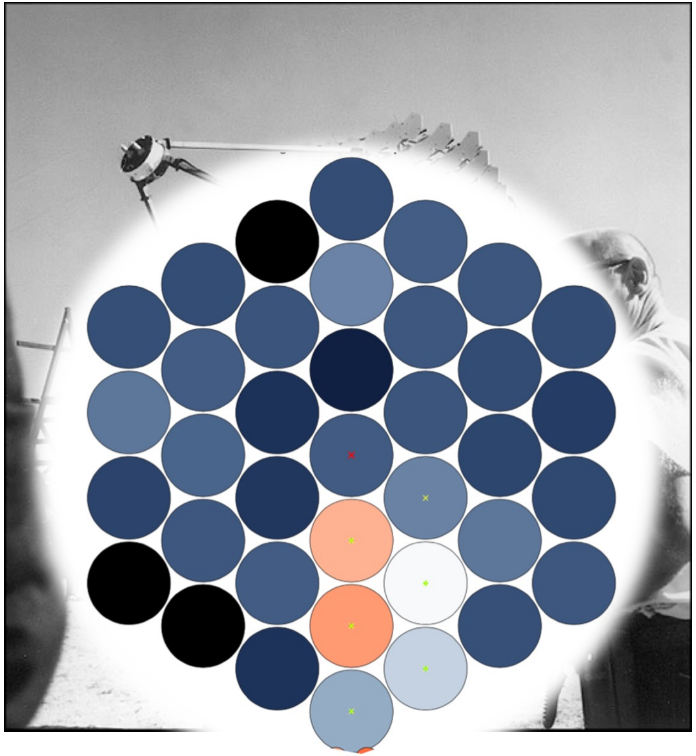


Whipple 1989 shower image



Modern camera

1989 VS TODAY



Whipple 1989 shower image

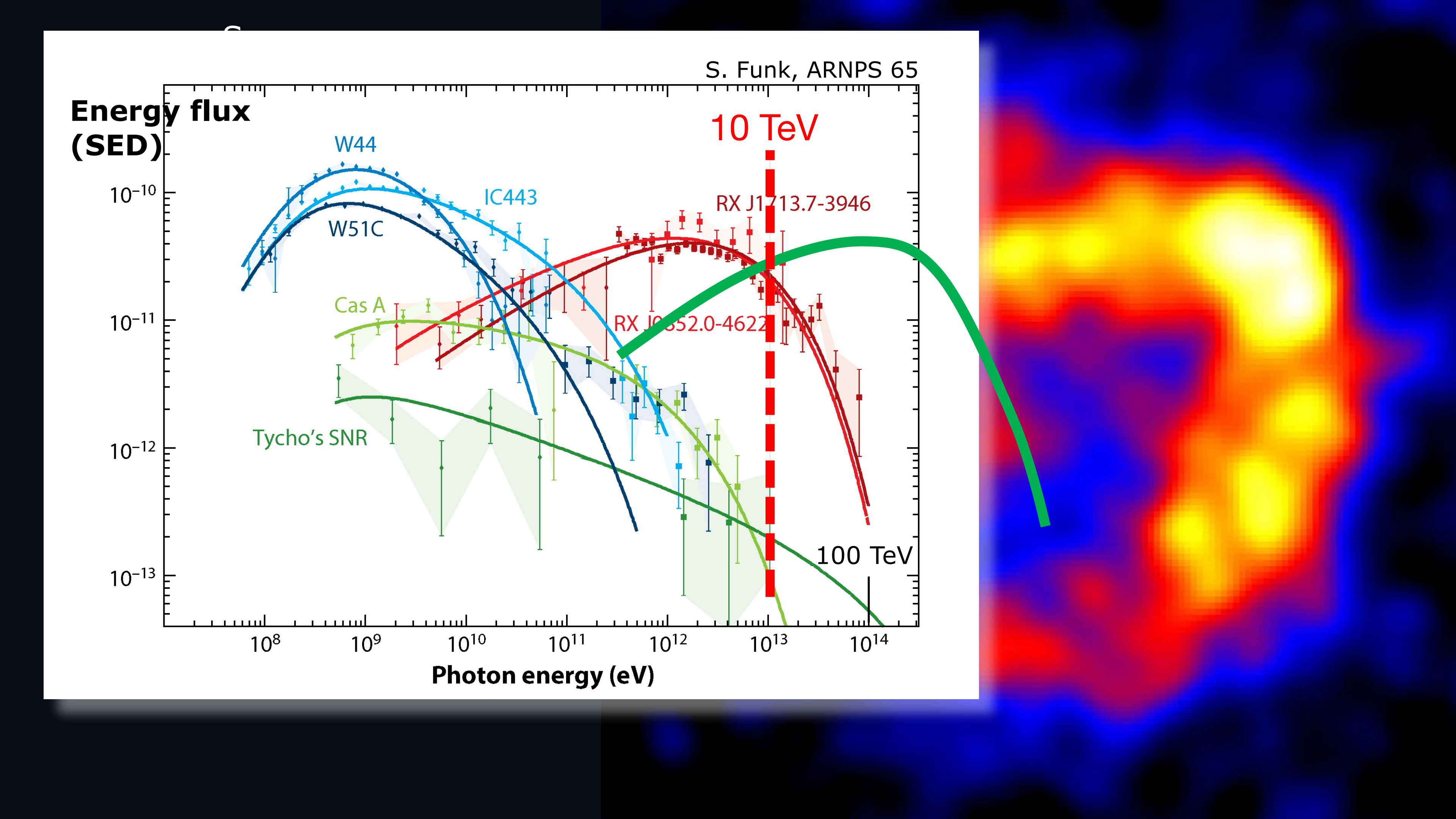
Modern array

(H.E.S.S.) in Namibia

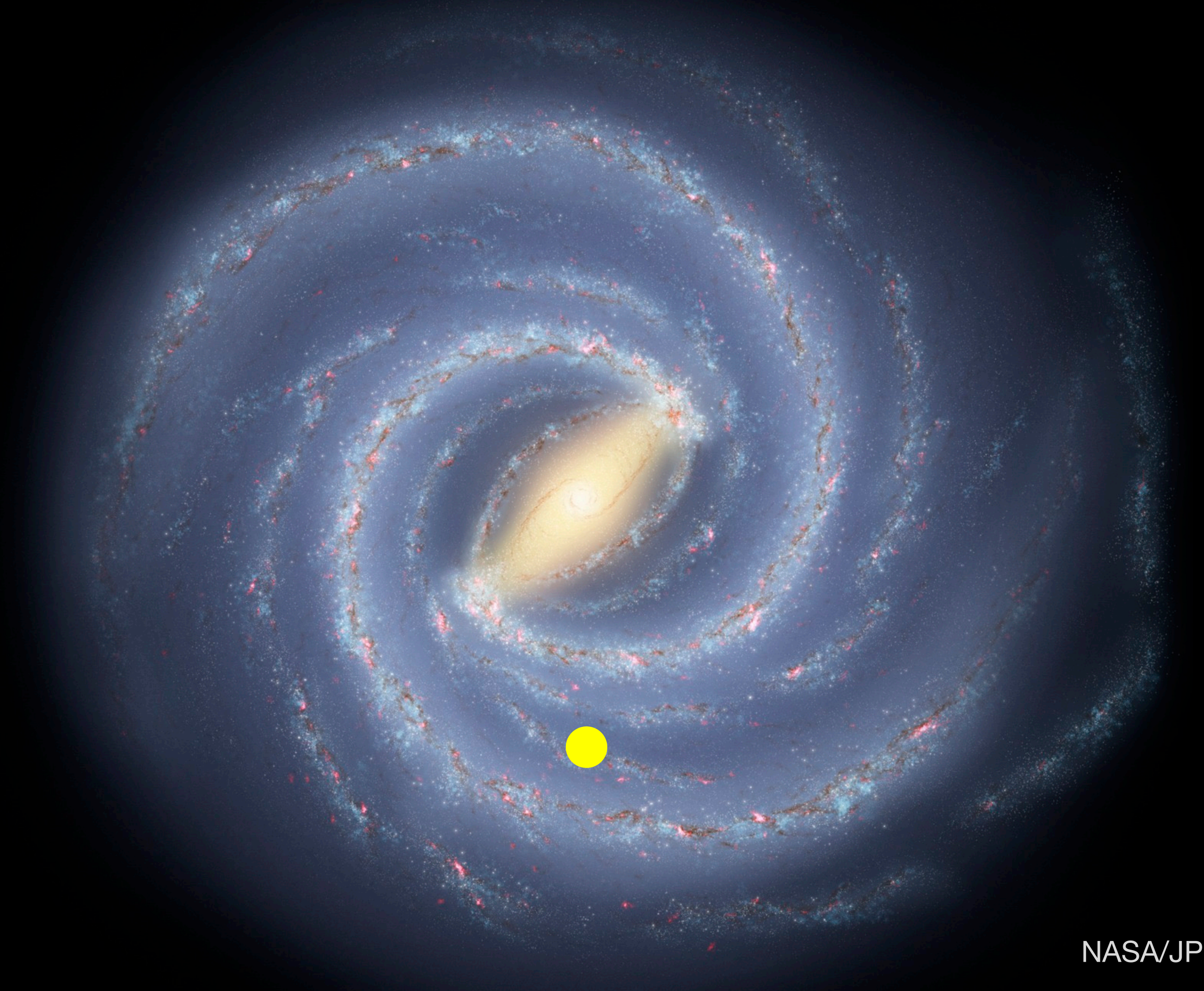
4 x 108 m^2 (since 2003)
1 x 614 m^2 (since 2012)

combining telescopes of different size
to increase the energy range

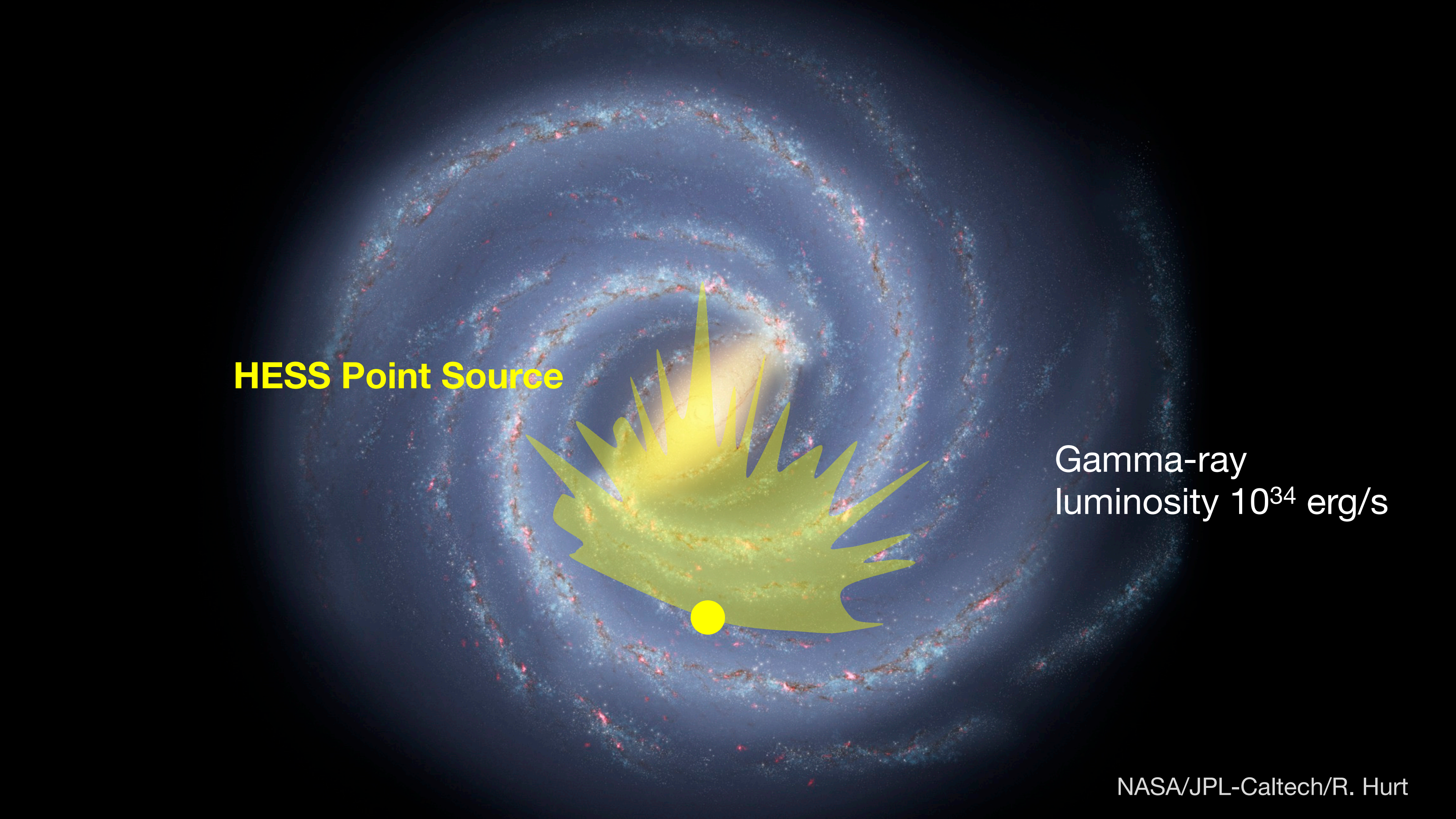
2003-09

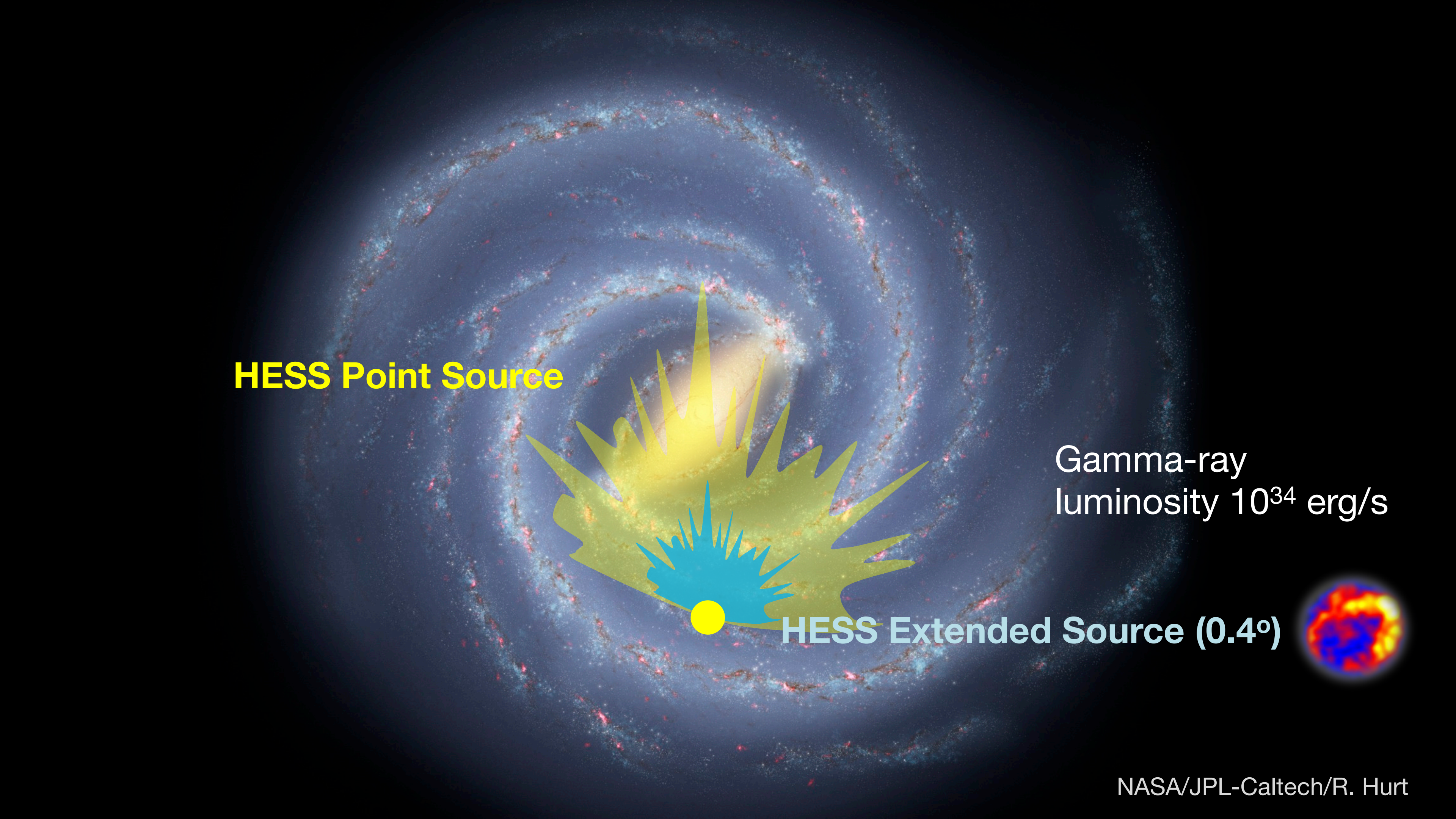


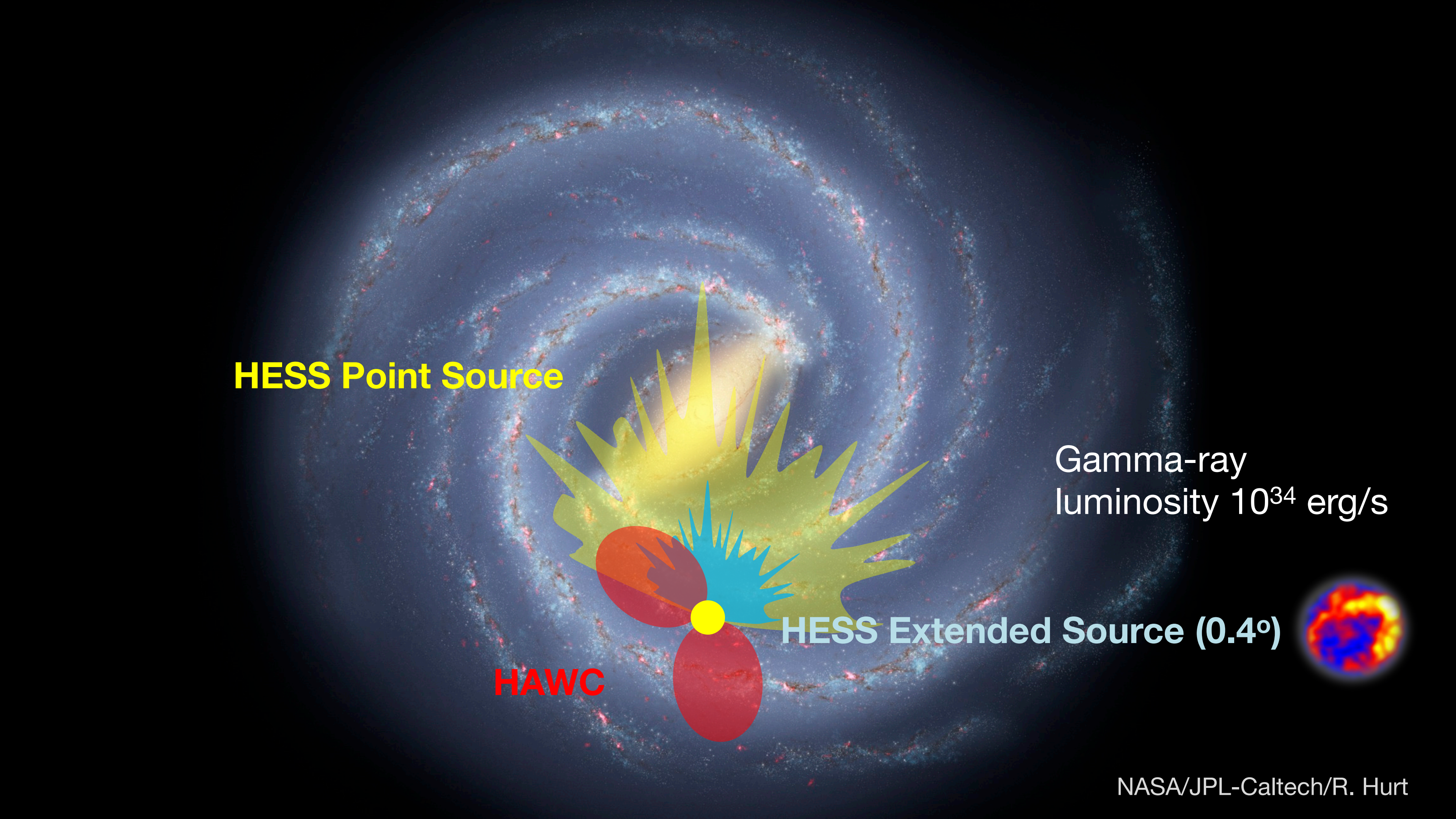
S. Funk, ARNPS 65
Energy flux (SED)
10 TeV
W44
IC443
W51C
RX J1713.7-3946
Cas A
RX J0852.0-4622
Tycho's SNR
100 TeV
10−10
10−11
10−12
10−13
10^8
10^9
10^10
10^11
10^12
10^13
10^14
Photon energy (eV)



NASA/JPL-Caltech/R. Hurt

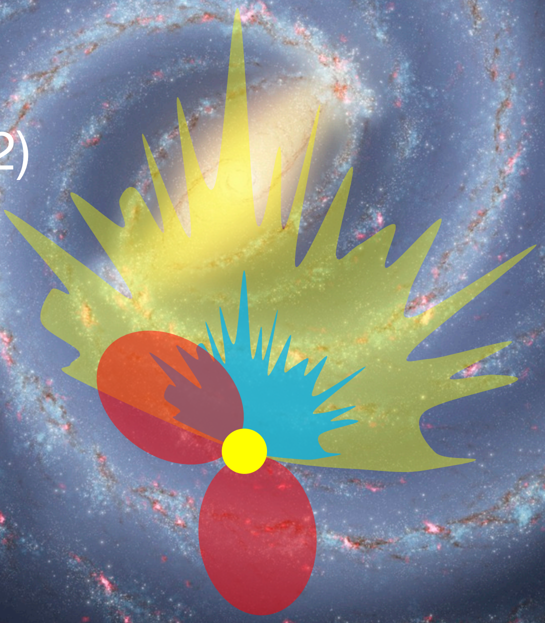

HESS Point Source
Gamma-ray
luminosity 10^{34} erg/s
NASA/JPL-Caltech/R. Hurt


HESS Point Source
Gamma-ray luminosity 10^34 erg/s
HESS Extended Source (0.4°)
NASA/JPL-Caltech/R. Hurt

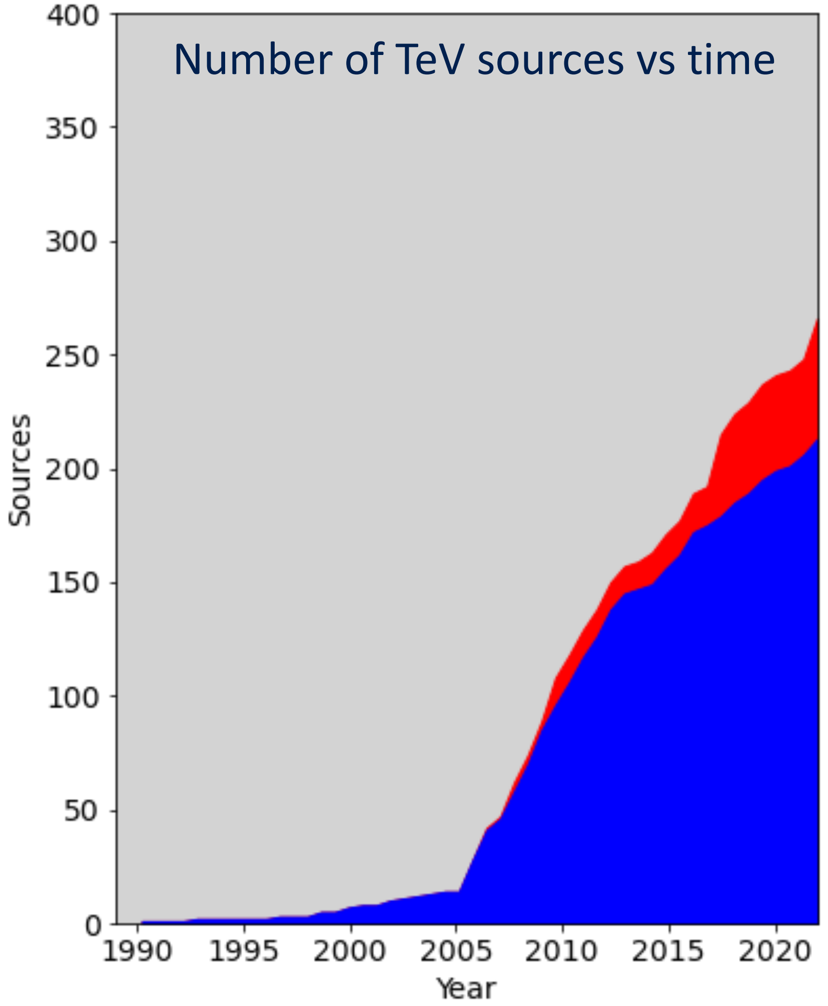

HESS Point Source
Gamma-ray
luminosity 10^{34} erg/s
HESS Extended Source (0.4°)
HAWC
NASA/JPL-Caltech/R. Hurt

Design drivers

- Sensitivity (x10)
- Full-sky coverage
- Wide energy range – 20 GeV to 300 TeV
- Larger field of view (x2)
- Few arc-min angular resolution
- Rapid slewing for transient follow-up



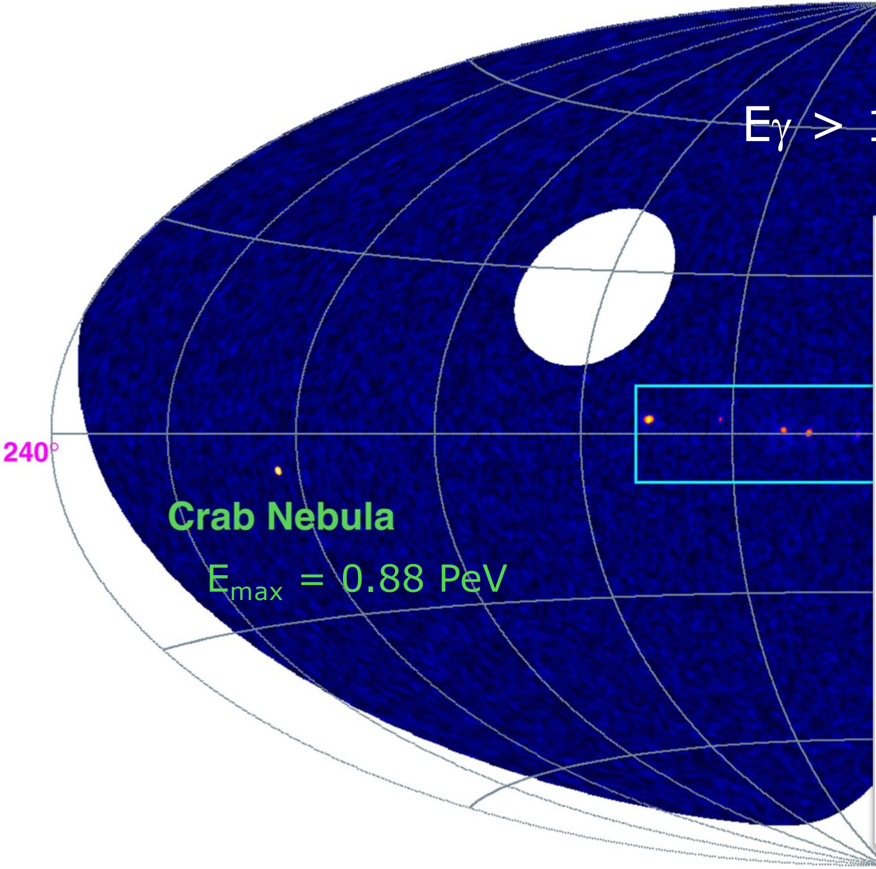
NASA/JPL-Caltech/R. Hurt


Number of TeV sources vs time
Sources
Year
400
350
300
250
200
150
100
50
0
1990
1995
2000
2005
2010
2015
2020

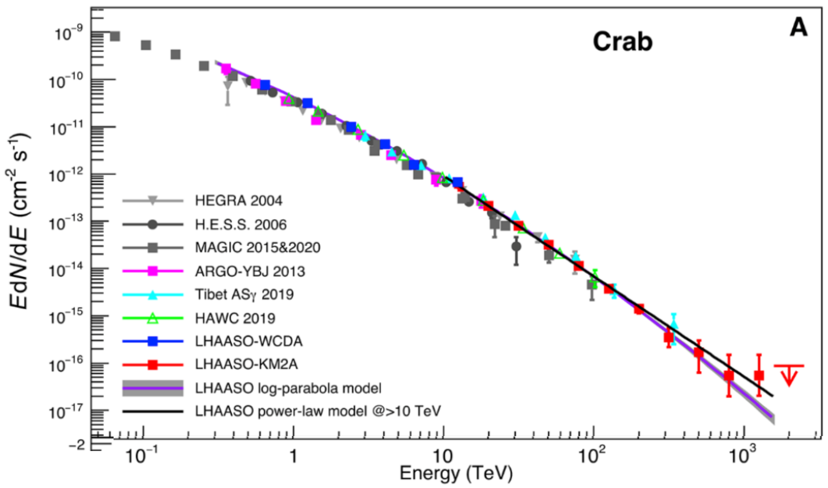

LHAASO
Sichuan, China
4410 m asl
400
350
300
250
200
150
100
50
Sources
2000
LHAASO
HAWC
MILAGRO
TIBET

THE PeV (10^{15} eV) SKY

LHAASO Coll., Z. Cao et al., Nature, 17 May 2021

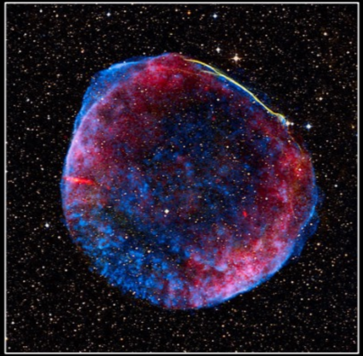


Z. Cao et al., Science 8 Jul 2021



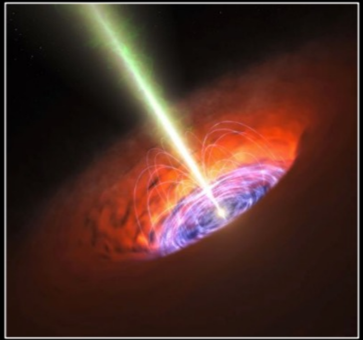
Theme 1: Cosmic Particle Acceleration

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



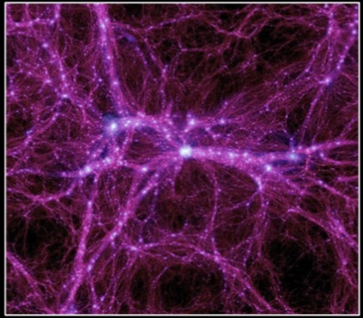
Theme 2: Probing Extreme Environments

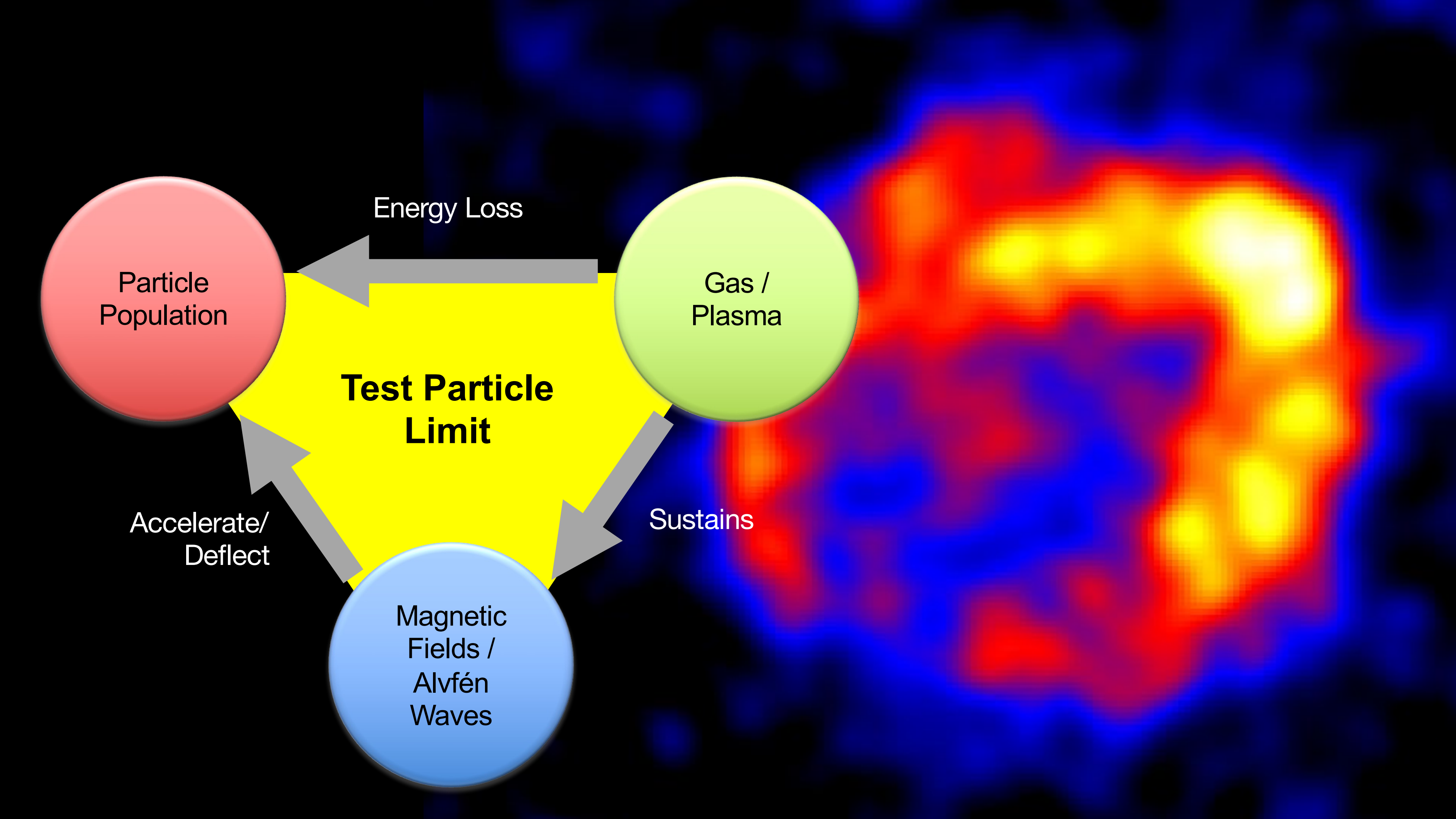
- Processes close to neutron stars and black holes?
- Characteristics of relativistic jets, winds and explosions?
- Cosmic voids: their radiation fields and magnetic fields



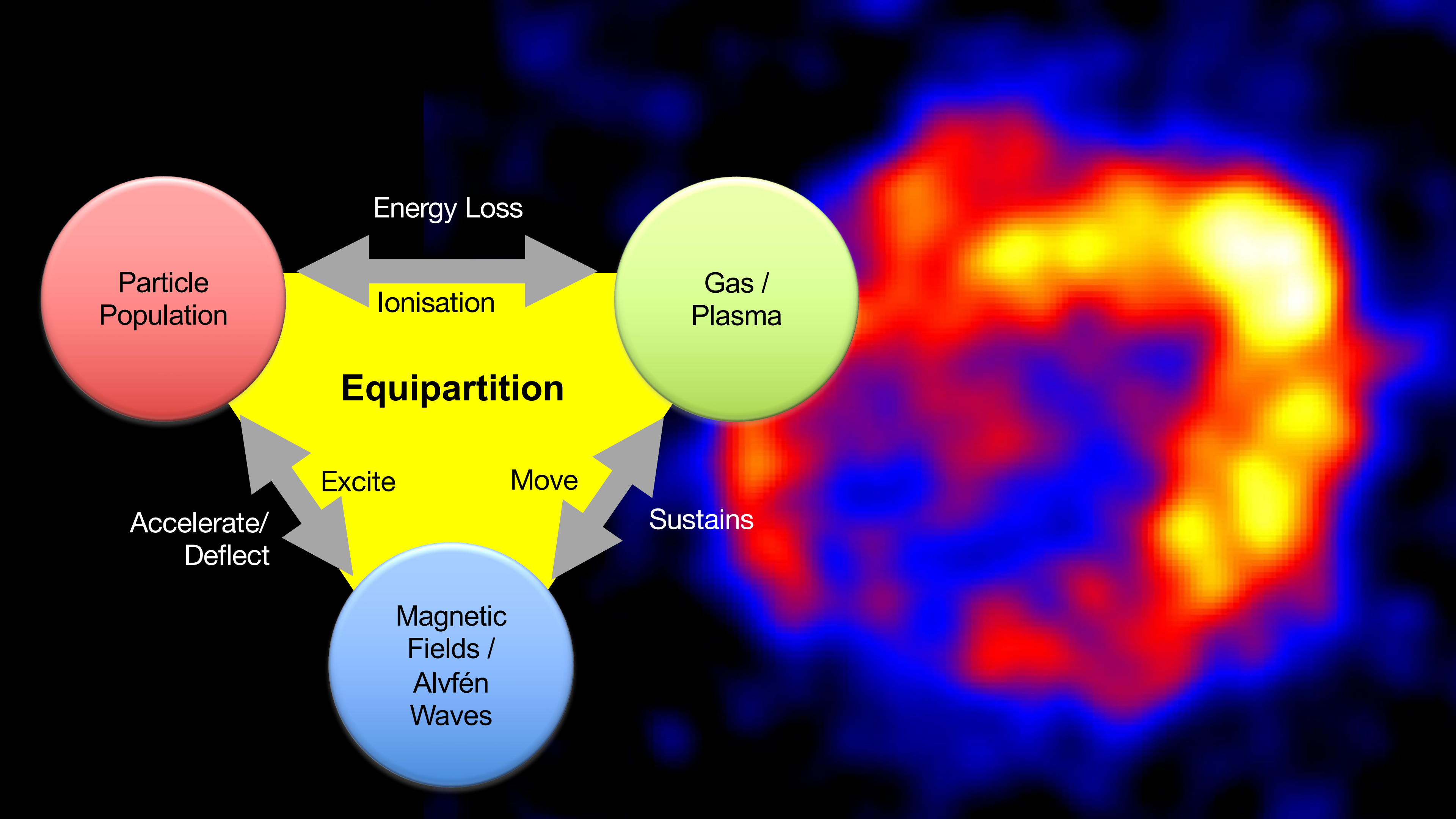
Theme 3: Physics Frontiers

- What is the nature of Dark Matter?
- Is the speed of light a constant?
- Do axion-like particles exist?





