The Cherenkov Telescope Array

teresa.Montaruli@unige.ch

for the CTA Consortium

Sugar 2015, Genève, Jan. 23, 2015

UNIVERSITÉ DE GENÈVE

The CTA Consortium (CTAC)

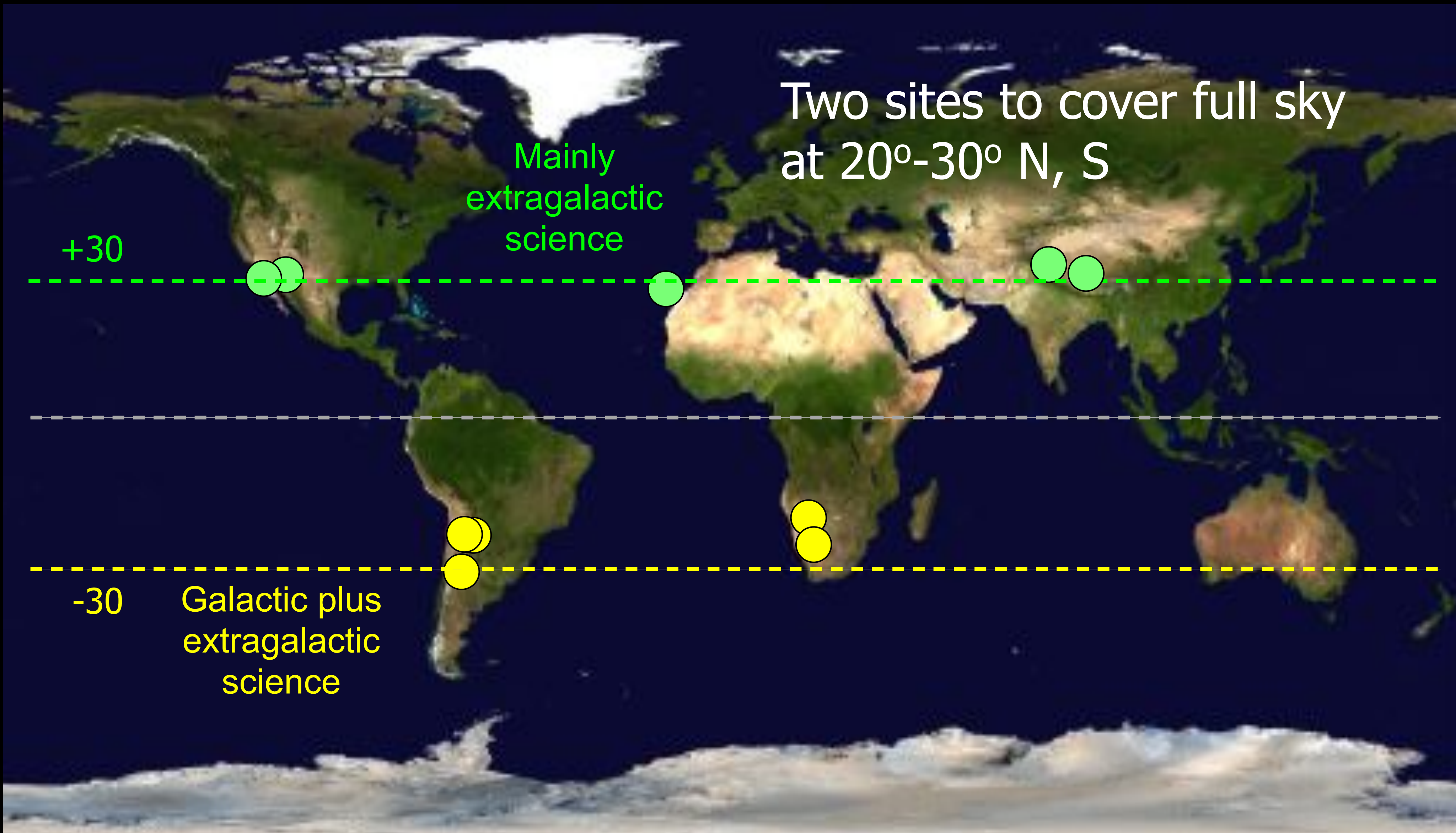
28 countries and 178 Institutions to form the CTA Consortium, 375 FTE, about 1193 scientists

http://cta-observatory.org/

Interim Legal Entity: CTA GmbH founded by Germany, Italy and Switzerland

Construction through in-kind contributions

CTA Sites

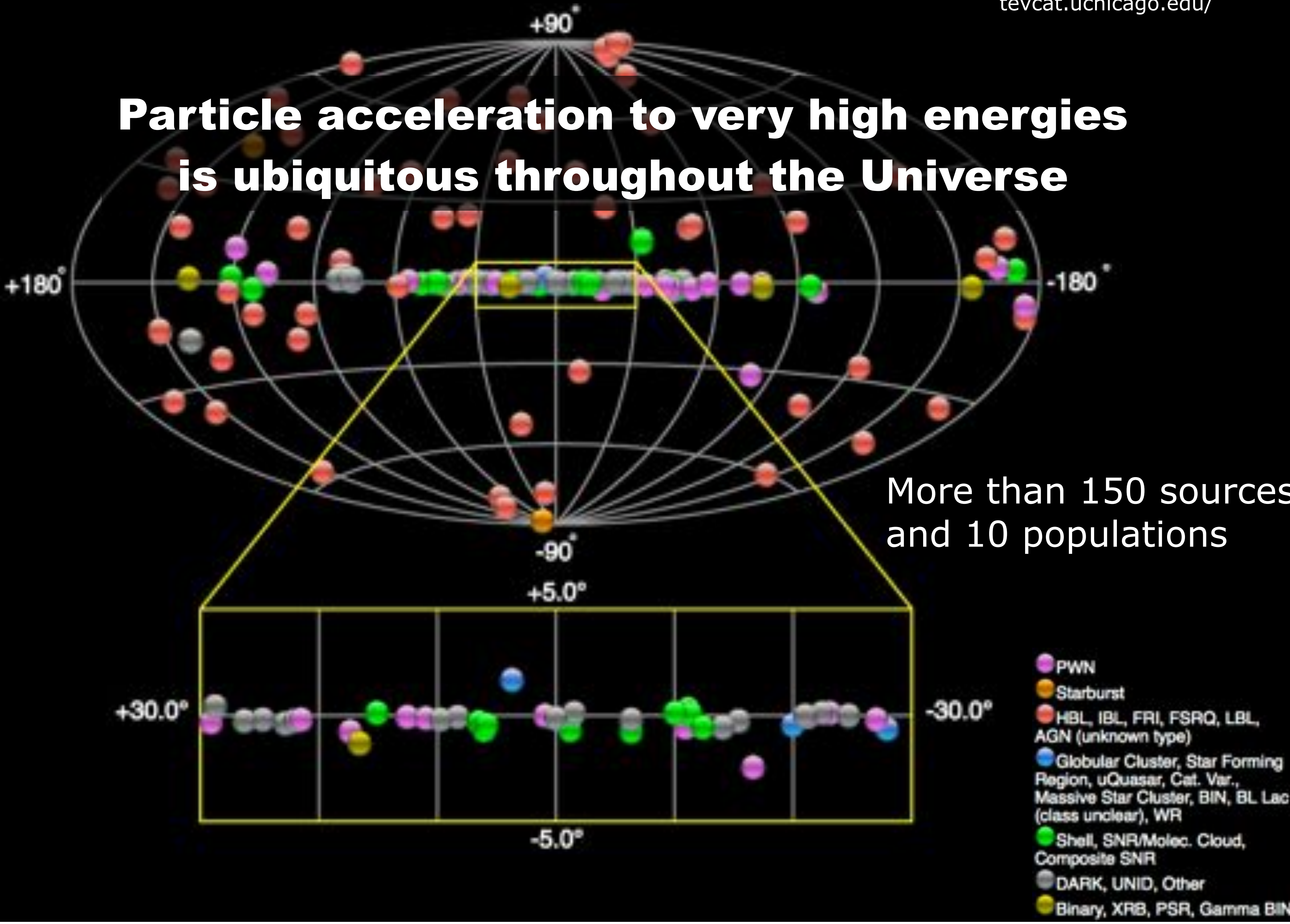

Two sites to cover full sky
at 20º-30º N, S
Mainly
extragalactic
science
+30
-30
Galactic plus
extragalactic
science

CTA Sites: Candidates

+additional lower priority candidates

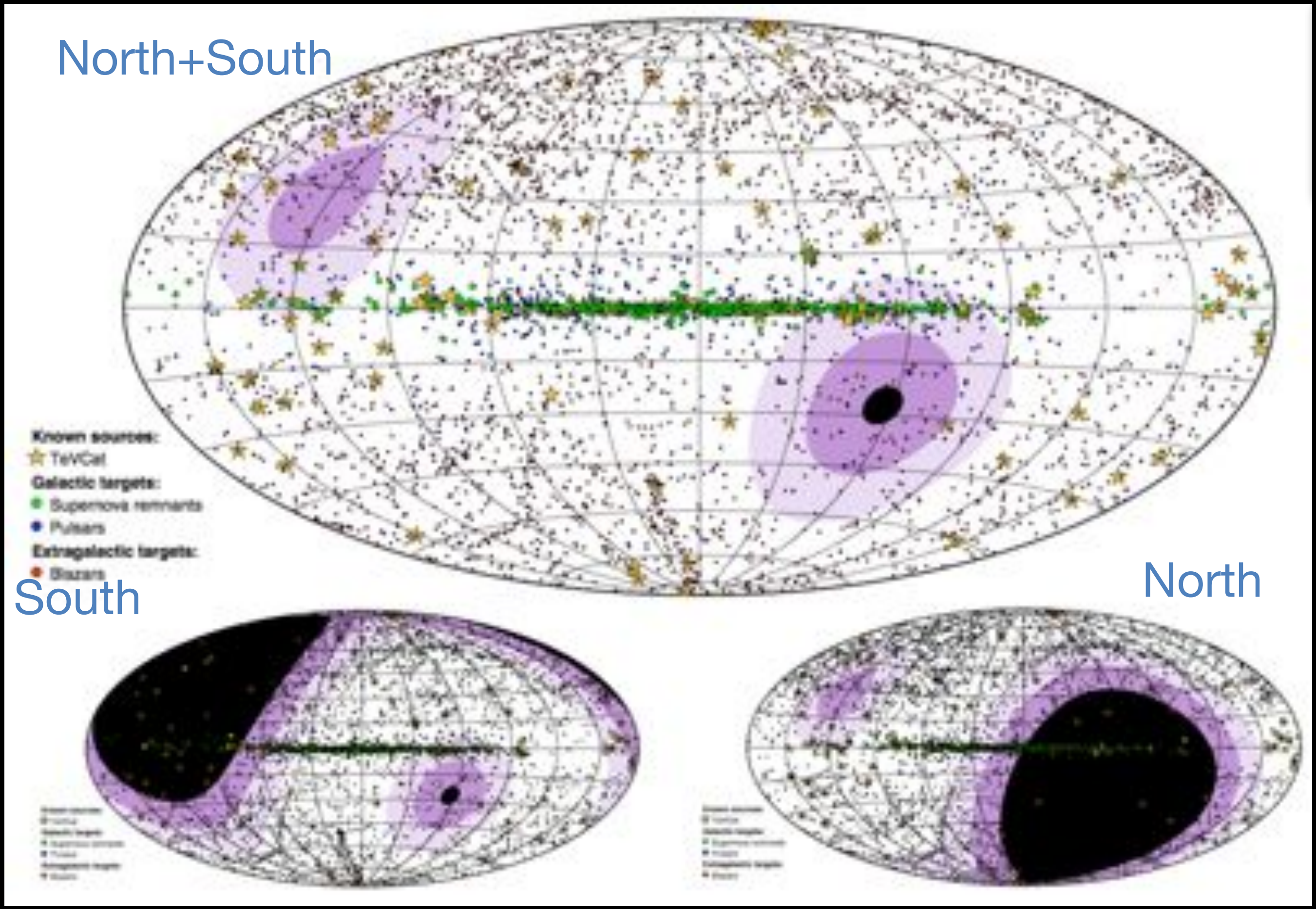
tevcat.uchicago.edu/

Particle acceleration to very high energies is ubiquitous throughout the Universe



More than 150 sources and 10 populations

The Sites and sky coverage



>60° zenith
45°-60°
30°-45°

South: ESO CHILE close to E-ELT (ok on Dec 4, 2014) or Aar in Namibia

Decision: June/July 2015
Negotiation started with countries in Oct. 2014
North: decision for which site to negotiate with in Spring 2015 (Arizona, Canary Islands, San Pedro Martir)

BASELINE:
SOUTHERN AND NORTHERN SITES

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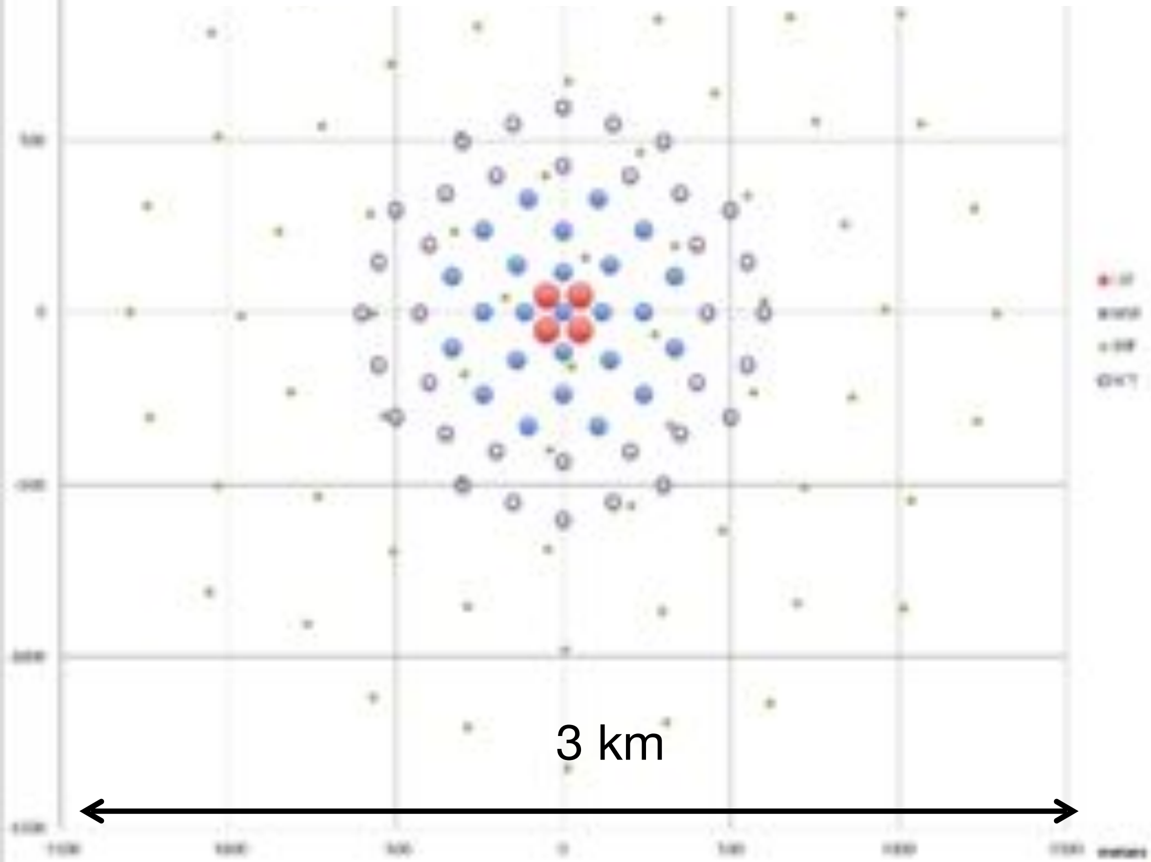
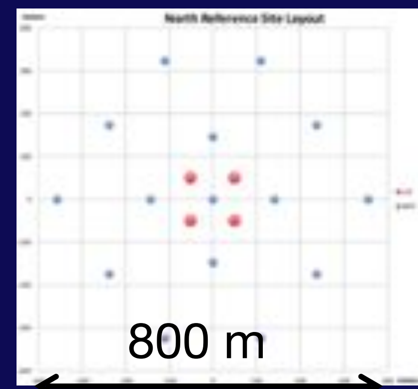
South site

4 large 23 m telescopes: LST (20-200 GeV)
25 medium12 m telescopes: MST (200 GeV-5 TeV)
24 medium 10 m SCT expansion (US)
70 small 4 m telescopes: SST (5 TeV – 300 TeV)



North site

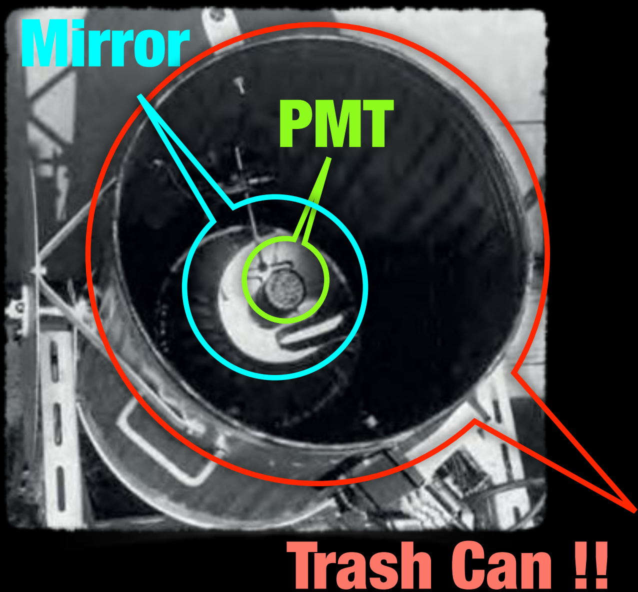
4 large LST
15 medium MST



~2/3 of all current sources in Southern sky

Builds up on experience…

Galbraith, W., Jelley, J.V..
1953, Nature,171,349

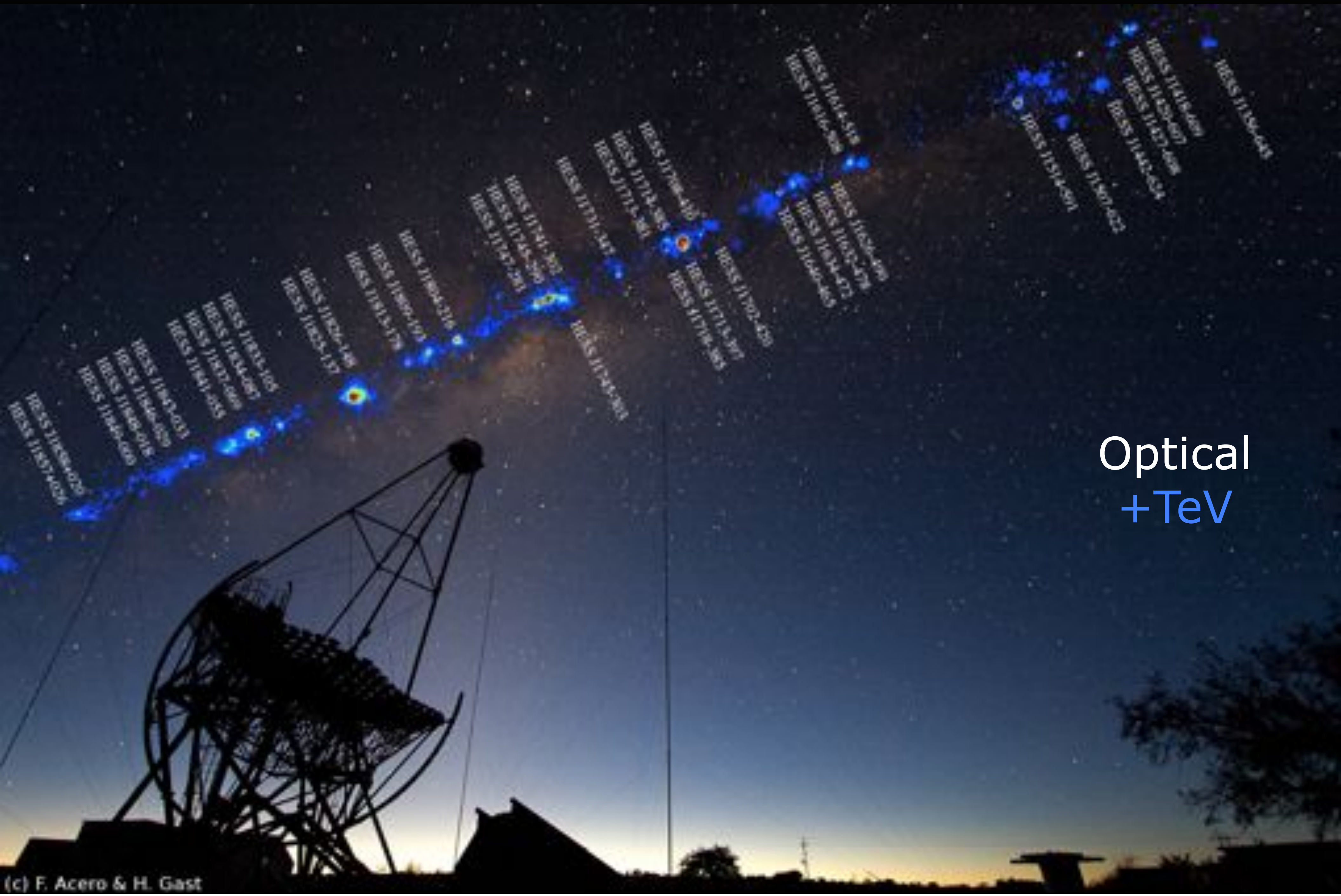


H.E.S.S TELESCOPES (NAMIBIA)

VERITAS TELESCOPES (Arizona)

MAGIC TELESCOPES (LA PALMA)


Optical
© Fabio Acero


Optical
+TeV
(c) F. Acero & H. Gast

Why an Open Access Observatory?