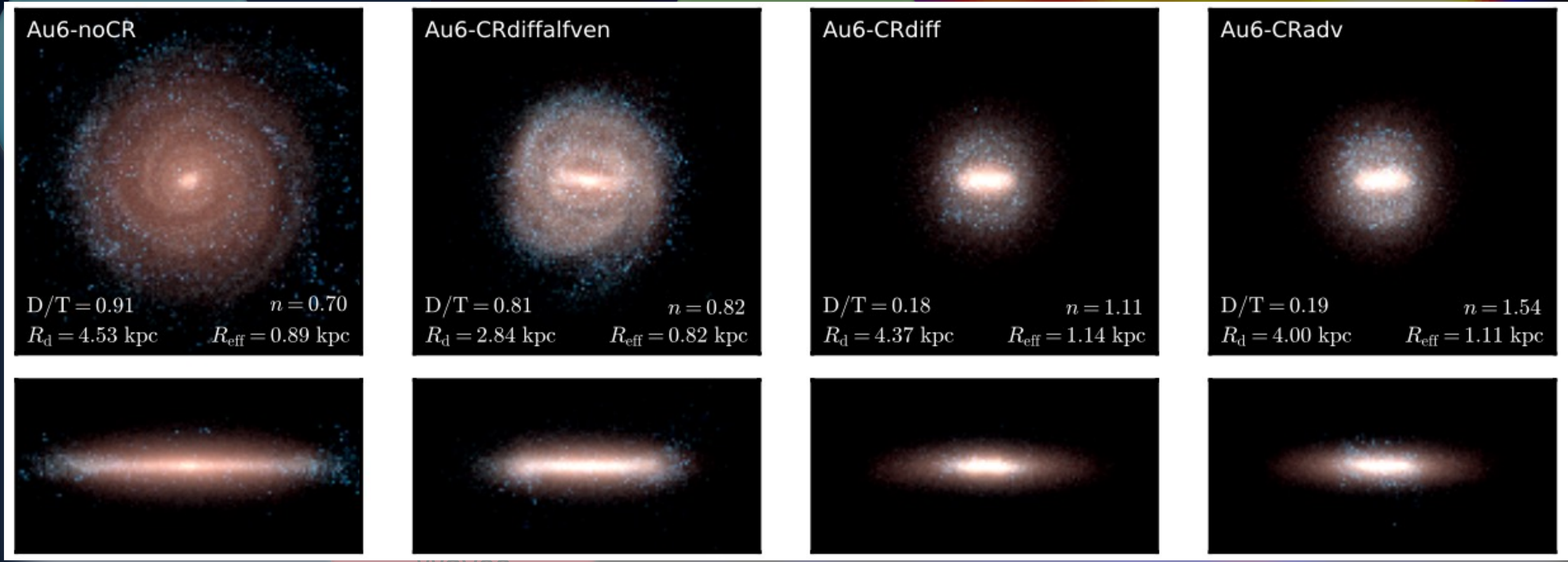
Energy Loss
Particle Population
Gas / Plasma
Test Particle Limit
Accelerate/ Deflect
Sustains
Magnetic Fields / Alvfén Waves



Energy Loss
Particle Population
Ionisation
Gas / Plasma
Equipartition
Excite
Move
Accelerate/ Deflect
Sustains
Magnetic Fields / Alvfén Waves

COSMIC RAYS & GALAXY FORMATION

Energy Loss



T. Buck, C. Pfrommer, R. Pakmor, R.J. J. Grand, V. Springel,
arXiv:1911.00019

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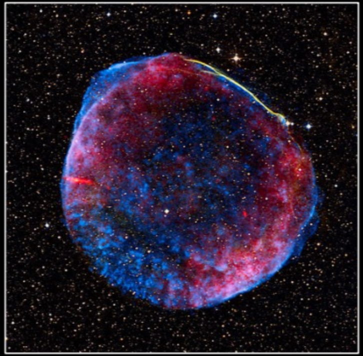

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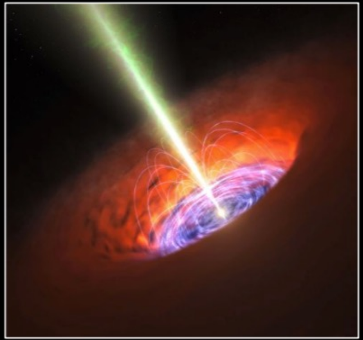

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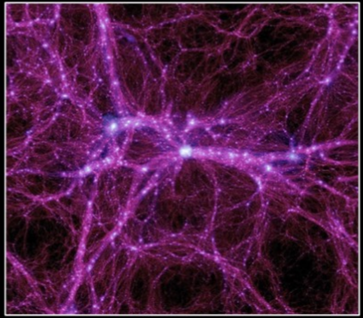
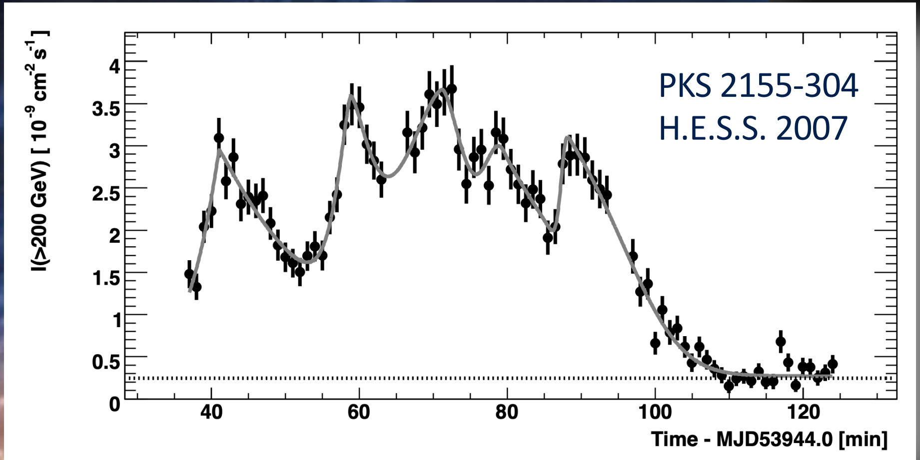


CHALLENGE: COMPACT OBJECTS AS ACCELERATORS



AGN:

What is the jet made of?

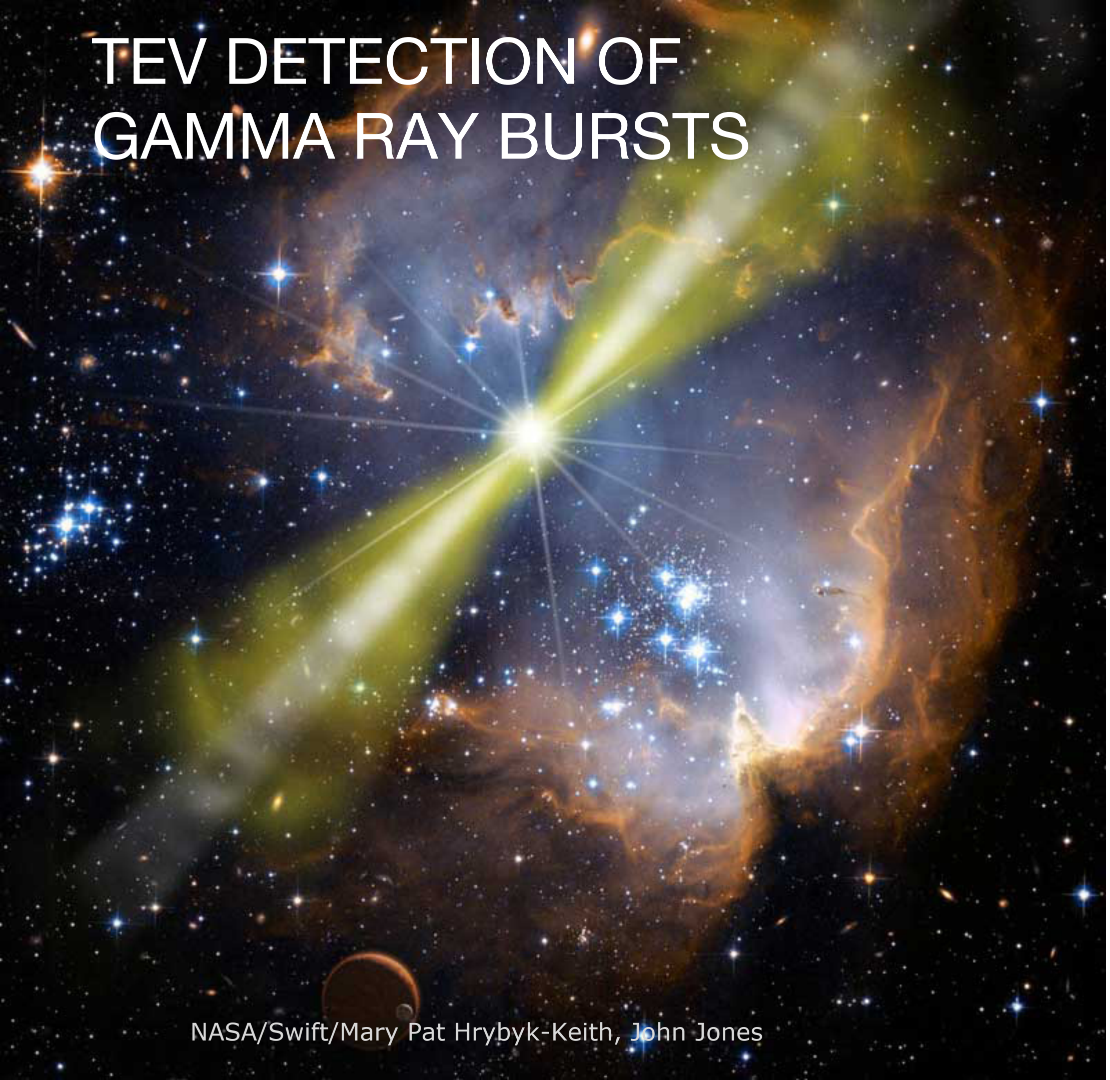
How is it launched?

How are particles accelerated?

What causes the variability?

Illustration: Scientific American

TEV DETECTION OF GAMMA RAY BURSTS



NASA/Swift/Mary Pat Hrybyk-Keith, John Jones

GRB 190114C

MAGIC Coll. +

Nature 575 (2019) 455

Nature 575 (2019) 459

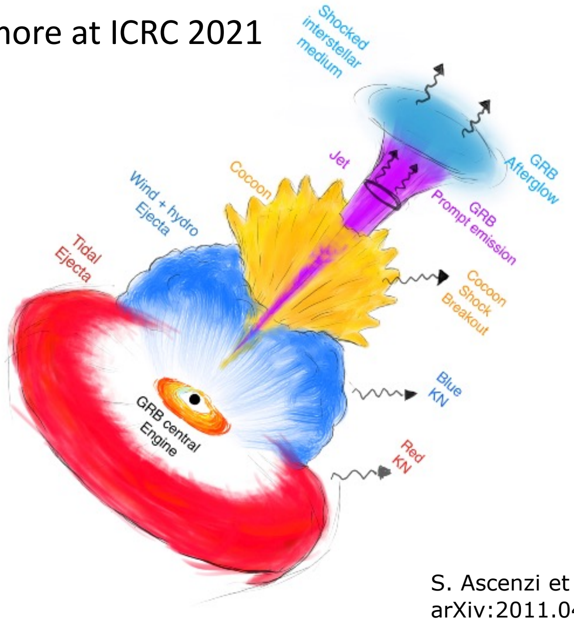
GRB 180720B

H.E.S.S. Coll., Nature 575 (2019) 464

GRB 190829A

H.E.S.S. Coll., Science 372 (2021) 1081

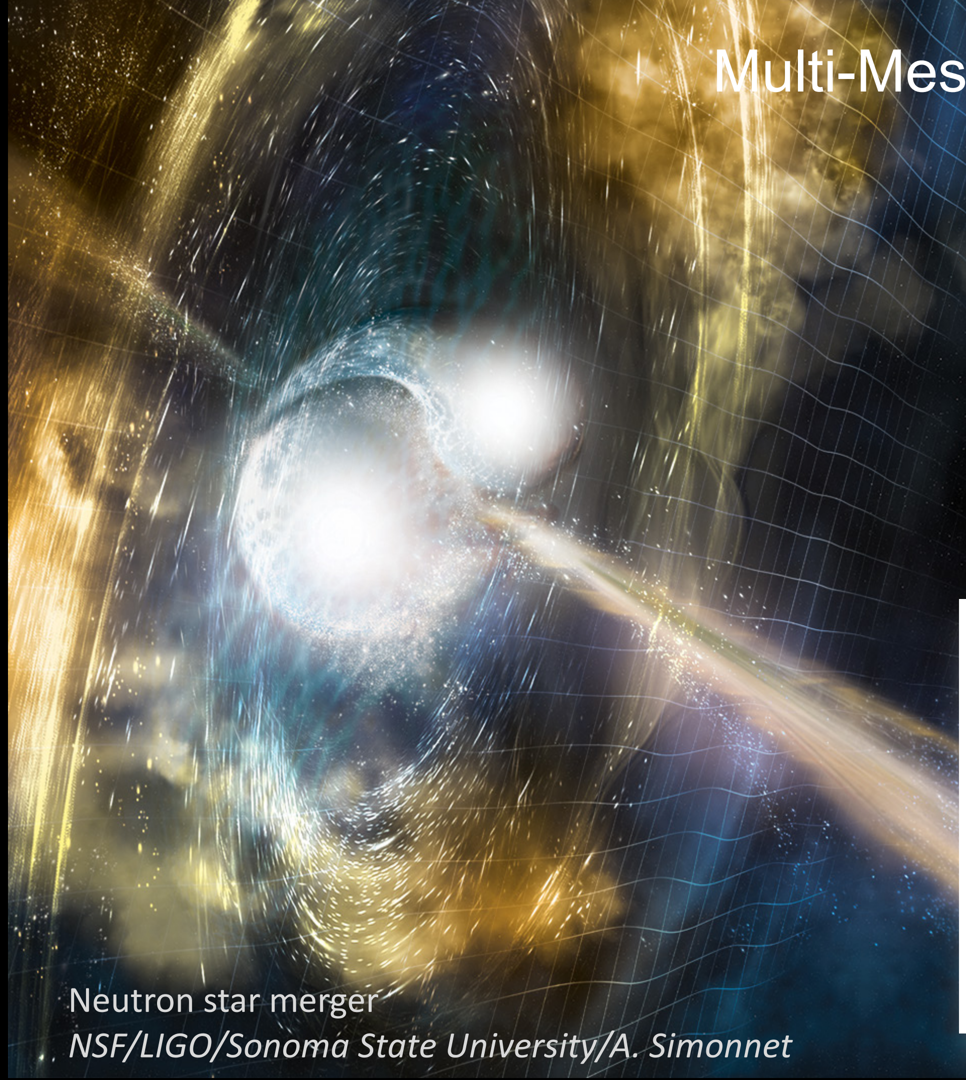
+ 2 more at ICRC 2021



S. Ascenzi et al.
arXiv:2011.04001

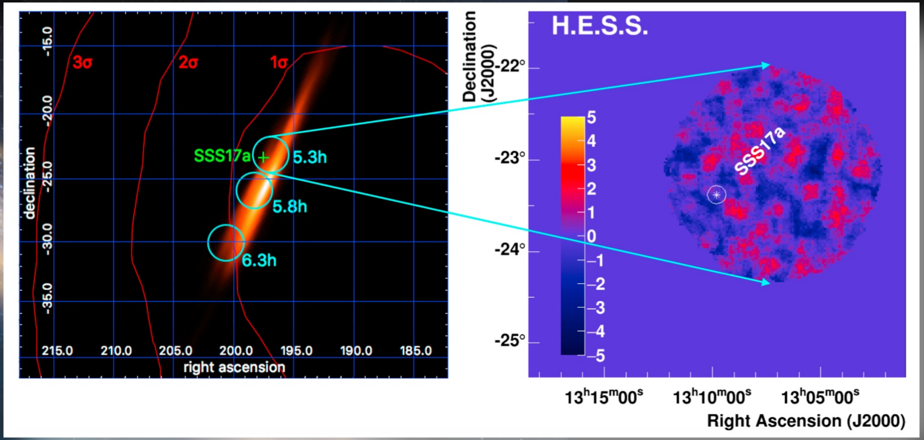
Multi-Messenger Observations of a Binary Neutron Star Merger

LIGO, Virgo, Fermi GBM, INTEGRAL, …
ApJL 848 (2017) L12

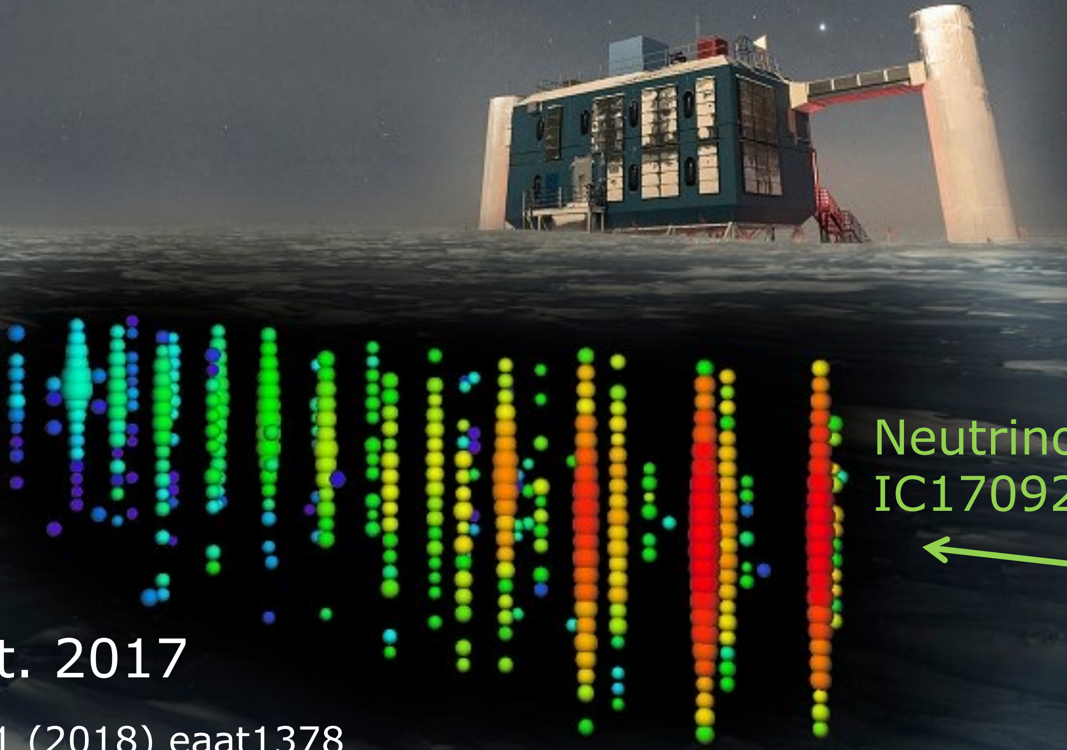


Neutron star merger
NSF/LIGO/Sonoma State University/A. Simonnet

H.E.S.S. Coll., Astrophys. J. Lett. 850 (2017) L22

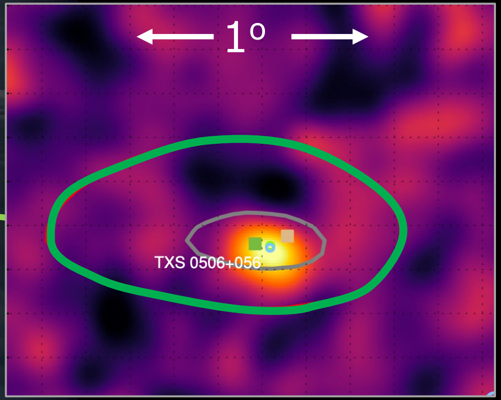


IceCube detection of a neutrino from the direction of AGN TXS0506+056, coincident with a gamma ray flare



Neutrino IC170922A

MAGIC detection

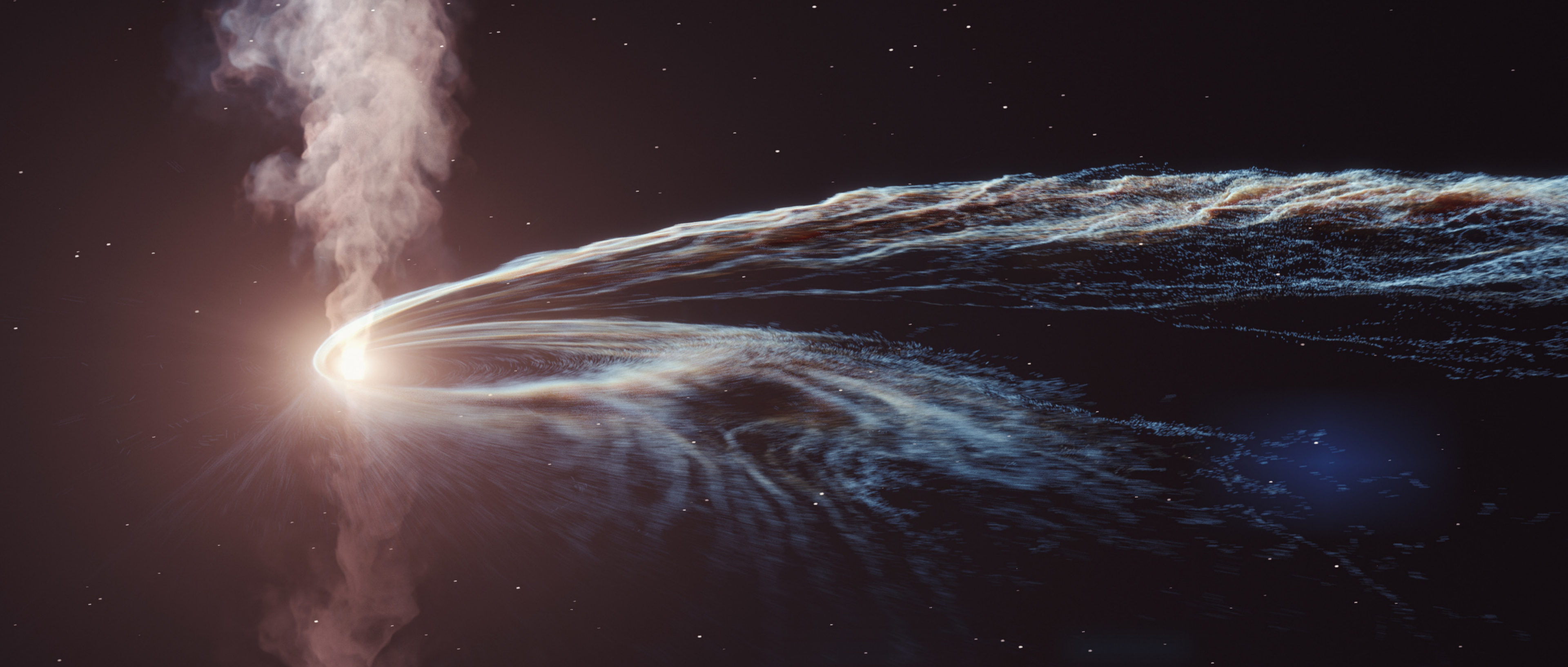


22. Sept. 2017

Science 361 (2018) eaat1378

A tidal disruption event coincident with a high-energy neutrino

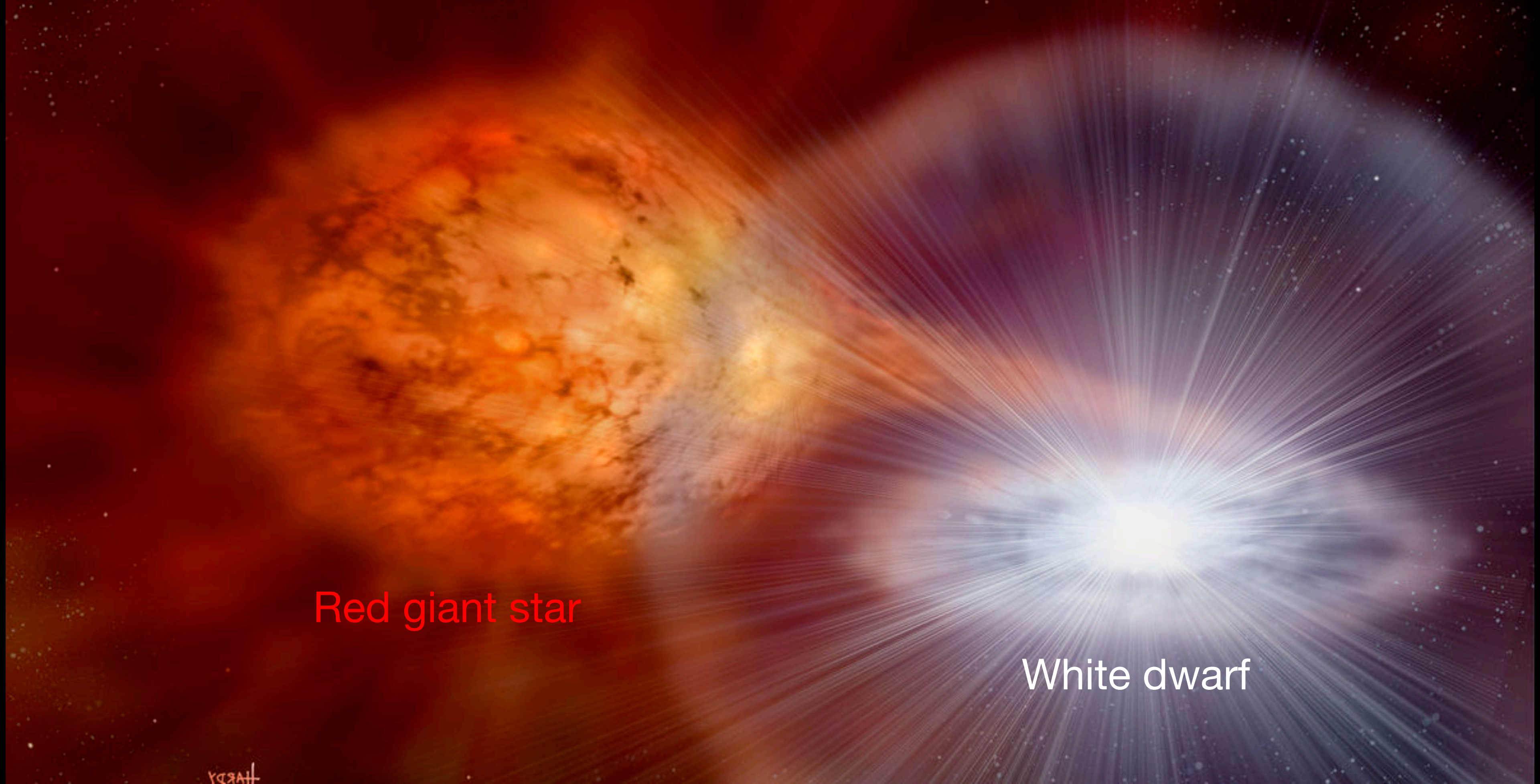
R. Stein et al., Nature Astronomy 5, 510–518 (2021)



Coincident with IceCube Neutrino IC191001A

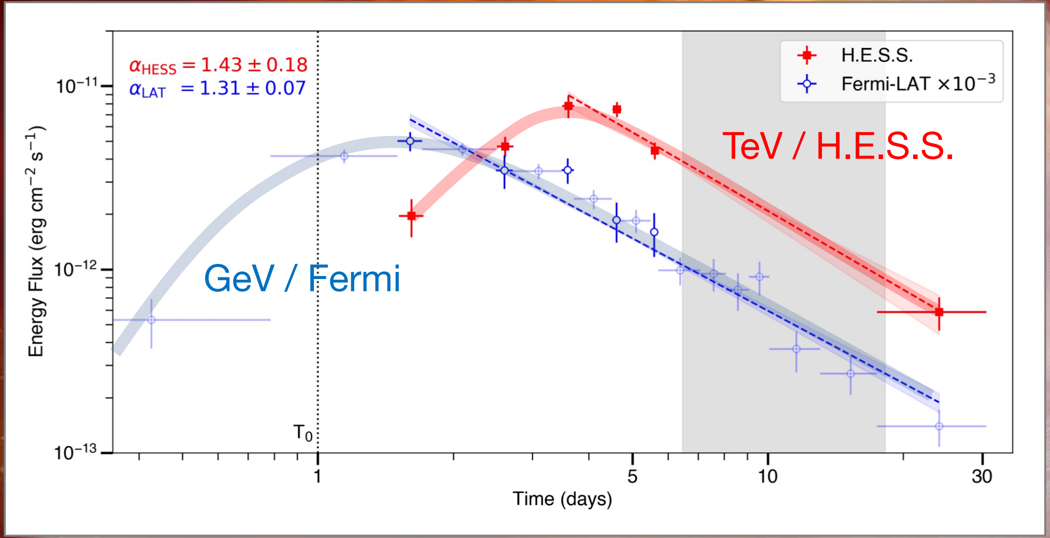
Source:DESY, Science Communication Lab

Recurrent nova RS Ophiuchi as TeV source



Recurrent nova RS Ophiuchi as TeV source

H.E.S.S. ATEL #14844, Aug. 10
H.E.S.S. Science Mar. 2022
MAGIC arXiv:2202.07681



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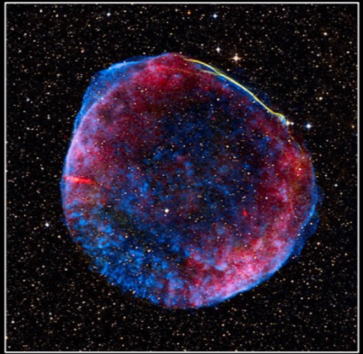

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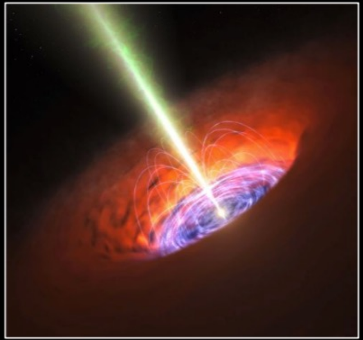

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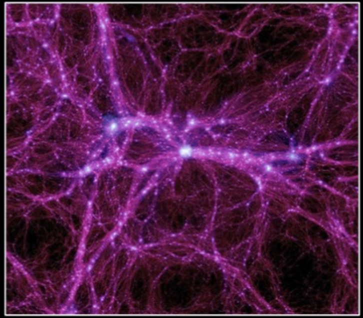
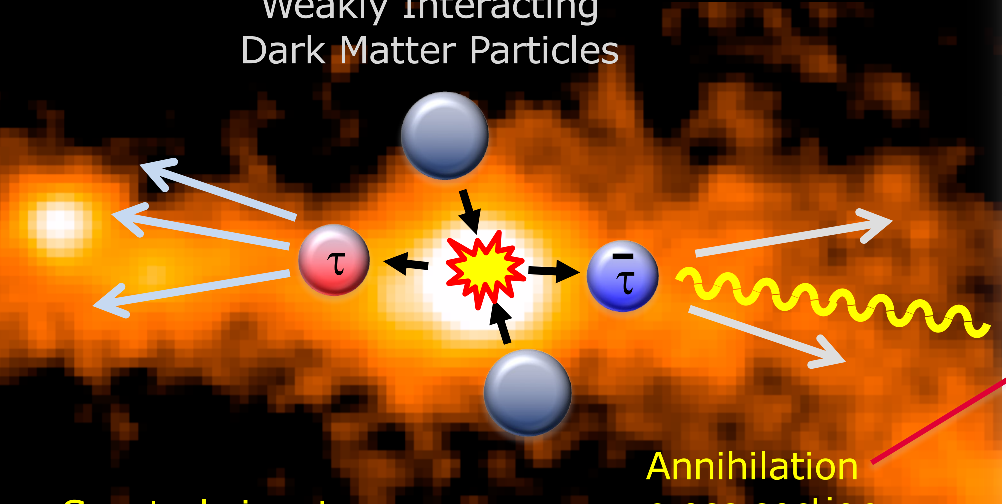
- Is the speed of light a constant?
- Do axion-like particles exist?