Large investment of a world-wide community can only be open access.

Recommendation of ASTRONET Panel-A on High-Energy Astrophysics, Astroparticle and Gravitational Waves:
Strengthen multi-wavelength collaborations through dedicated programmes and grants"

ApPEC draft of Roadmap: "…**in the next decade or two we will collect the harvest of the recently opened high-energy gamma-ray astronomy" and see the opening of the new astronomies: gravitational waves, neutrinos and high-energy cosmic rays**".

ESFRI Roadmap Category 2: **an experiment that can be ready for construction in 2015.**

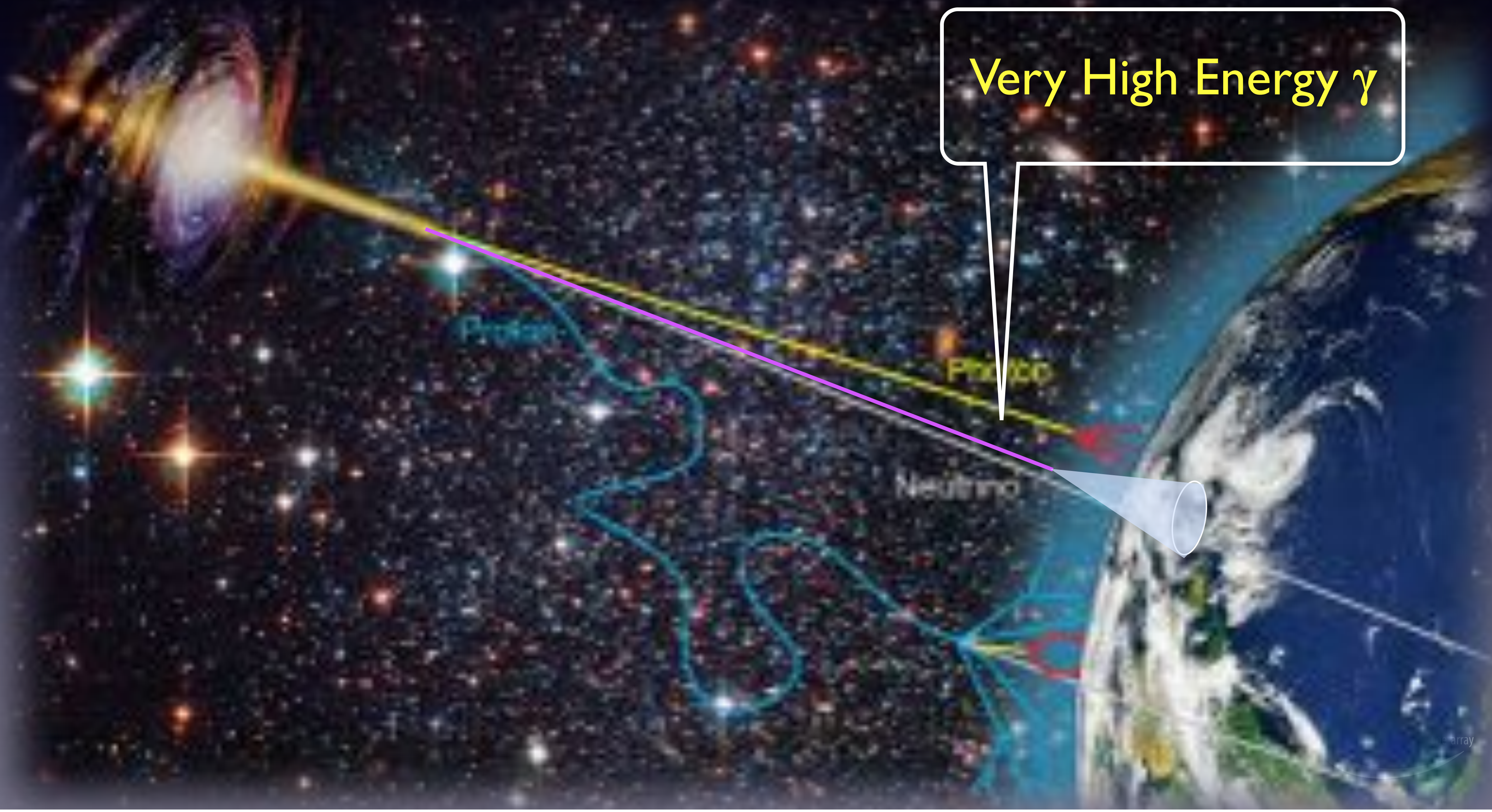
HIGH-IMPACT OBSERVATORIES

Rank	Facility	Citations	Participation
1	SDSS	1892	14.3%
2	Swift	1523	11.5%
3	HST	1078	8.2%
4	ESO	813	6.1%
5	Keck	572	4.3%
6	CFHT	521	3.9%
7	Spitzer	469	3.5%
8	Chandra	381	2.9%
9	Boomerang	376	2.8%
10	HESS	297	2.2%

High-Impact Astronomical Observatories:
http://www.nature.com/news/2009/090206/full/news.2009.81.html and arXiv:0901.4552

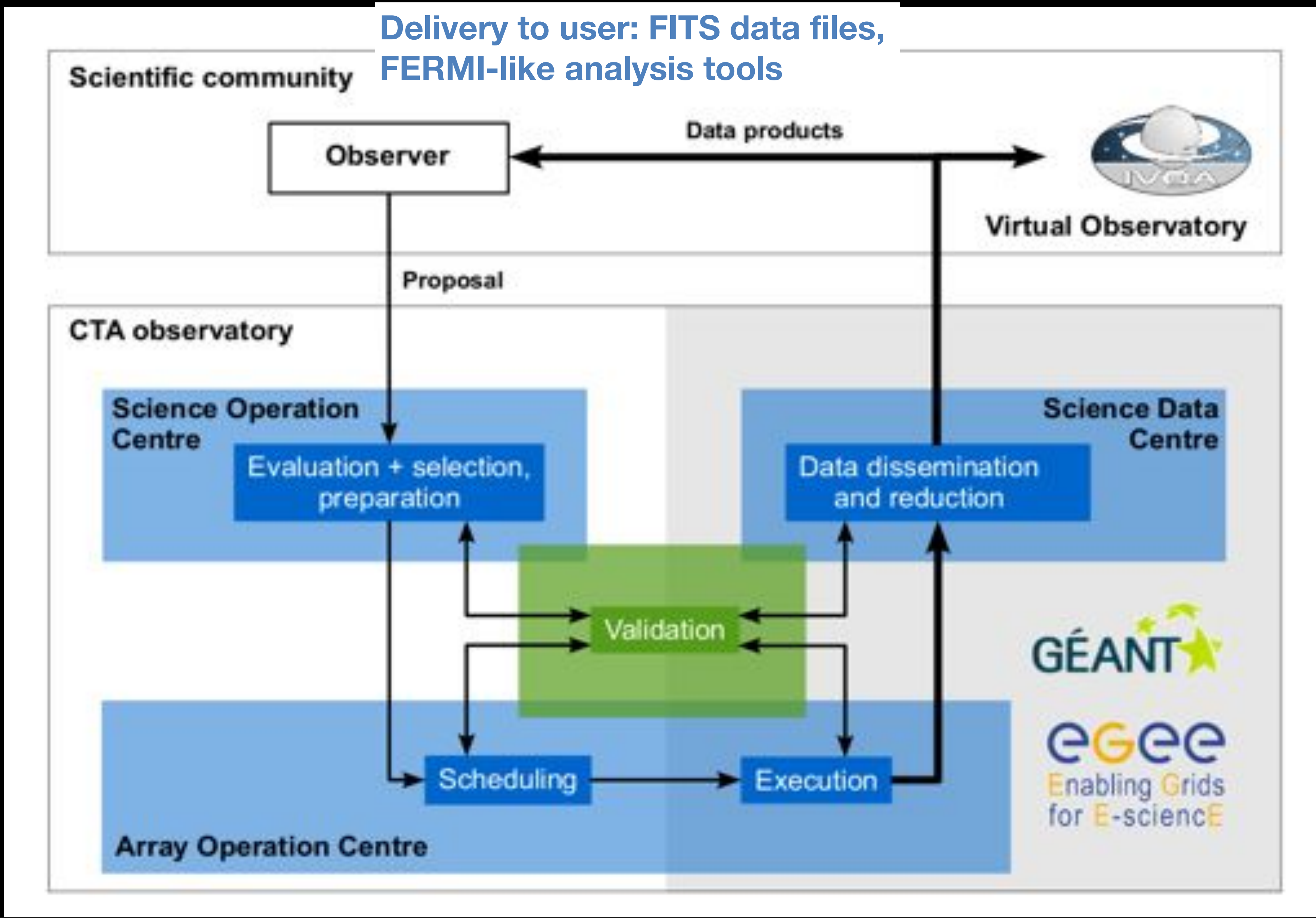
The Astronomies

Hints from UHECRs but composition is a potential issue
The neutrino astronomy birth with IceCube (see JA Aguilar's talk) - covers Gpc scale
Gravitational waves not shown but discovery expected with upgraded interferometers



FOR THE FIRST TIME IN THIS FIELD: OPEN ACCESS

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



Requirement & Drivers

Energy coverage down to 20 GeV Discovery domain : GRBs, Dark Matter

Energy coverage up to 300 TeV (Pevatrons, hadron acceleration)

Good energy resolution of ~10-15% (lines, cutoffs)

Large Field of view 8-10° (surveys, extended source, flares)

Rapid Slew (20 s) to catch flares (Pevatrons)

10x Sensitivity & Collection Area (nearly every topic)

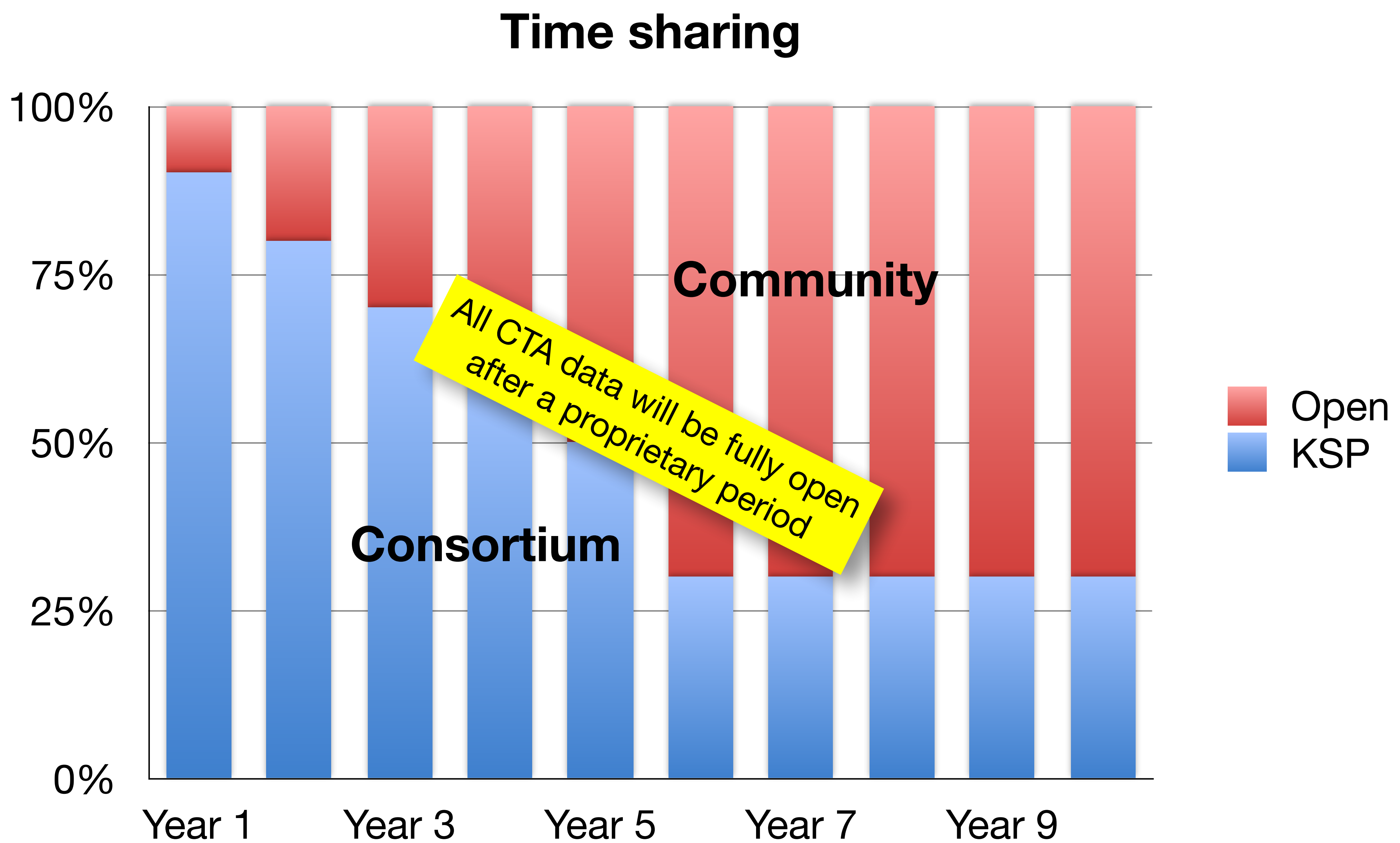
Angular resolution < 0.1° above 200 GeV *source morphology*

KEY SCIENCE PROJECTS

1. CTA Galactic Plane Survey
2. CTA Extragalactic Survey
3. Exploring extreme particle acceleration in the Galaxy
4. Probing DM with precision measurements of the Galactic Center
5. CTA studies on active galaxies
6. On the connection between cosmic rays and the star-formation process
7. Observations of clusters of galaxies
8. Observations of the LMC
9. Observations of the Cygnus region
10. Observation of Galactic DM dominated targets
11. Observations of transient phenomena

Between them a few will be selected by a committee of experts

FROM KSP TO CTAO



Astroparticle Physics 43 (2013)

High Energy Astrophysics Quests:

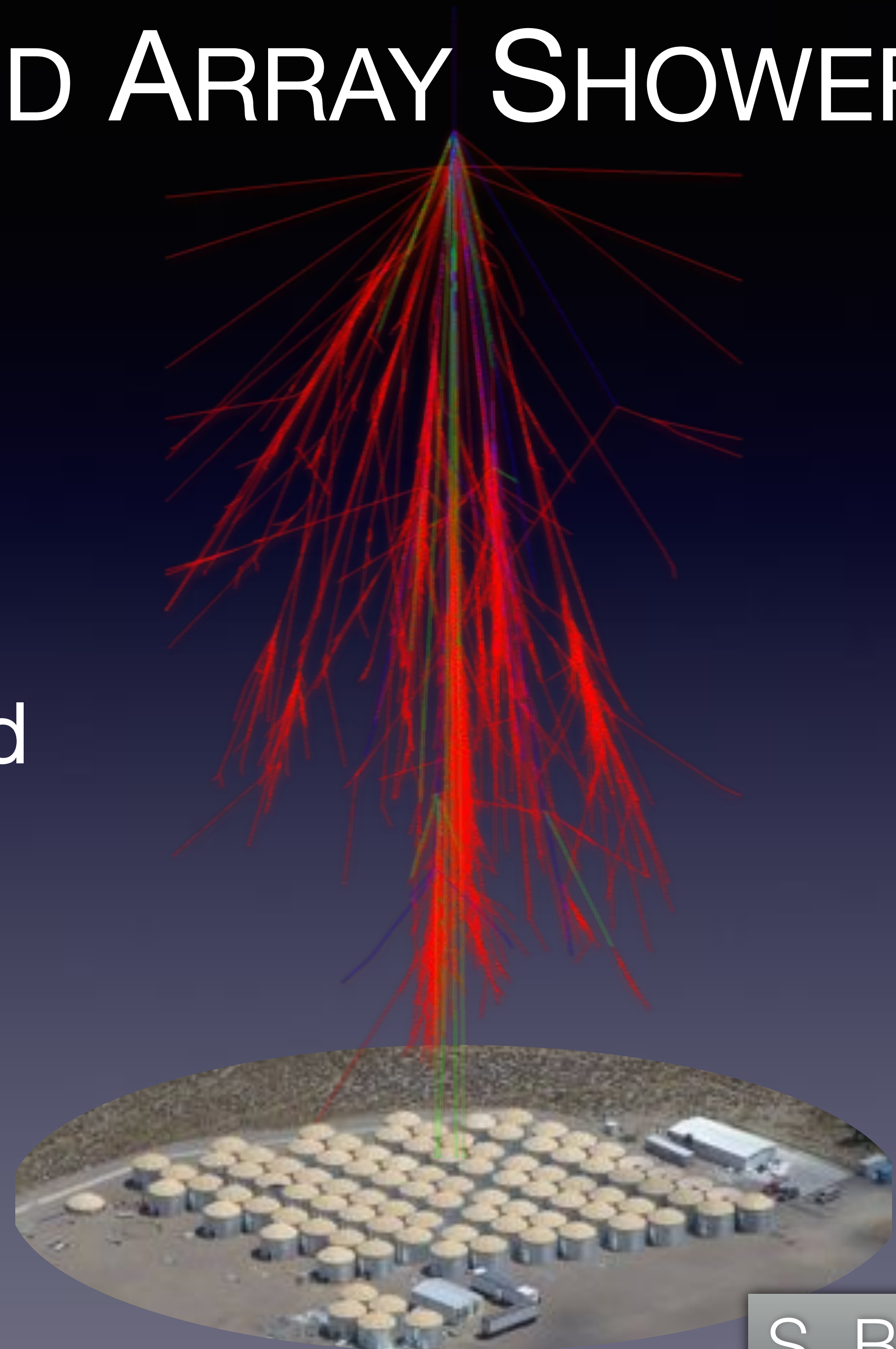
- **The understanding of the origin and role of the relativistic cosmic particles,** the cosmic rays, that populate our Galaxy and continuously hit our atmosphere. The scope of CTA is to identify their sources, to understand the role that CRs rays play in feedback on star formation and galaxy evolution

Discover new classes of objects or known sources not seen before in gamma-rays from ground (unid sources also extended, GRB, Fermi bubbles…)

- **Probing extreme environments, such as neutron stars, black holes and gamma-ray bursters.** The scope is to understand the processes at work close to neutron stars and black holes, the characteristics of relativistic winds, the intensity and evolution of magnetic fields accelerating radiation in these sources, the reason why the hadron acceleration is less efficient than expected.
- **Exploring frontiers in physics**, what is the nature of the dark matter and how it is distributed in the universe, axion particles interplay with magnetic fields, quantum gravitational effects in photon propagation.