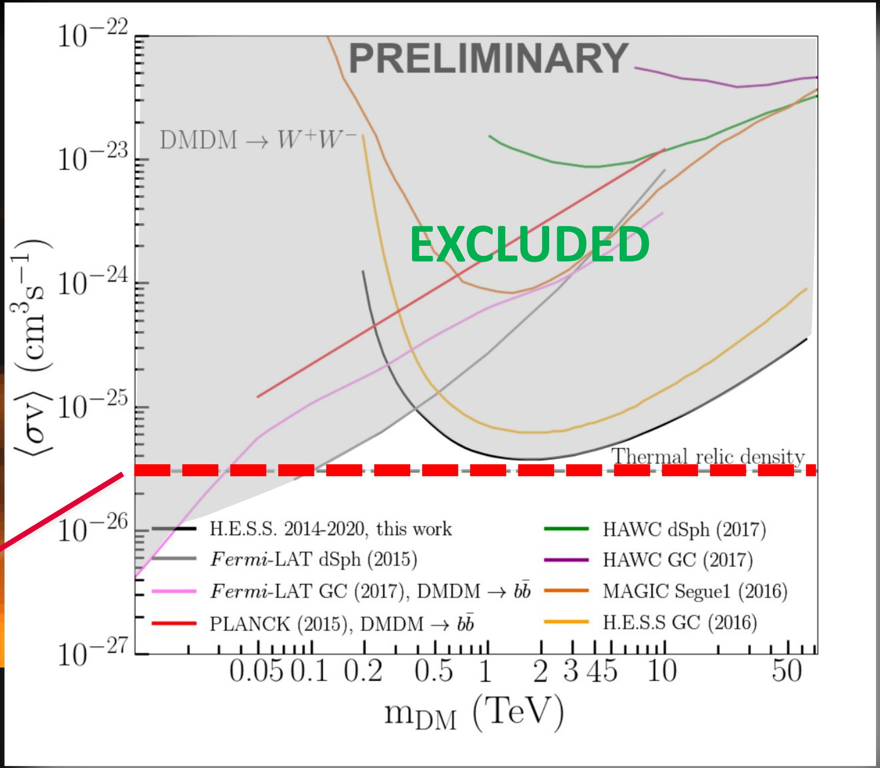
CHALLENGE: DARK MATTER @ GC

Weakly Interacting
Dark Matter Particles



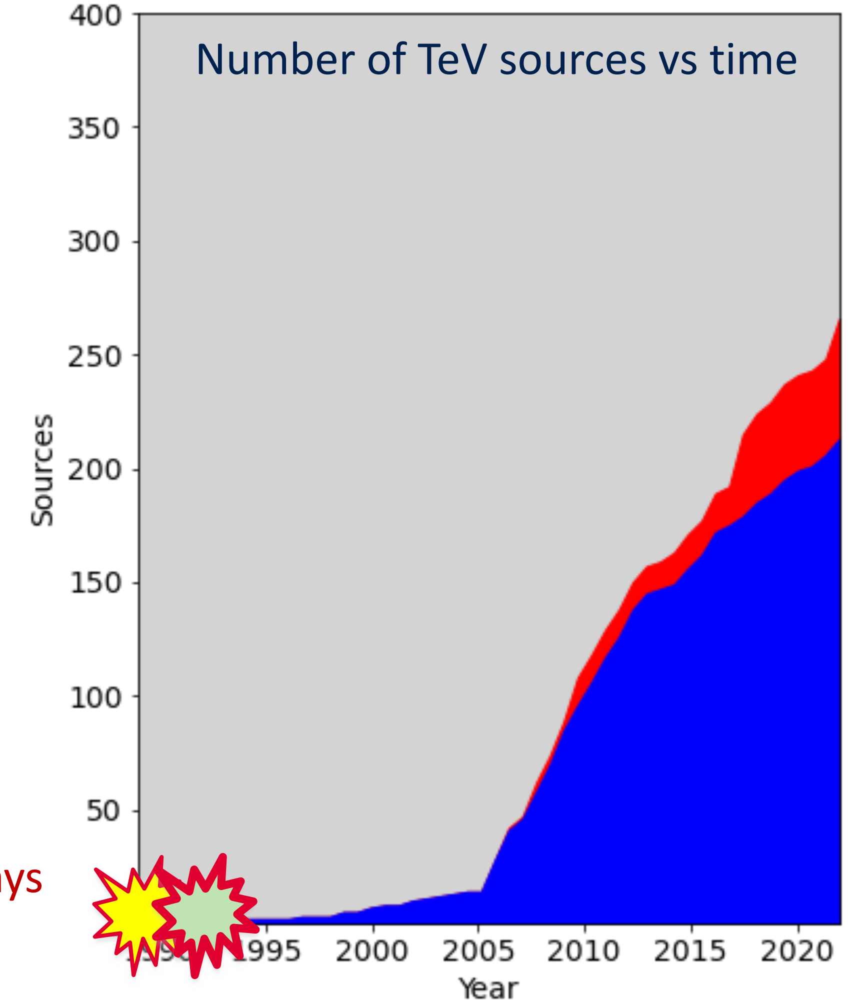
Spectral signature
known from particle physics

Annihilation
cross section
"known" from
Dark Matter
abundance



A. Montanari et al, PoS (ICRC2021)511

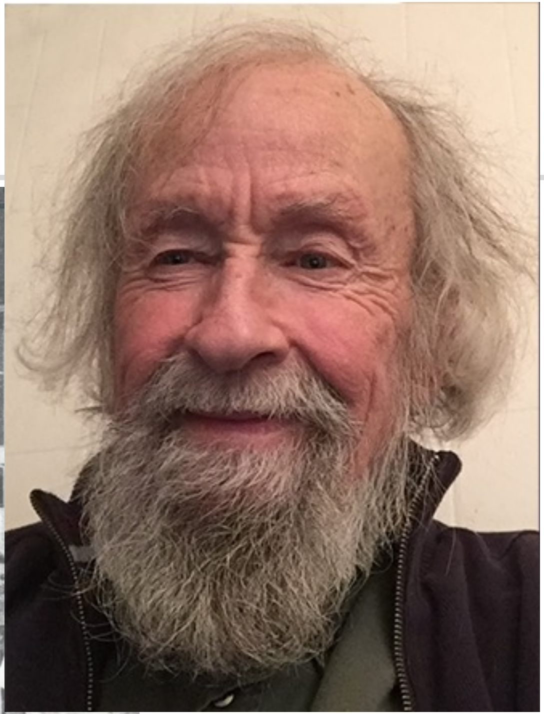
A BIT MORE HISTORY



1989:
Discovery of TeV gamma rays from the Crab Nebula

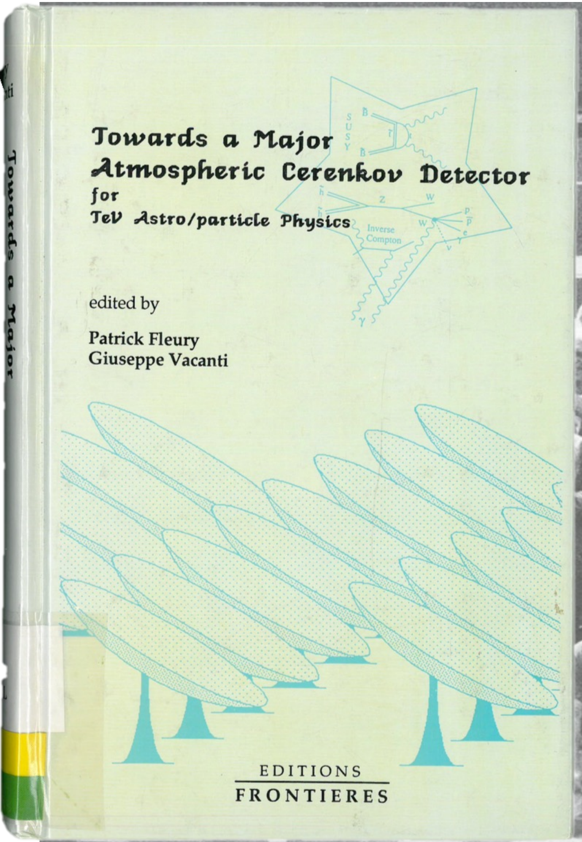
THE 1992 PALAISEAU WORKSHOP

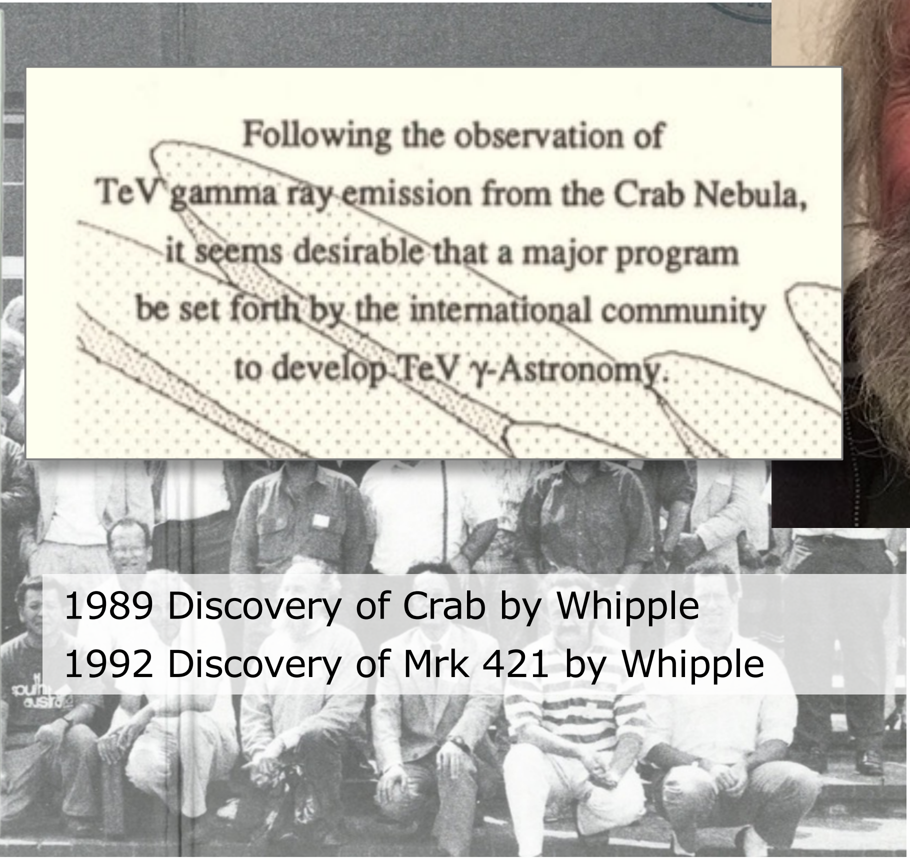
organized by Patrick Fleury and Guiseppe Vacanti

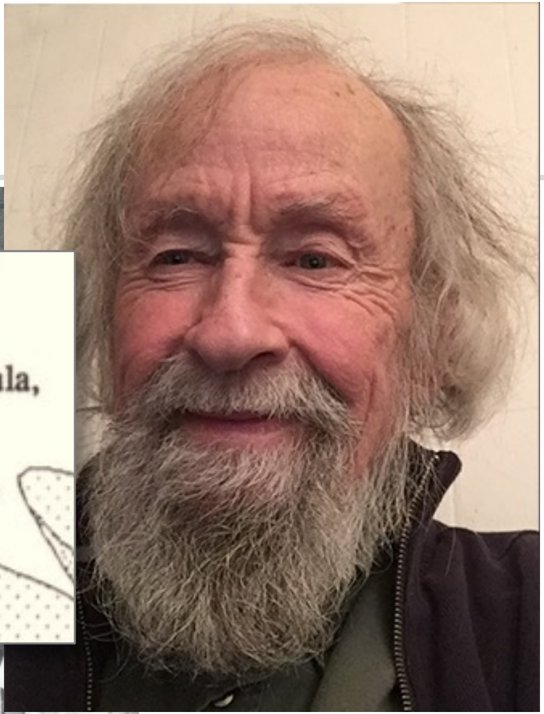


THE 1992 PALAISEAU WORKSHOP

organized by Patrick Fleury and Guiseppe Vacanti

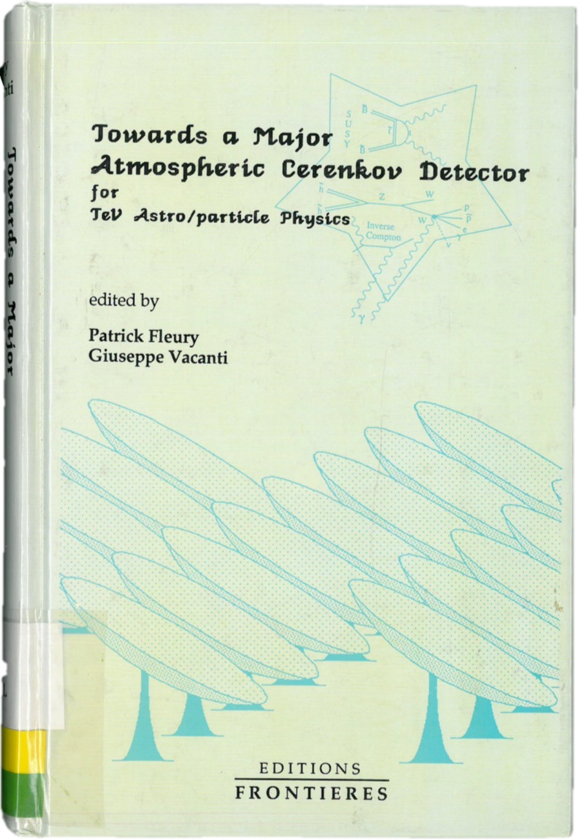


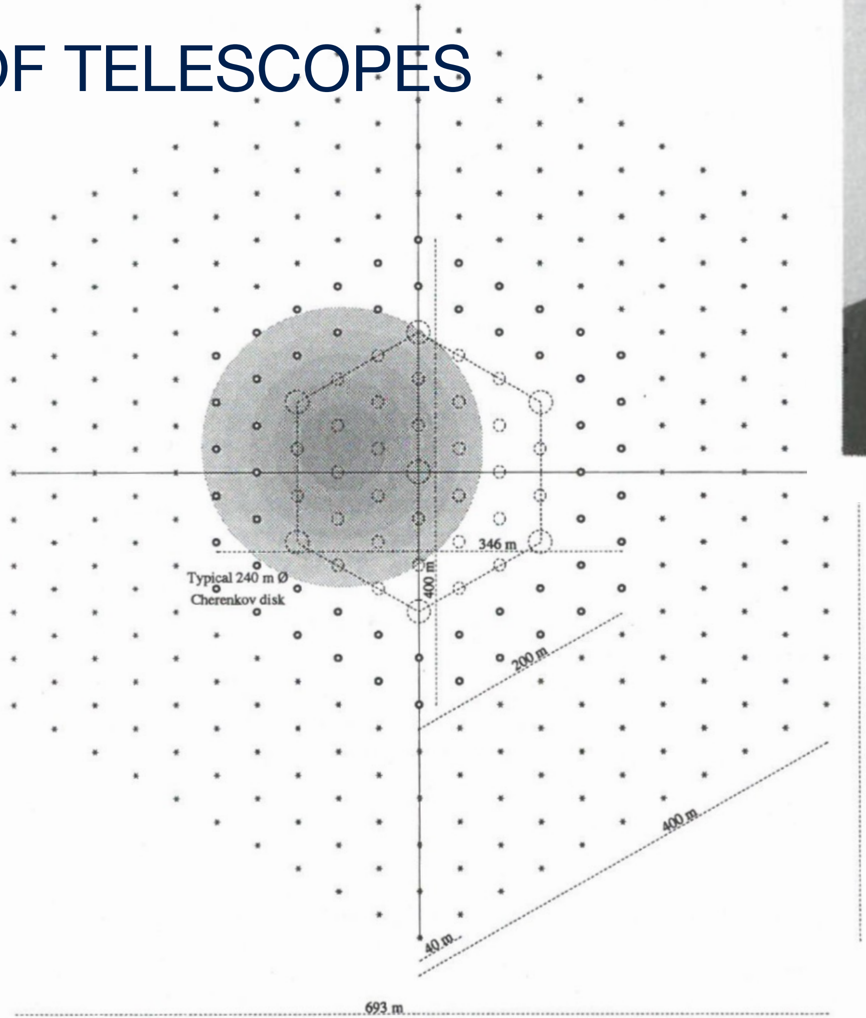

Following the observation of TeV gamma ray emission from the Crab Nebula, it seems desirable that a major program be set forth by the international community to develop TeV γ-Astronomy.



1989 Discovery of Crab by Whipple
1992 Discovery of Mrk 421 by Whipple

LARGE ARRAYS OF TELESCOPES

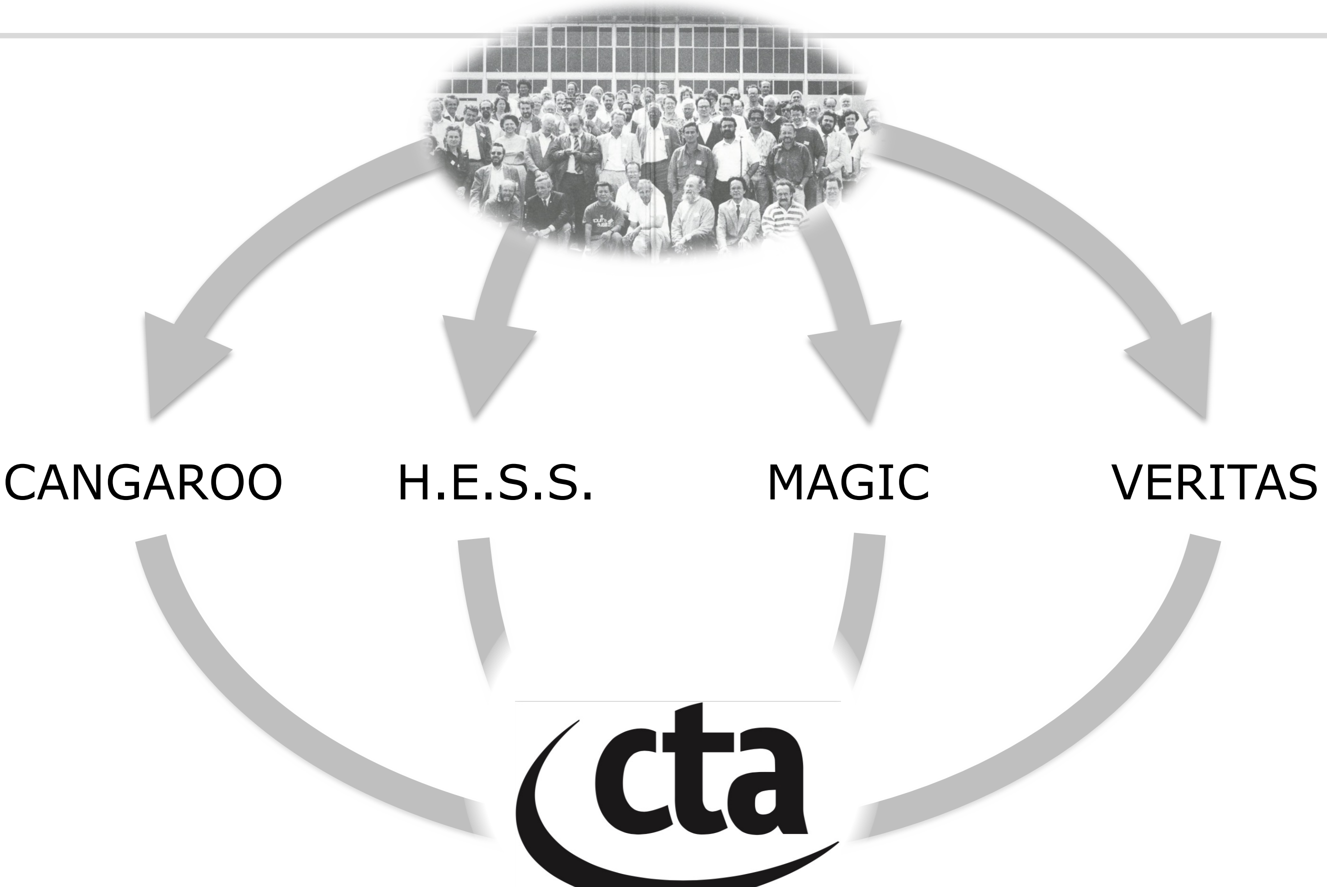




AFTER PALAISEAU & FOLLOW-UP WORKSHOPS

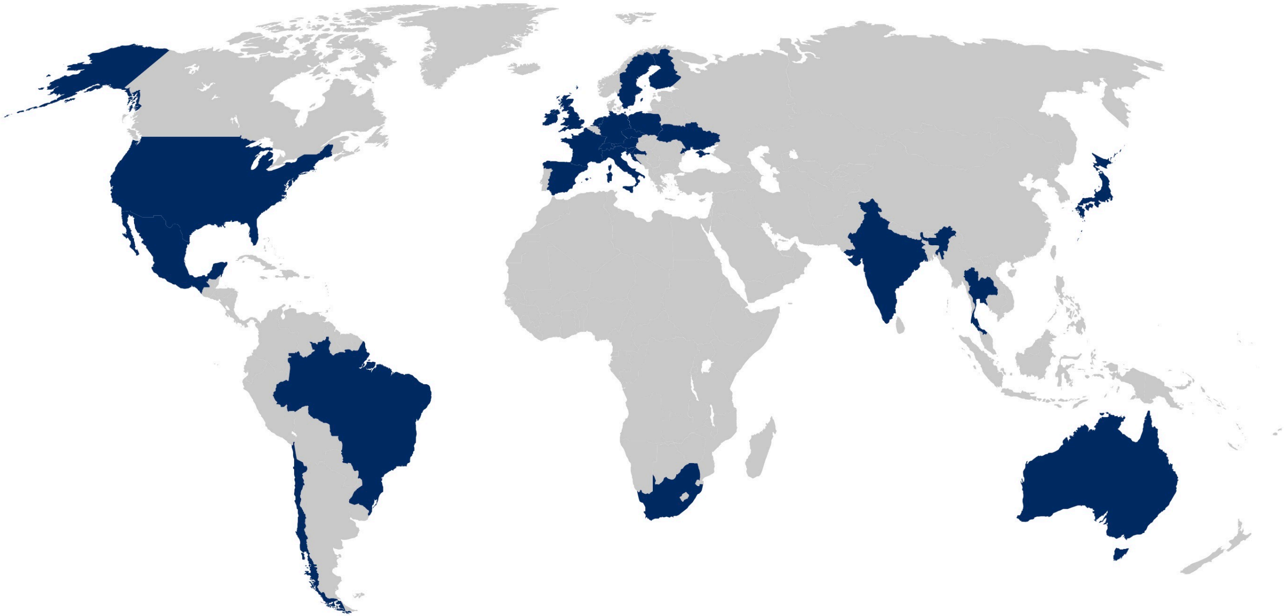
CANGAROO H.E.S.S. MAGIC VERITAS

... BUT WE FINALLY GOT IT RIGHT!




THE CHERENKOV
TELESCOPE ARRAY

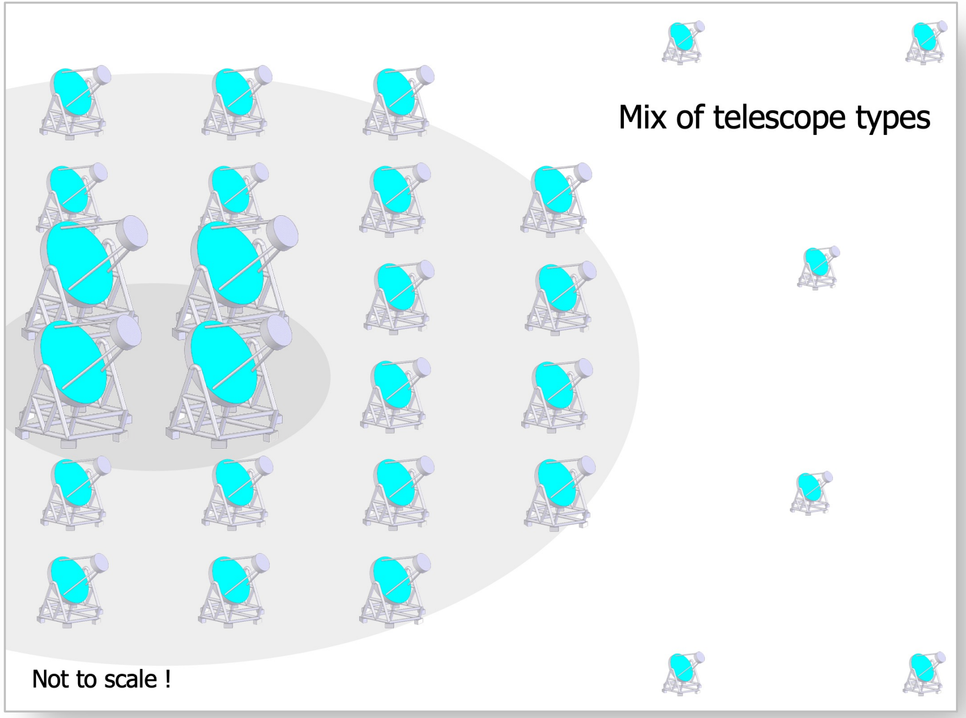
THE CTA CONSORTIUM

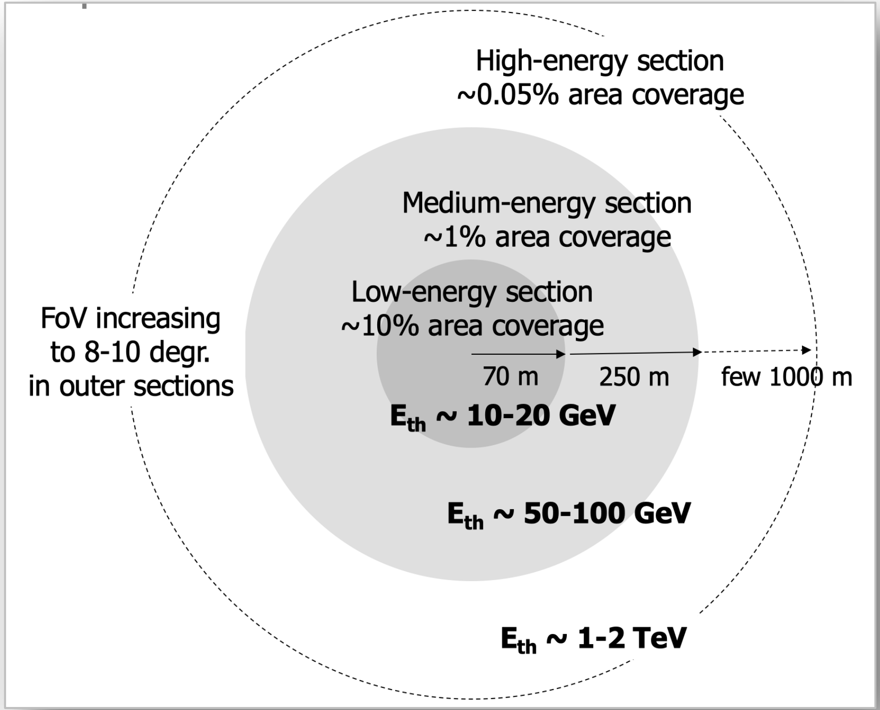


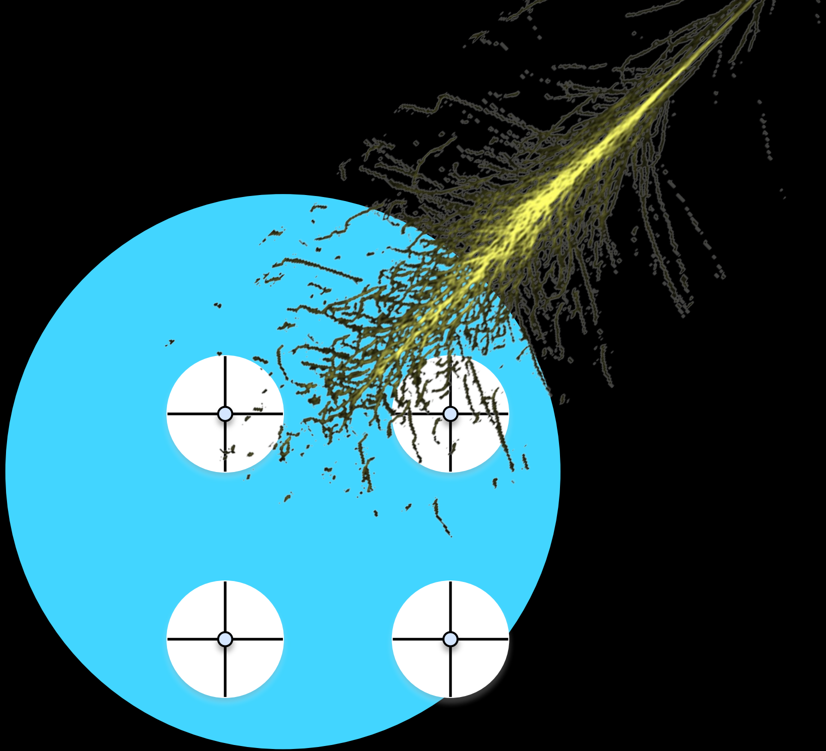
25 Countries
over 150 Institutes
about 1500 Members

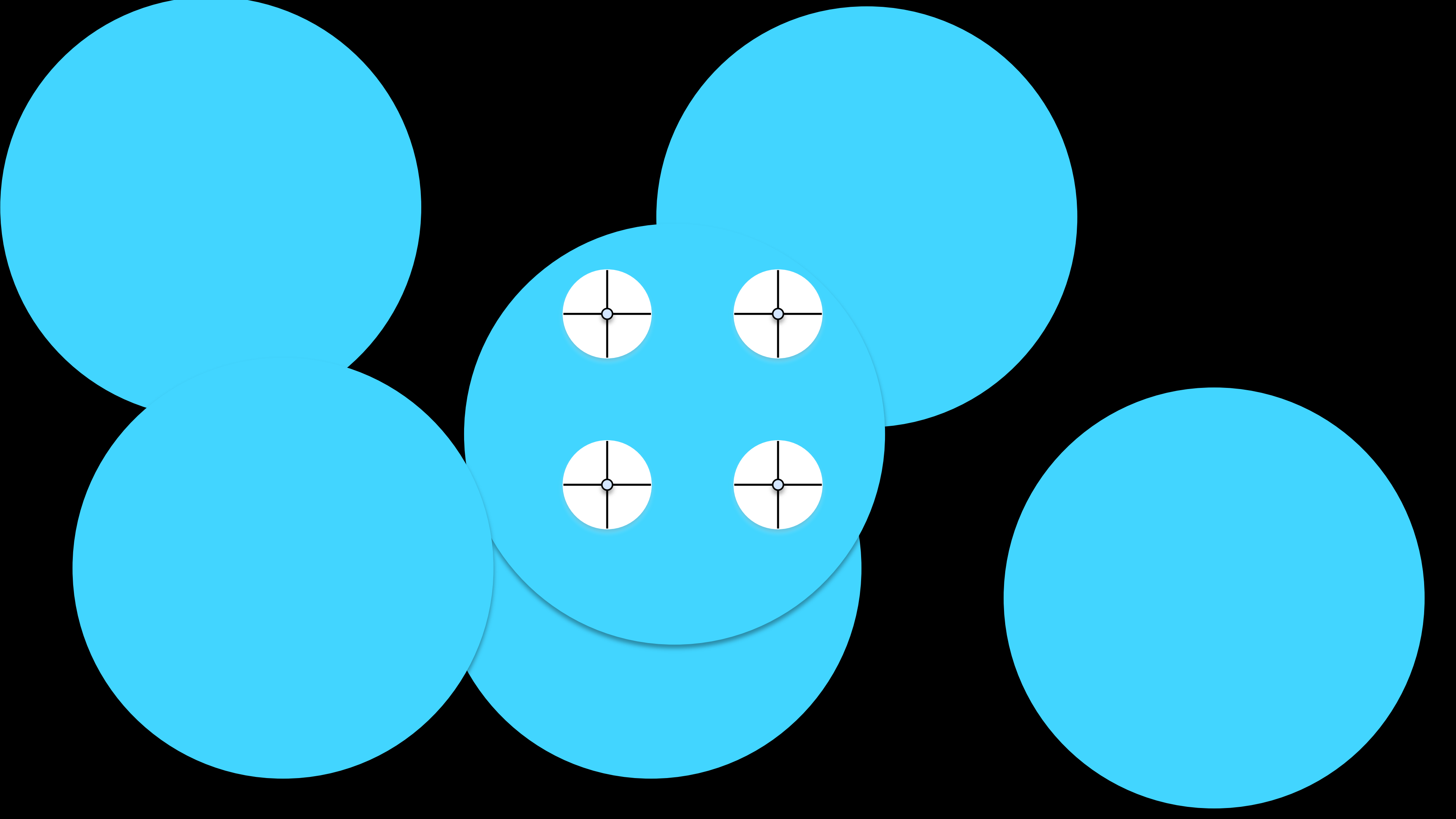
Effort started in 2006

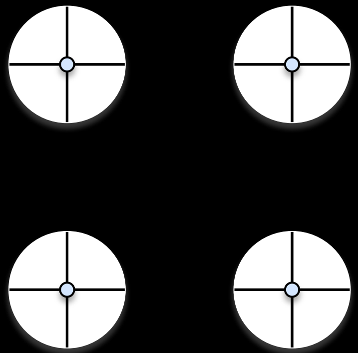
MARCH 8, 2006, ESFRI BRUSSELS

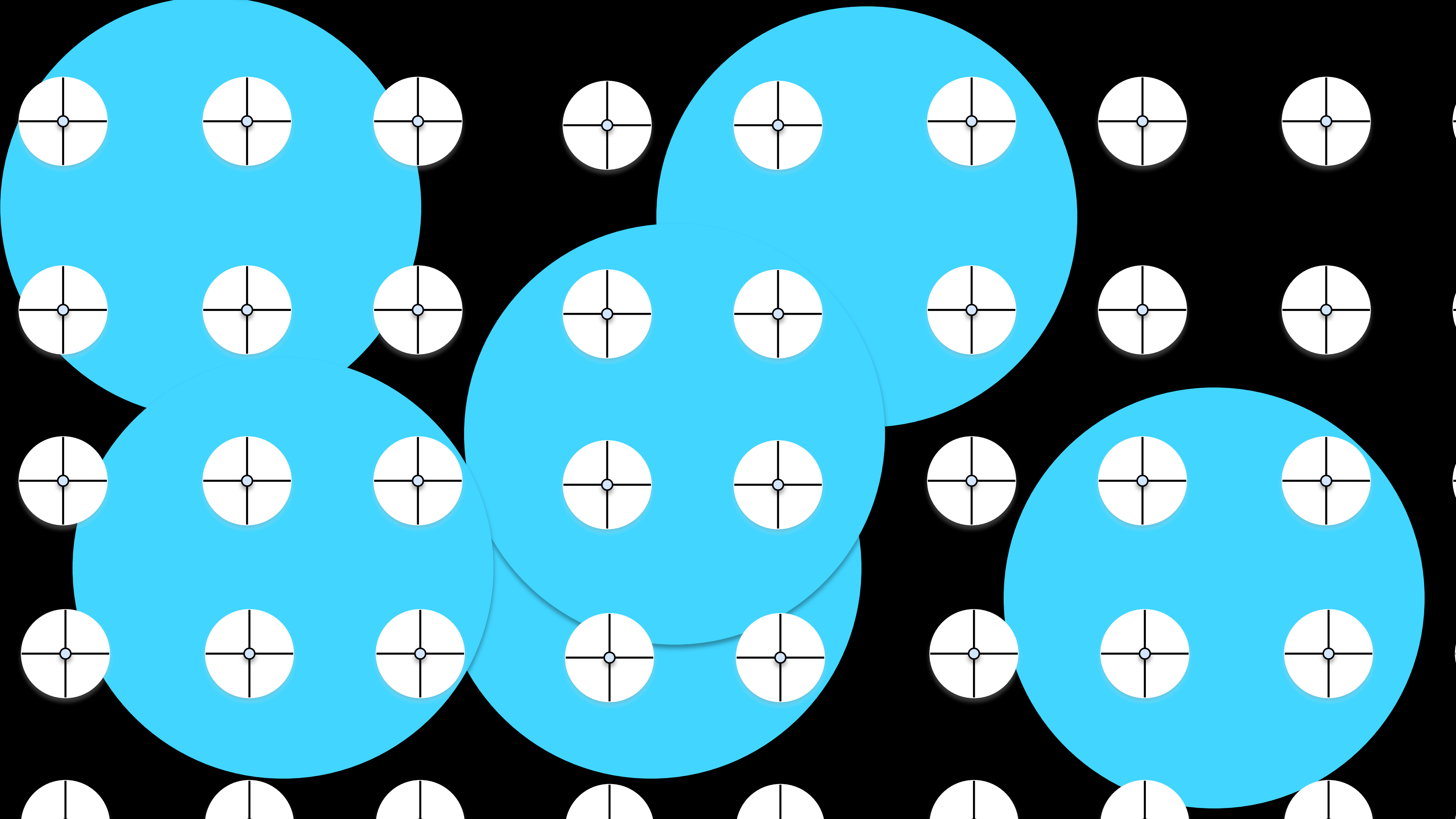




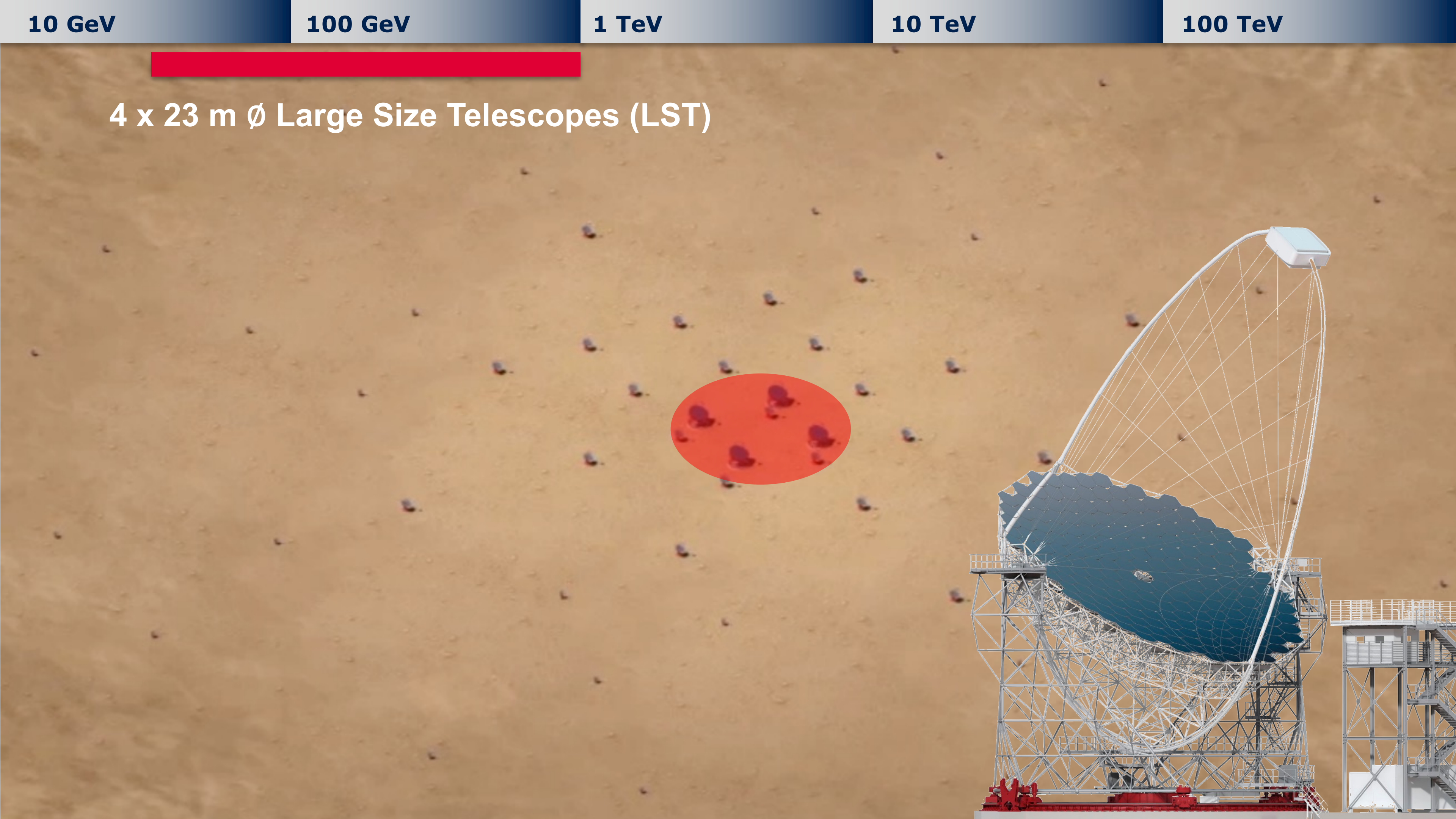








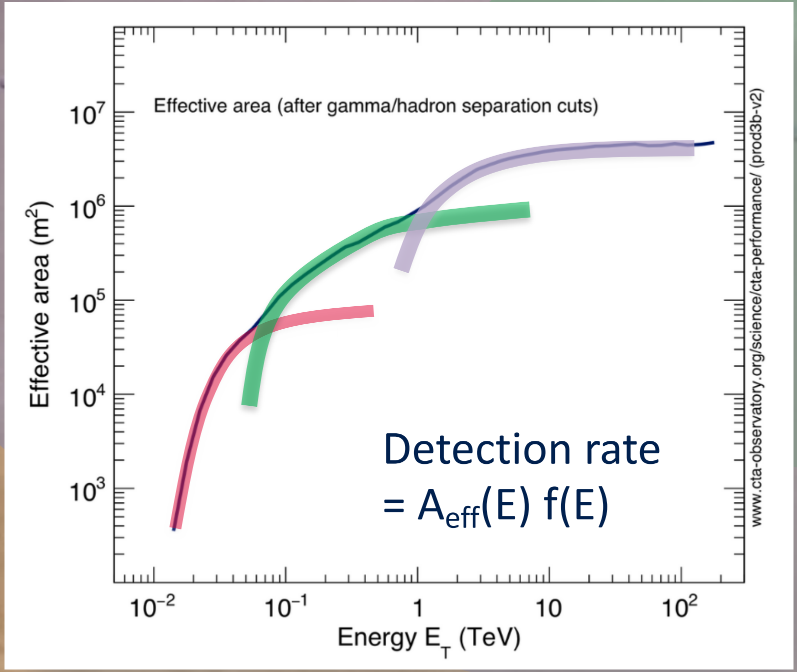
10 GeV | 100 GeV | 1 TeV | 10 TeV | 100 TeV


10 GeV
100 GeV
1 TeV
10 TeV
100 TeV
4 x 23 m Ø Large Size Telescopes (LST)


10 GeV
100 GeV
1 TeV
10 TeV
100 TeV
25 x 12 m ø Medium Size Telescopes (MST)
(North: 15)

10 GeV | 100 GeV | 1 TeV | 10 TeV | 100 TeV

70 x 4 m ø Small Size Telescopes (SST) (South)



Detection rate
$= A_{eff}(E)\ f(E)$

Compared to current instruments
up to 400 x increased survey speed

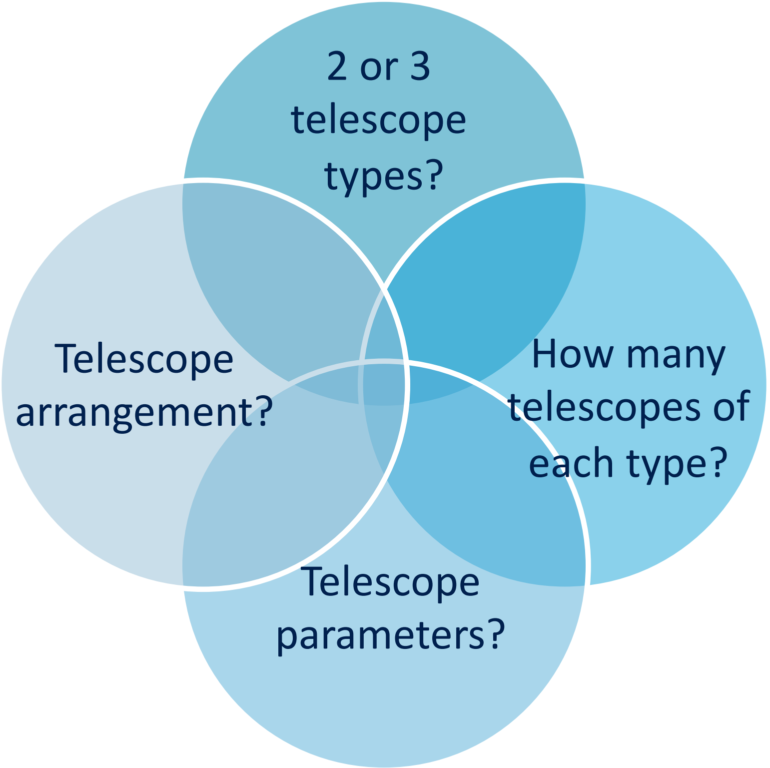
OPTIMIZING THE CTA ARRAYS

K. Bernlöhr et al., Astropart. Phys. 43 (2013) 171

T. Hassan et al., Astropart. Phys. 93 (2017) 76

A. Acharyya et al., arXiv 1904.01426 (2019)

Questions



Approach

- Experience, analytical models & cost models
- Square grids of telescopes
- Plausible array layouts
- Freeze telescope numbers and parameters
- Optimize and fine-tune layout (at % level)

Simulations using tens of millions CPU-h

OPTIMIZING THE CTA ARRAYS

K. Bernlöhr et al., Astropart. Phys. 43 (2013) 171

T. Hassan et al., Astropart. Phys. 93 (2017) 76

A. Acharyya et al., arXiv 1904.01426 (2019)

Questions

2
tele
ty

Telescope arrangement?

Tele
para

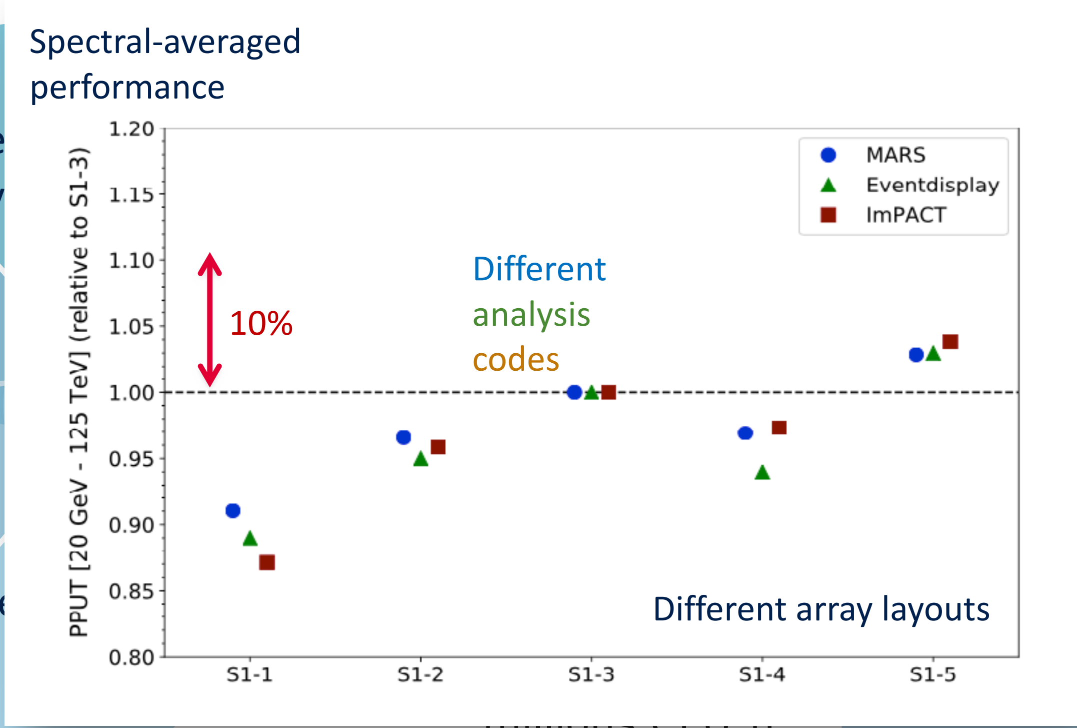
Approach

copes

outs

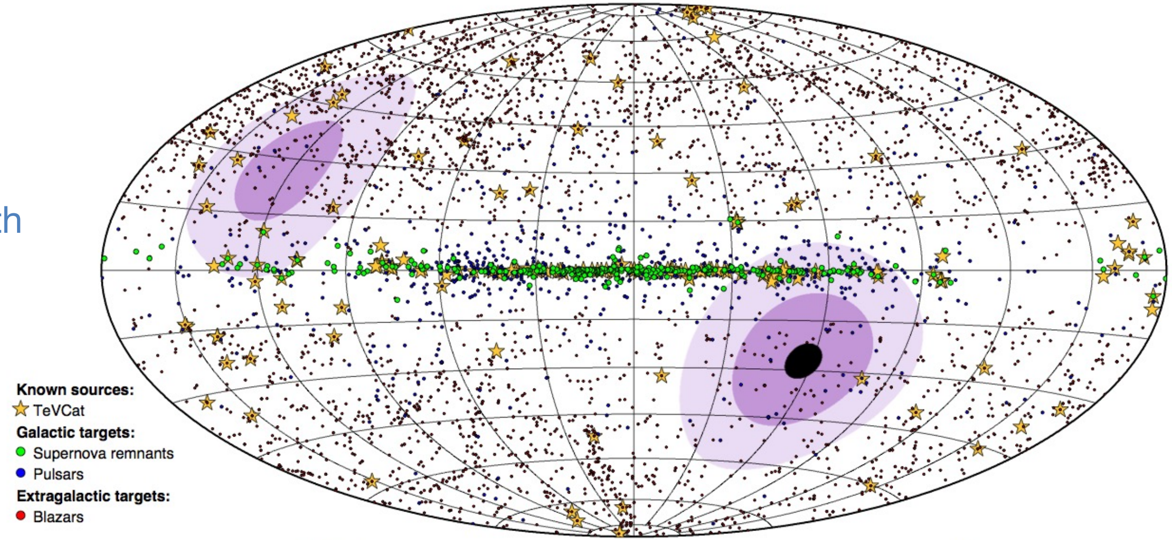
e numbers
s

d fine-tune layout (at % level)



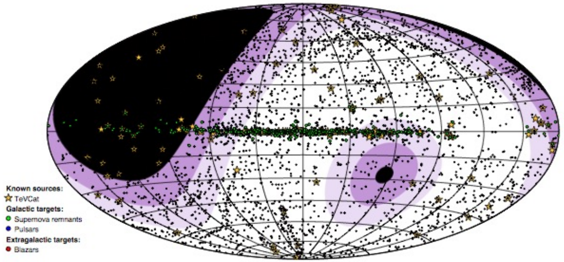
DESIGN DRIVER: FULL-SKY COVERAGE

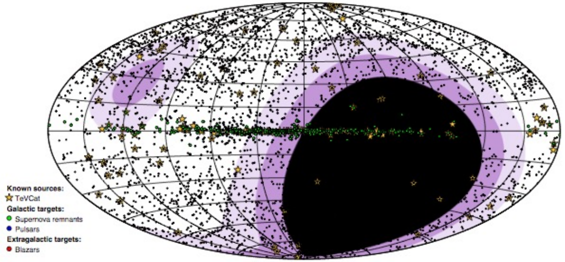
North+South



>60° zenith
45°-60°
30°-45°

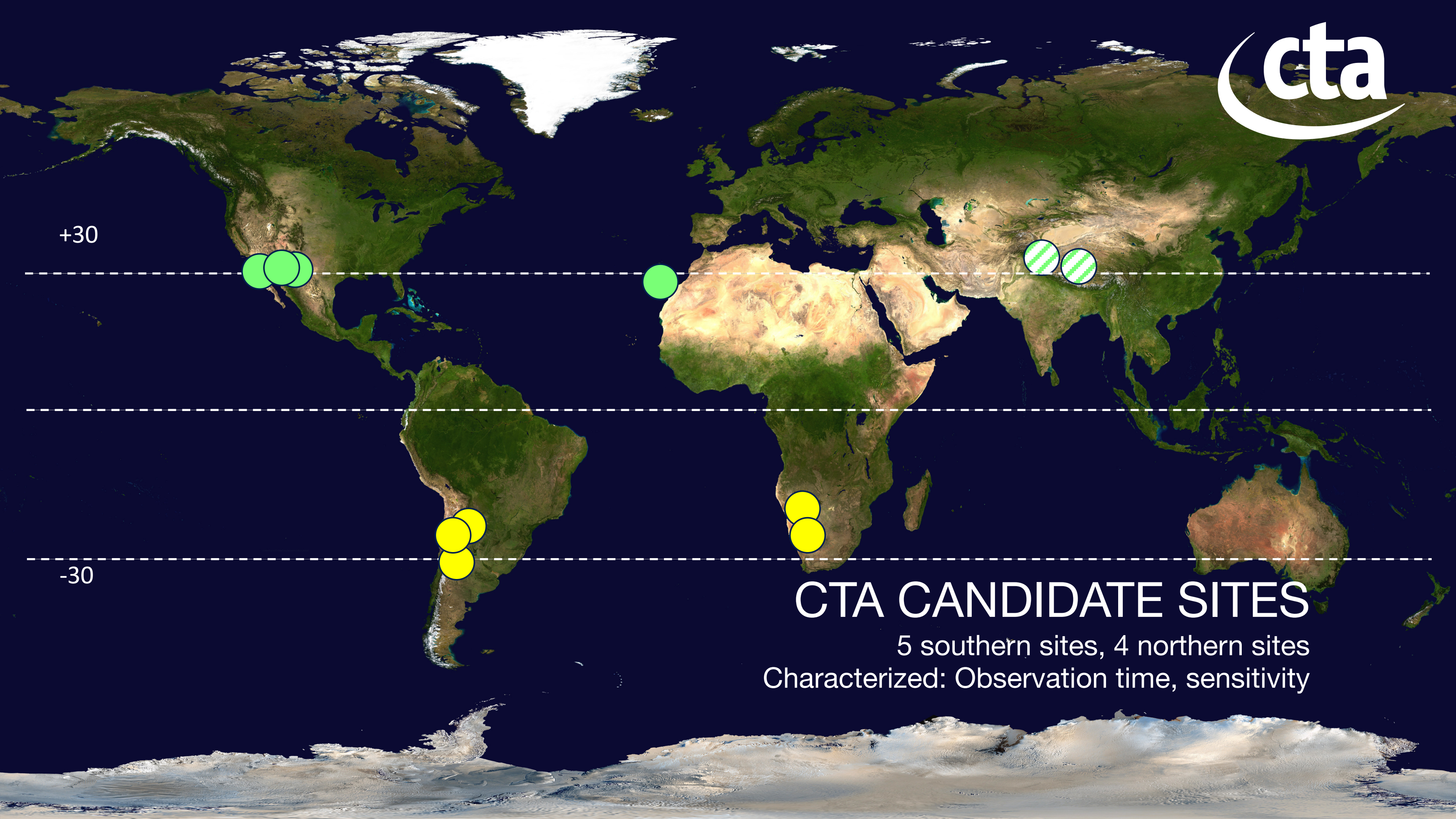
South



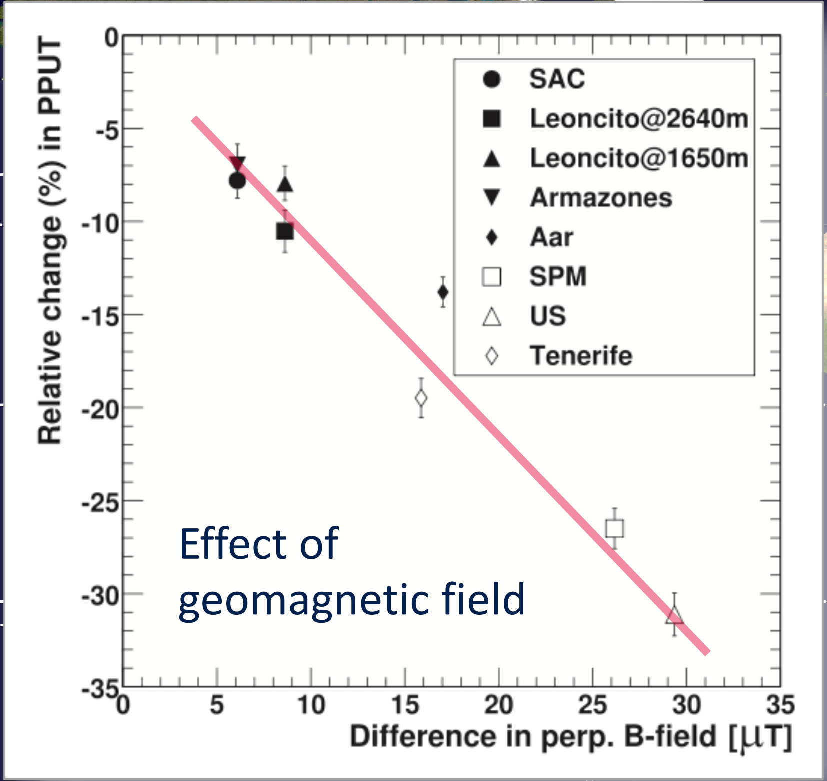


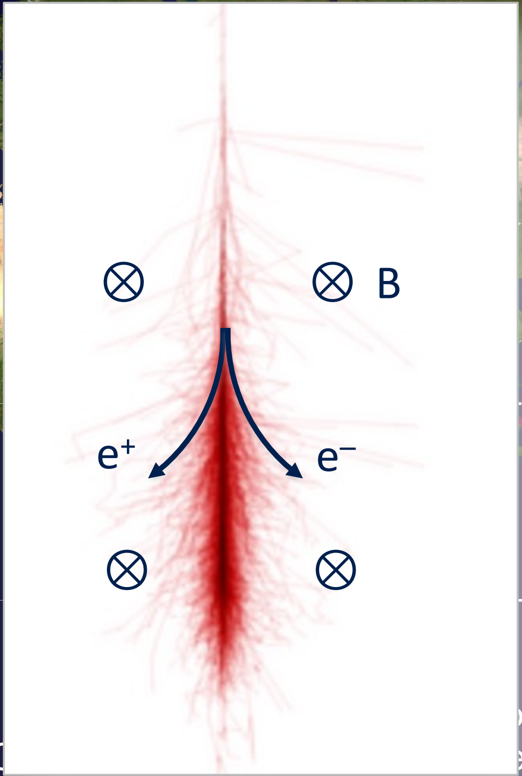
North


CTA Site Selection
2008 - 2018


cta
+30
-30
CTA CANDIDATE SITES
5 southern sites, 4 northern sites
Characterized: Observation time, sensitivity

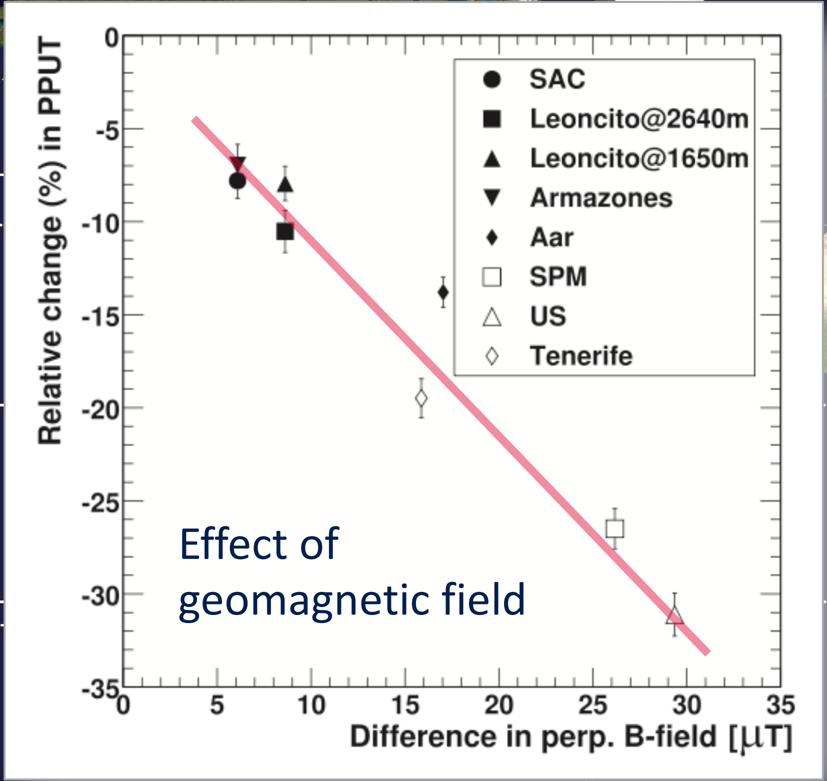
PPUT = Spectral-averaged performance

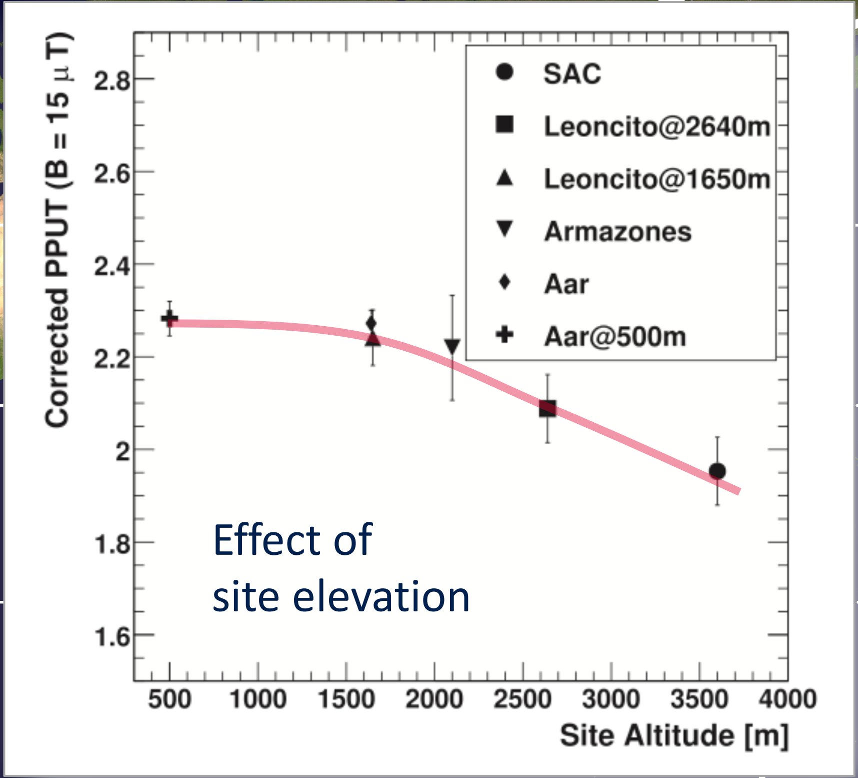




T. Hassan et al.,Astroparticle Physics 93 (2017) 76–85

SITES
...rthern sites
C... ...e, sensitivity



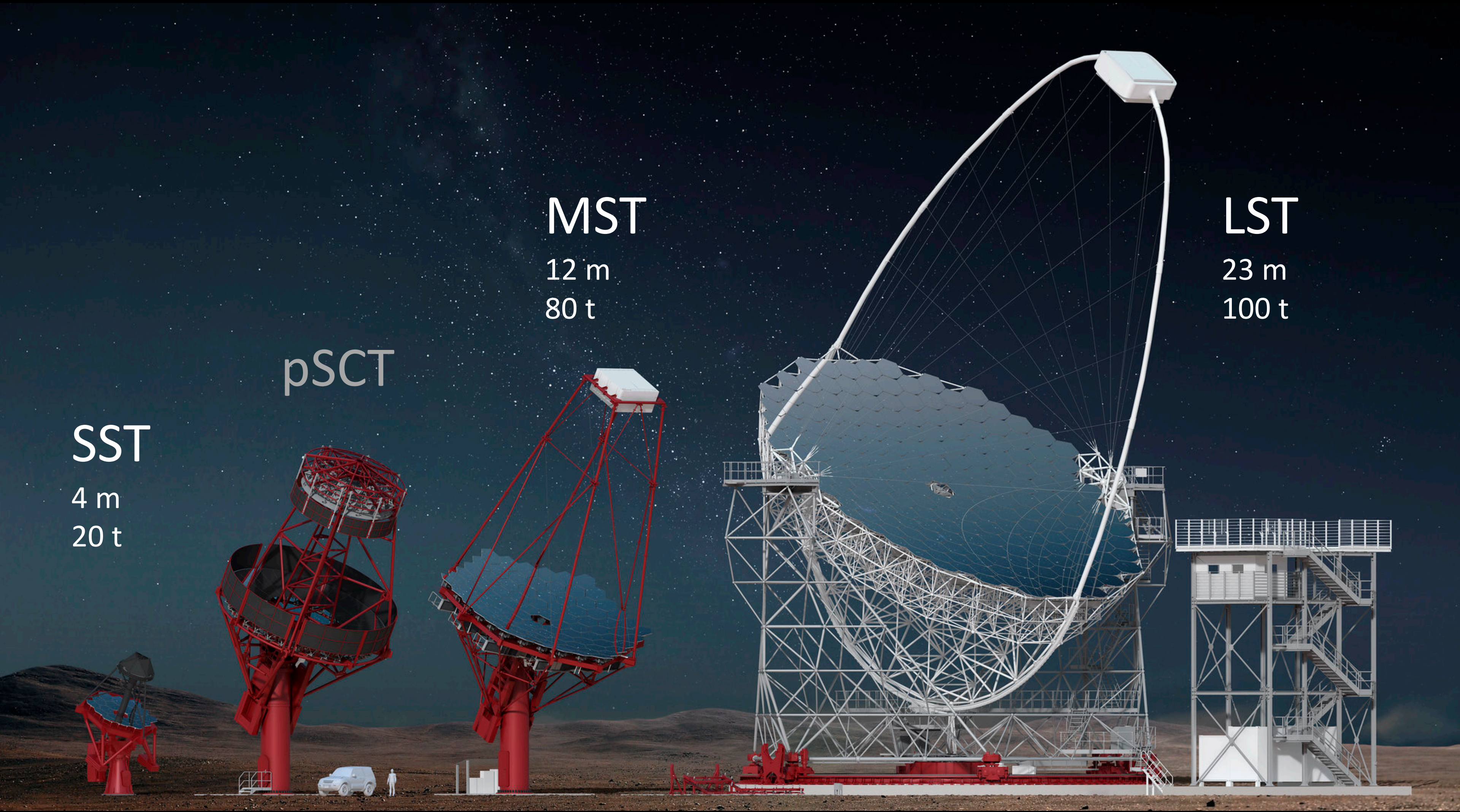


T. Hassan et al.,Astroparticle Physics 93 (2017) 76–85


CTA ARRAY SITES
CTA North
ORM La Palma, Spain
CTA South
ESO, Chile

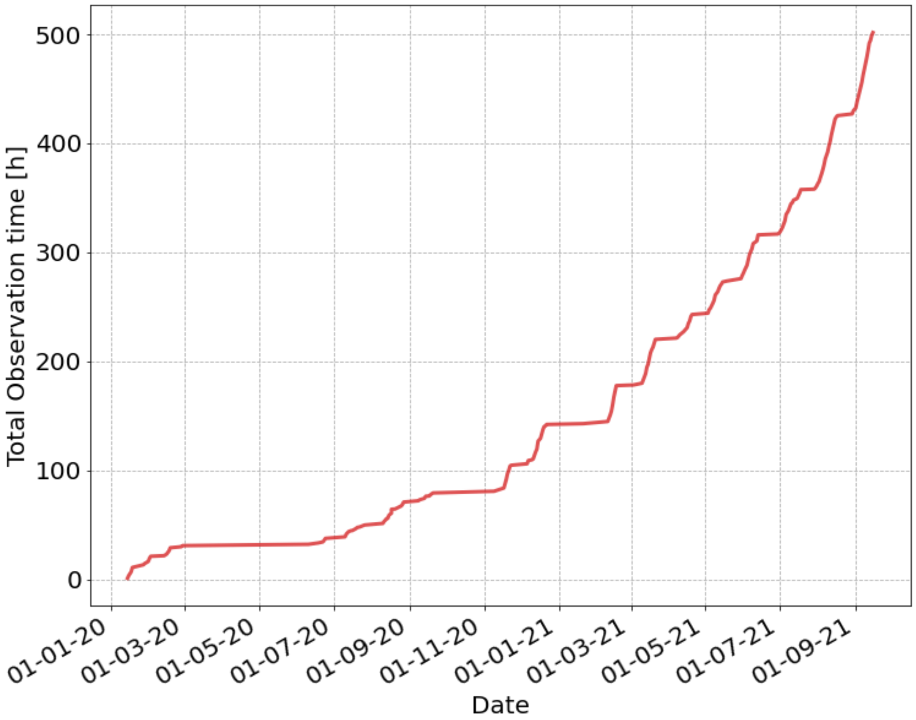

CTA-South Site
ESO Paranal
Vulcano Llullaillaco
6739 m, 190 km east
Cerro Armazones
E-ELT
Cherenkov Telescope Array Site
Cerro Paranal
Very Large Telescope

CTA TELESCOPES & CTA CONSTRUCTION


SST
4 m
20 t
pSCT
MST
12 m
80 t
LST
23 m
100 t

	Large-Sized Telescope (LST)	Medium-Sized Telescope (MST)			Small-Sized Telescope (SST)
		FlashCam	NectarCam	SCT	
Energy range (in which subsystem provides full system sensitivity)	20 GeV – 150 GeV	150 GeV – 5 TeV			5 TeV – 300 TeV
Number of telescopes (alpha configuration)	0 (South) 4 (North)	14 (South)	9 (North)		37 (South) 0 (North)
Optical design	Parabolic	Modified Davies-Cotton		**Schwarzschild- Couder**	**Schwarzschild - Couder**
Primary reflector diameter	23.0 m	11.5 m		9.7 m	4.3 m
Secondary reflector diameter	--	--		5.4 m	1.8 m
Effective mirror area (including shadowing)	370 m^2	88 m^2		41 m^2	>5 m^2
Total weight	114 t	82 t		80 t	17.5 t
Field of view	4.3 deg	**7.7 deg**	**7.9 deg**	**7.6 deg**	**8.8 deg**
Number of pixels in Cherenkov camera	**1855**	**1758**	**1855**	**11328**	**2048**
Pixel size (imaging)	0.1 deg	0.18 deg	0.18 deg	**0.067 deg**	0.16 deg
Photodetector type	**High-QE PMT**	**HIGH-QE PMT**	**High-QE PMT**	**SiPM**	**SiPM**
Telescope readout event rate (before array trigger for MSTs and SSTs)	**>7.0 kHz**	**>6 kHz**	**>7.0 kHz**	**>3.5 kHz**	>0.6 kHz
Availability	**>95%**	**>97%**			**>97%**
Positioning time to any point in the sky (>30° elevation)	**20 s**	90 s			90 s

LST1 COMMISSIONING



Data taken January 2020 – September 2021: >500h

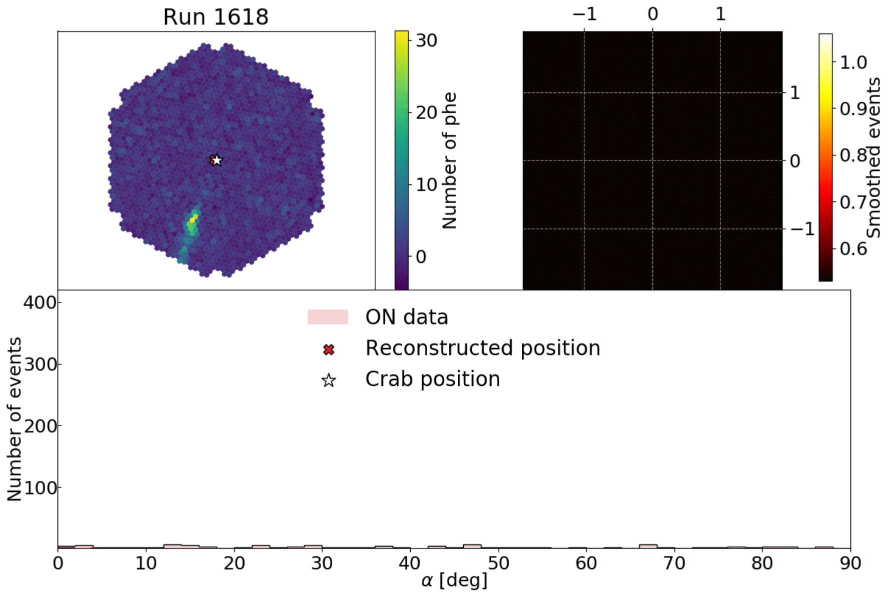
LARGE-SIZED TELESCOPE

PoS(ICRC2021)806

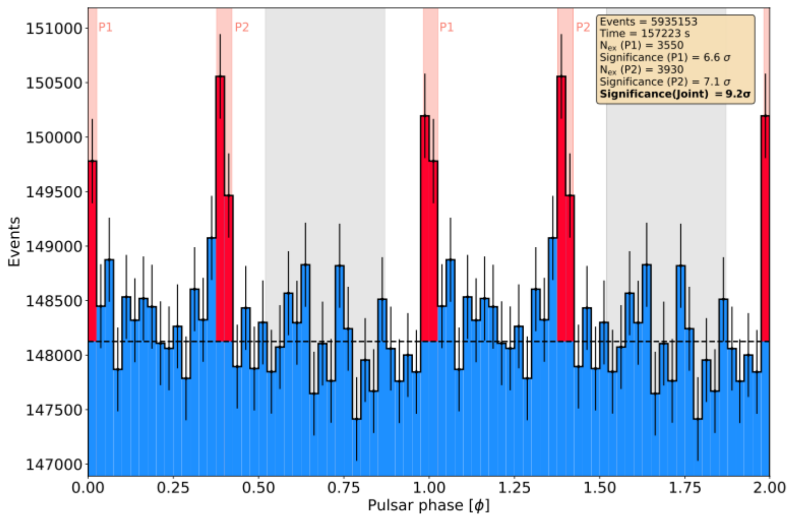
LST 1 inauguration in Oct. 2018
Commissioning & science verification