EAS - Extended Array Shower

- 24 hour duty cycle
- Wide field of View
- High Energy threshold



S. Benzvi
HAWC

P.E. in the Image

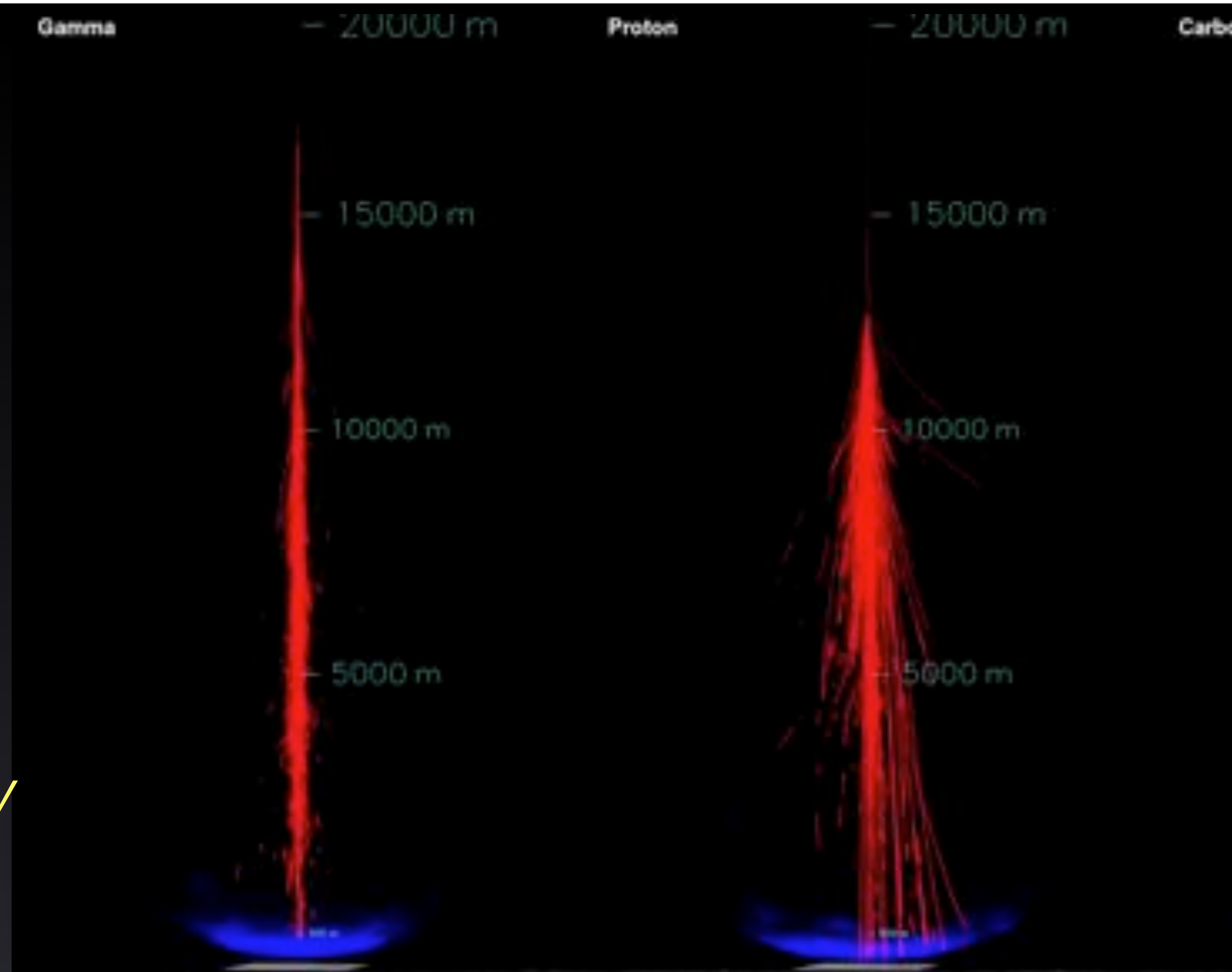
↳ *Shower Energy*

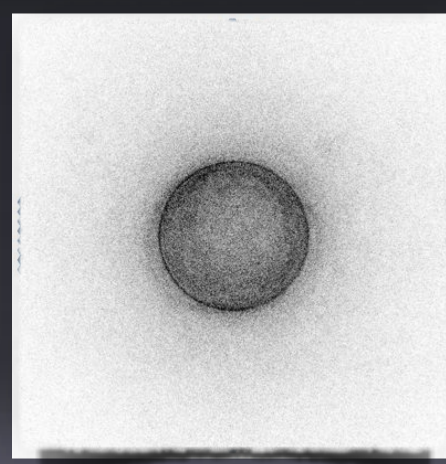
Image Shape

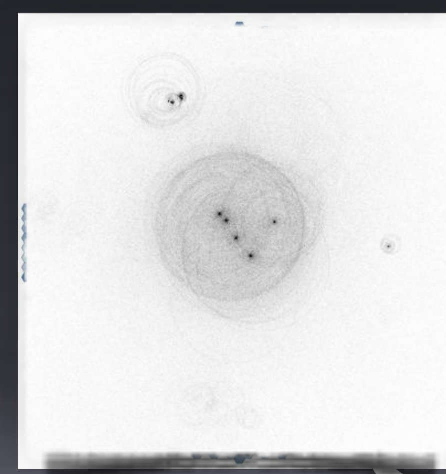
↳*gamma-hadron discrimination*

Orientation of gamma-ray image

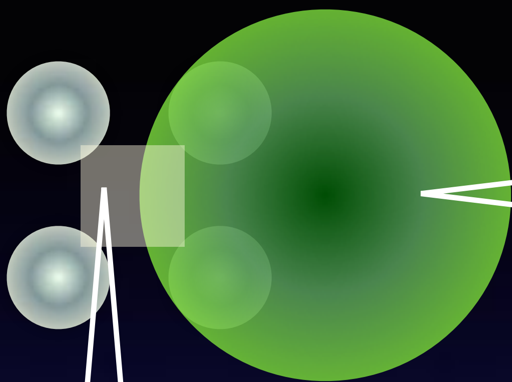
↳ *Shower Direction*





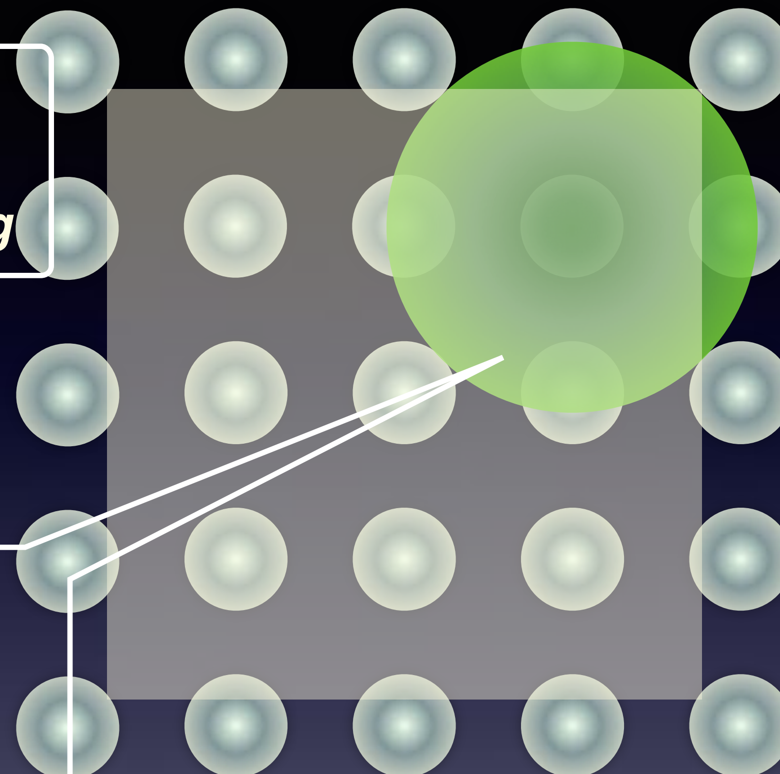


From current arrays to CTA

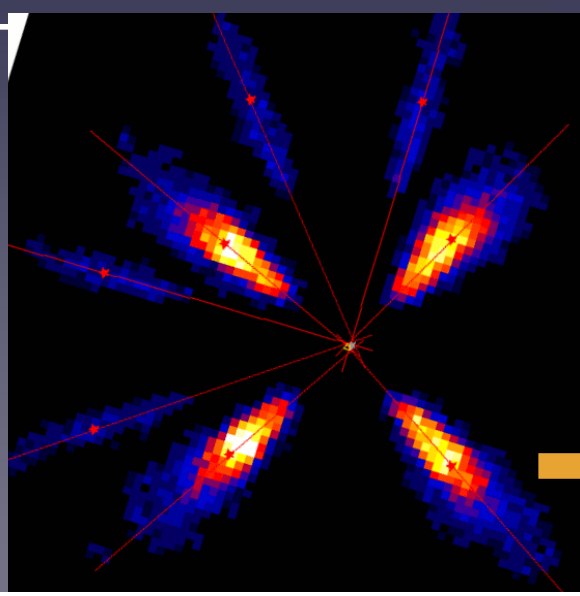


Light pool radius
R ≈ 100-15-m
≈ typical telescope Spacing

Sweet spot for best triggering & reconstruction …
most shower miss it!



- ✓ ***Large detection Area***
- ✓ ***More Images per shower***
- ✓ ***Lower trigger threshold***



✓ Improved angular resolution

✓ Improved background rejection power

➡ More telescopes!

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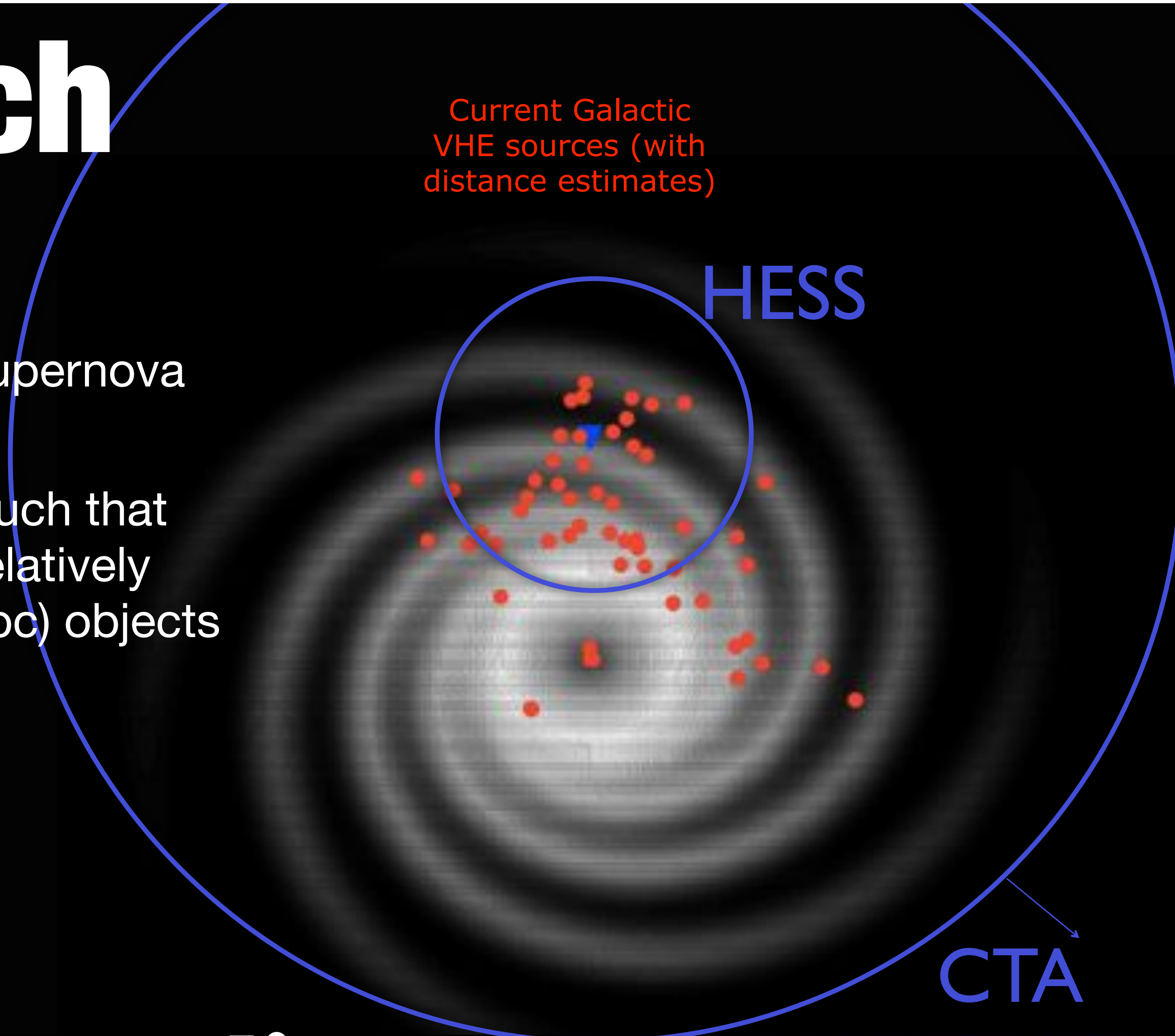
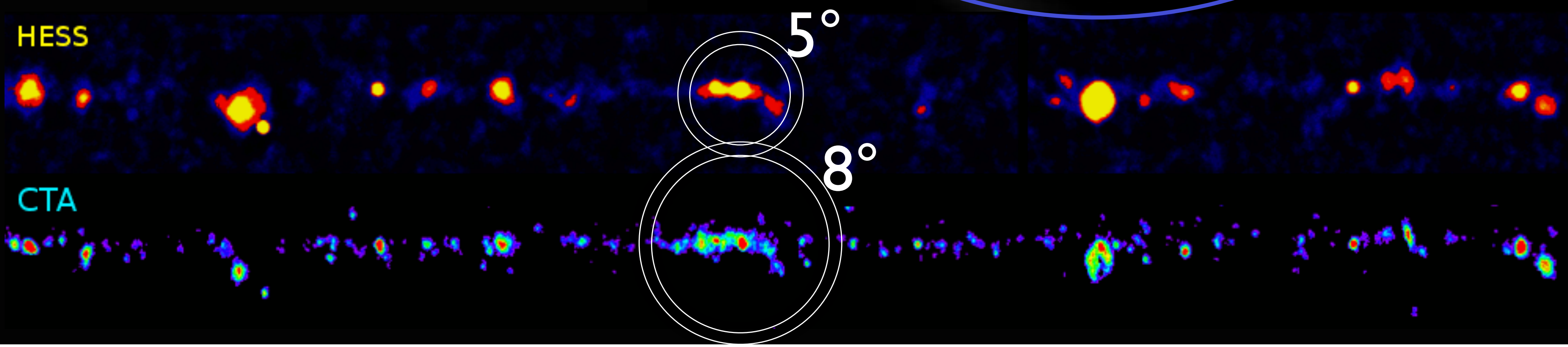
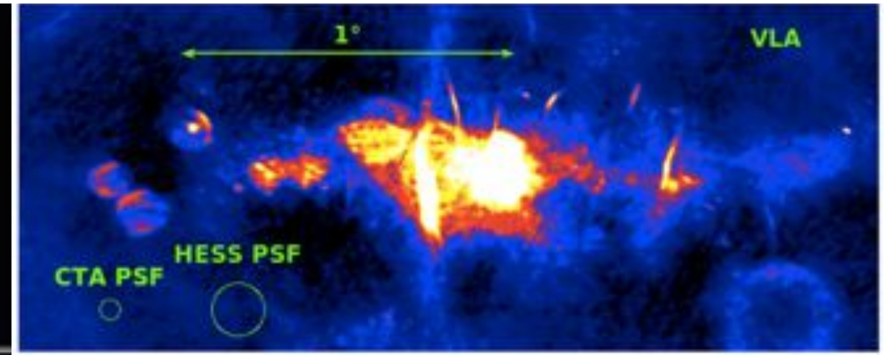
CTA Reach

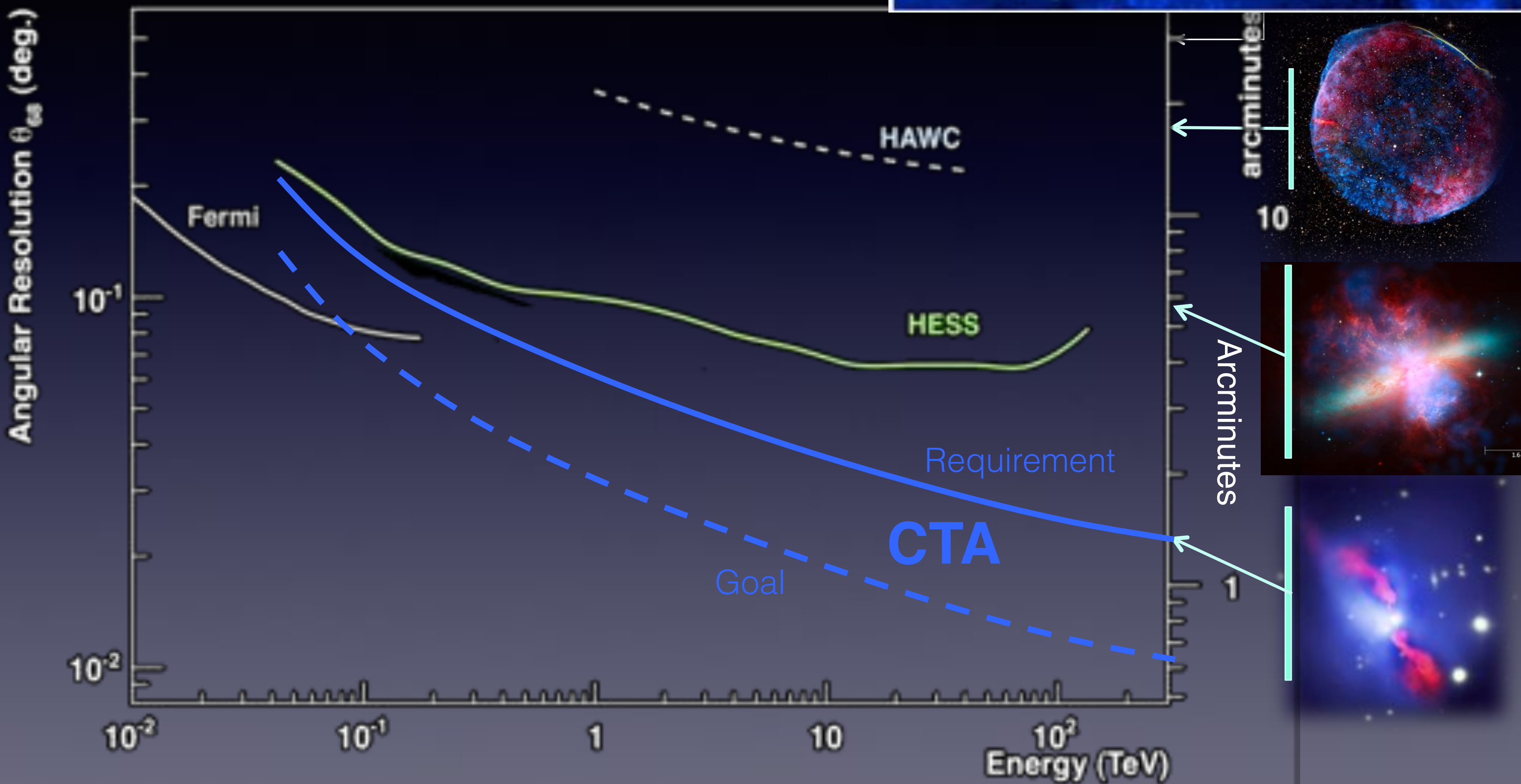
- ➡e.g. **Galactic objects**
  - Newly born pulsars and the supernova remnants
    - have typical brightness such that HESS etc can see only relatively local (typically at a few kpc) objects
  - CTA will see **whole** Galaxy
- ➡Field of view + sens.
  - Survey speed ~300×HESS