AGN Detections: Mrk 501, Mrk 421, 1ES 1959+650, 1ES 0647+250 and PG 1553+113

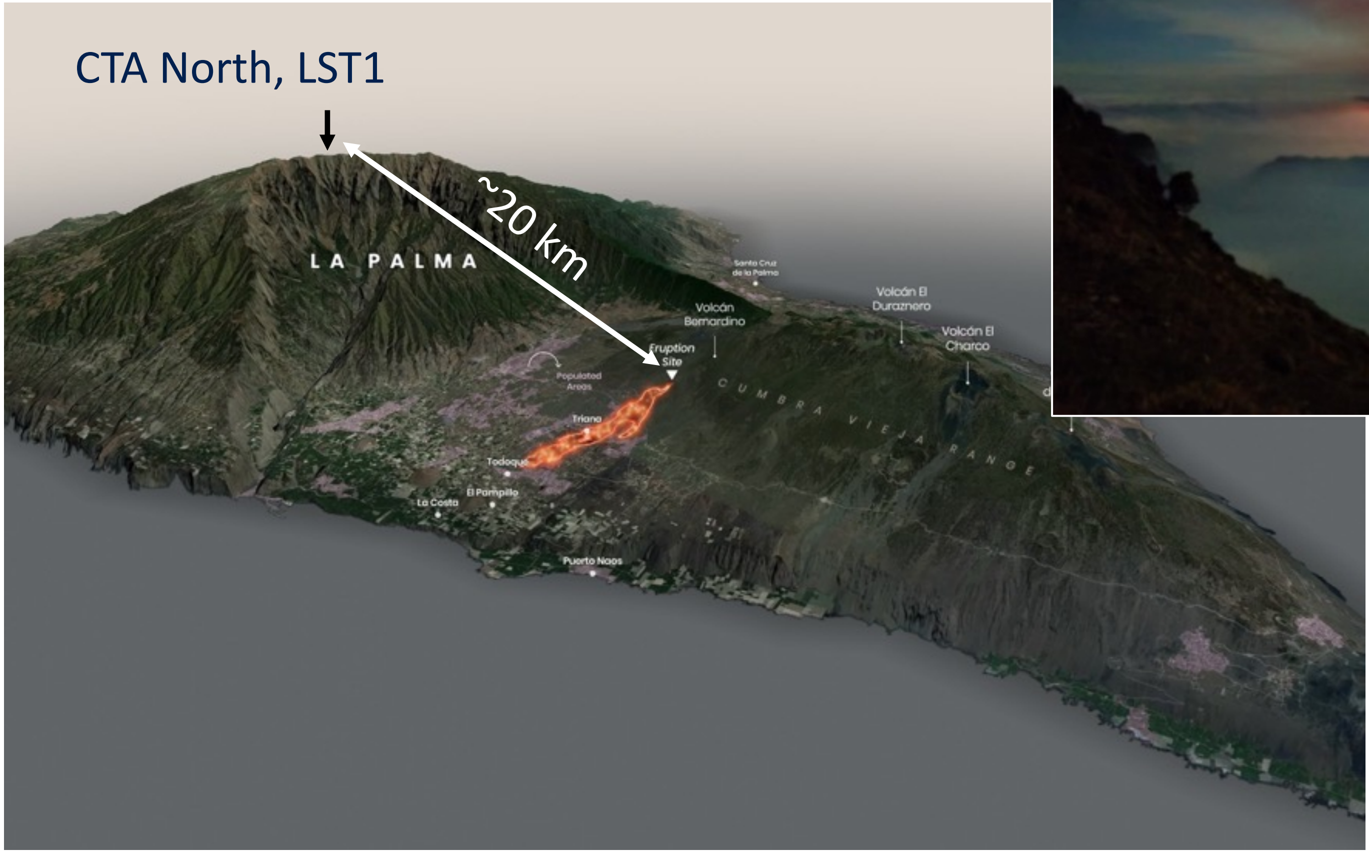
Nov. 2019: Detection of Crab Nebula



June 2020: Detection of Crab Pulsar



… UNTIL …



Lots of ashes, fortunately no permanent damage

LST2-4 IN PRODUCTION

MEDIUM-SIZED TELESCOPE

Prototype operated in Berlin-Adlershof for several years

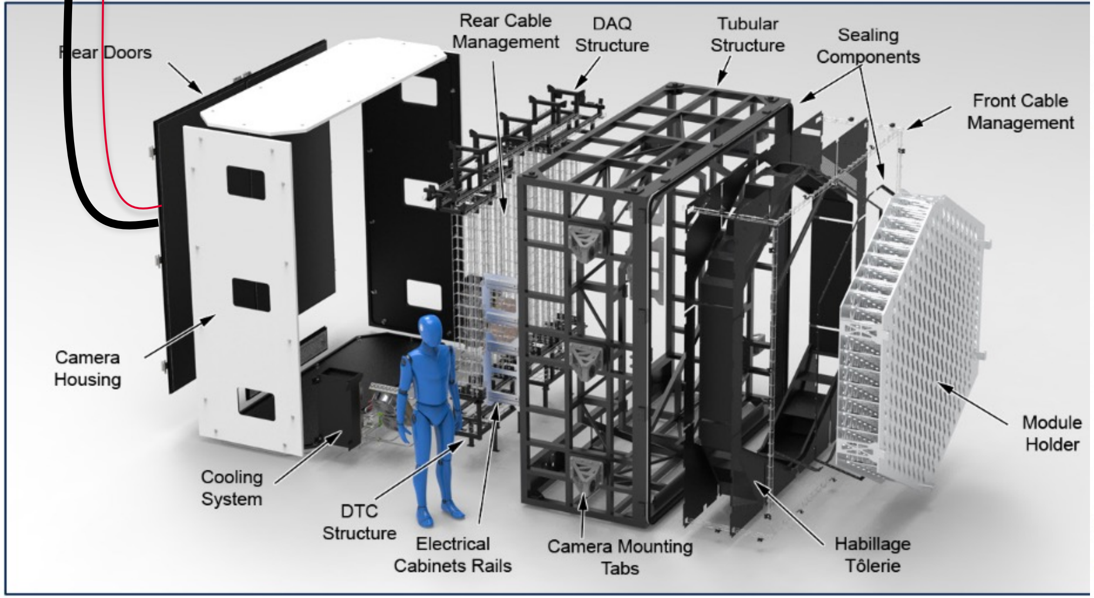
Two cameras:
NectarCAM (North) and **FlashCam** (South)

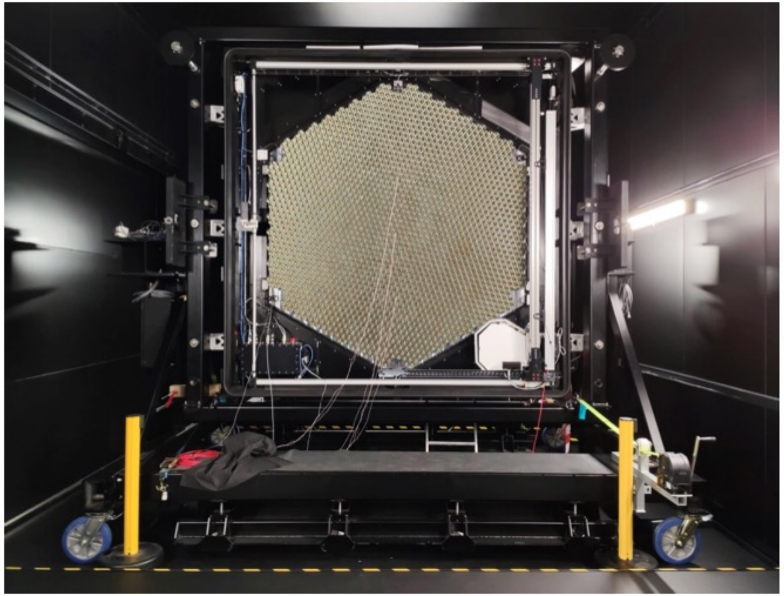
NectarCAM: NECTAr GHz analog memory ring sampler ASIC

FlashCam: commercial 250 MHz Flash-ADCs; digital trigger

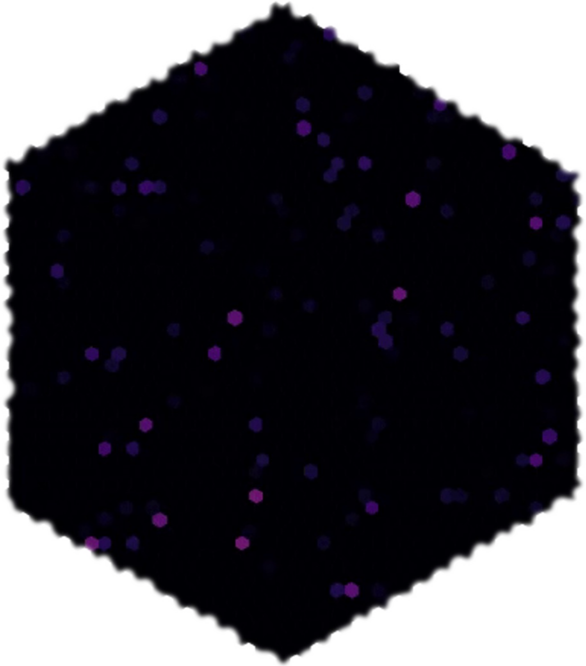
NectarCAM

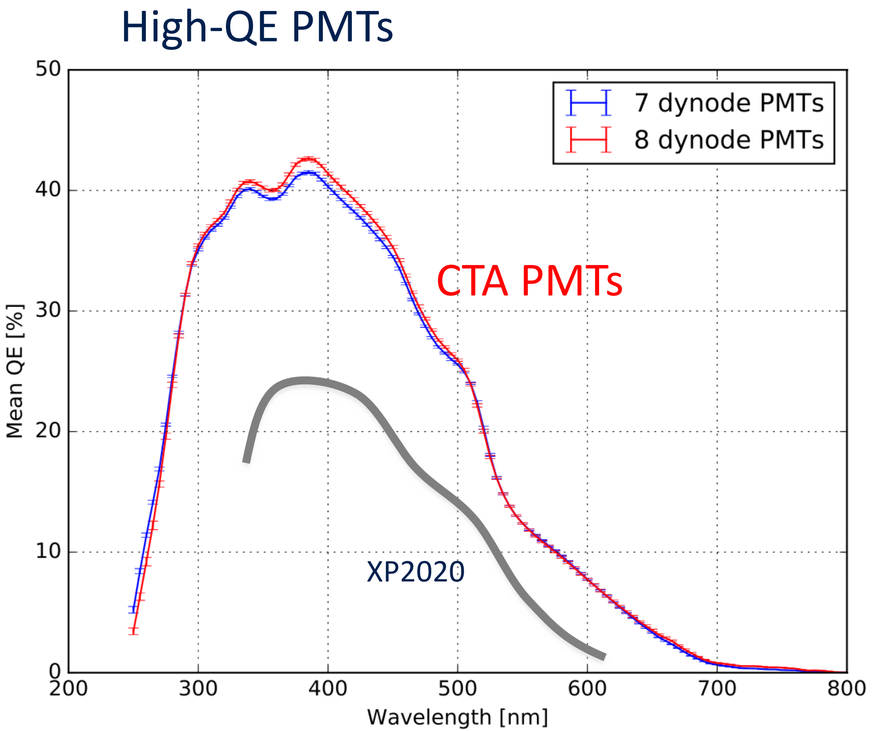
All electronics in camera body
Connection: power & ethernet



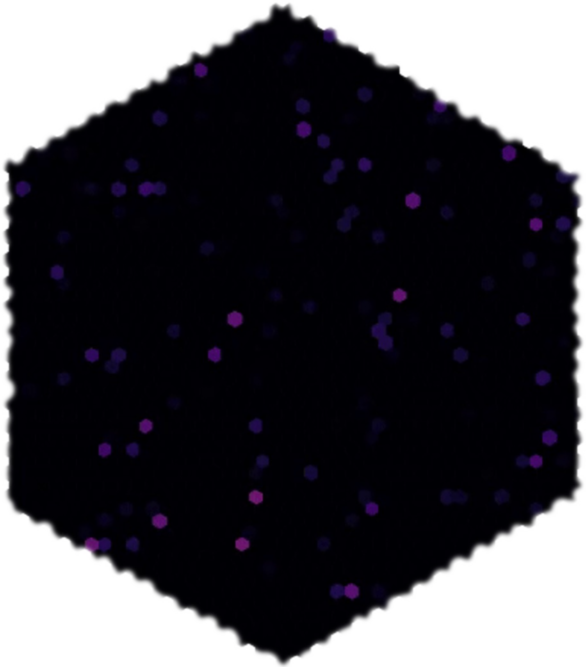


CHERENKOV CAMERA





CHERENKOV CAMERA



2000 Pixels
x 10^9 values per second
x 2 Byte
= 4 TB/s

Trigger processor (analog or digital)

Save certain images

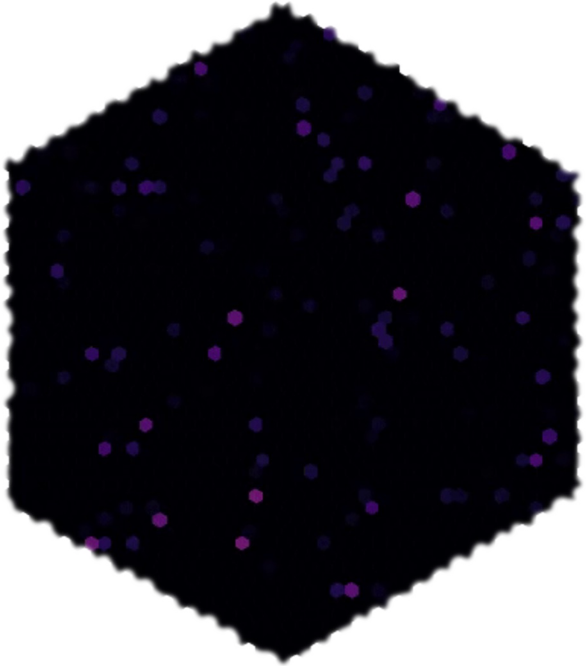
Decision takes some 10-100 ns

save image!

Temporary memory (analog or digital)

few kHz selected images to storage (< GB/s)

CHERENKOV CAMERA



Trigger processor (analog or digital)

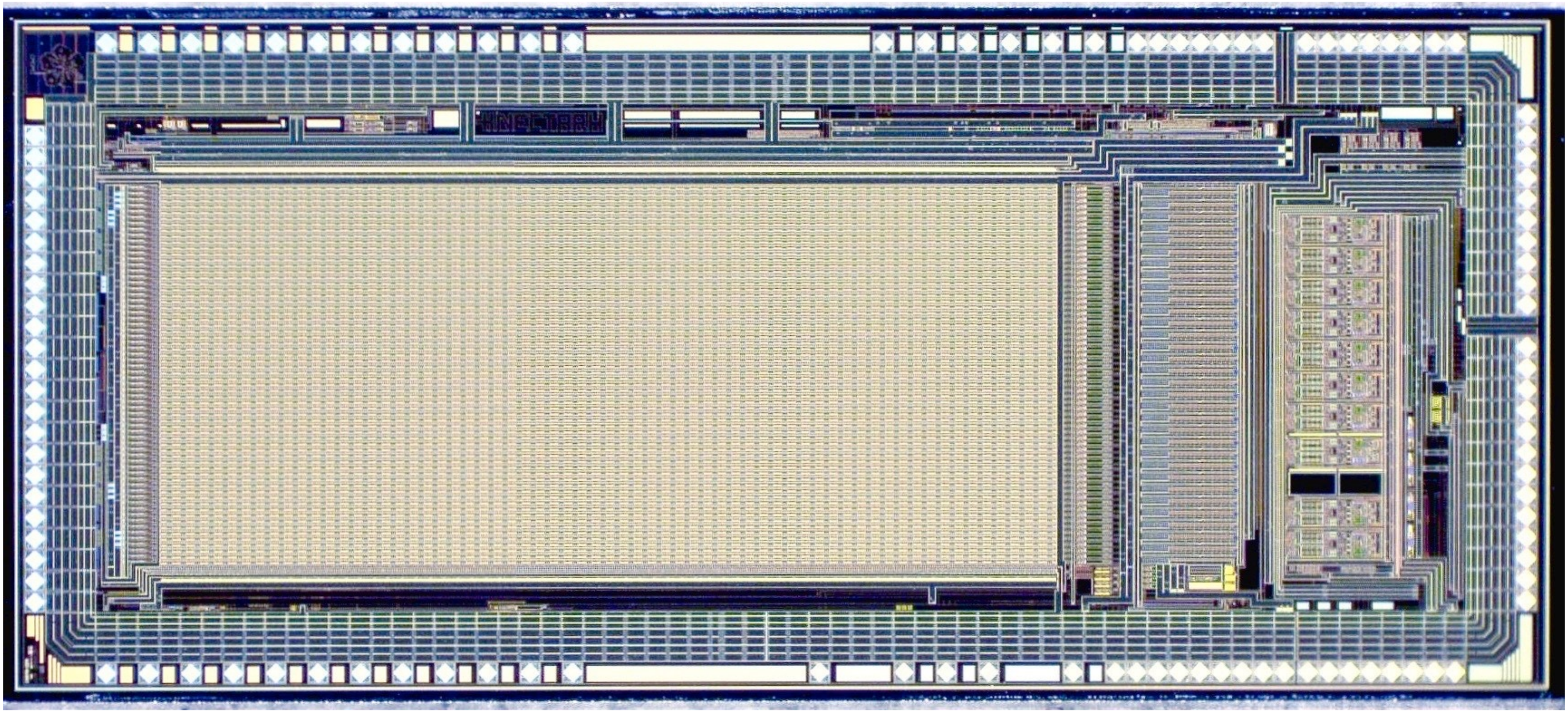
Save certain images

Decision takes some 10-100 ns

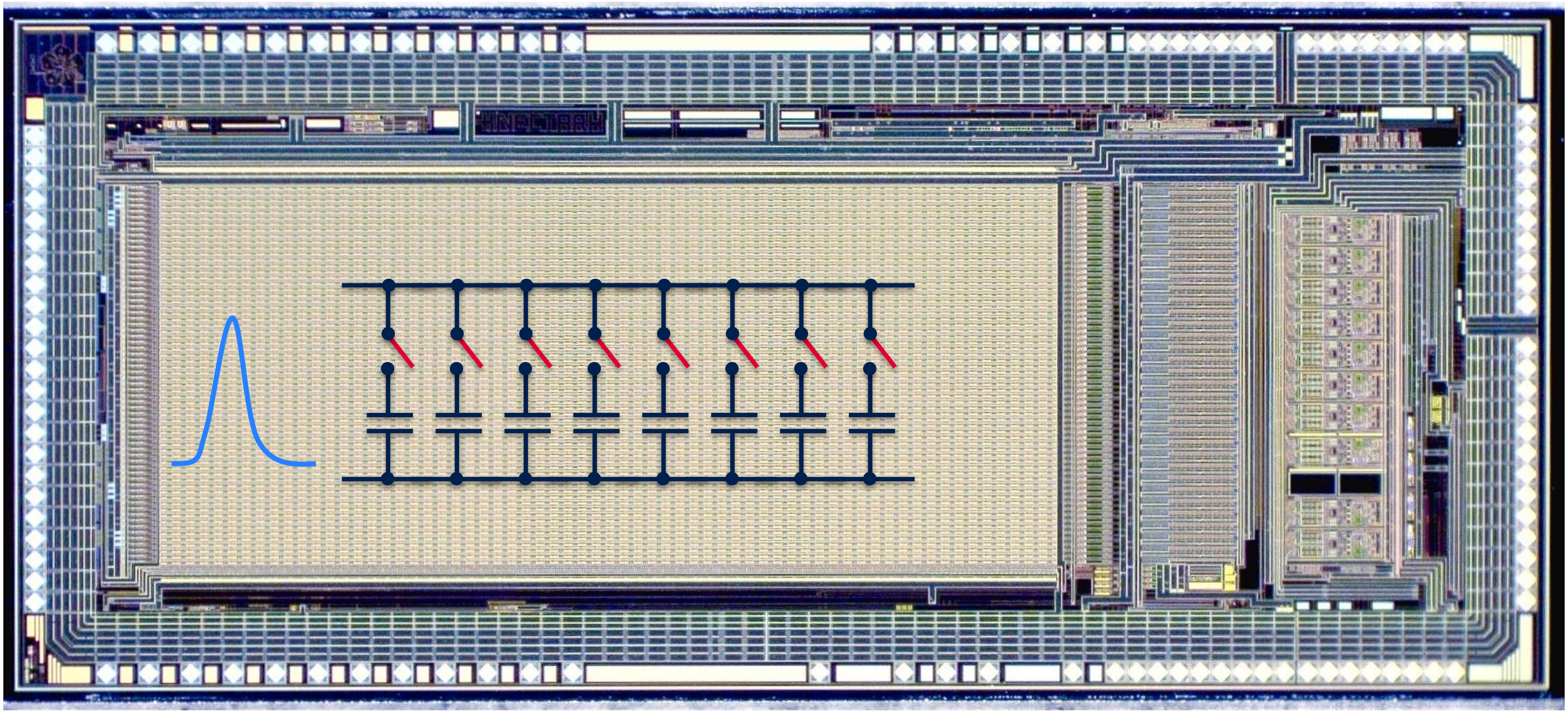
2000 channels
x 10^9 values per second
x 2 Byte
= 4 TB/s