CTA RESOLUTION





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BETTER ANGULAR RESOLUTION

_0.004°_
XMM 10 keV

_0.1°_
Simulation with current IACT

_0.02°_
CTA @ few TeV

➡ *sub-structure of SNR shock fronts will become visible at TeV energies;*

➡ *source morphologies*

Blasi's talk

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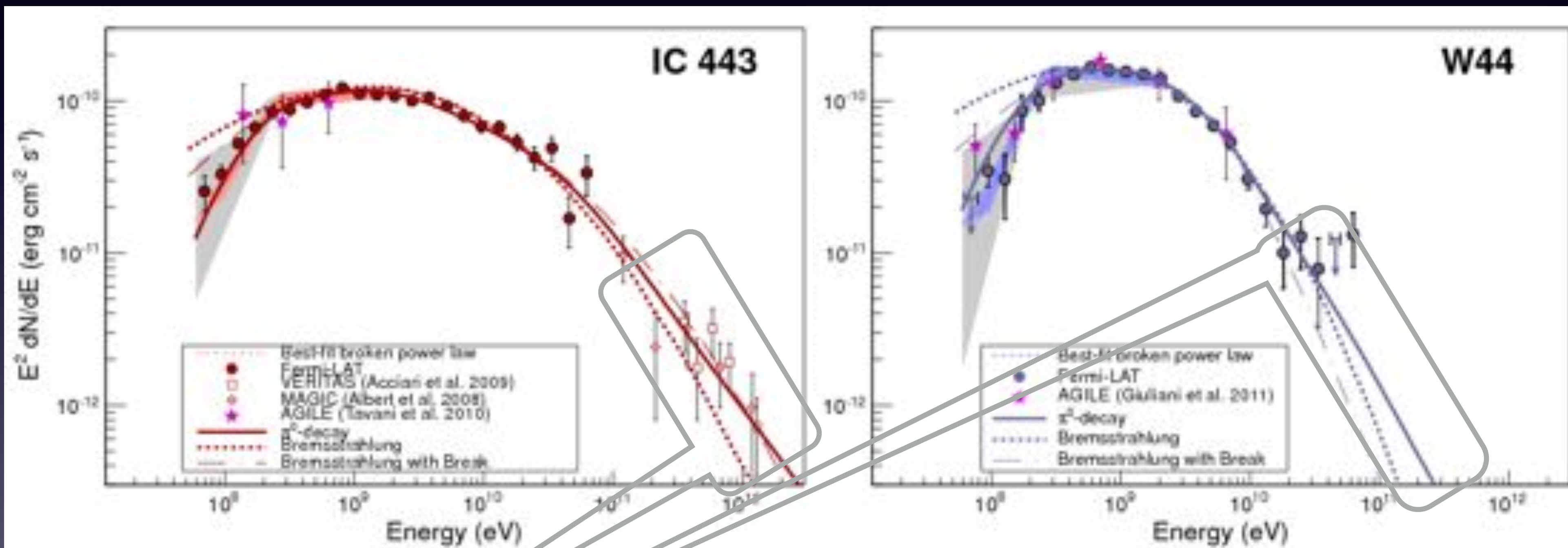
(V)HE Measurements

IC433 and W44 are older SNRs interacting with molecular clouds

W51C at this workshop



Ackermann et al. (Fermi Collaboration), Science, 339, 807 (2013)

Better data at higher energy are fundamental!
Serendipity still possible, see HESS J1641-463

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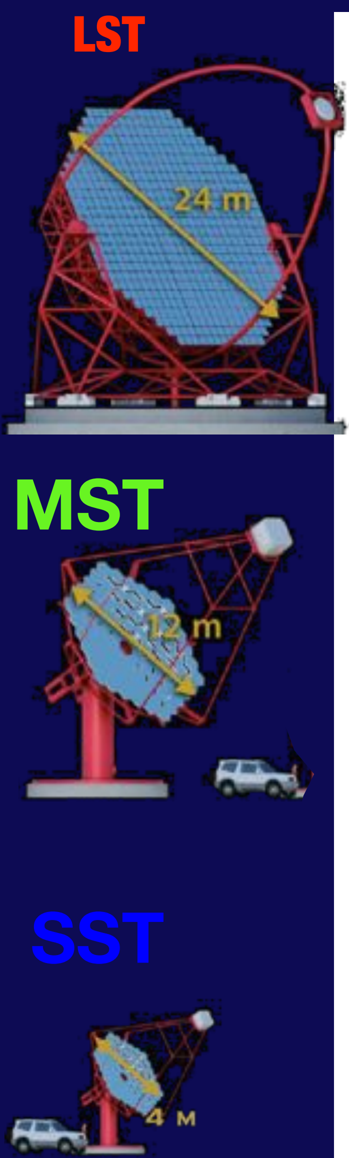
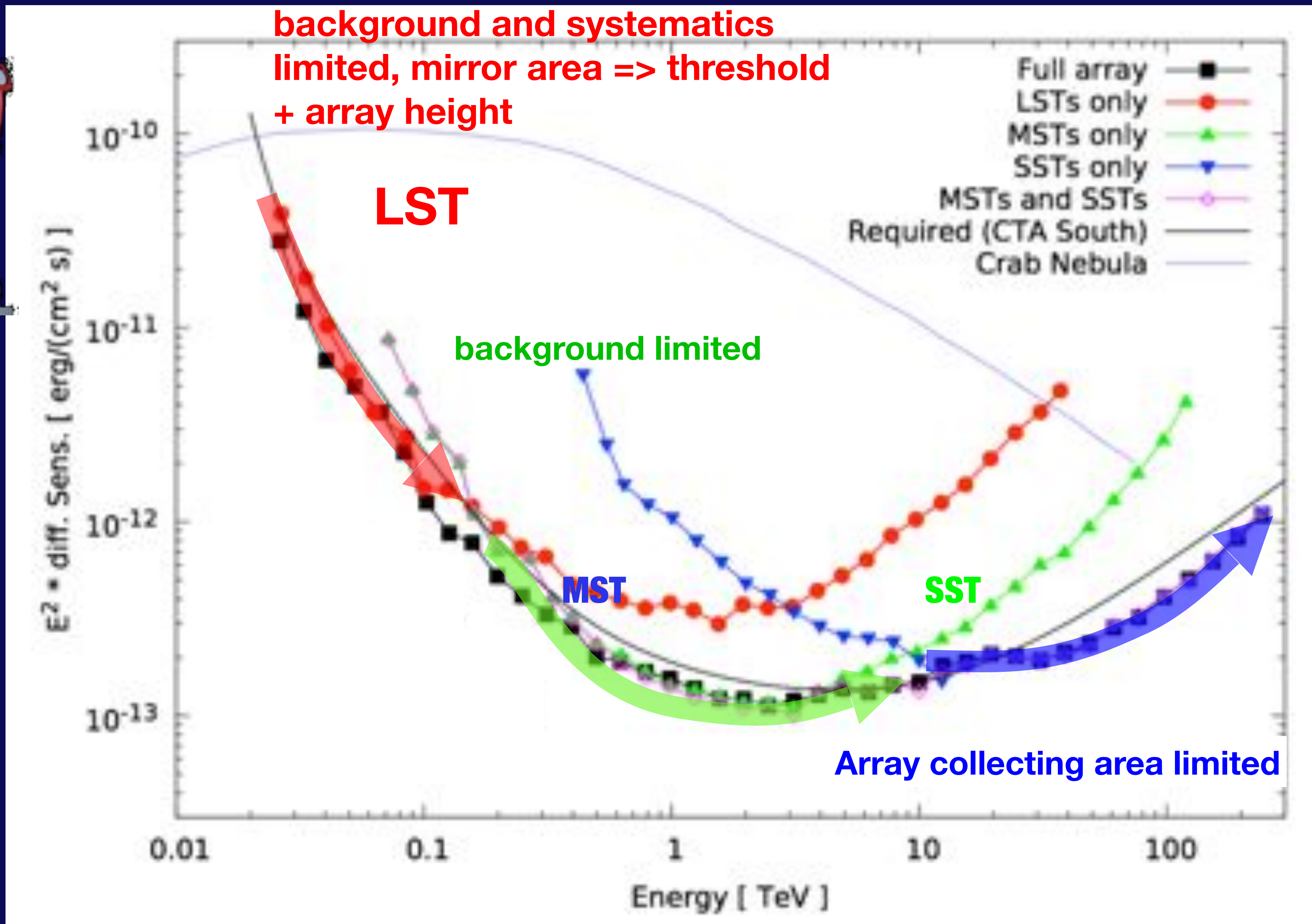
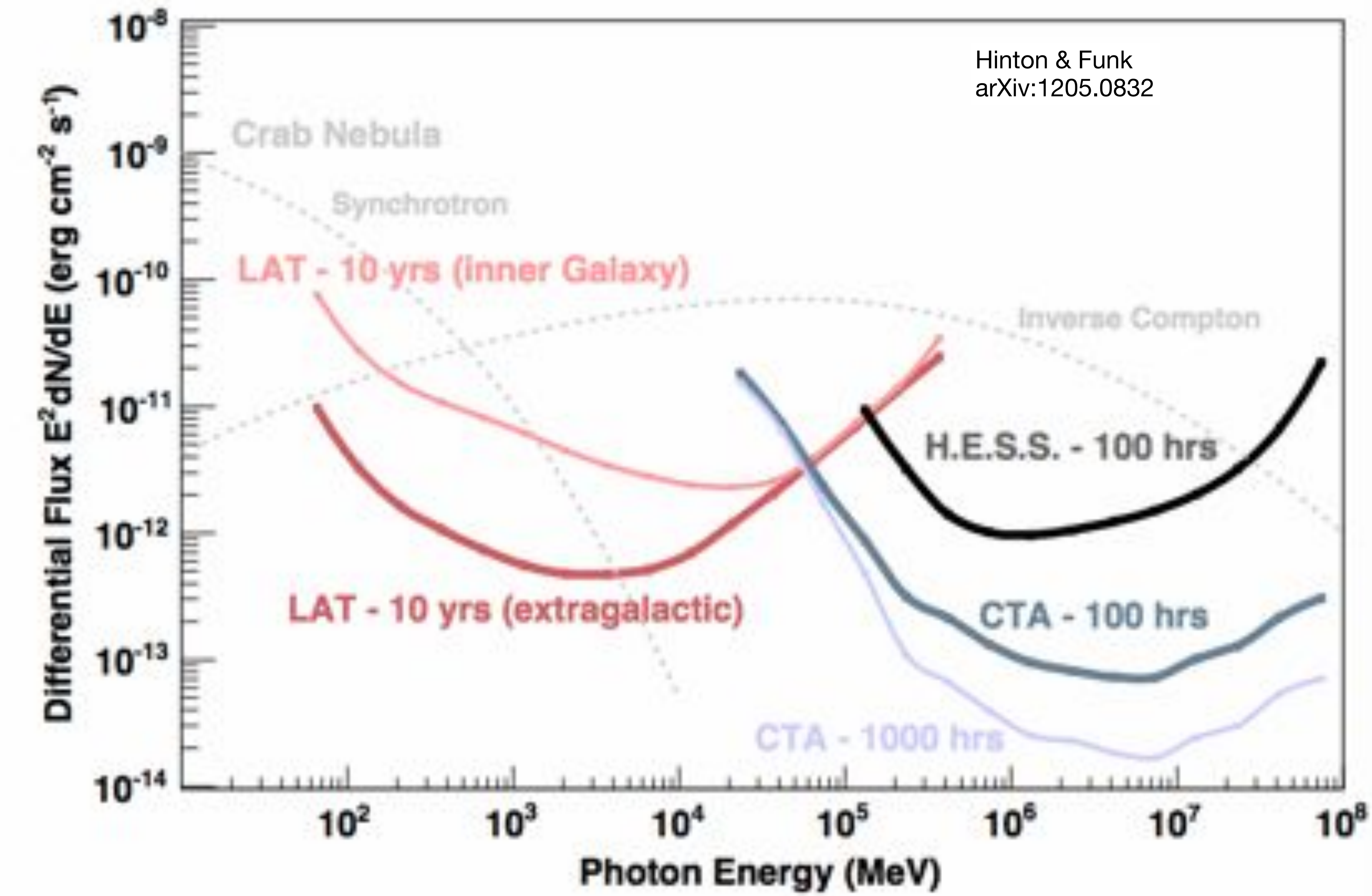
Sensitivity
for detection in each 0.2-decade energy band



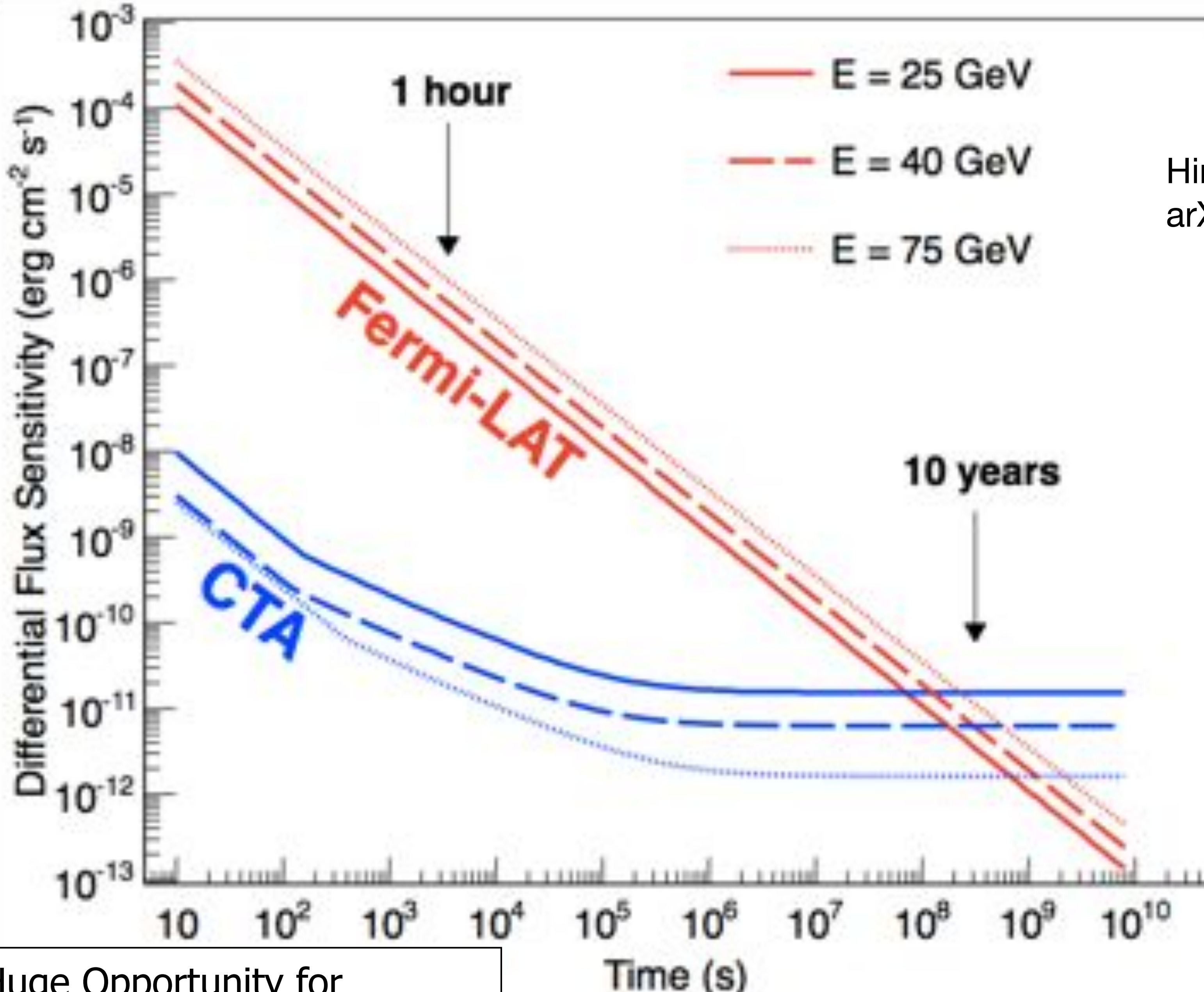


Differential flux sensitivity



Extend to uncovered energy range for discoveries

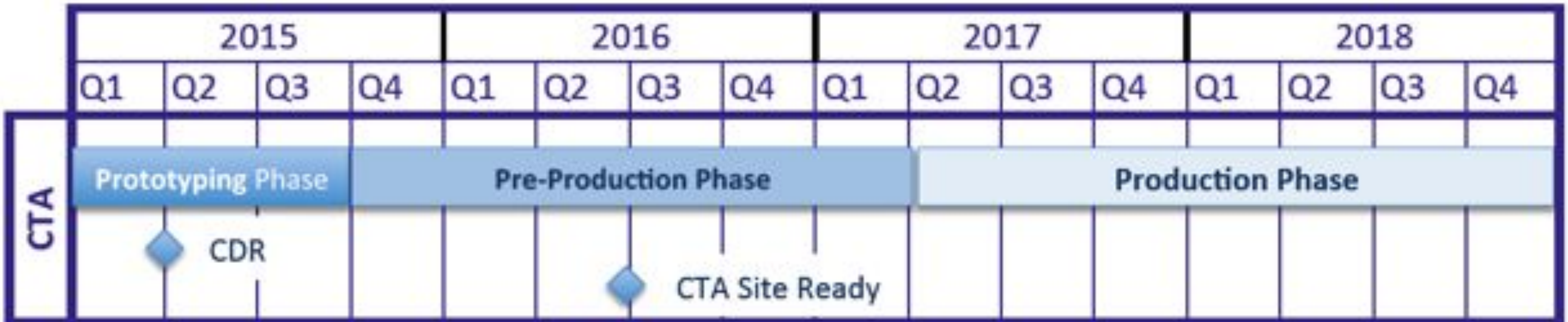
TRANSIENTS WITH CTA

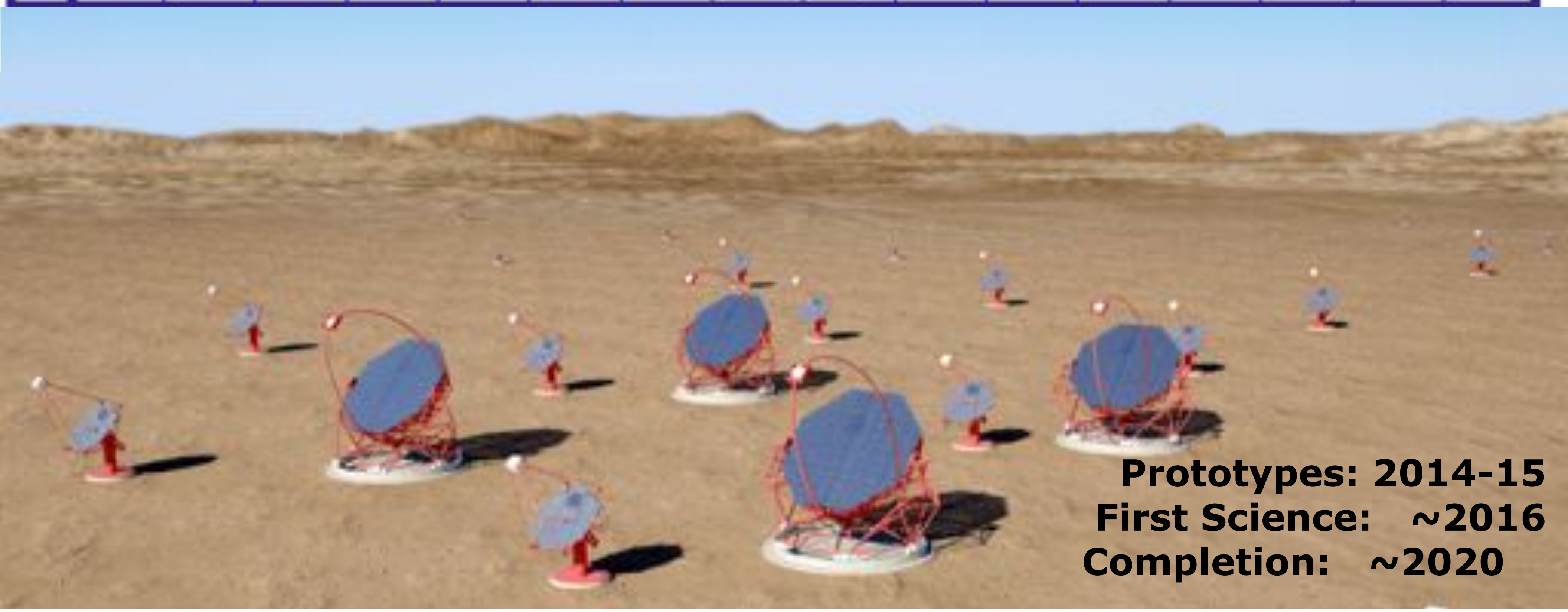


Hinton & Funk
arXiv:1205.0832

Huge Opportunity for
short-timescale phenomena:
GRBs, AGN/Microquasar flares, ...

THE CHERENKOV TELESCOPE ARRAY SCHEDULE





Prototypes: 2014-15
First Science: ~2016
Completion: ~2020

MST: INAUGURATION DESY-ZEUTHEN, MAY 2013

SST-1M Krakow 2nd June 2014 Official Inauguration

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

AGH
University of

Centrum Badań

Nicolaus Copernicus
Astronomical Center

Universität Zürich[UZH]

Institute of Nuclear Physics
Polish Academy of Science

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

ISDC
DATA CENTRE FOR ASTROPHYSICS

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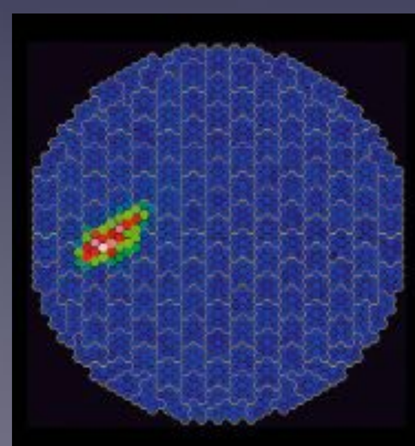
THE FACT LEGACY

- New approach, use GAPD-based camera on a Davies-Cotton telescope.
- Operation during Moonlight: ~30% larger duty cycle
- Excellent single PE sensitivity
- Lightweight and robust cameras
- No evidence of ageing after 18 months
- Current Photodetection Efficiency at around >35%.
- New developments are promising and can reach ~ 50% with negligible cross-talk and dark count

H.~Anderhub et al., JINST8 (2013), arXiv:1304.1710



Innovative camera records cosmic rays during full moon

CERN COURIER - Nov 23, 2011

One of the first showers recorded by FACT during a full moon.

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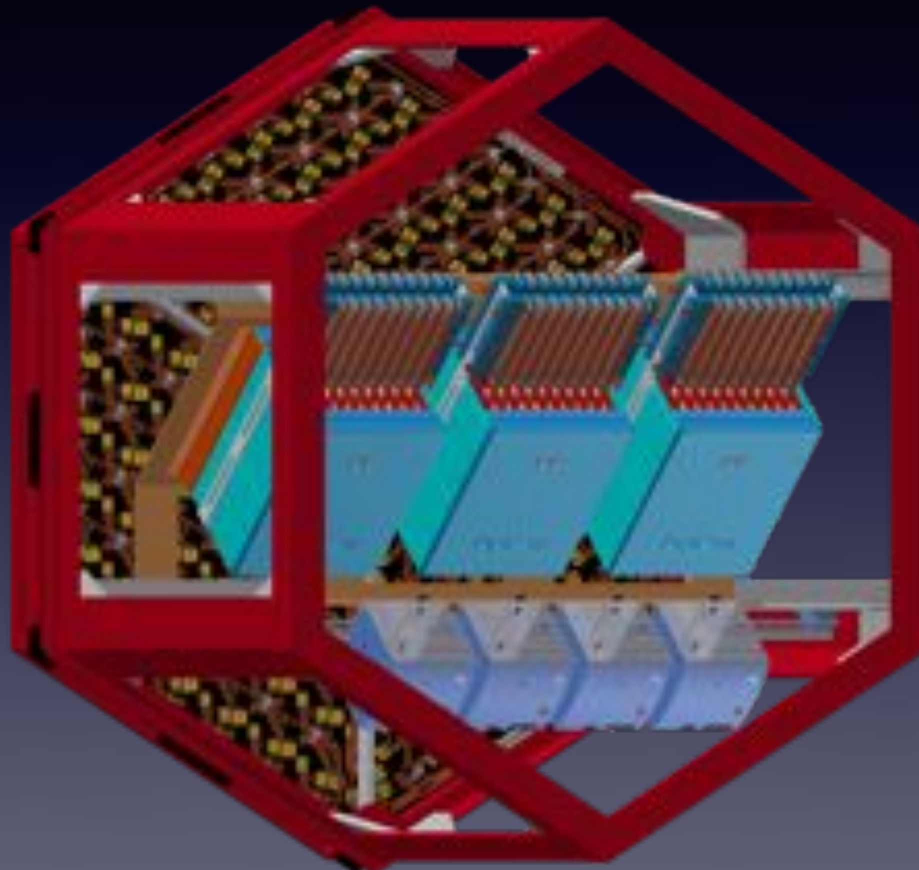
THE CAMERA CONCEPTS

- **Separation of PDP and Readout, analogue signal over CAT5/RJ45**
  - PDP - 88 cm flat-to flat
  - 1296 hexagonal pixel
  - power ~ 600 W
  - weight ~35 kg



- **DigiCam - fully digital readout**
  - *Data coming from PDP are digitised in FADC@250MHz*
  - *Fully configurable trigger logic in FPGA*
  - *Data shipped to a camera server*
  - *weight ~30 kg*
  - *Power ~ 1.5kW*

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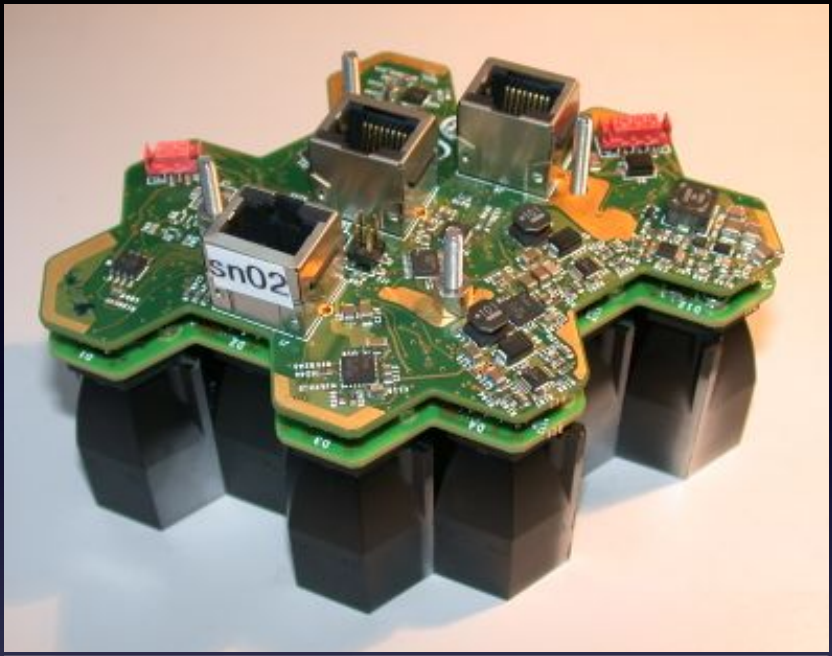
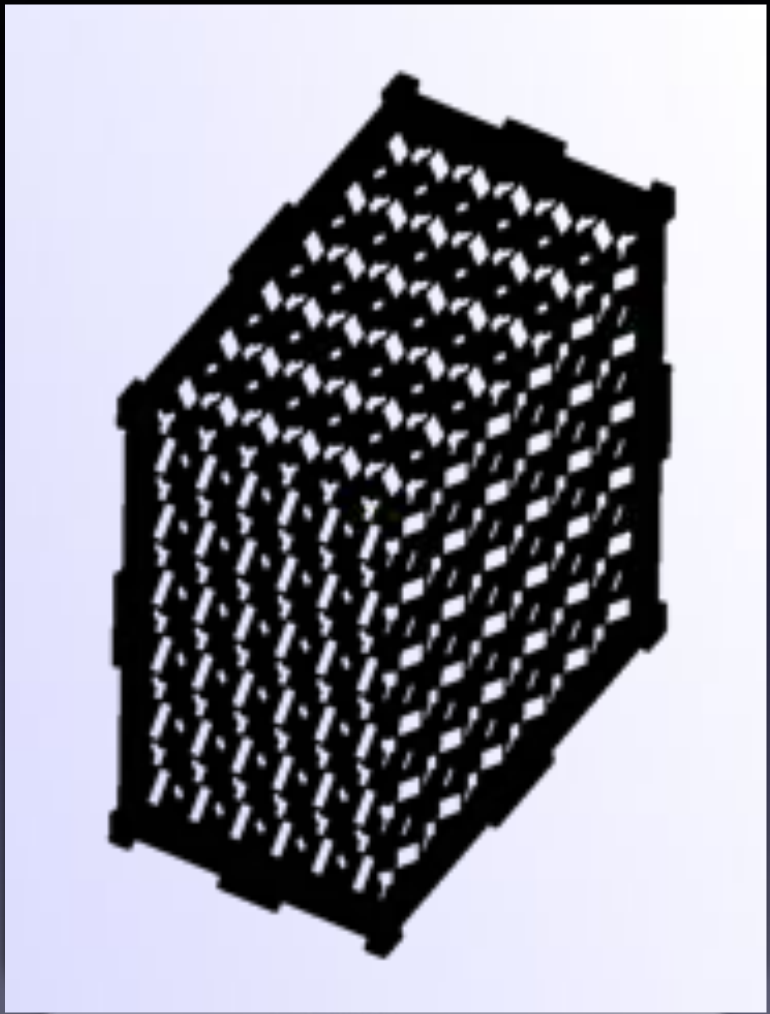
THE PHOTODETECTION PLANE





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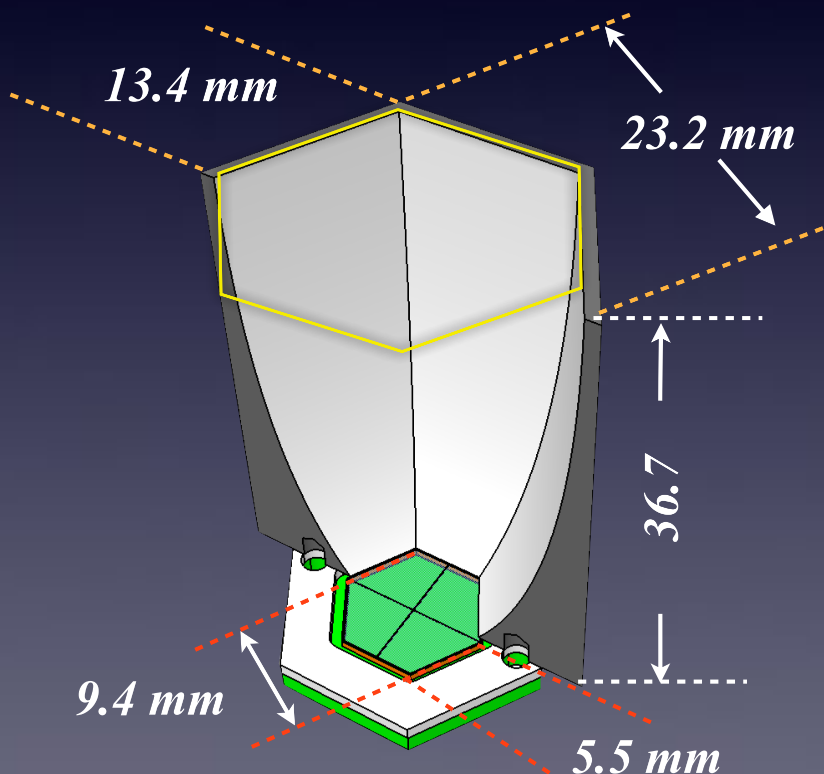
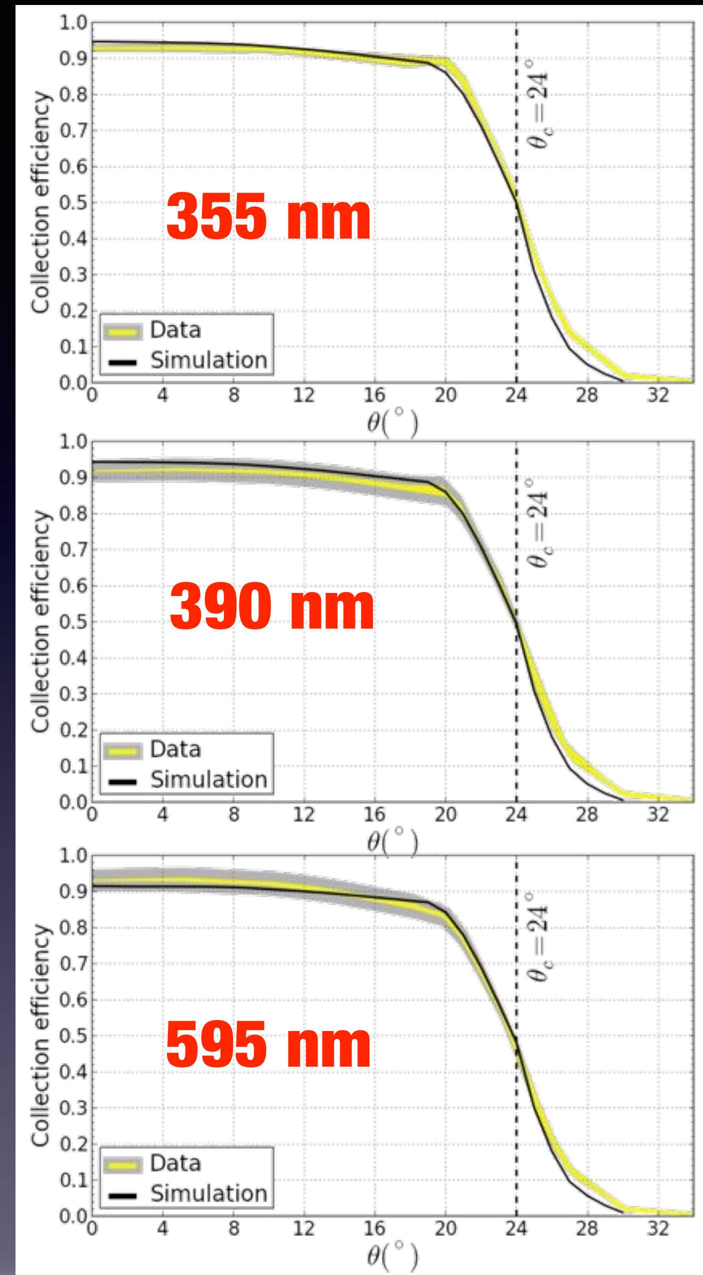
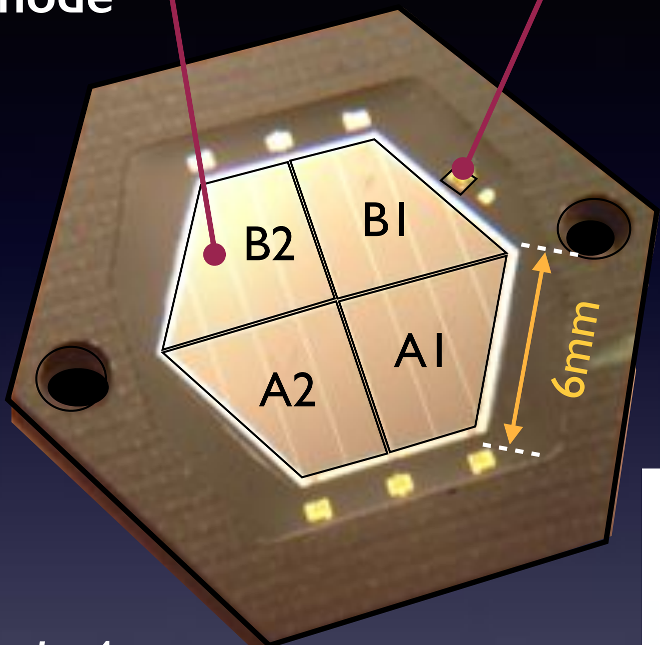




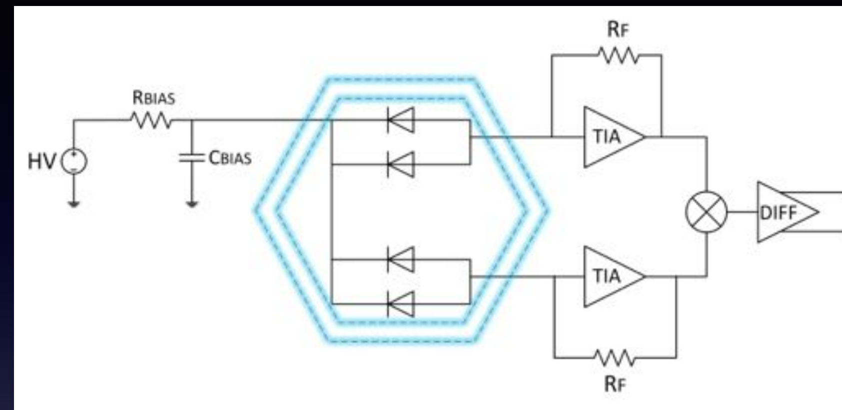
Point Spread Function ➡ Angular pixel size (0.25°) ➡ Top Physical size = 23.2