in the
old days

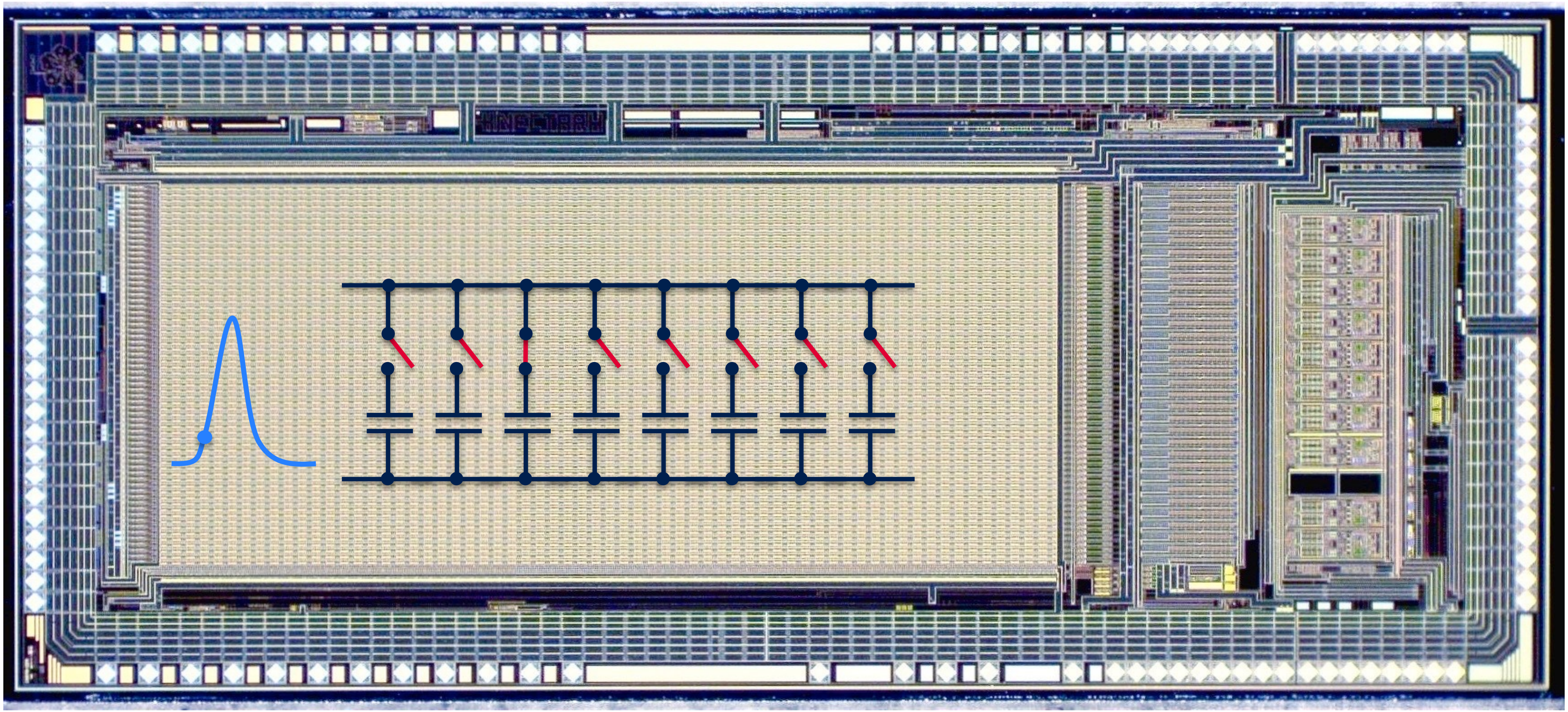
NECTAR ANALOGUE MEMORY



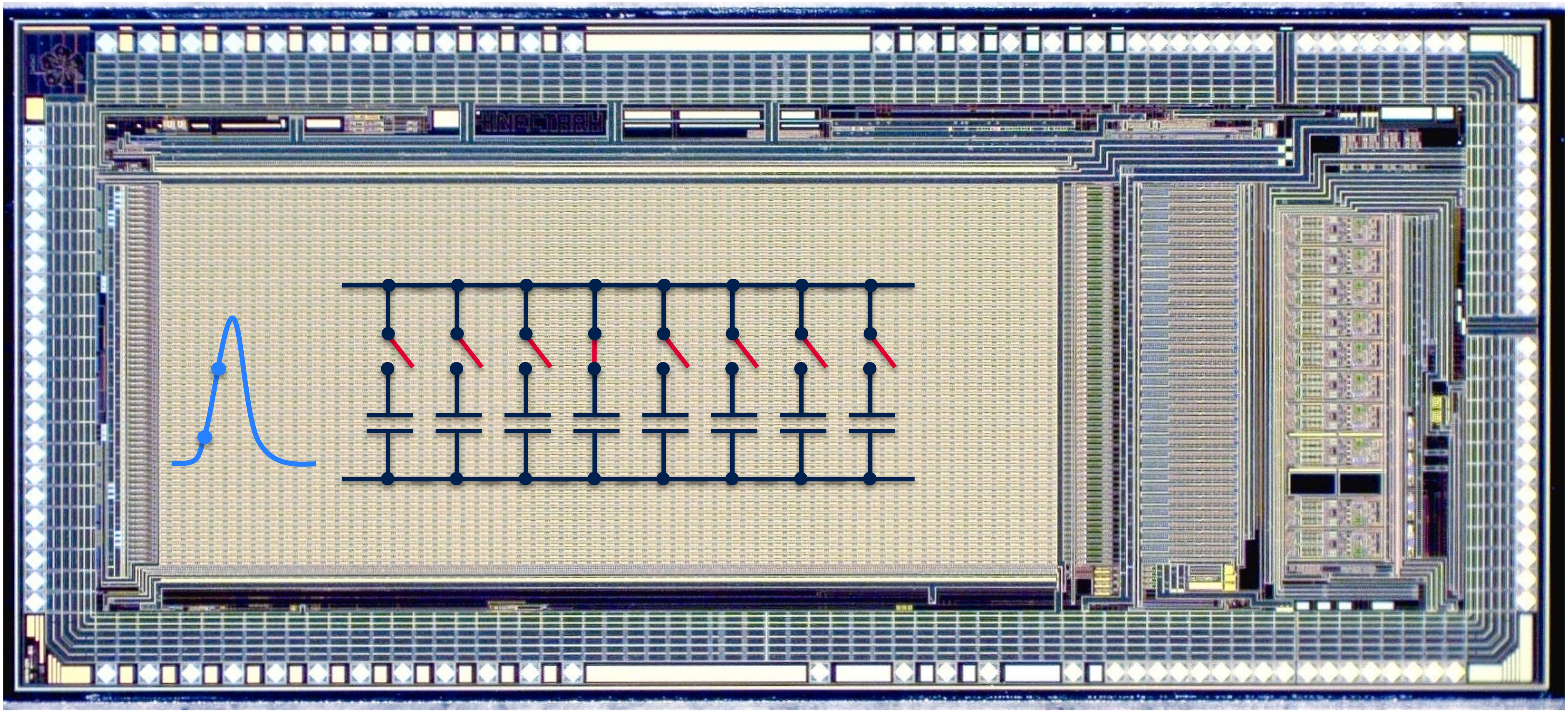
NECTAR ANALOGUE MEMORY



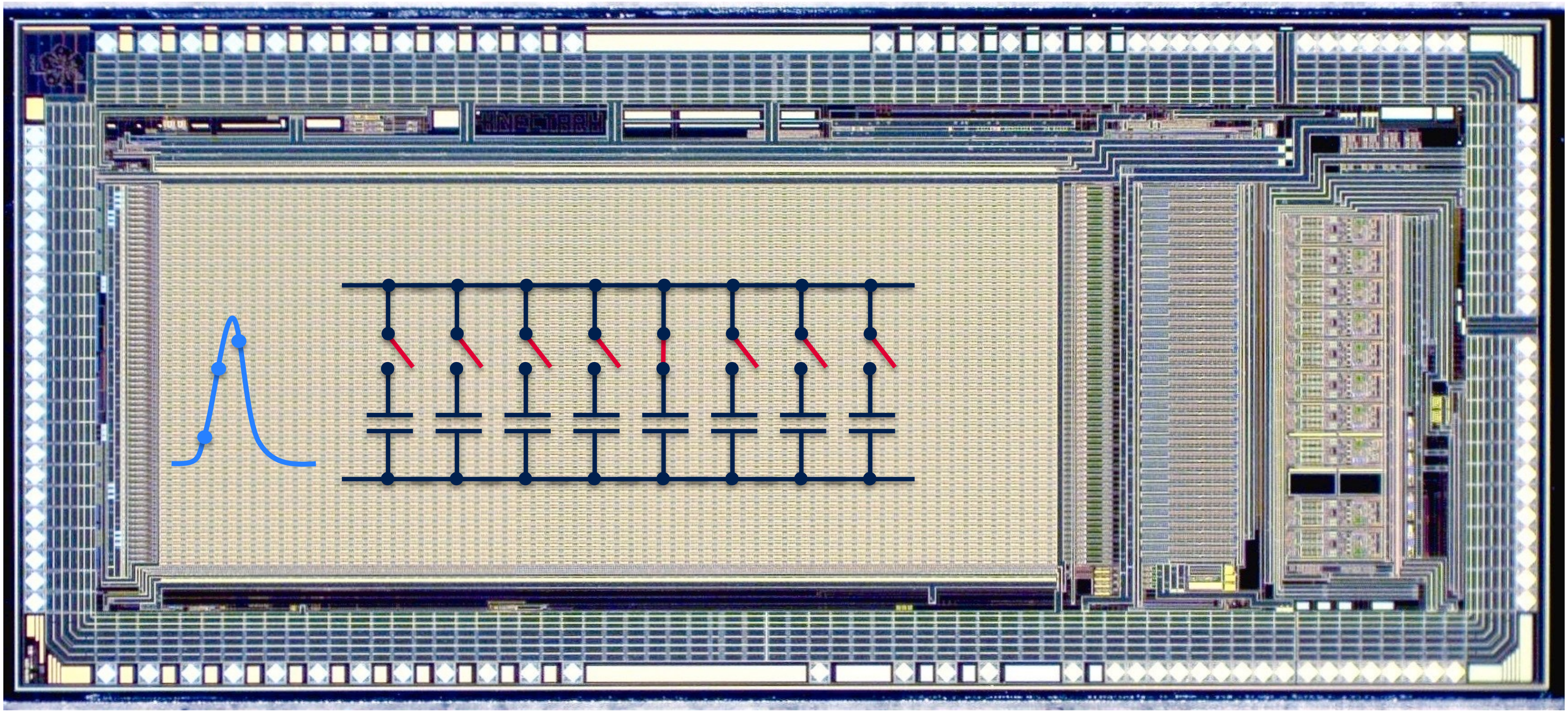
NECTAR ANALOGUE MEMORY



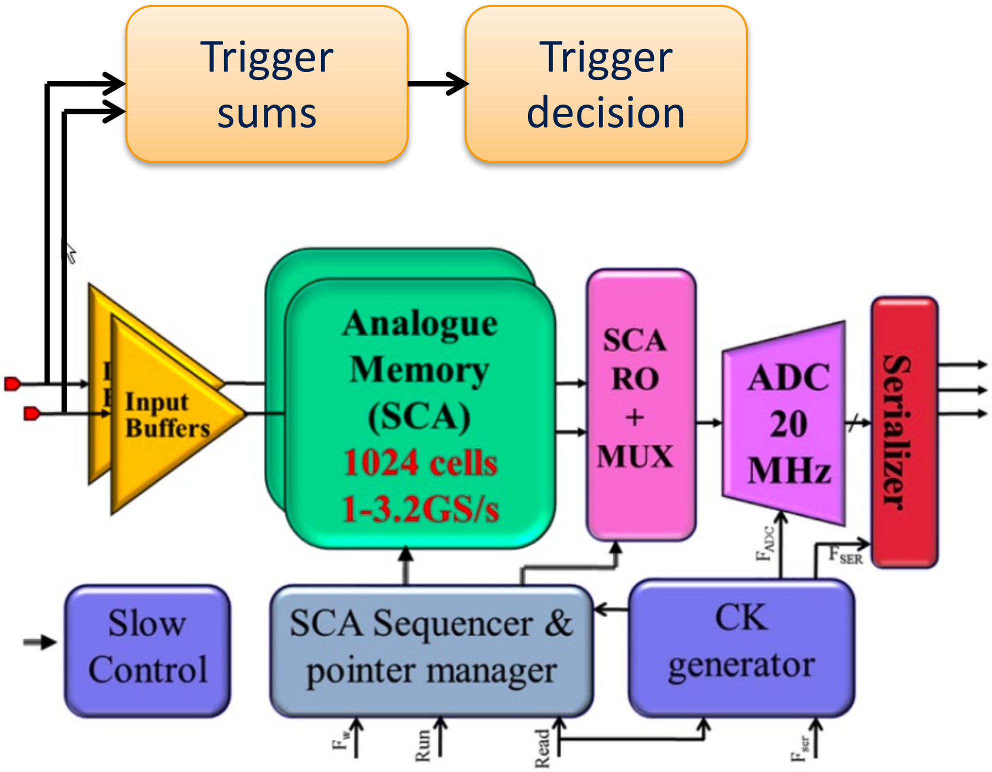
NECTAR ANALOGUE MEMORY

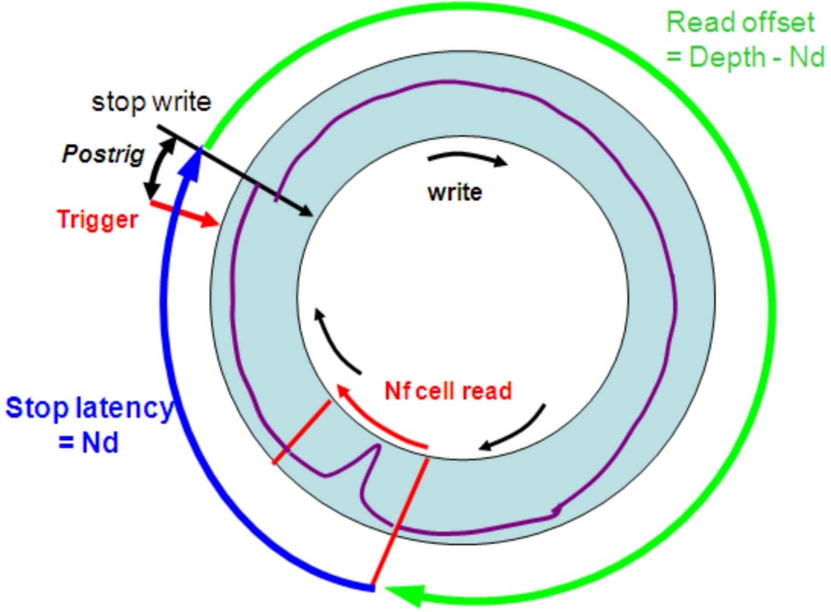


NECTAR ANALOGUE MEMORY



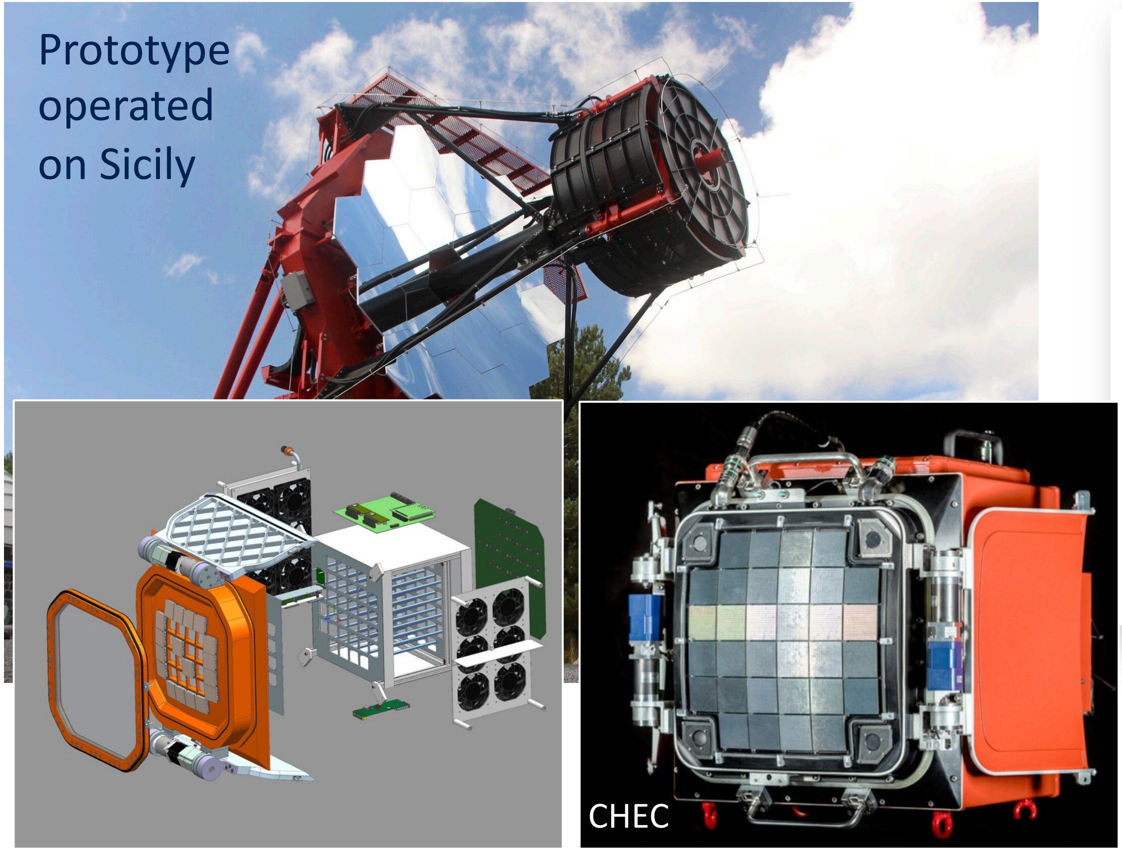
CAMERA BASICS

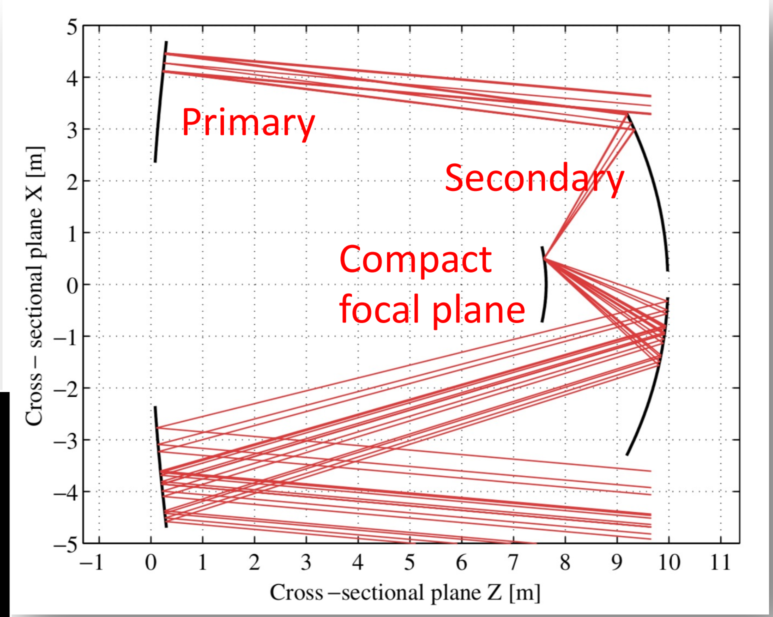




SMALL-SIZED TELESCOPE

Dual-mirror design
with SiPMT camera

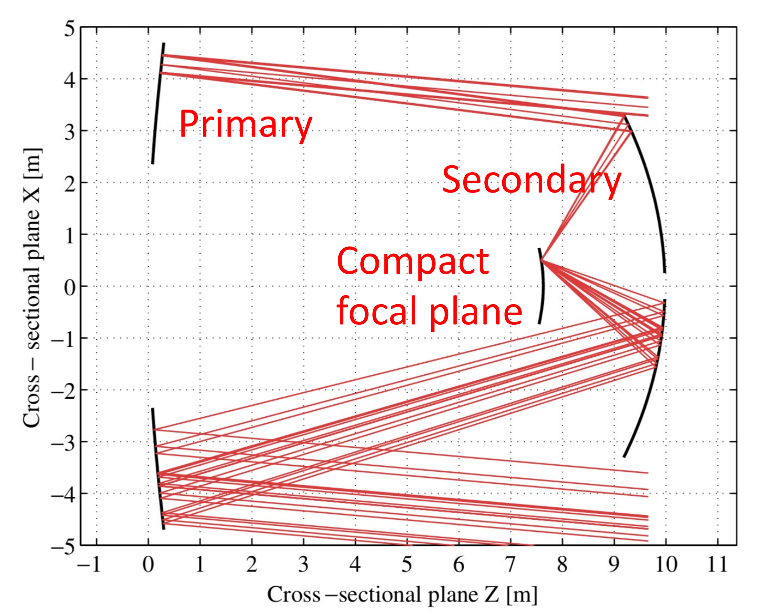




V. Vassiliev et al.
Astroparticle Physics
28 (2007) 10

SCT TELESCOPE

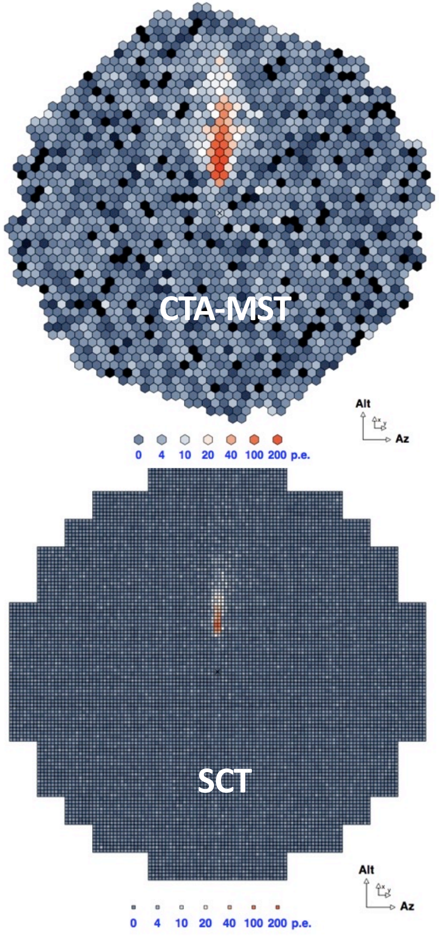
Dual-mirror design
with SiPMT camera



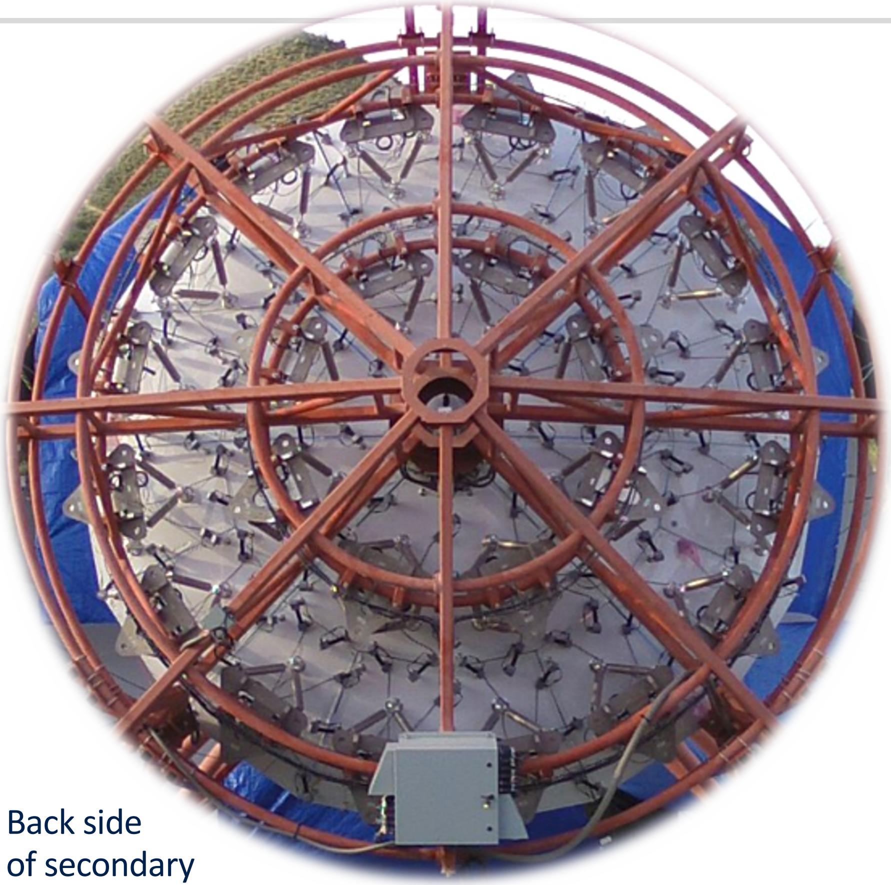
V. Vassiliev et al.
Astroparticle Physics
28 (2007) 10

Proposed for future expansion of CTA

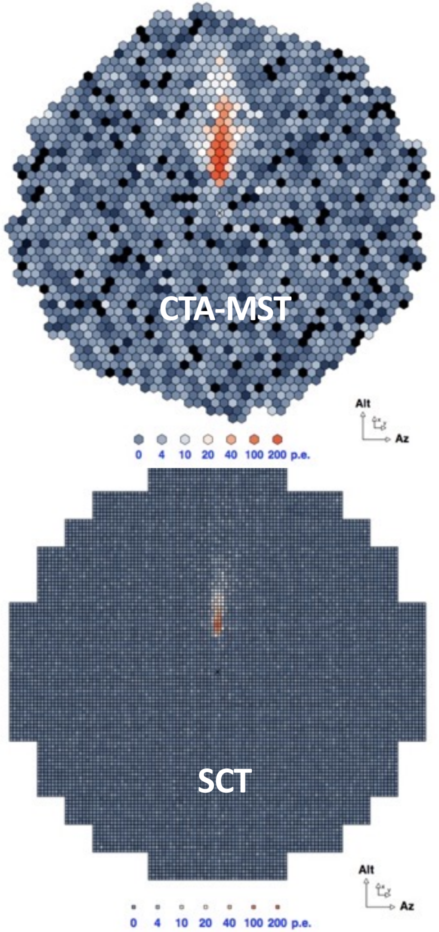
SCT TELESCOPE



SCT TELESCOPE



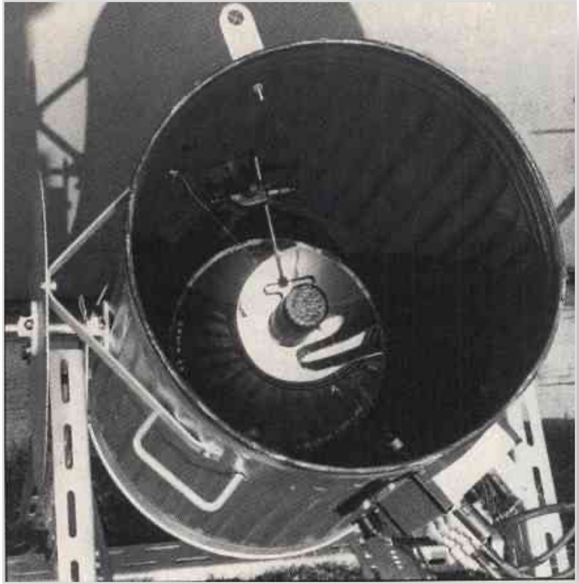
Back side
of secondary



SCT TELESCOPE

Somewhere on the Wipple observatory…

… EARLY CHERENKOV DETECTORS



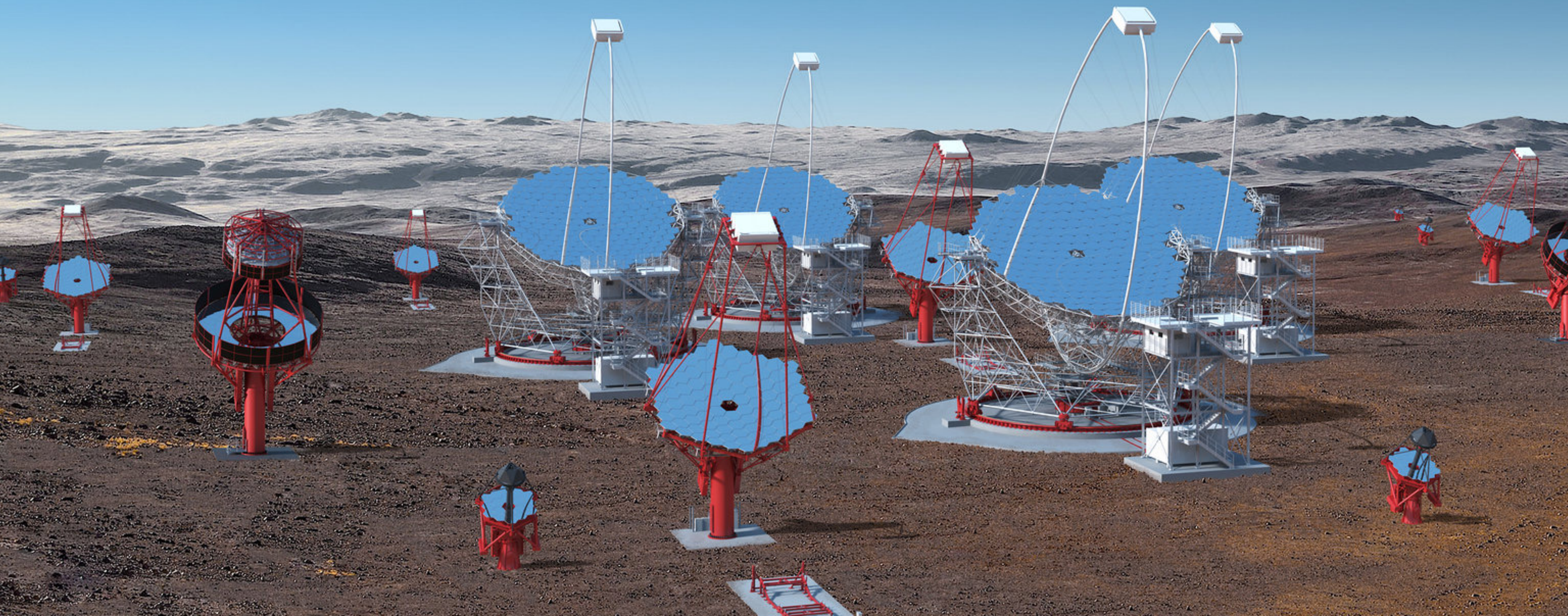
Galbraith and Jelley
1953

… Garbage cans and WWII search lights

Weekes and Rieke
1967, at the site of
the present Whipple Observatory

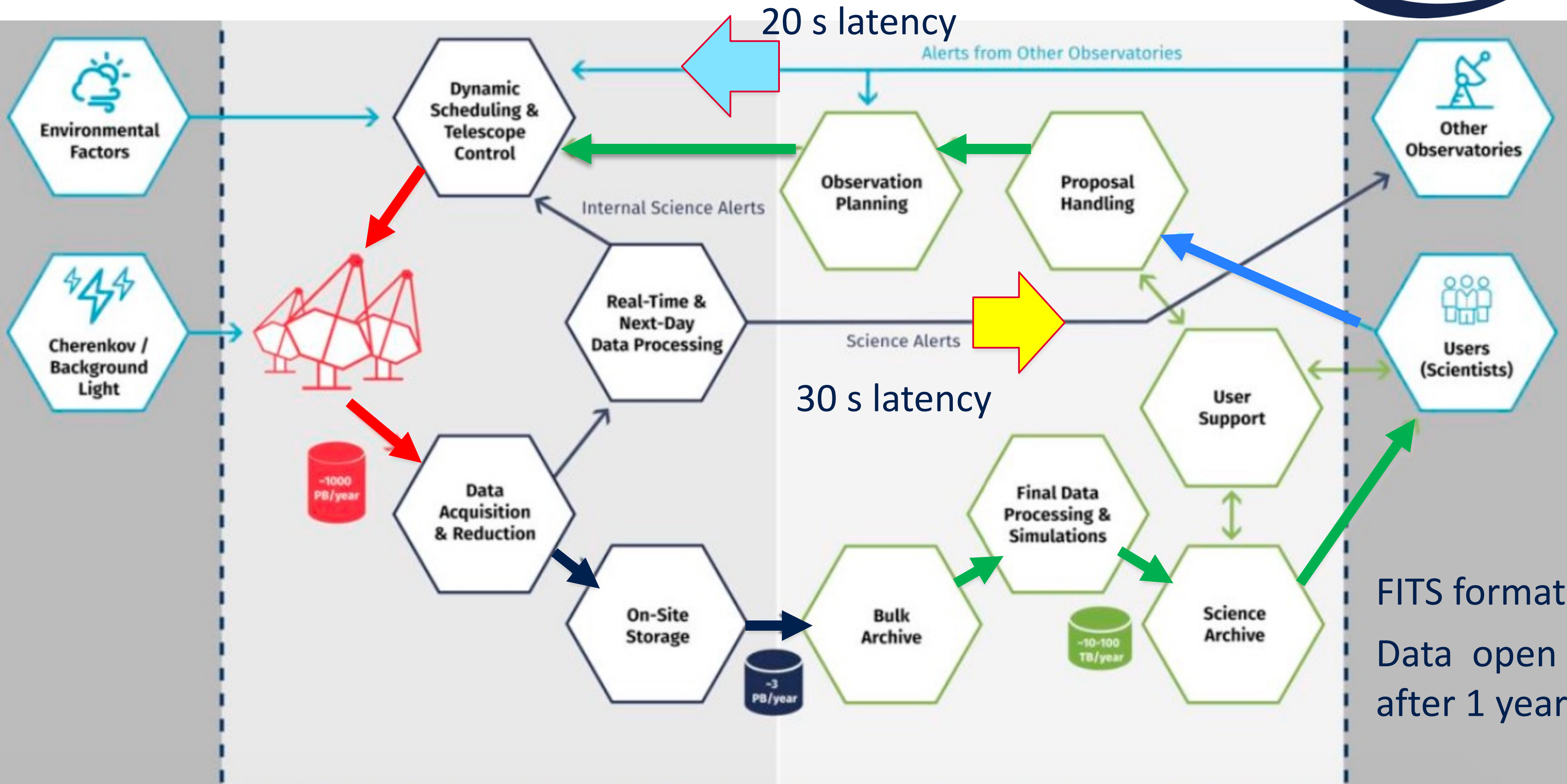
cherenkov telescope array

the observatory for ground-based gamma-ray astronomy



CTA OBSERVATORY

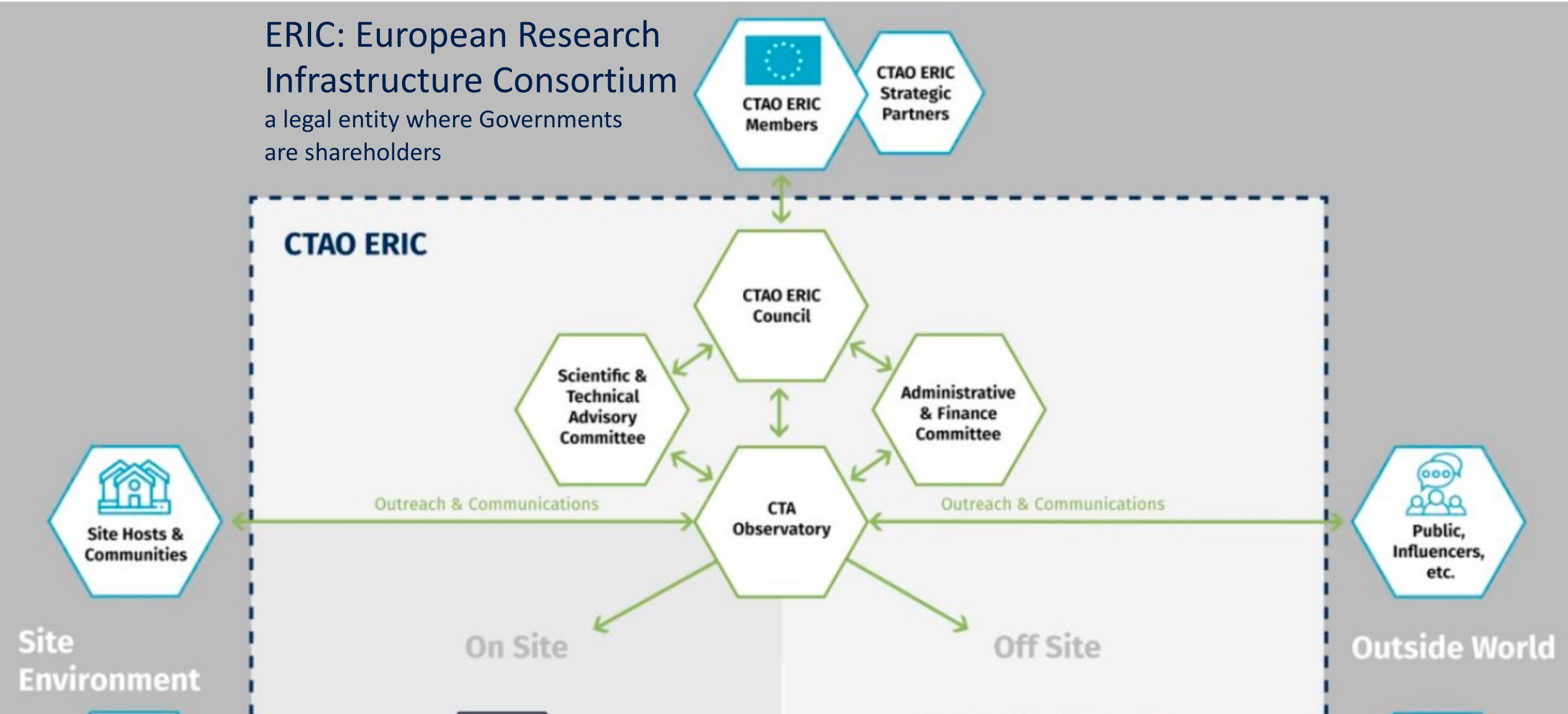
Alerts & ToOs



FITS format

Data open after 1 year

CTA OBSERVATORY



Late June 2021: Agreement reached on CTA configuration and funding; cost book and S&T description approved

First meeting of the Board of Government Representatives

for founding the CTA Observatory ERIC

(May 2018)

TOWARDS THE CTA OBSERVATORY

Funding limitations require temporary specialization of sites
(“Alpha Configuration”):

- North: Low energy / extragalactic science
  – all 4 LSTs but slightly reduced number of MSTs (15 ➜ 9)
- South: High energy / galactic science
  – initially no LSTs, reduced numbers of MSTs (25 ➜ 14), SSTs (70 ➜ 37)
  – highest priority for next step: adding LSTs

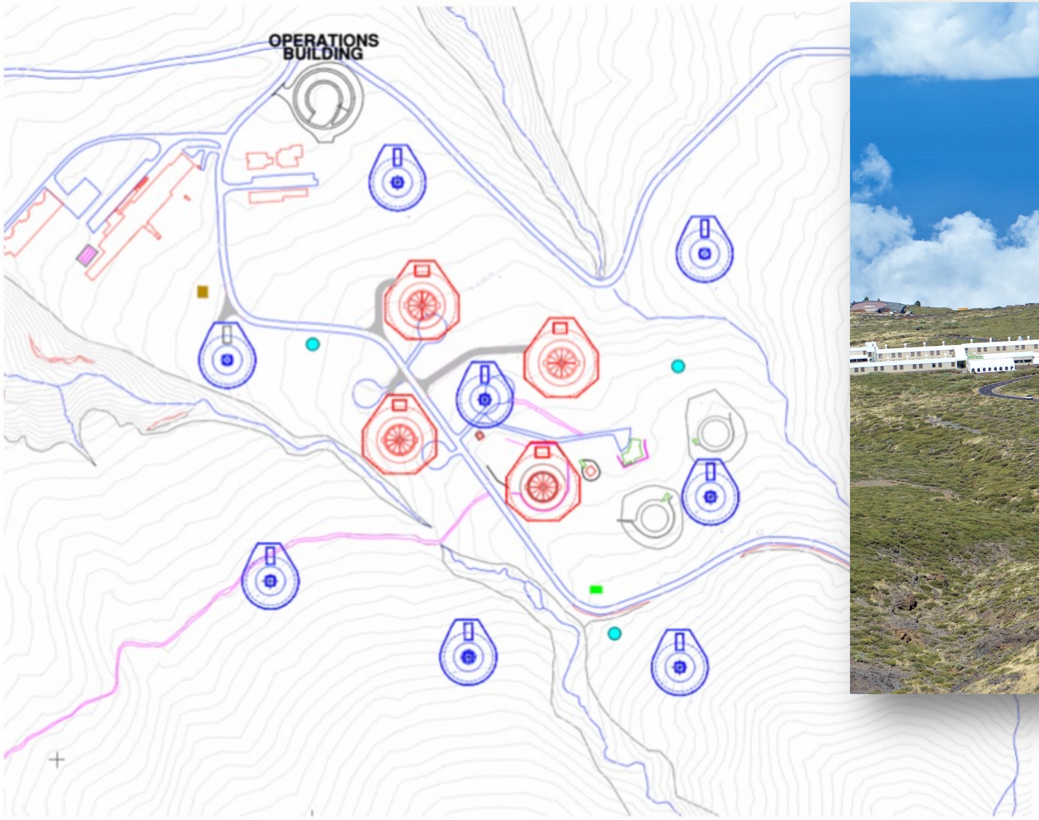
North:

- LST1 under commissioning
- Contracts for LST2-4 and 1st MST underway; for MST2-5 tender open

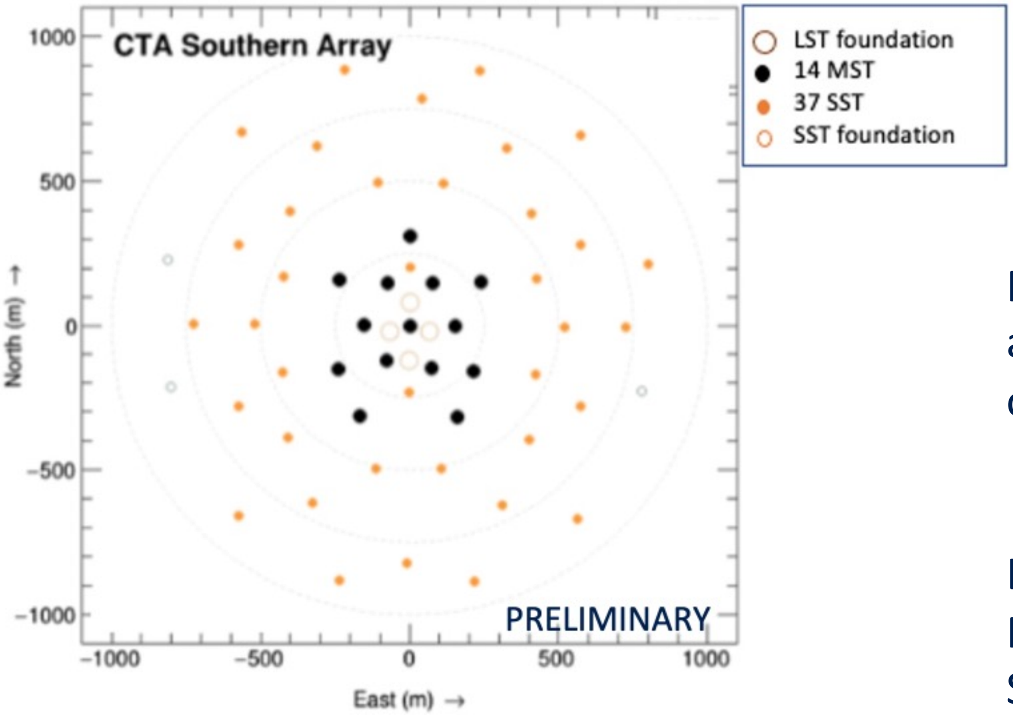
South:

- Construction of access road started
- Release of funding for large-scale construction after CTA Observatory ERIC is established (2022)
- 5 year construction phase (but early operation during construction)

CTA NORTH ARRAY only large and medium-sized telescopes



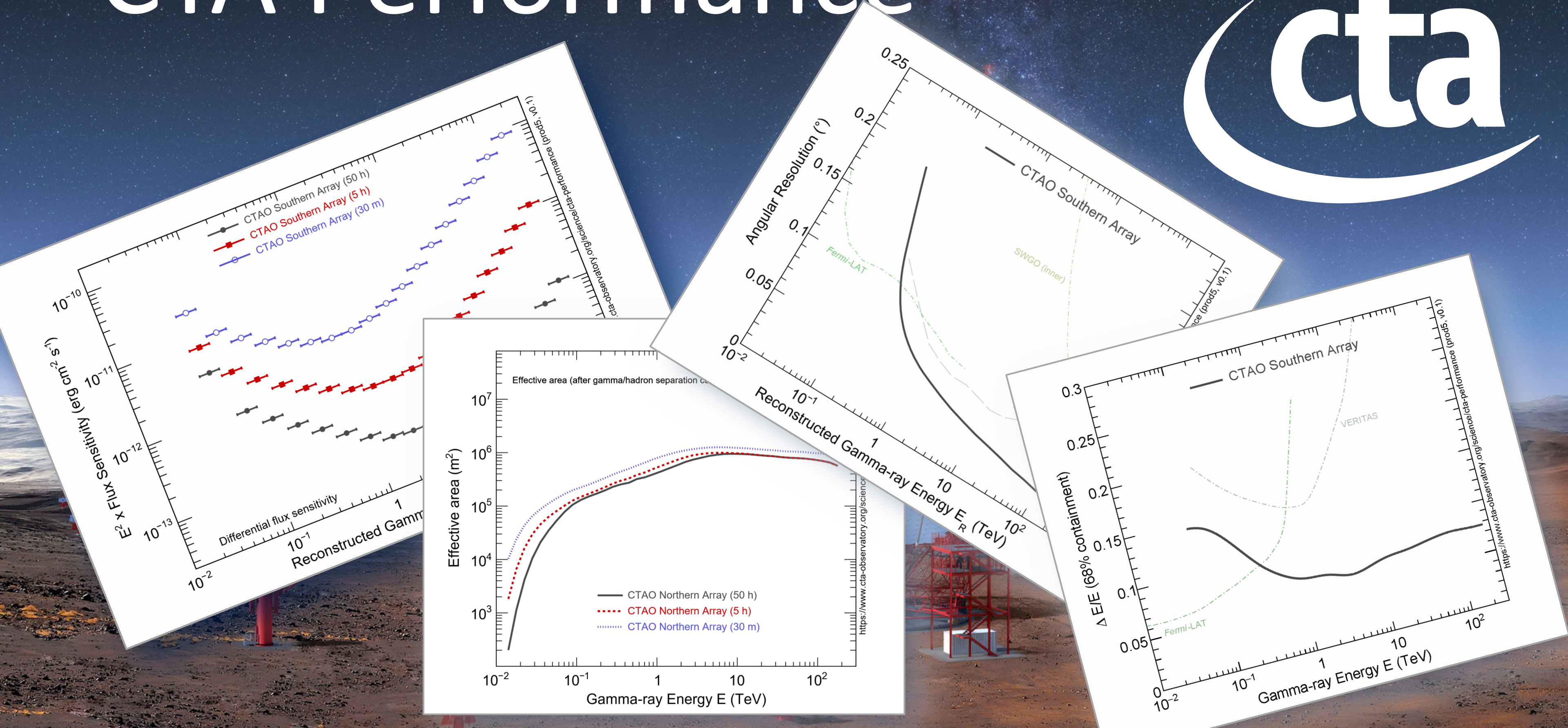
CTA SOUTH ARRAY initially only small and medium sized telescopes



Fine-tuning of placement of alpha configuration telescopes ongoing

	Omega	→	Alpha config.
LST	4	→	4 foundations
MST	25	→	14
SST	70	→	37

CTA Performance

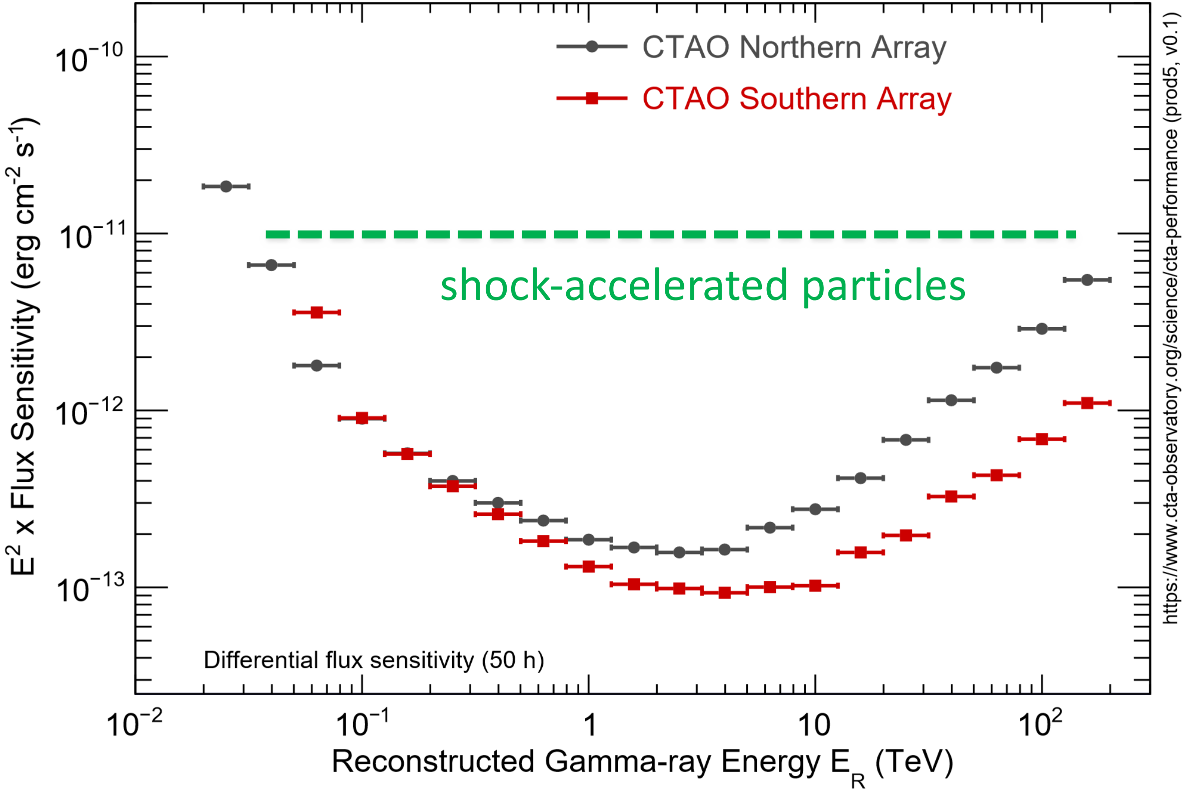


SENSITIVITY OF THE CTA ARRAYS

$E^2\phi(E)$ =
$E^2 dN/dE$ =
$E\, dN/d\log(E)$

Energy flux per log(E) interval

for $dN/dE \sim E^{-2}$
$E^2\phi(E)$ = const



Sensivity quoted for enery bins of 0.2 decades

Alpha Configuration, 50 h

SENSITIVITY OF THE CTA ARRAYS

$E^2\phi(E) =$
$E^2 dN/dE =$
$E\ dN/d\log(E)$

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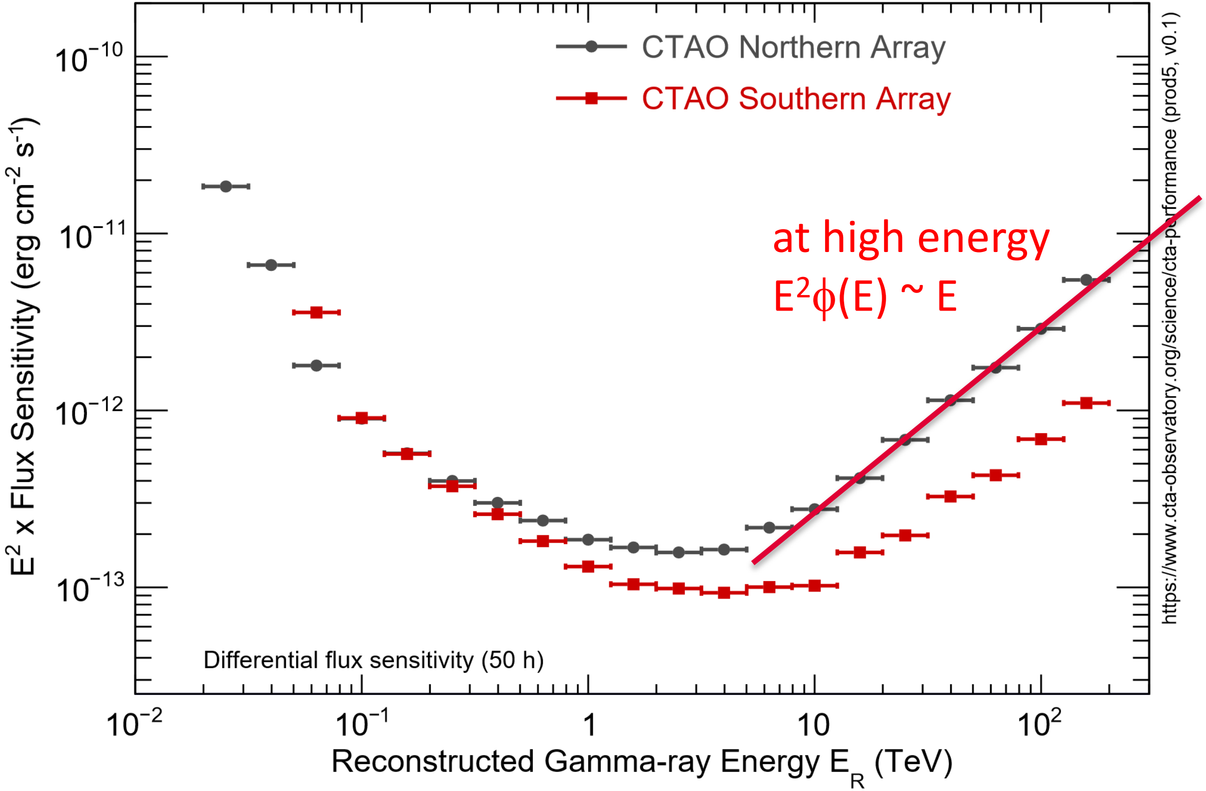

at least 10 gamma rays detected per log(E) bin
→
$dN/d\log(E) = \text{const}$
$E dN/d\log(E) \sim E$