f/D & Camera Diameter ➡ Cut-off Angle (24°) ➡ Cone Height = 36.7 mm

The new Hexagonal G-APD



The S12516(X) sensor



Channels: 4

Area: 23.8 mm

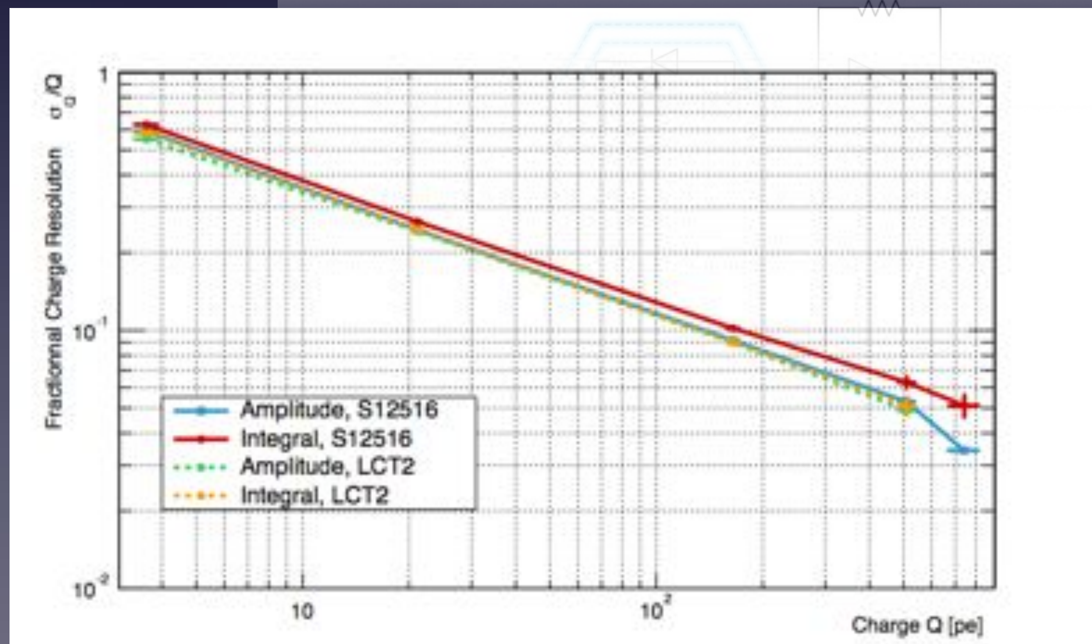
Cell size: 50 µm x 50 µm

Fill factor: 61.5%

N. pixels: 9210 pixels/ch

Capacitance: 840 pF/ch

DC rate: 2-3 MHz/ch



Now using new LCT2 technology from Hamamatsu

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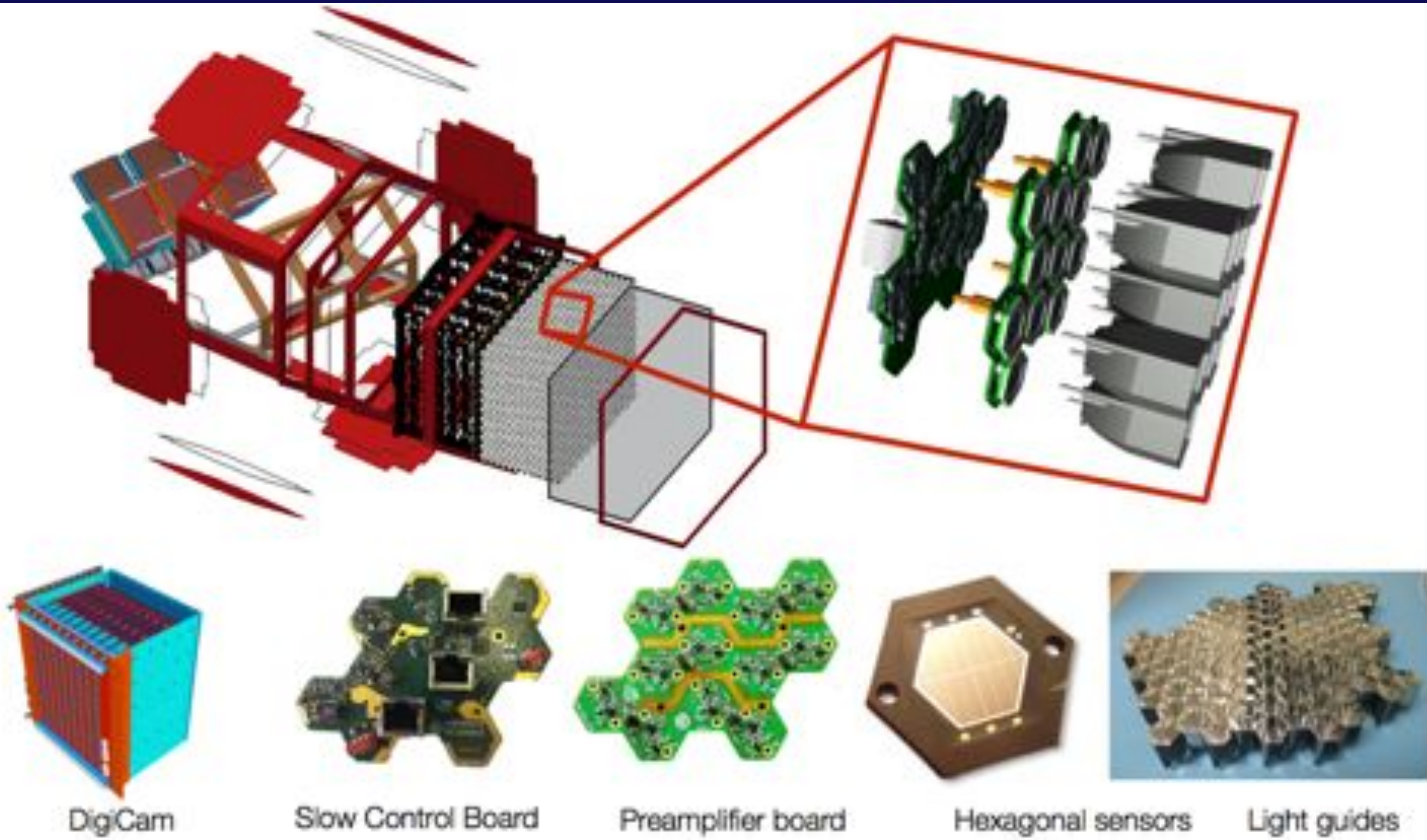
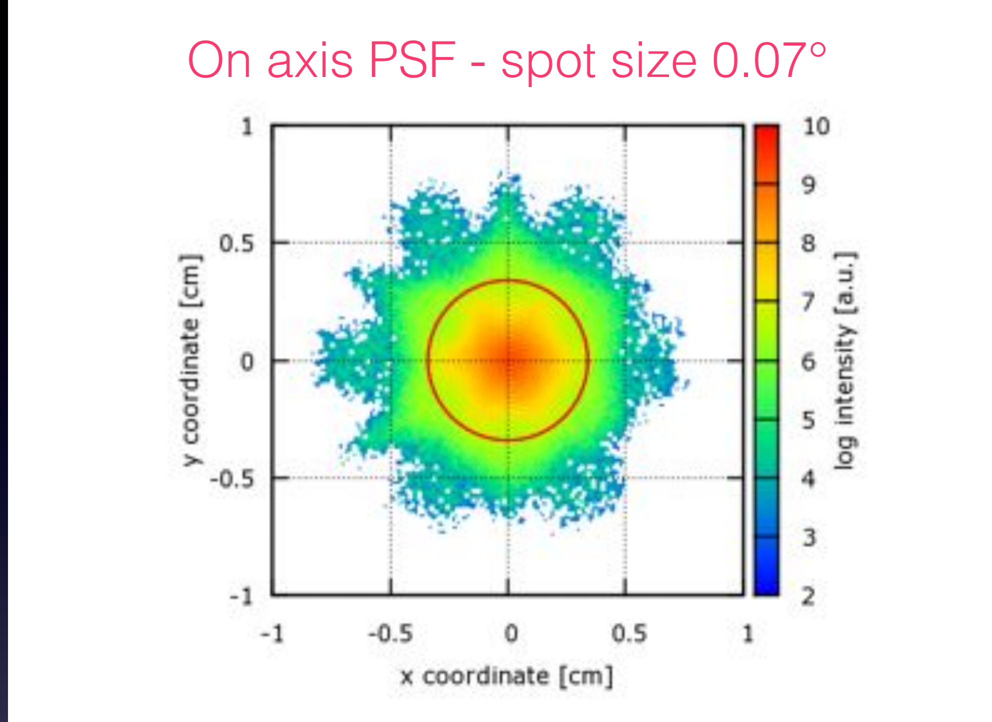
SILICON PMT CAMERA

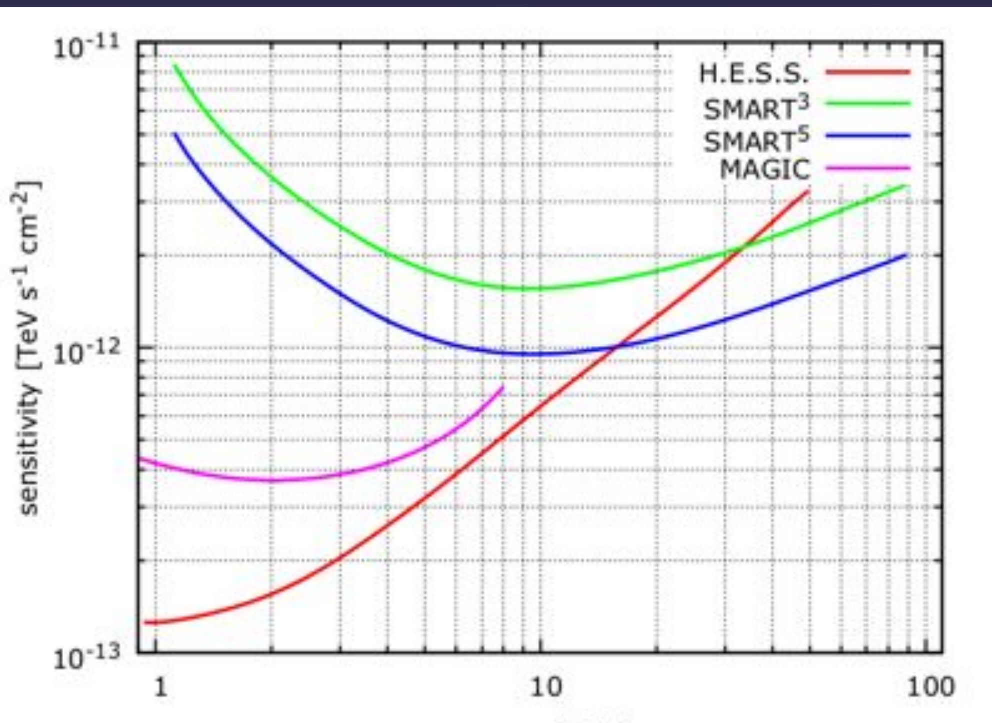


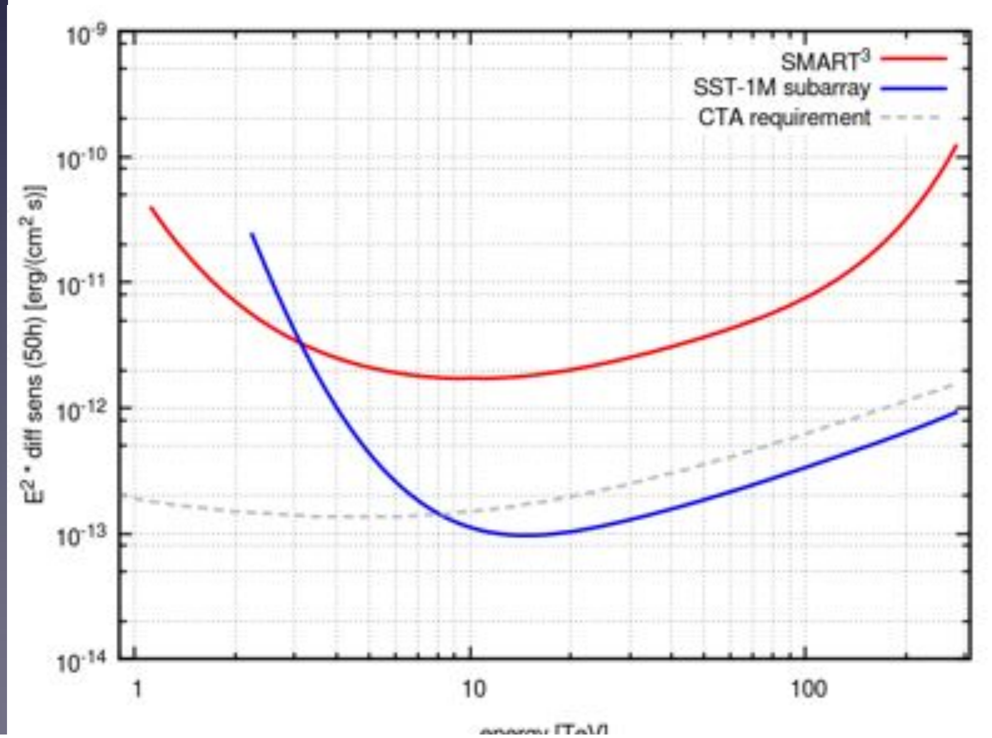
SST-1M

70 SST: WITH A SPACING BY 250 M

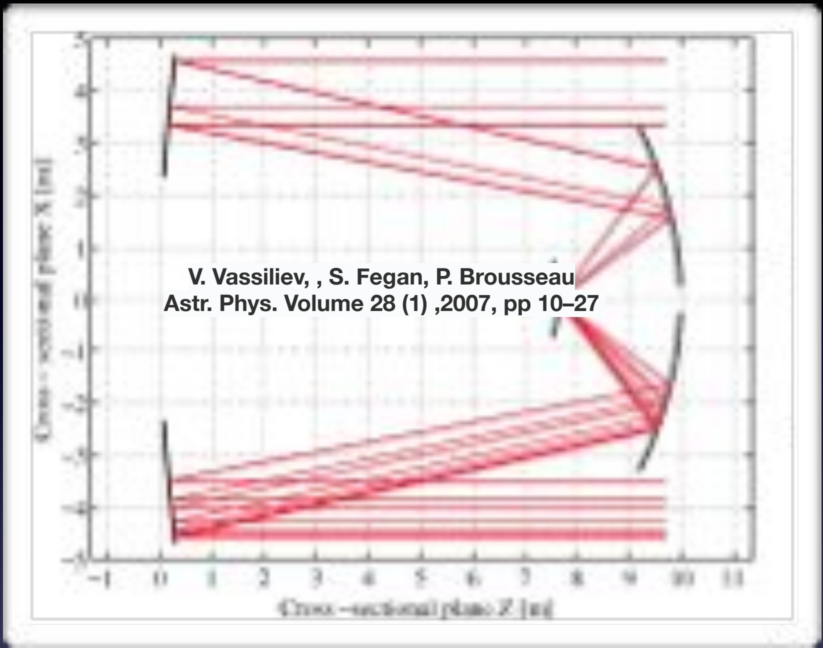
- Davies-Cotton Design
- 4m diameter single mirror
- f/D = 1.4
- SiPM camera with new hexagonal sensor following FACT steps







DUAL-MIRROR TELESCOPE



- **Two SST-2M projects**
- **Higher-performance telescope with small pixels (SCT)**

▸ Reduce camera size (power consumption)

▸ More uniform PSF across FoV than DC

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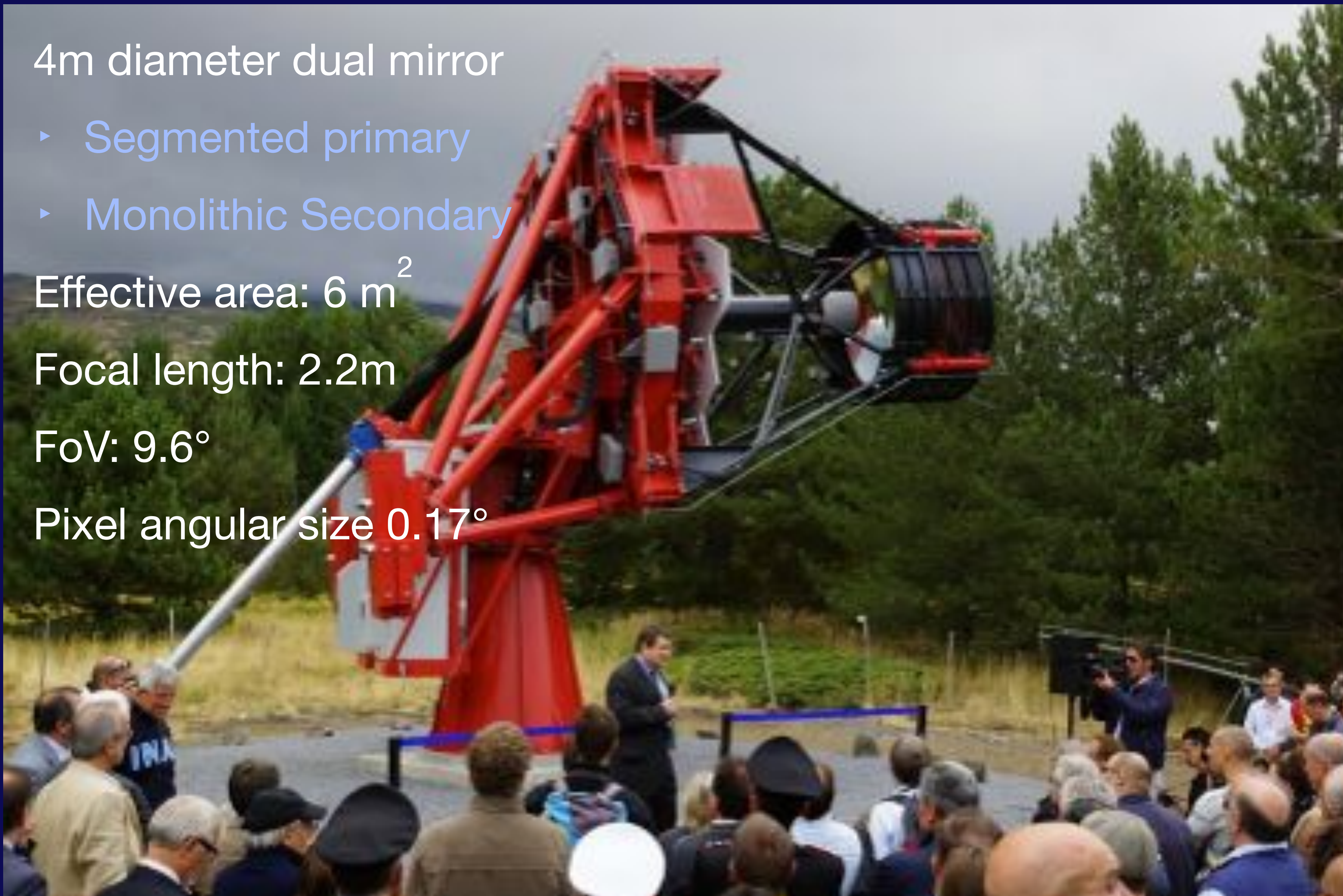
DUAL MIRROR ASTRI SST

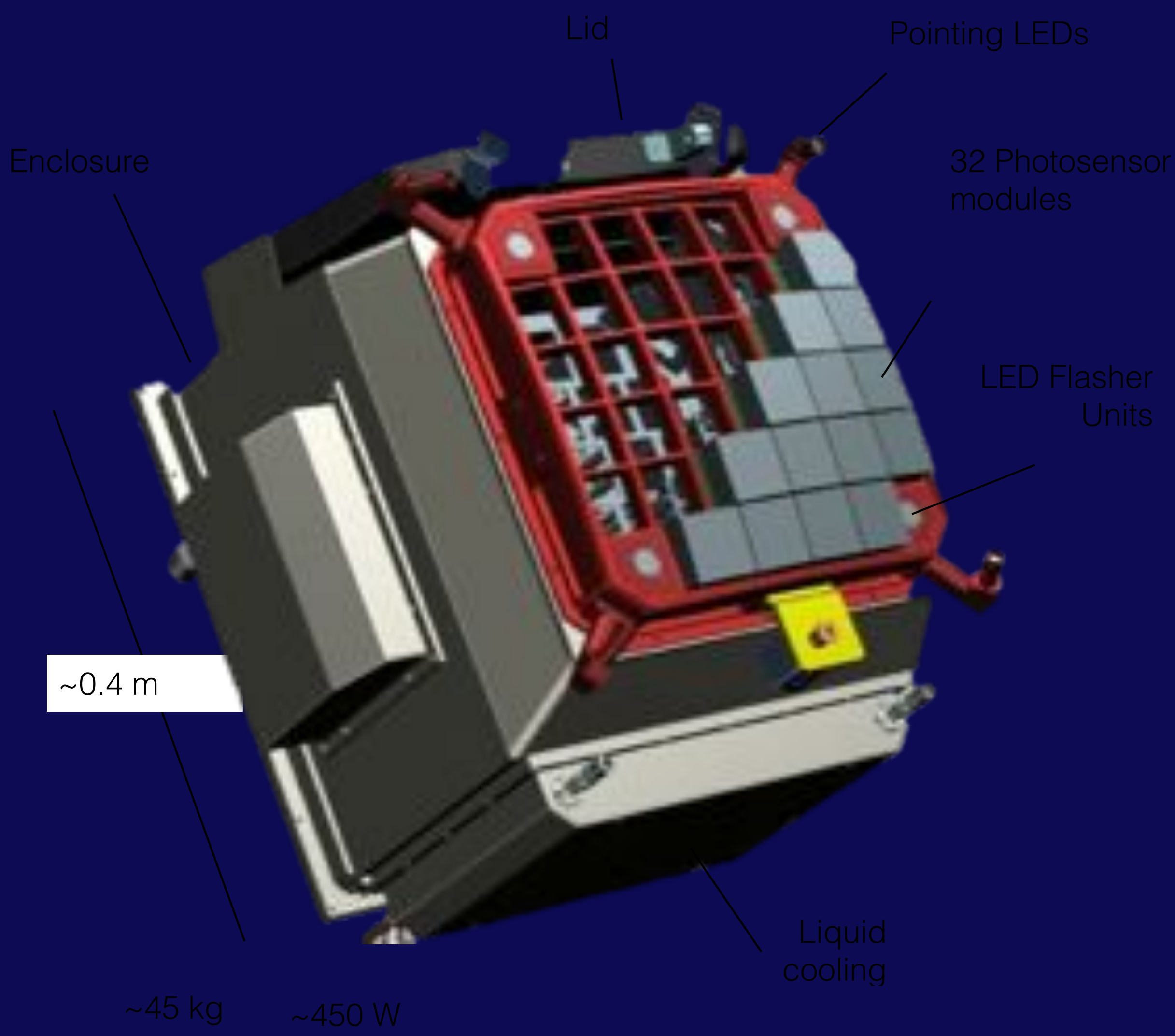
PROTOTYPE INAUGURATION SEPT 24

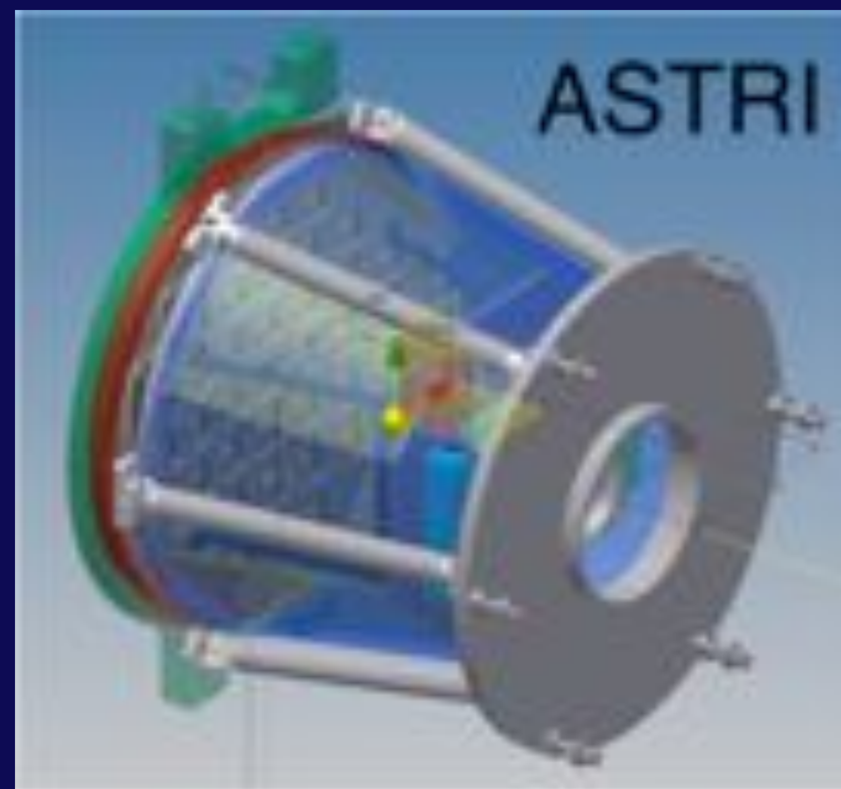
- 4m diameter dual mirror
  - Segmented primary
  - Monolithic Secondary
- Effective area: 6 m^2
- Focal length: 2.2m
- FoV: 9.6°
- Pixel angular size 0.17°