SENSITIVITY OF THE CTA ARRAYS

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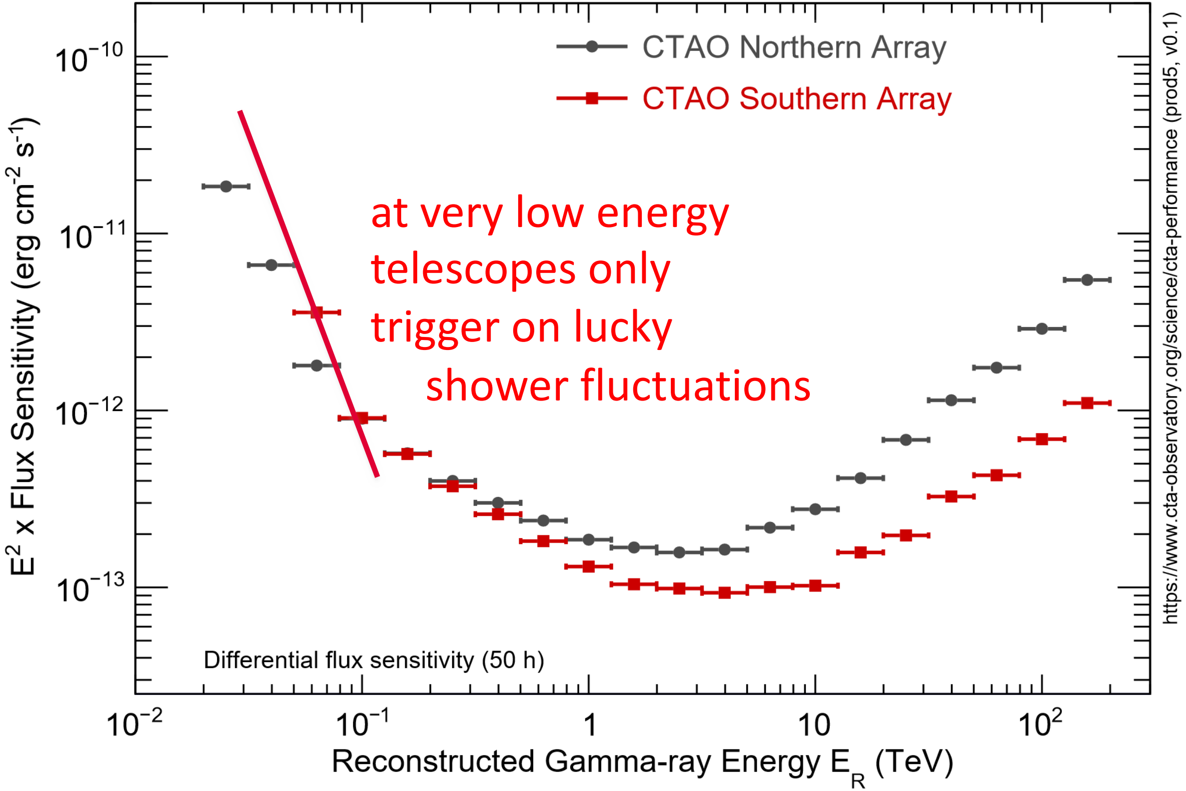

SENSITIVITY OF THE CTA ARRAYS

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interval

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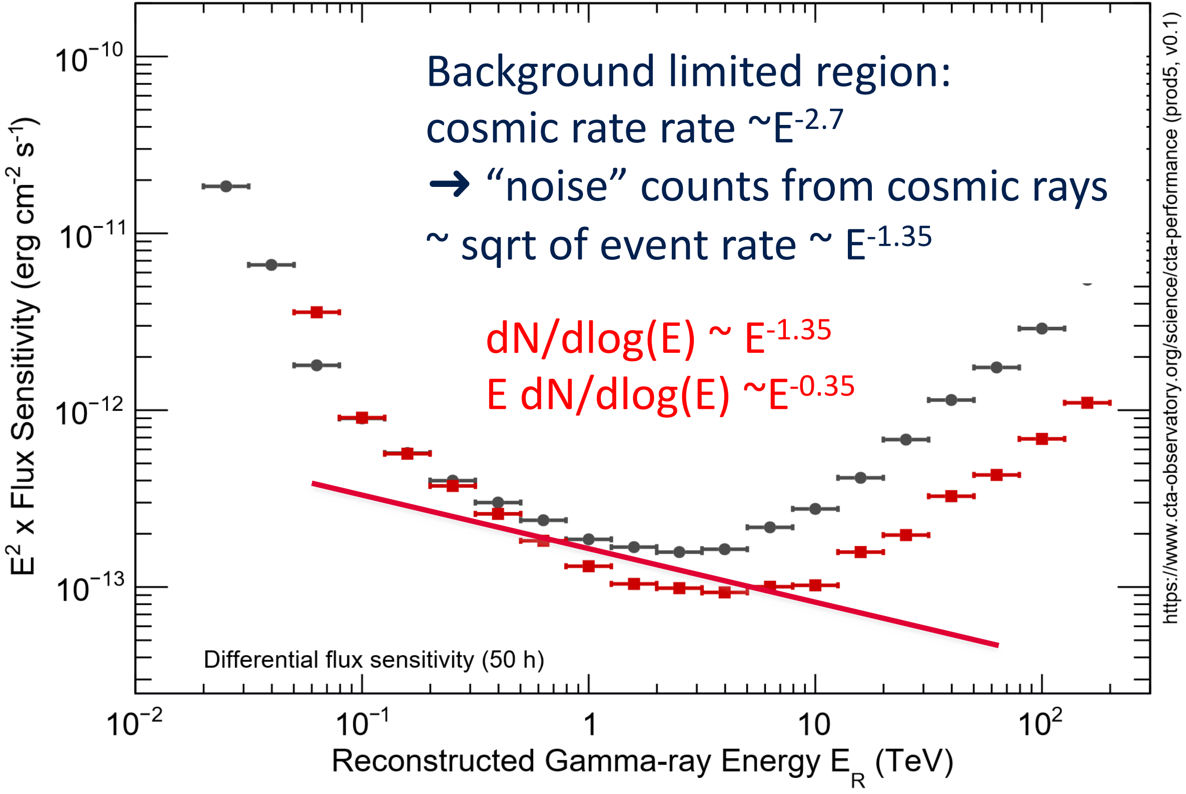
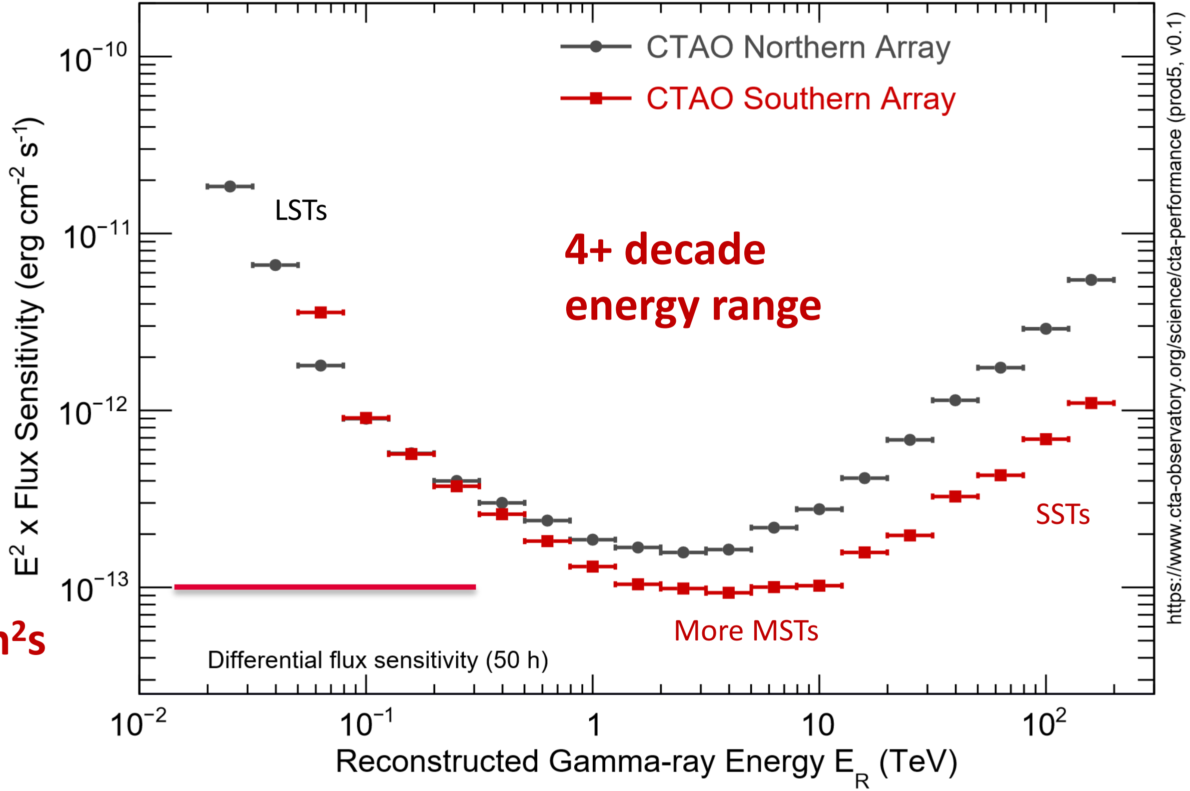


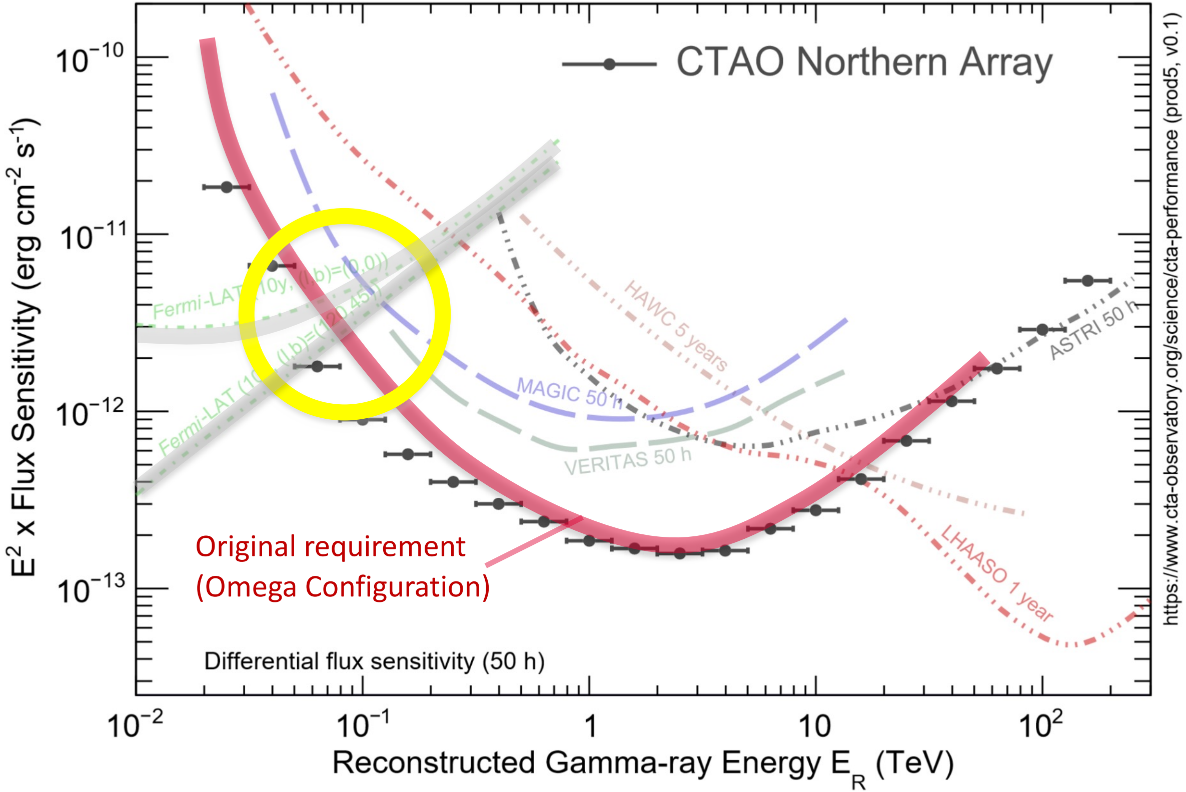
SENSITIVITY OF THE CTA ARRAYS



From 10^{-12} erg/cm^{2}s to 10^{-13} erg/cm^{2}s

Alpha Configuration, 50 h

SENSITIVITY: NORTHERN ARRAY

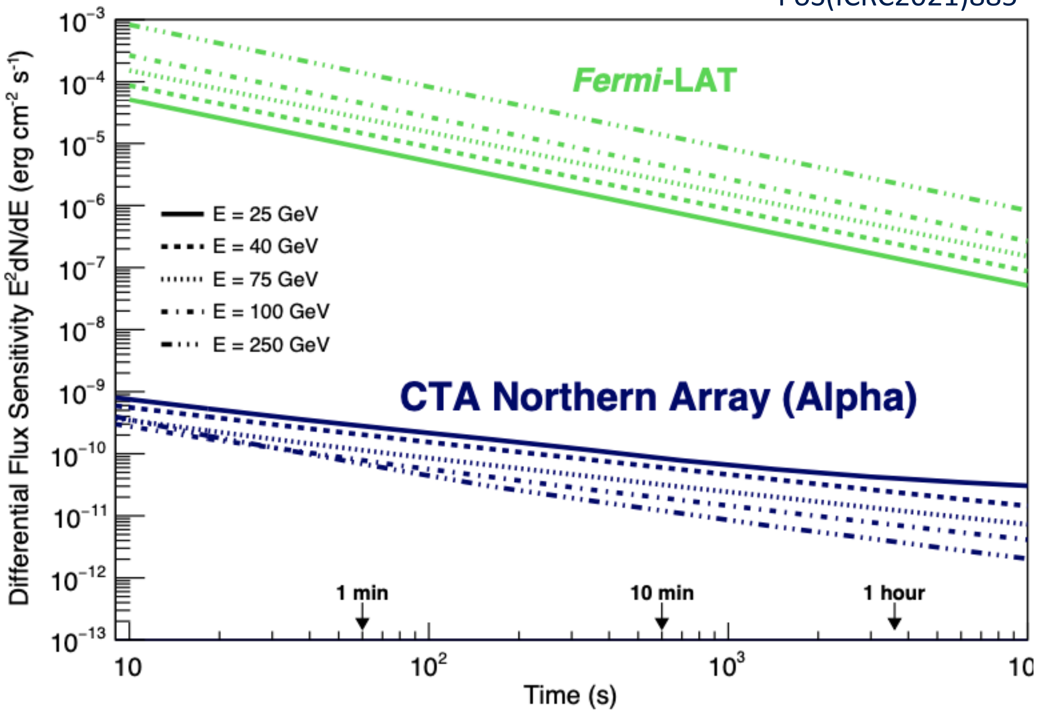


Alpha Configuration, 50 h

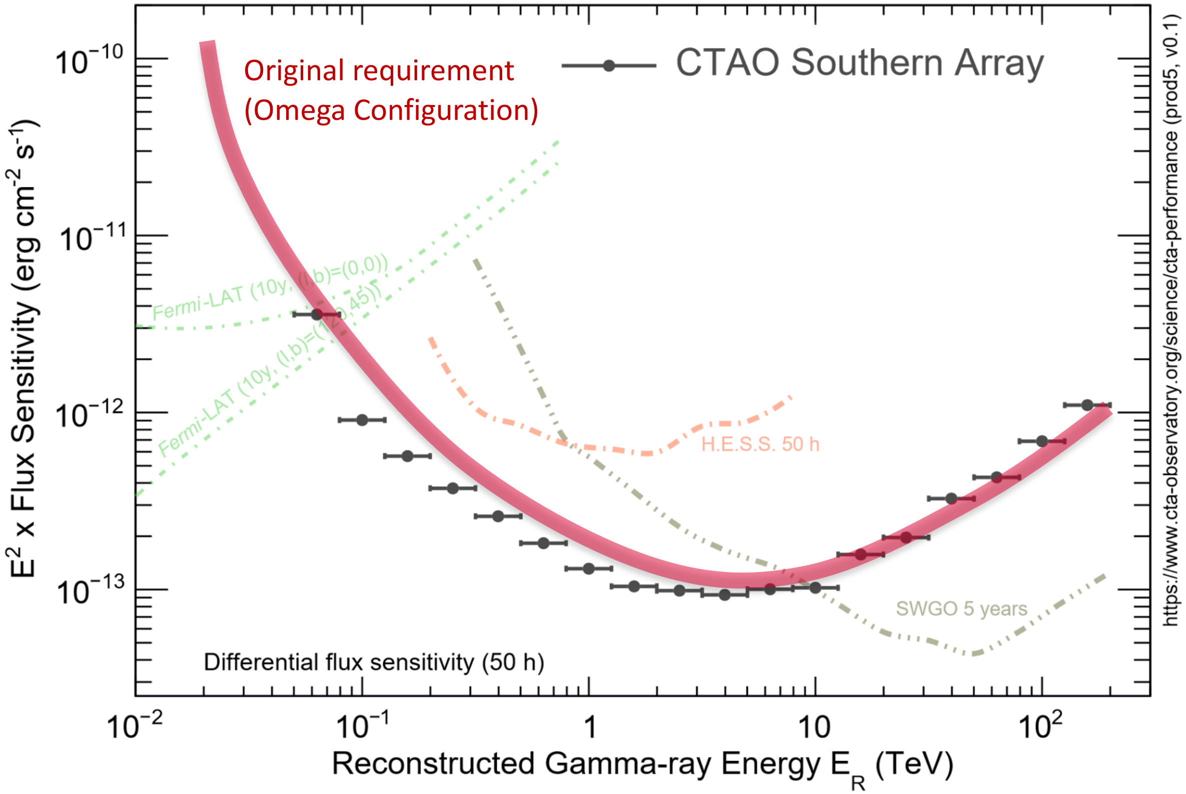
SENSITIVITY (FLARING SOURCES)

On time scales < 1 h
CTA is 10^3 times (at 25 GeV)
to 10^6 times (at 250 GeV)
more sensitive
than Fermi

PoS(ICRC2021)885



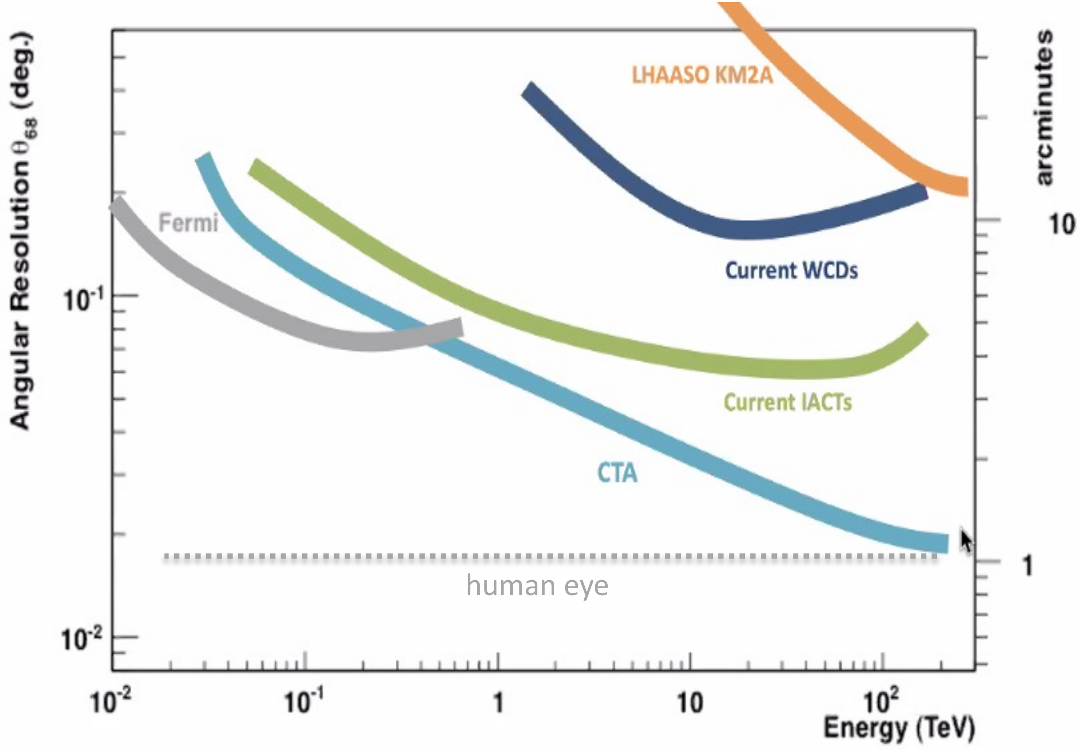
SENSITIVITY: SOUTHERN ARRAY

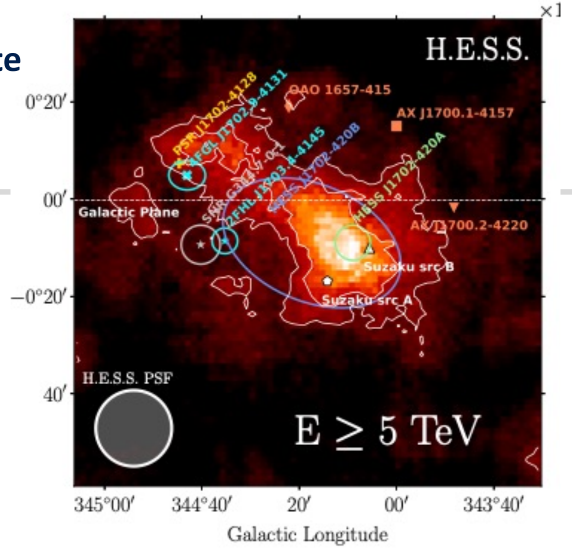


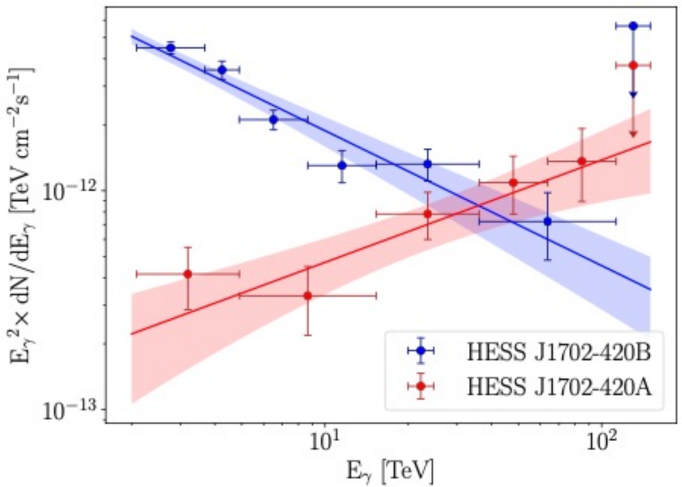
Alpha Configuration, 50 h

ANGULAR RESOLUTION

Pevatron candidate
HESS J1702-420
arXiv:2106.06405



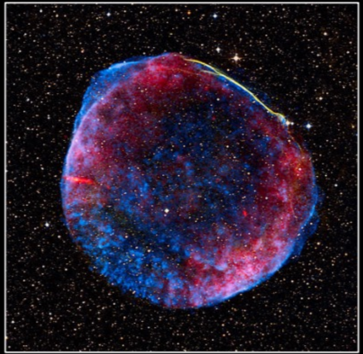




www.worldscientific.com/
worldscibooks/10.1142/
10986

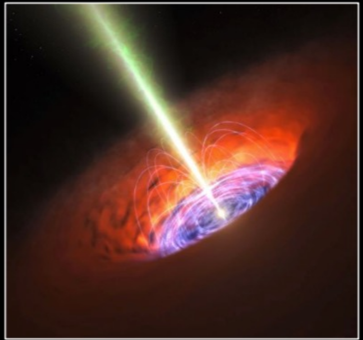
Theme 1: Cosmic Particle Acceleration

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



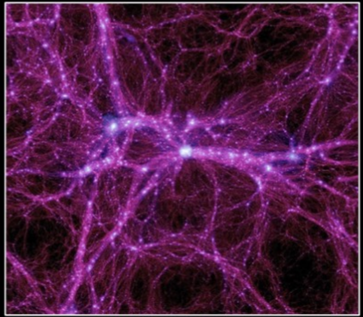
Theme 2: Probing Extreme Environments

- Processes close to neutron stars and black holes?
- Characteristics of relativistic jets, winds and explosions?
- Cosmic voids: their radiation fields and magnetic fields



Theme 3: Physics Frontiers

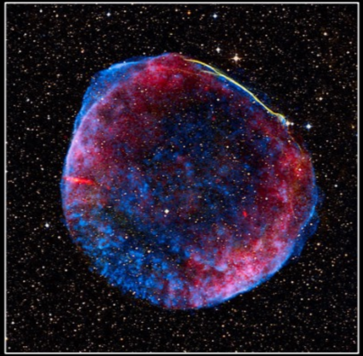
- What is the nature of Dark Matter?
- Is the speed of light a constant?
- Do axion-like particles exist?

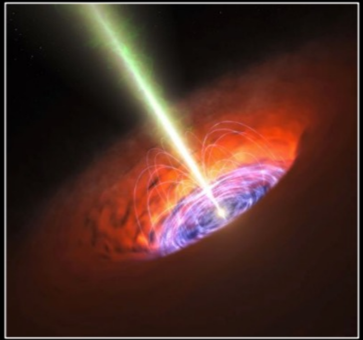


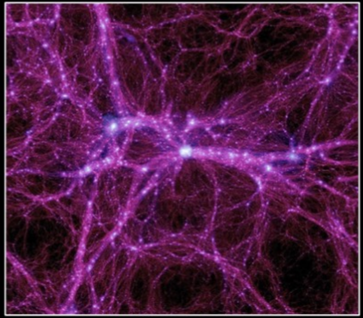
Addressing these questions requires large and coherent data sets, including

- Sky surveys for a census of cosmic accelerators
- Deep observations of key objects
- Long-term observations of variable sources
- Rapid follow-up of transient phenomena

→ Key Science Projects







KEY SCIENCE PROJECTS

1. Dark Matter Programme
2. Galactic Centre
3. Galactic Plane Survey
4. Large Magellanic Cloud Survey
5. Extragalactic Survey
6. Transients
7. Cosmic-ray PeVatrons
8. Star-forming Systems
9. Active Galactic Nuclei
10. Cluster of Galaxies
11. Beyond Gamma Rays

Surveys

Key objects

www.worldscientific.com/worldscibooks/10.1142/10986

GALACTIC CENTER & DARK MATTER KSPs

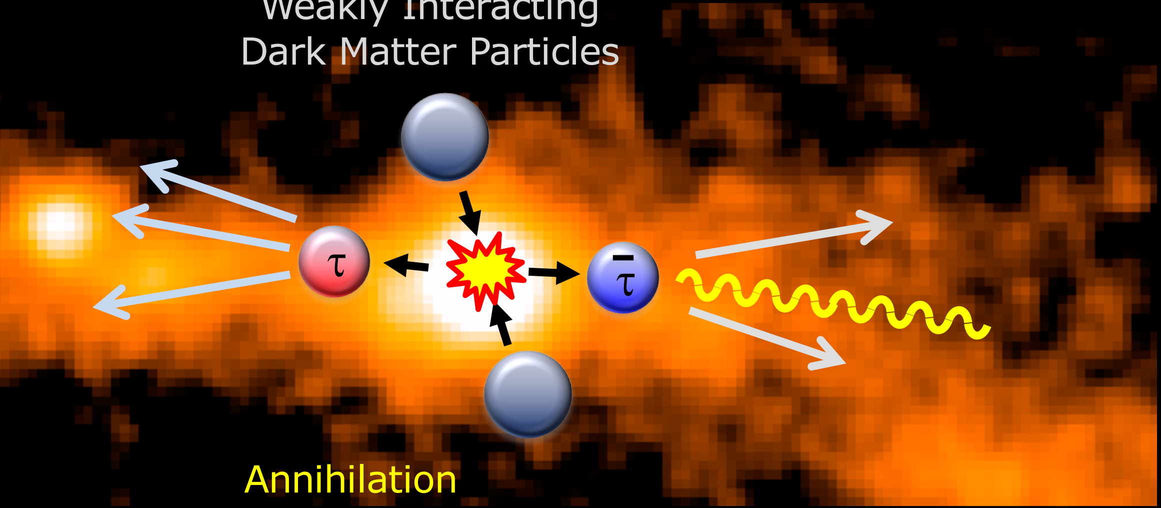
X-Ray:NASA/CXC/UMass/D. Wang et al.; Radio:NRF/SARAO/MeerKAT

ESO

NASA/ESA

GALACTIC CENTER & DARK MATTER KSPs

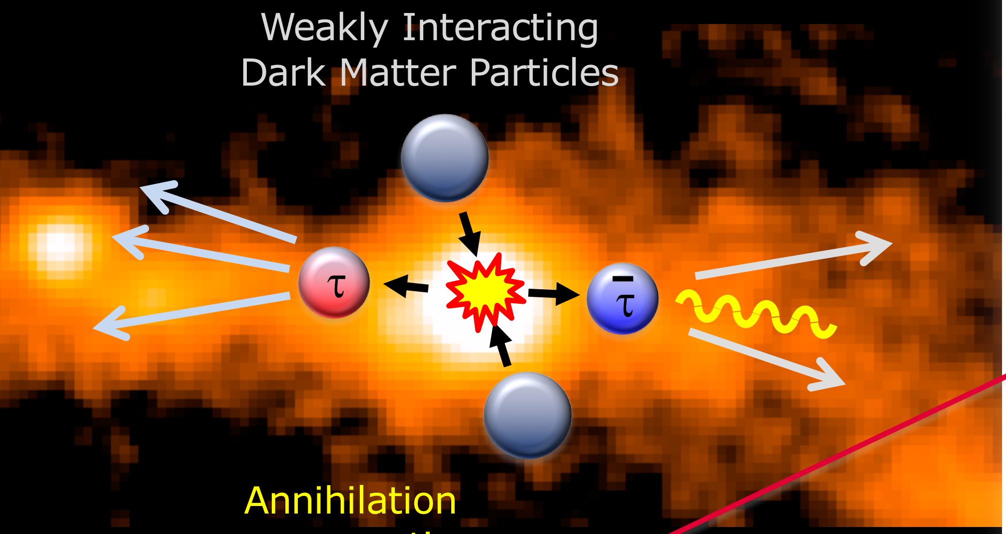
Weakly Interacting
Dark Matter Particles

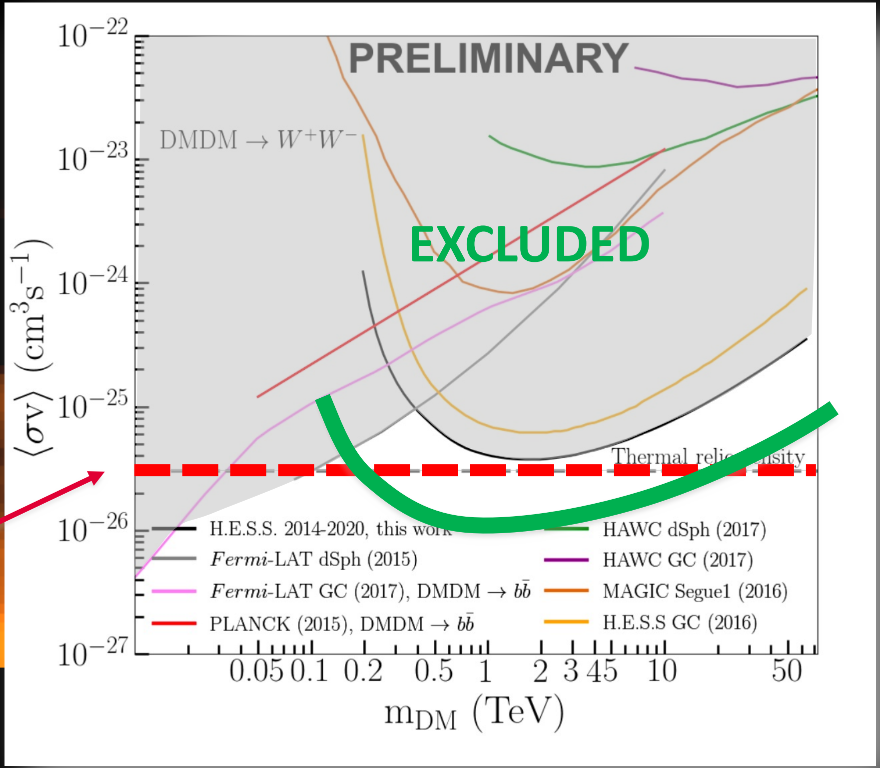


Annihilation
cross section
"known" from
Dark Matter
abundance

Characteristic spectral signature
known from particle physics

GALACTIC CENTER & DARK MATTER KSPs

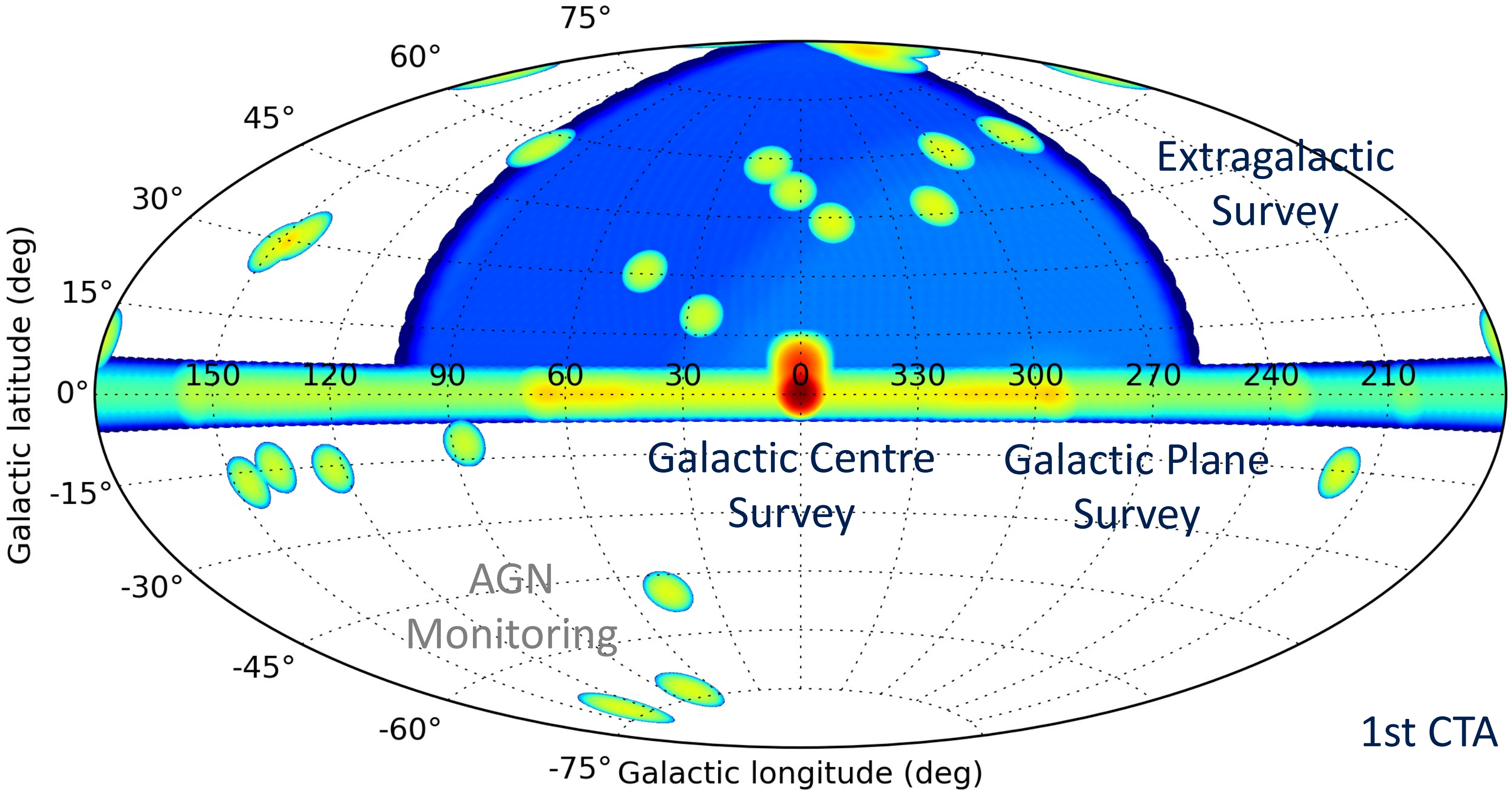




Annihilation cross section "known" from Dark Matter abundance

arXiv:2007.16129
A. Montanari et al, PoS (ICRC2021)511

SURVEY KSPs

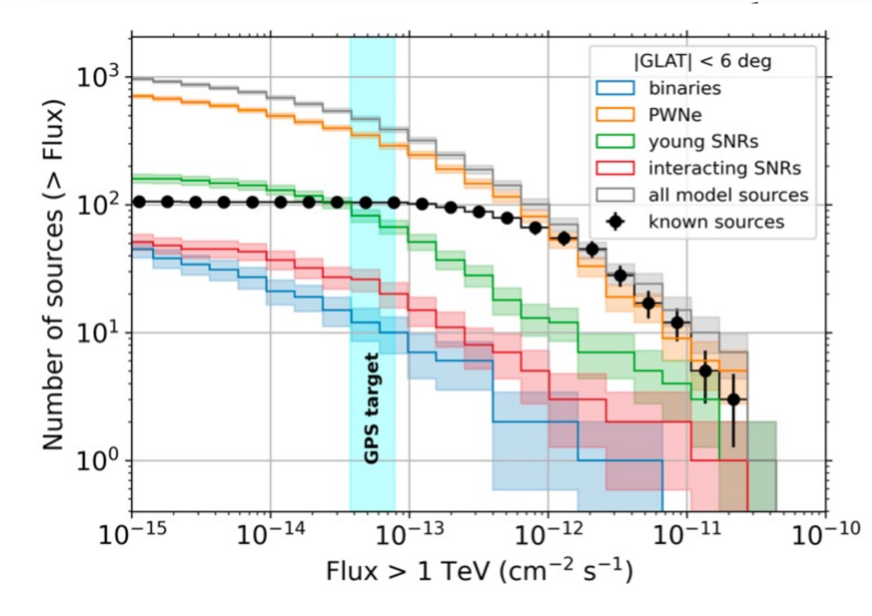


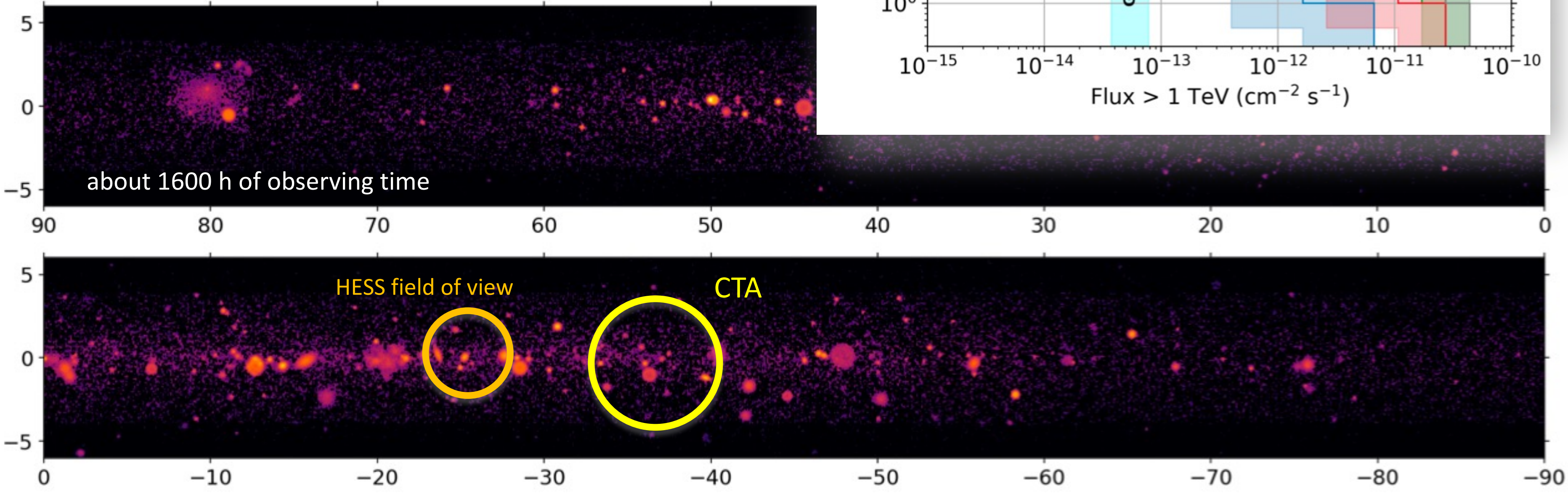
Exposure
1st CTA Data Challenge

GALACTIC PLANE SURVEY

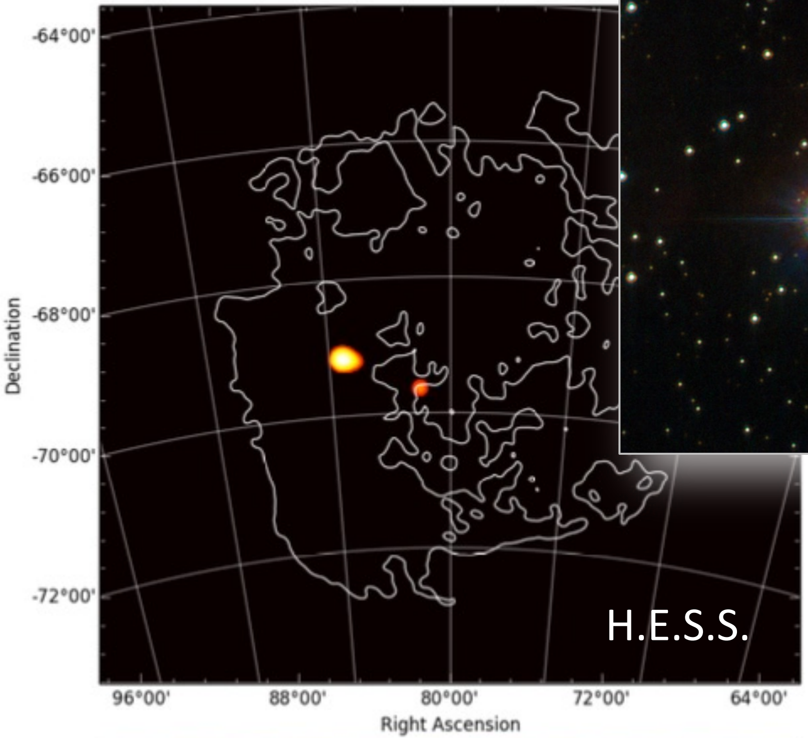
PoS(ICRC2021)886

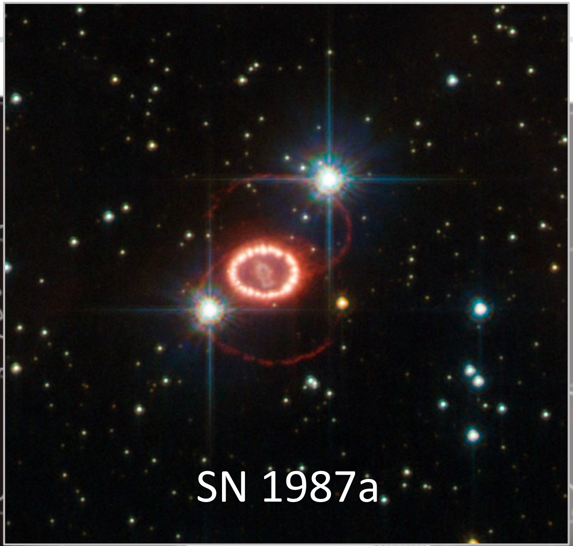
expect about
500 source detections

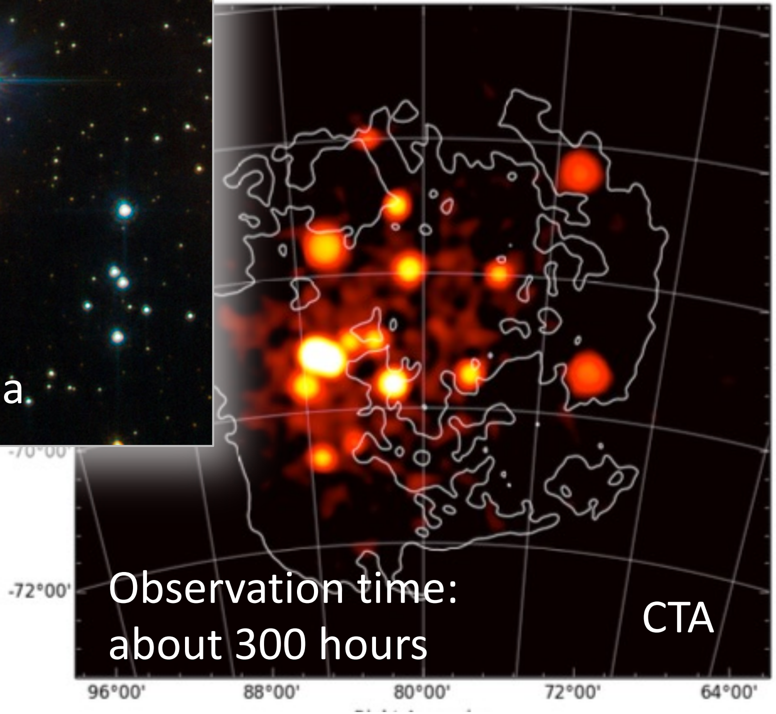




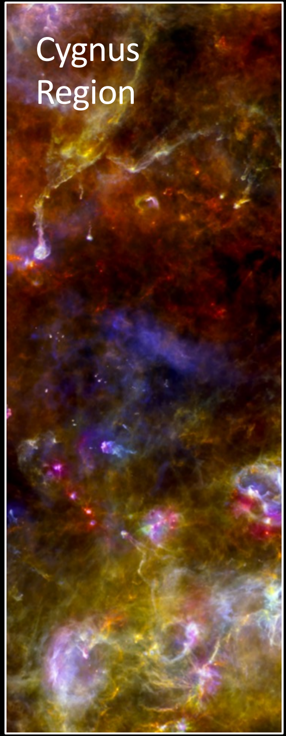
LARGE MAGELLANIC CLOUD





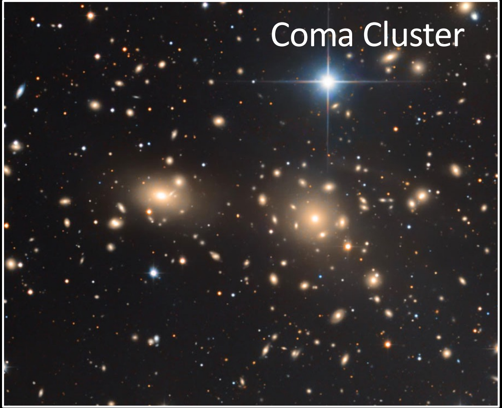


A CENSUS OF COSMIC PARTICLE ACCELERATORS

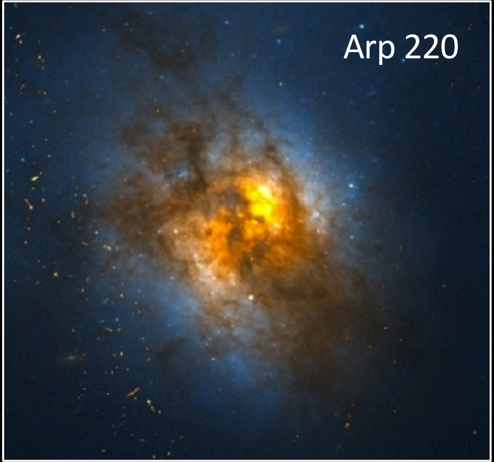


J.Fritz,
W. Pietsch,
R. Gendler

Hubble Heritage Team



R. Carroll,
R. Gendler
B. Franke



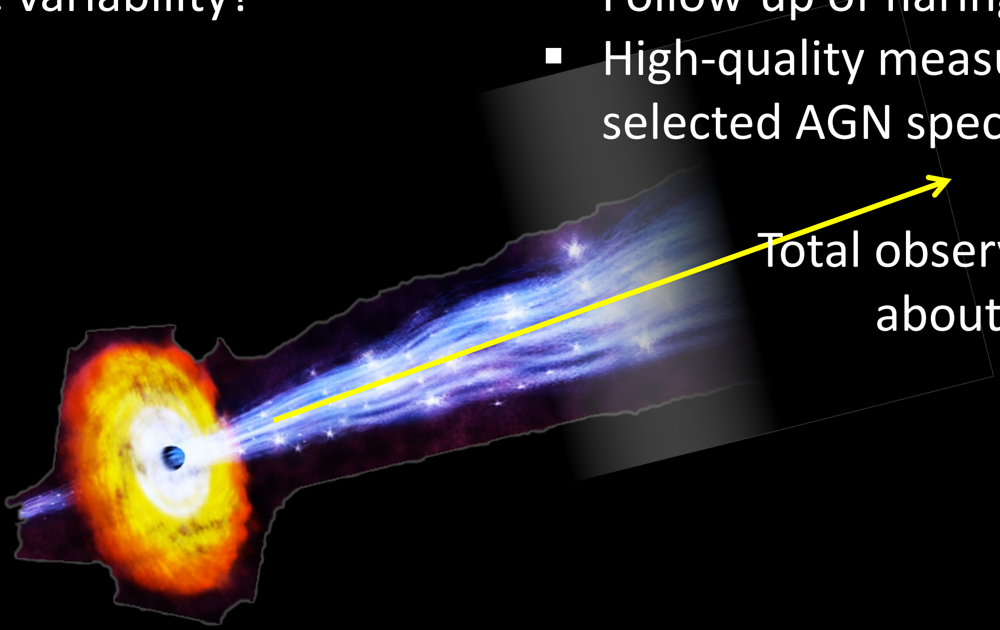
Univ. of Oklahoma
& NASA

ACROSS ALL COSMIC SCALES

AGN KEY SCIENCE PROJECT

What is the jet made of?
How is it launched?
What causes the variability?

- Long-term monitoring of selected AGN over 10 years
- Follow-up of flaring AGN
- High-quality measurement of selected AGN spectra

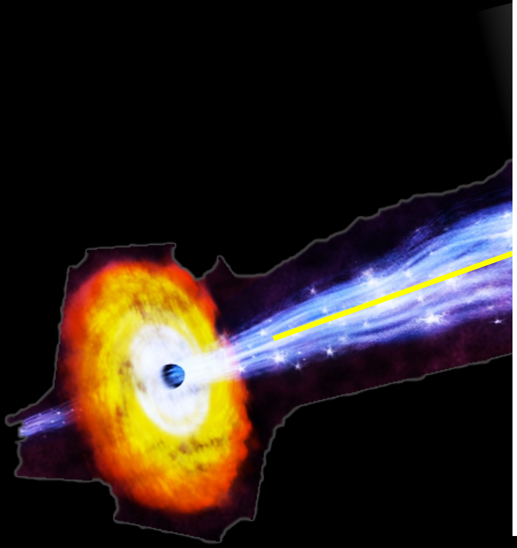


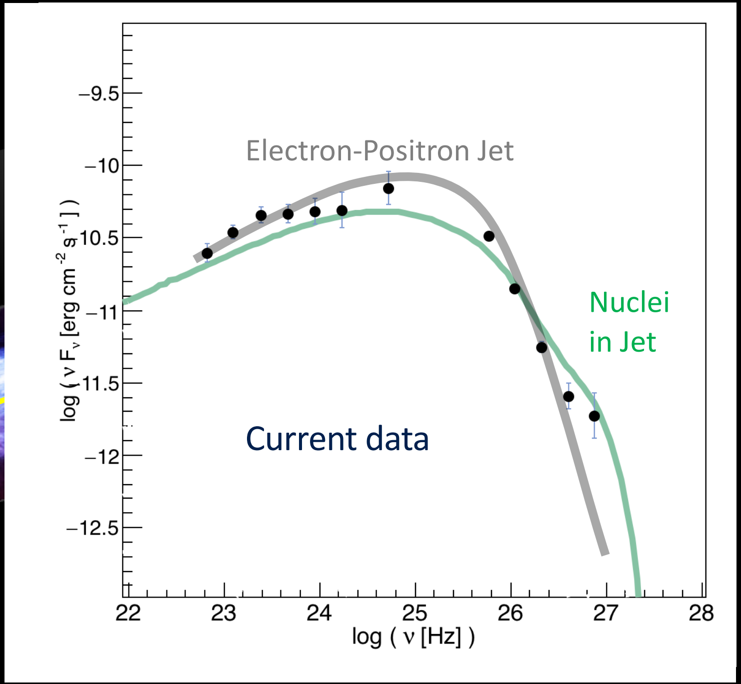
Total observation time:
about 3000 hours

AGN KEY SCIENCE PROJECT

What is the jet made of?
How is it launched?
What causes the variability?

from: Science with CTA
www.worldscientific.com/worldscibooks/10.1142/10986





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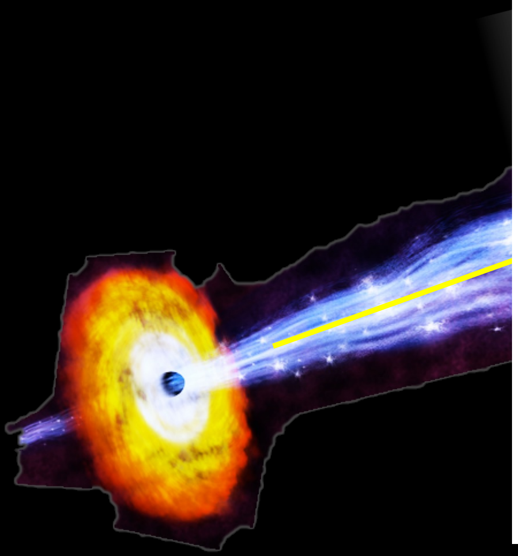
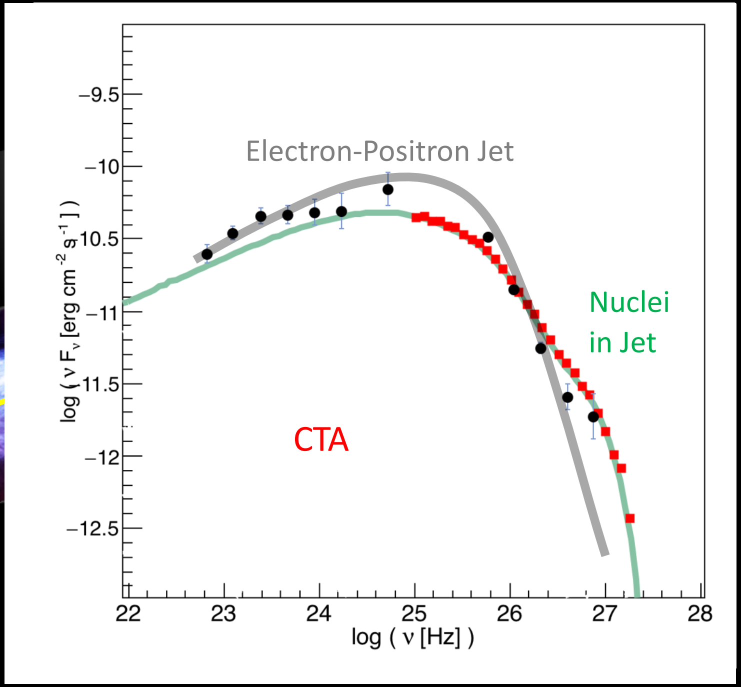
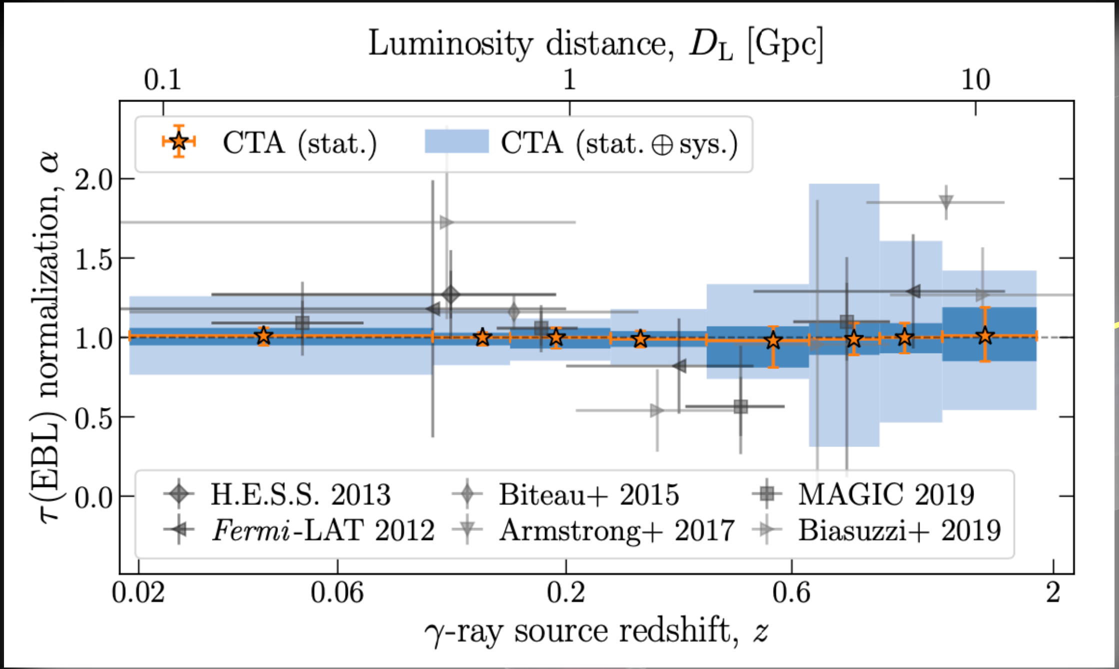
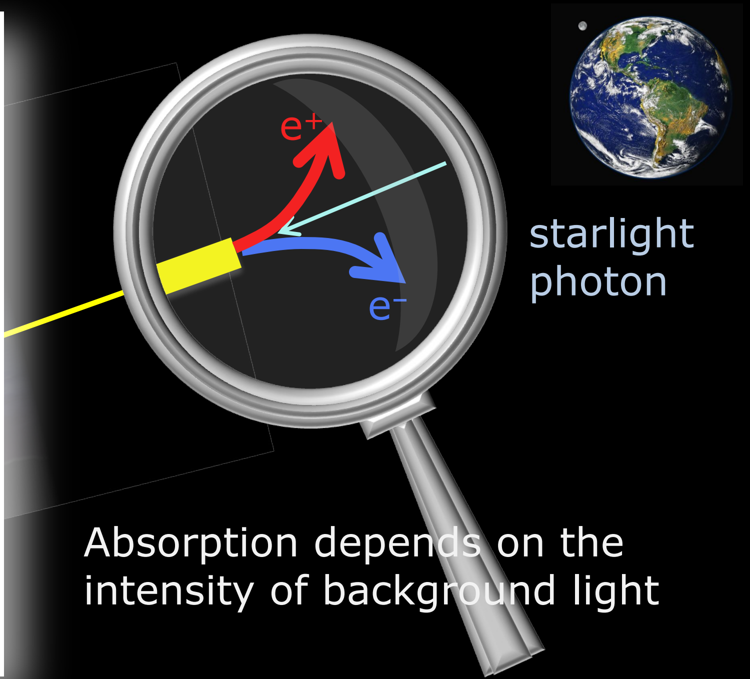




PHOTON PROPAGATION: EXTRAGALACTIC BACKGROUND LIGHT

arXiv:2010.01349

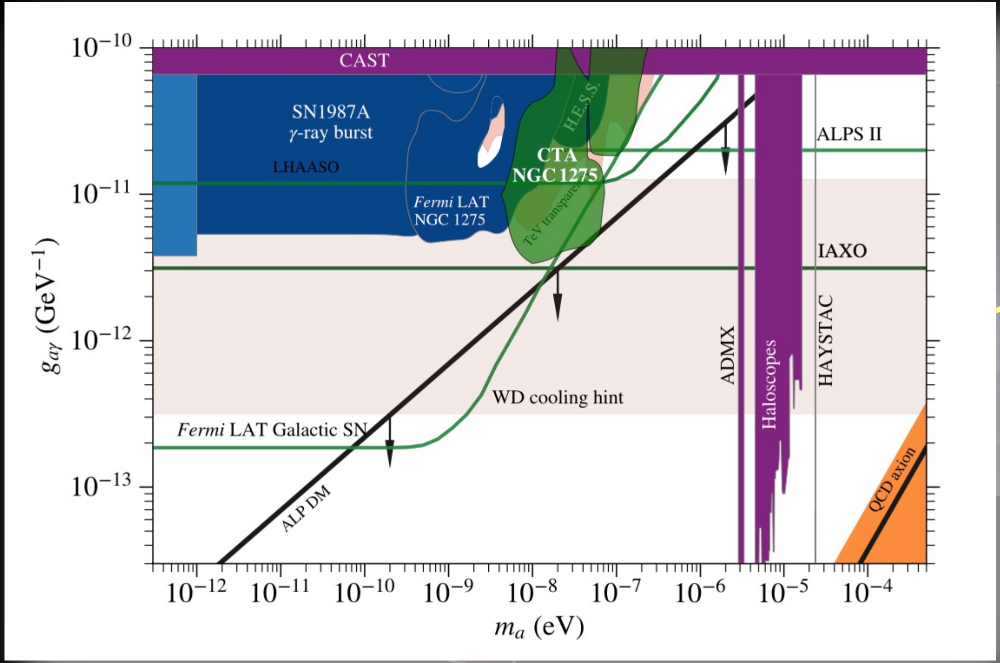




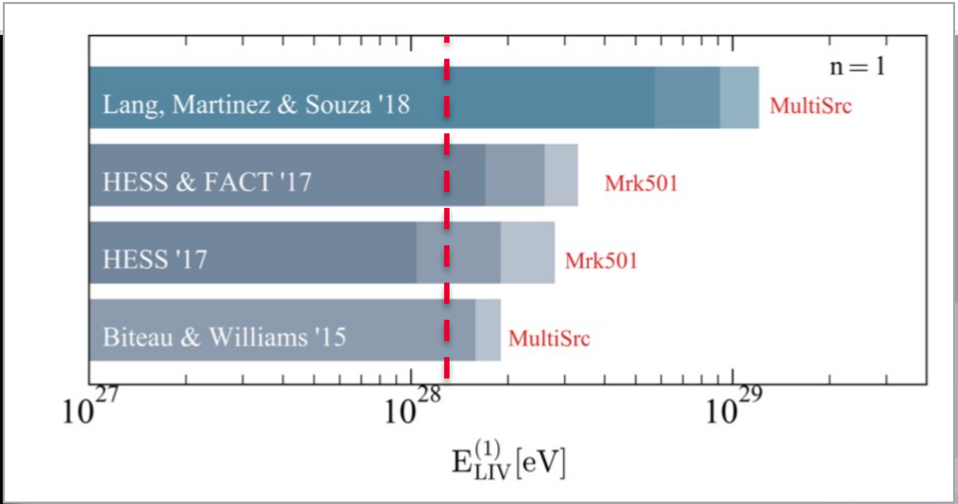
Absorption depends on the intensity of background light

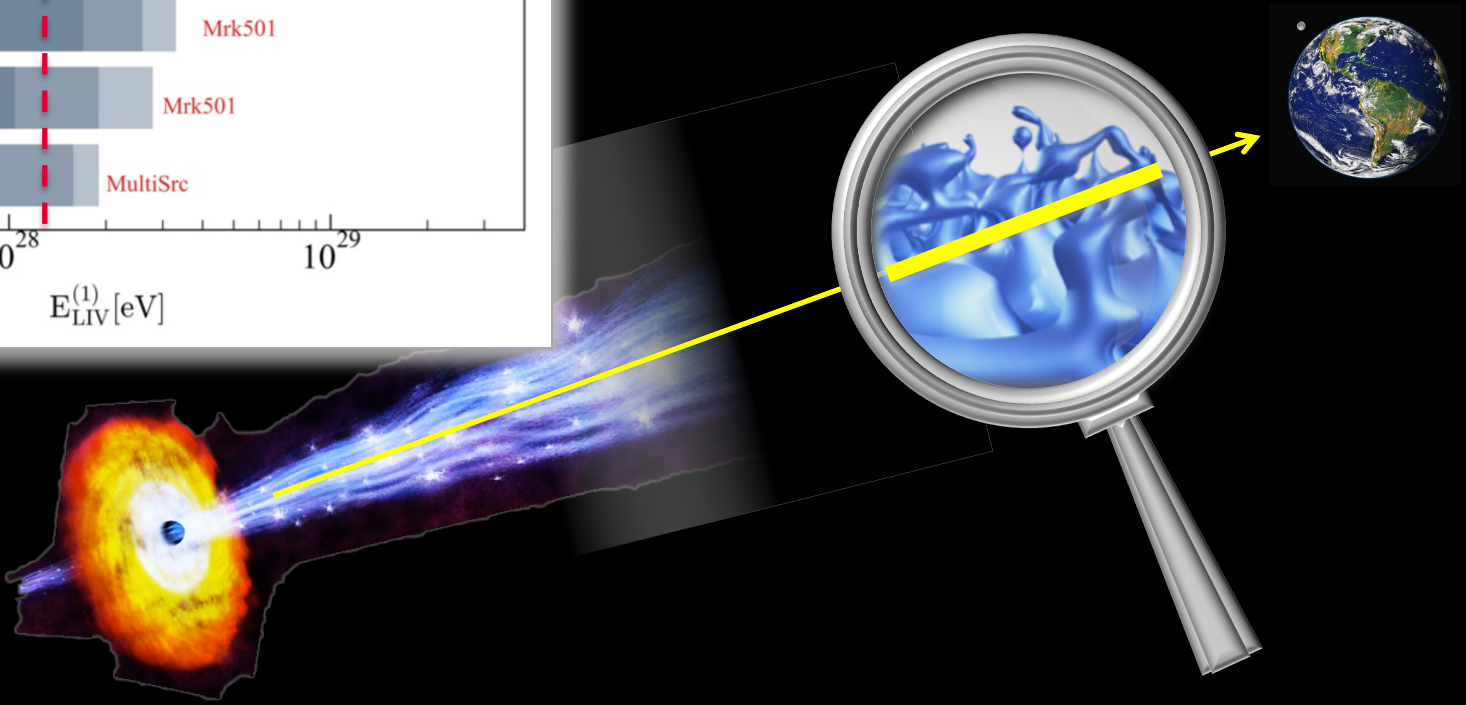
PHOTON PROPAGATION: PHOTON-AXION OSCILLATIONS

arXiv:2010.01349



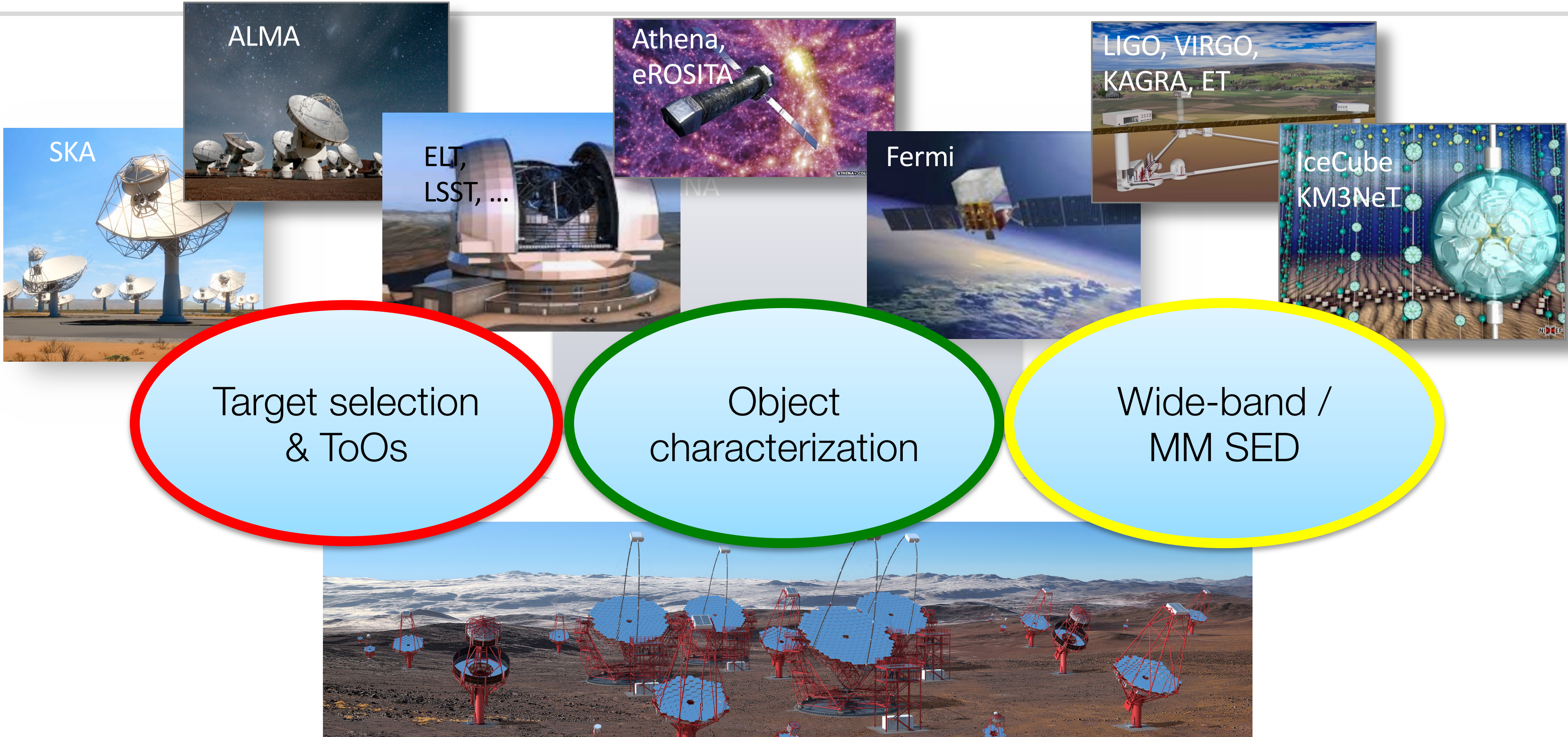
PHOTON PROPAGATION: VIOLATION OF LORENTZ INVARIANCE



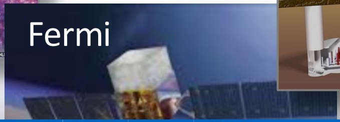


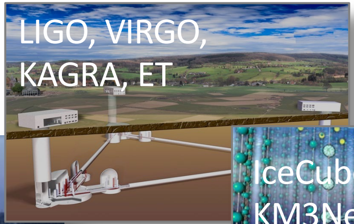
Current instruments:
H. Martinez-Huerta et al.
arXiv:1901.03205

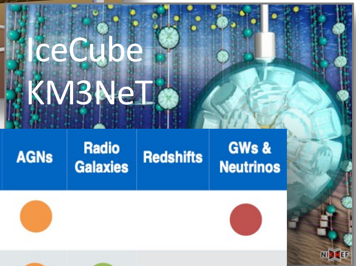
KSPs LIVE IN A MULTIWAVELENGTH & MULTIMESSENGER WORLD



KSPs LIVE IN A MULTIWAVELENGTH & MULTIMESSENGER WORLD







Target selection & ToOs

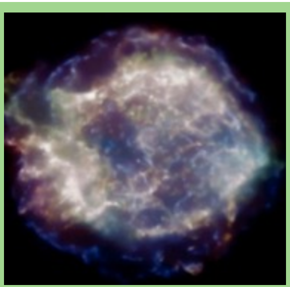
cl

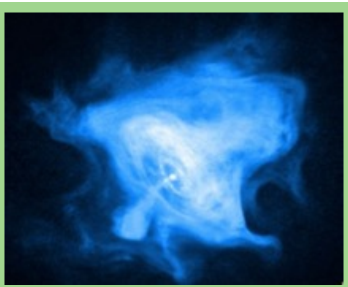
Band or Messenger	Astrophysical Probes	Galactic Plane Survey	LMC & SFRs	CRs & Diffuse Emission	Galactic Transients	Starburst & Galaxy Clusters	GRBs	AGNs	Radio Galaxies	Redshifts	GWs & Neutrinos
Radio	Particle and magnetic-field density probe. Transients. Pulsar timing.	Essential	Essential	Essential	Essential	Essential	Important	Important			Useful
(Sub)Millimetre	Interstellar gas mapping. Matter ionisation levels. High-res interferometry.	Essential	Essential		Essential	Essential	Useful	Important	Essential		
IR/Optical	Thermal emission. Variable non-thermal emission. Polarisation.	Essential	Essential		Important	Useful	Important	Essential	Essential	Essential	Useful
Transient Factories	Wide-field monitoring & transients detection. Multi-messenger follow-ups.				Important		Essential	Important			Important
X-rays	Accretion and outflows. Particle acceleration. Plasma properties.	Essential	Important	Important	Essential	Important	Essential	Essential	Essential		Important
MeV-GeV Gamma-rays	High-energy transients. Pion-decay signature. Inverse-Compton process	Essential	Important		Essential	Important	Essential	Essential	Essential		Essential
Other VHE	Particle detectors for 100% duty cycle monitoring of TeV sky.	Essential	Important		Essential	Important	Important	Essential			Essential
Neutrinos	Probe of cosmic-ray acceleration sites. Probe of PeV energy processes.	Useful	Useful	Important		Useful	Important	Important			Essential
Gravitational Waves	Mergers of compact objects (Neutron Stars). Gamma-ray Bursts.						Important				Essential

Essential
Important
Useful

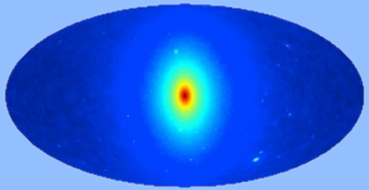
CTA: ENABLING A “PHASE TRANSITION” IN VERY HIGH ENERGY GAMMA RAY ASTRONOMY

In-depth understanding of known objects and their mechanisms





Expected discoveries of new object classes



The fun part:
Things we haven’t thought of

?