DUAL MIRROR SST

Alternative version: CHECS (SiPM) and CHECM (Multianode PMTs) And ASTRI (lightweight structure, different electronics, low power)





LARGE TELESCOPE (LST)

23 m diameter
389 m^2 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

LST FULL PROTOTYPE

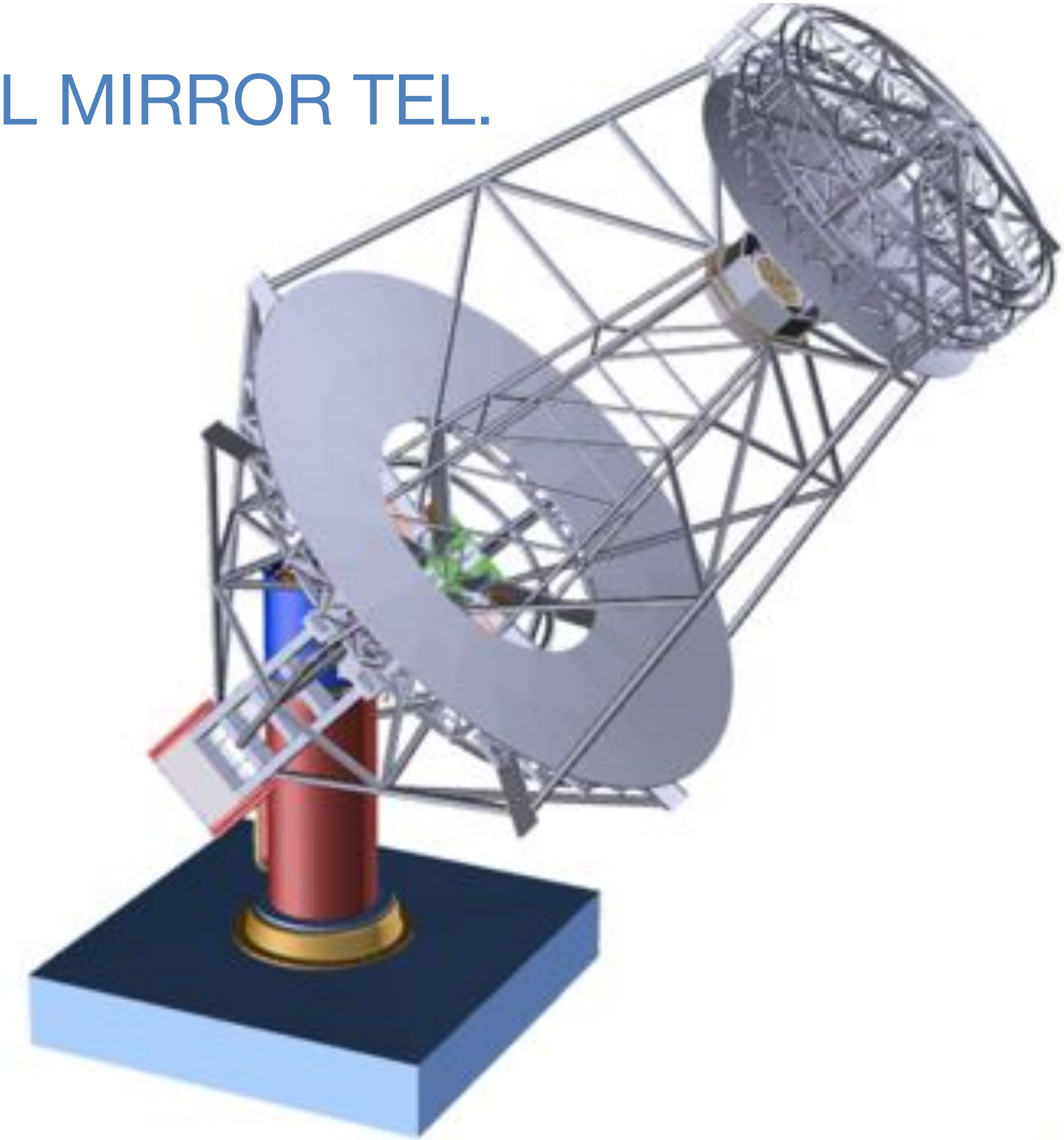
Will be constructed on La Palma, starting in 2015

Dish structure prototype

Elevation drive prototype

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

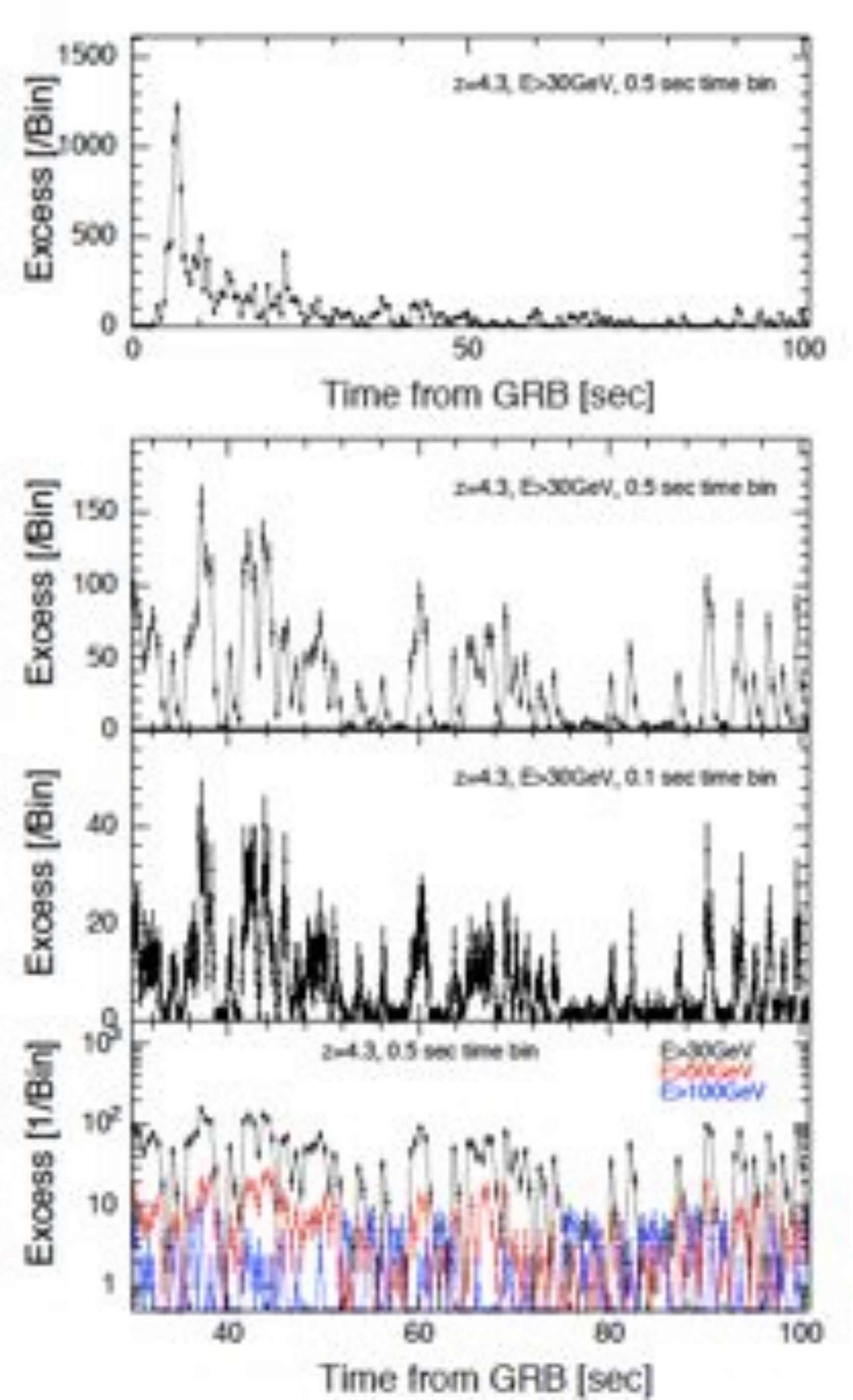
8° field of view
11328 x 0.07° SiPMT pixels
Target readout ASIC

Extend South array by adding 24 SCTs

➜ increased γ-ray collection area

➜ improved γ-ray angular resolution

LOW ENERGY DISCOVERY DOMAIN: GRBS



Much larger area than Fermi will allow the energy dependent reconstruction of the lightcurve.
From arXiv:1301.3014: Simulated light curves of GRB080916C at z = 4.3 for CTA array E.
The EBL model of Razzaque&Dermer 2009 was assumed.
The pointing error of alerting satellites reduces the discovery rate to order of 1/yr for E> 20 GeV and delay time of 20 s

DARK MATTER SEARCHES

$$\frac{d\phi_\gamma}{dE_\gamma} = \underbrace{\frac{1}{4\pi}\frac{<\sigma_{\rm ann} v>}{2m^2_{\rm WIMP}}\sum_f BR_f \frac{dN^f_\gamma}{dE_\gamma}}_{\rm Particle\ Physics} \times \underbrace{\int_{\Delta\Omega} d\Omega' \int_{\rm los} \rho^2 dl(r,\theta')}_{\rm Astrophysical\ factor\quad J(\Delta\Omega)}$$

BOTH PARTICLE PHYSICS AND ASTROPHYSICS TERMS HAVE UNKNOWNS

Assumptions must be made on one to put constraints on the other

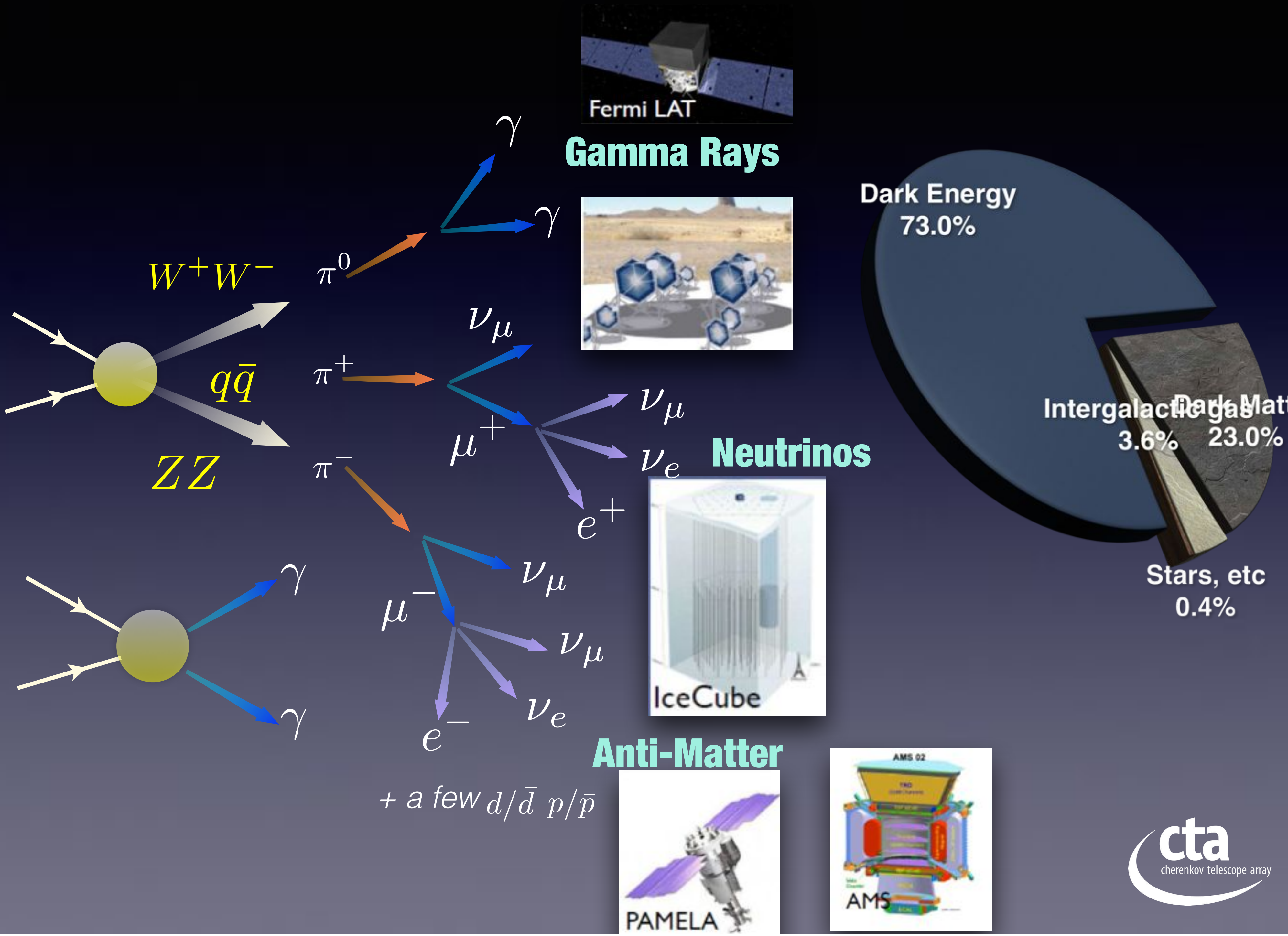
ASTROPHYSICAL UNCERTAINTIES

Density profile of dark matter

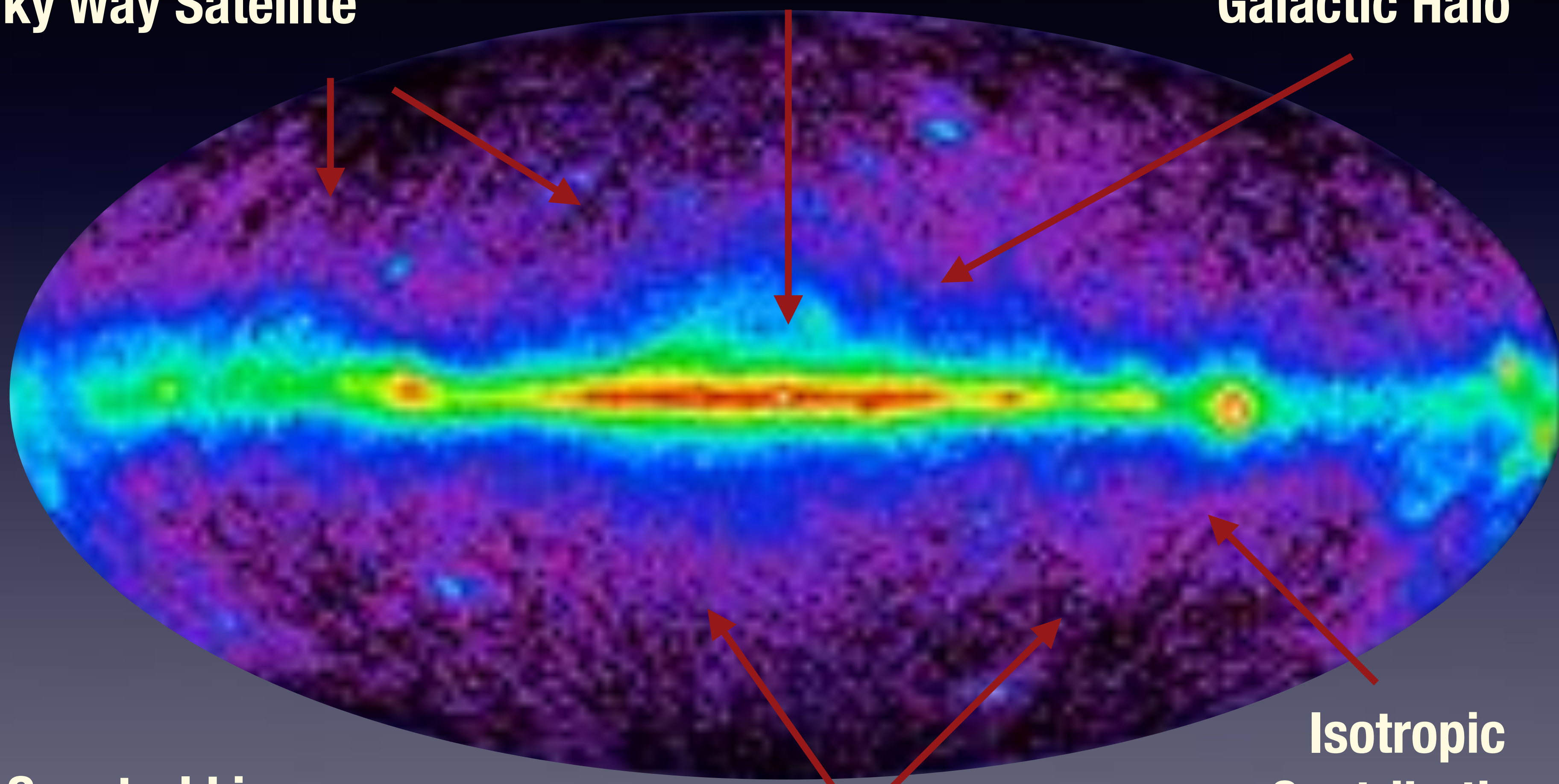
Astrophysical interference

cta cherenkov telescope array

Indirect Searches for Dark Matter



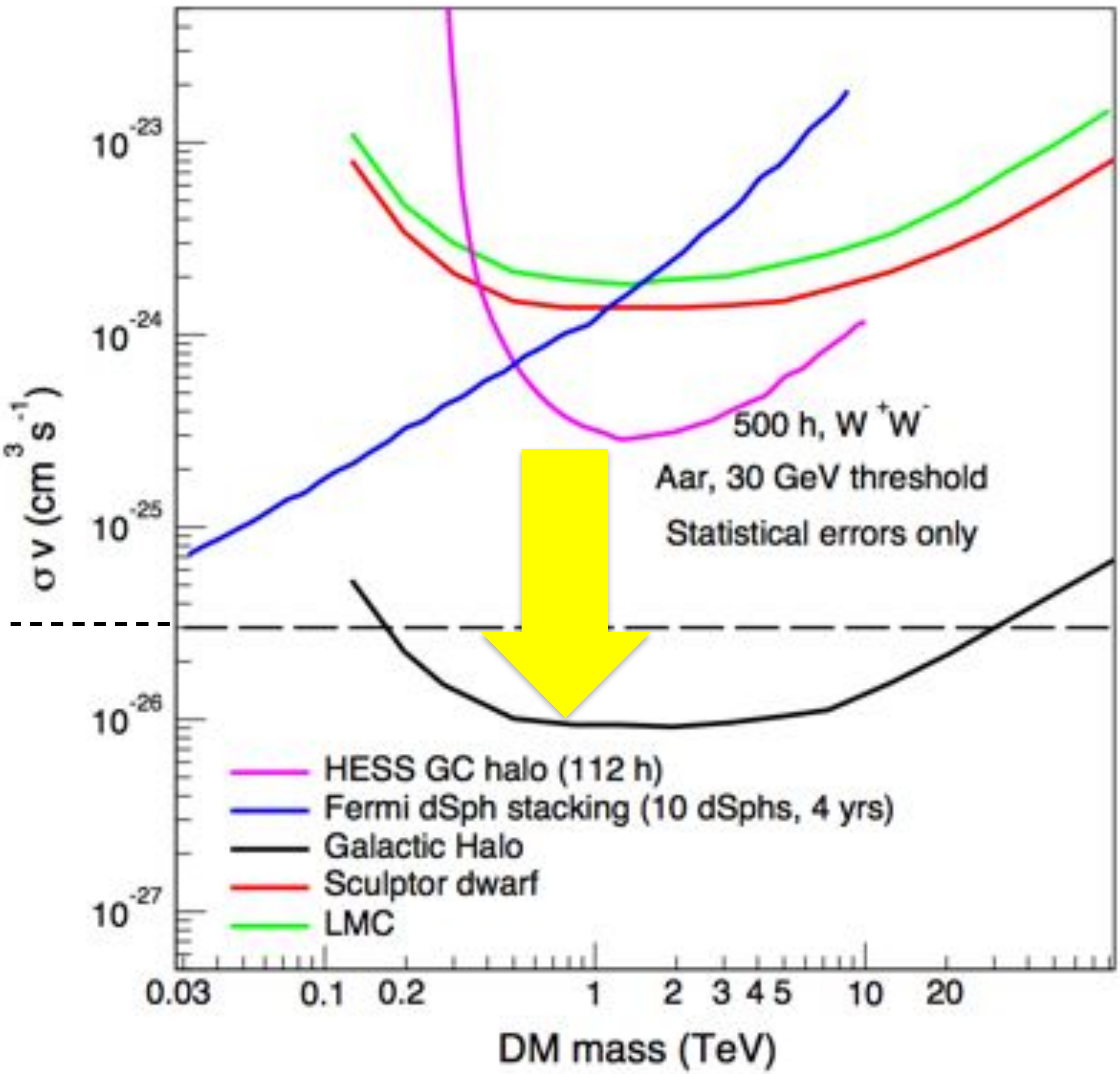
Targets for indirect DM searches



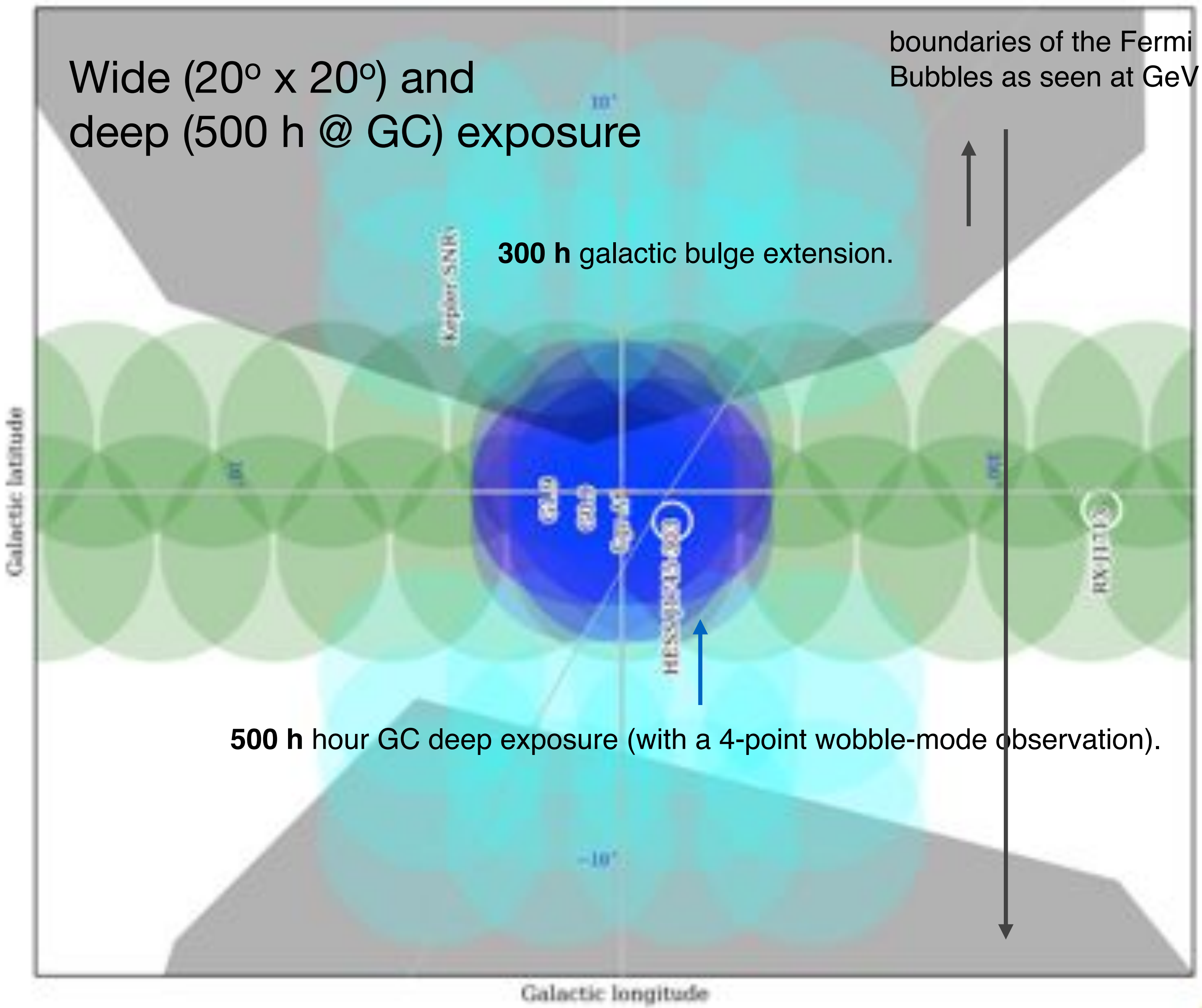
cta
cherenkov telescope array

CTA DM REACH

Canonical DM annihilation X-sect



KSP OBSERVATION STRATEGY



Wide (20° x 20°) and
deep (500 h @ GC) exposure

boundaries of the Fermi Bubbles as seen at GeV energies.

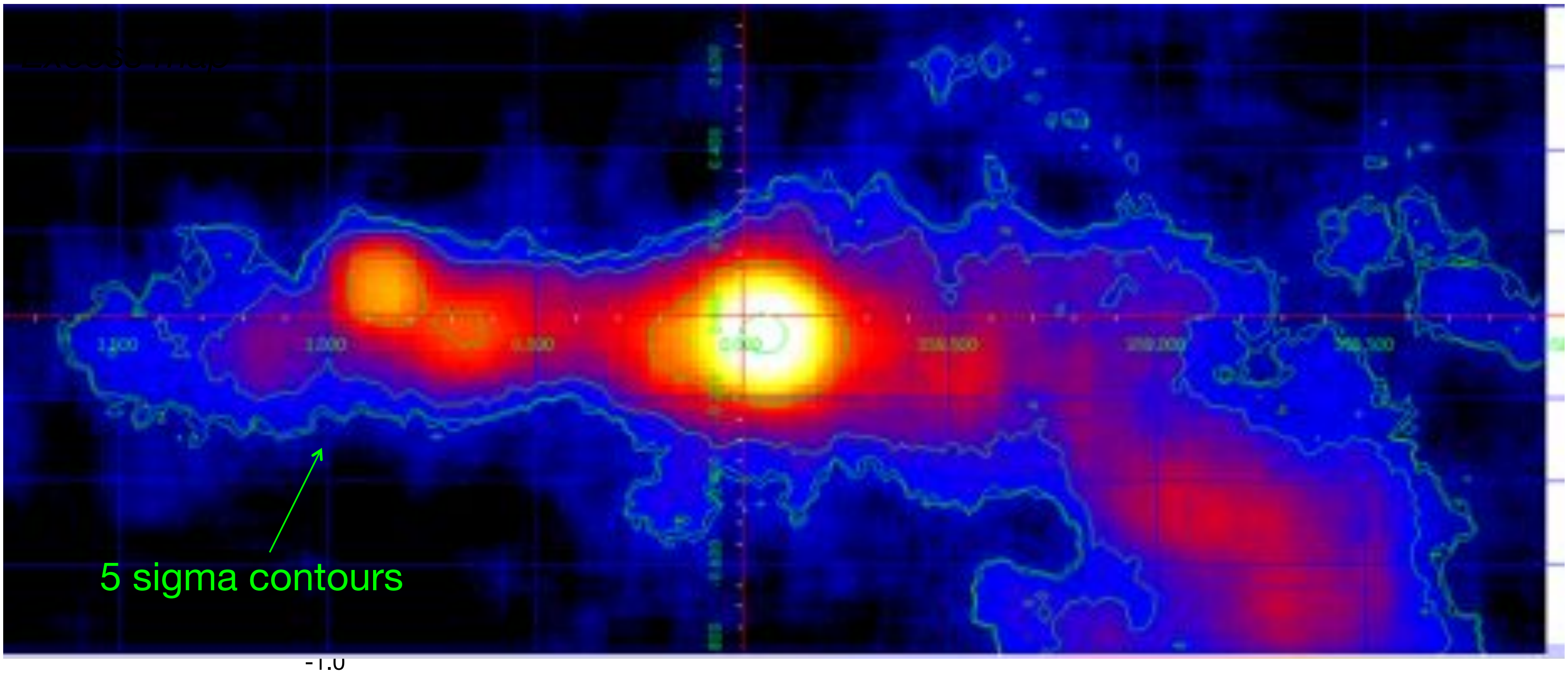
300 h galactic bulge extension.

500 h hour GC deep exposure (with a 4-point wobble-mode observation).

GALACTIC CENTER REGION

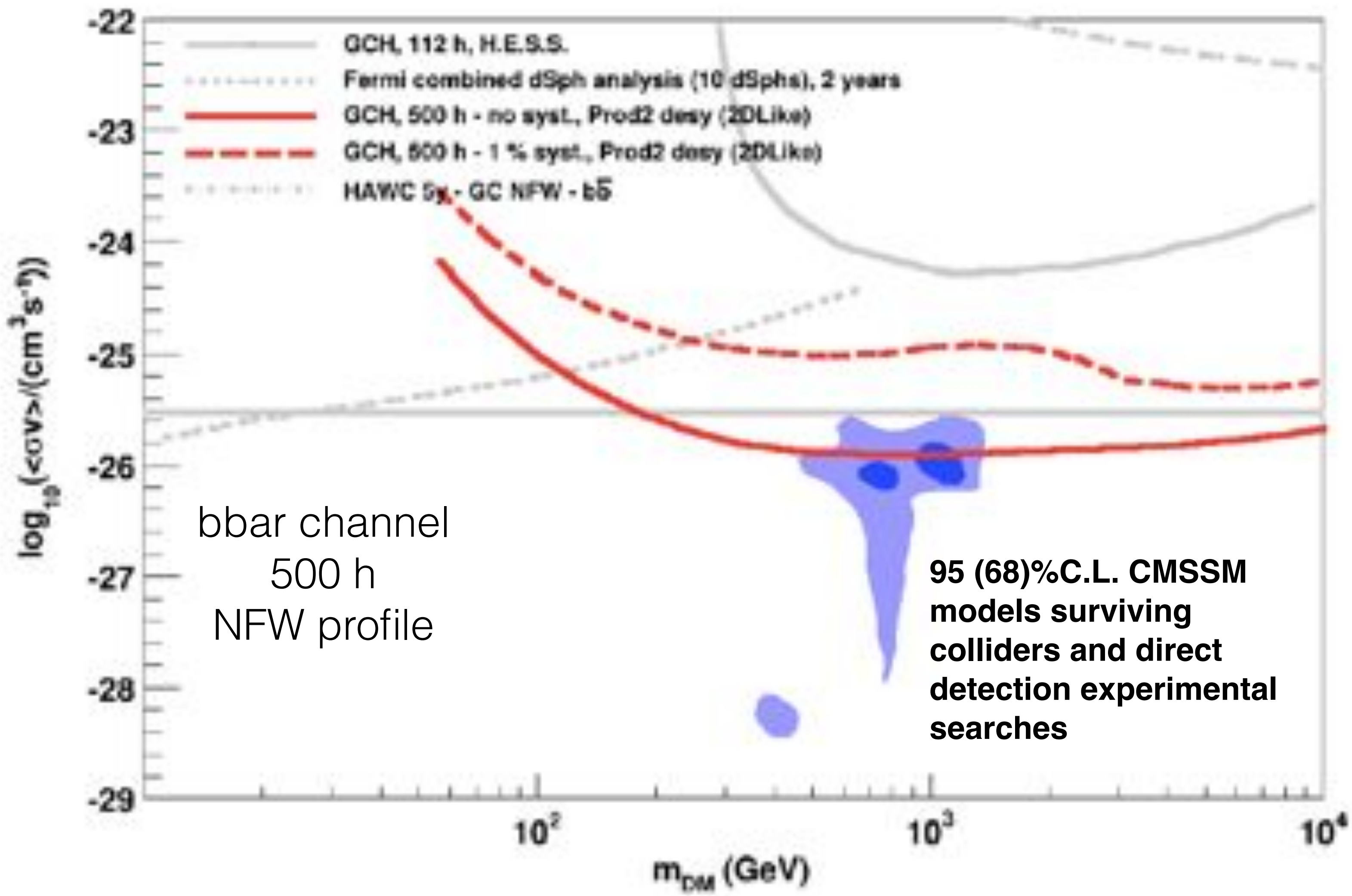
Complex, structured VHE source
Gas clouds illuminated by Pevatron?

Dark matter halo emission?
Launch of Fermi bubbles?

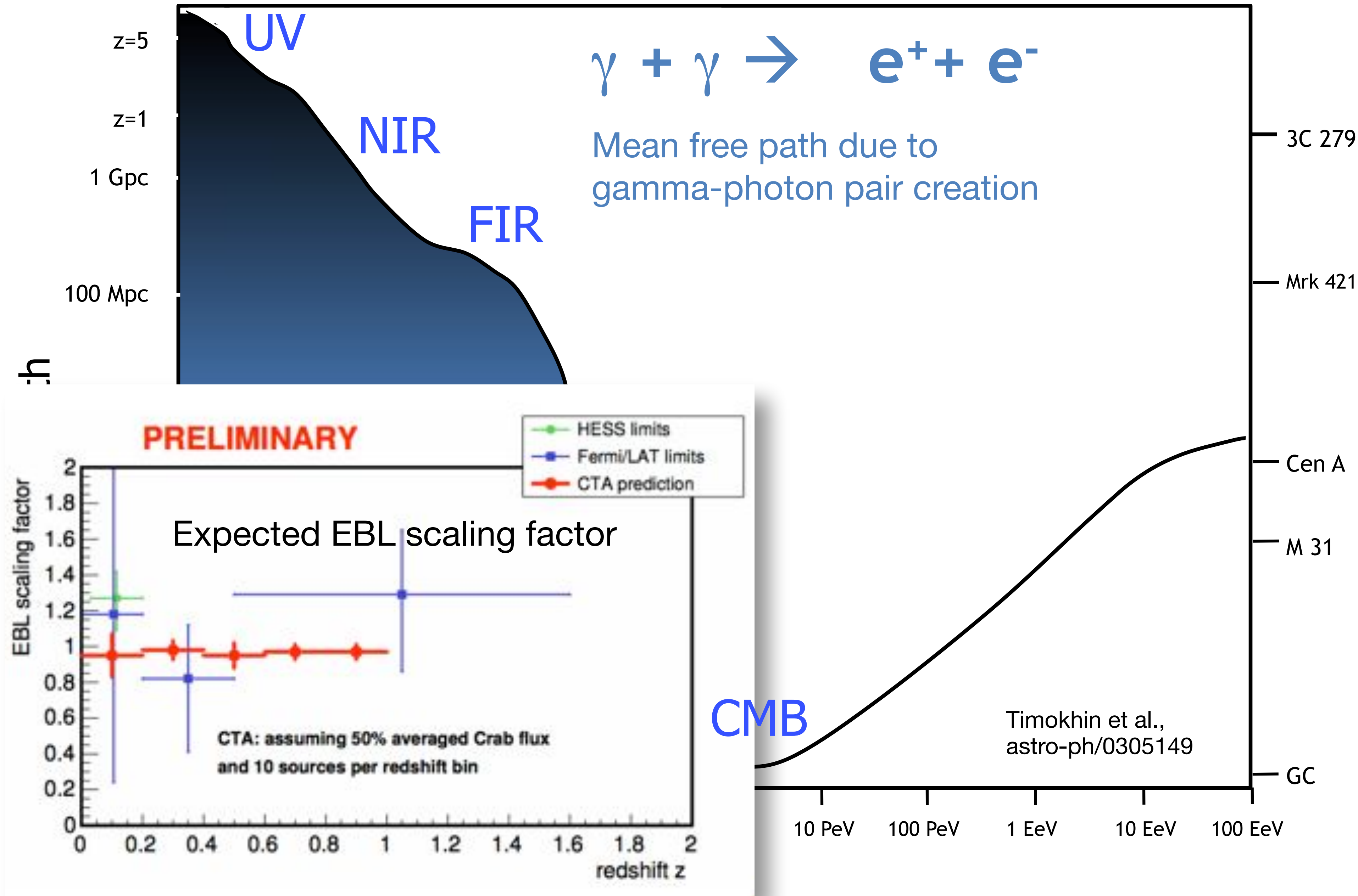


2°
300 pc

CTA SENSITIVITY TO DM IN THE GALACTIC CENTRE



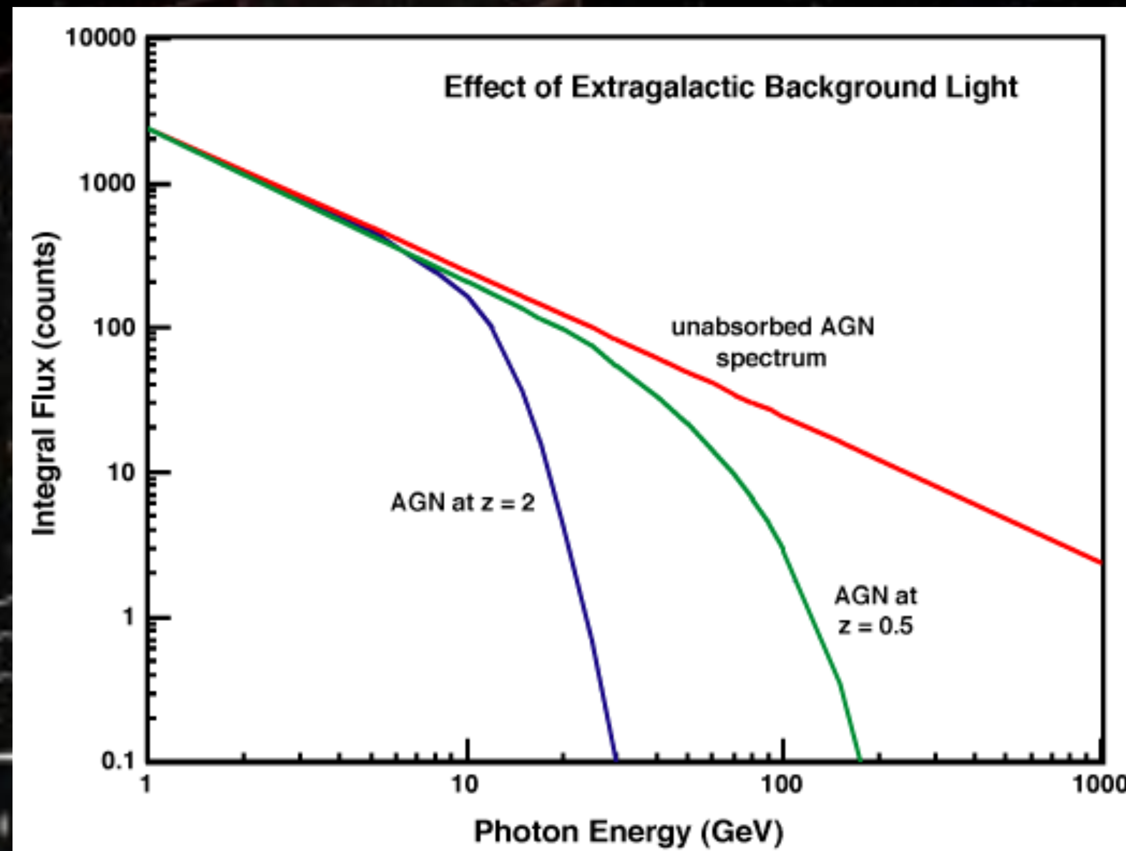
CTA REACH:
THE GAMMA RAY HORIZON

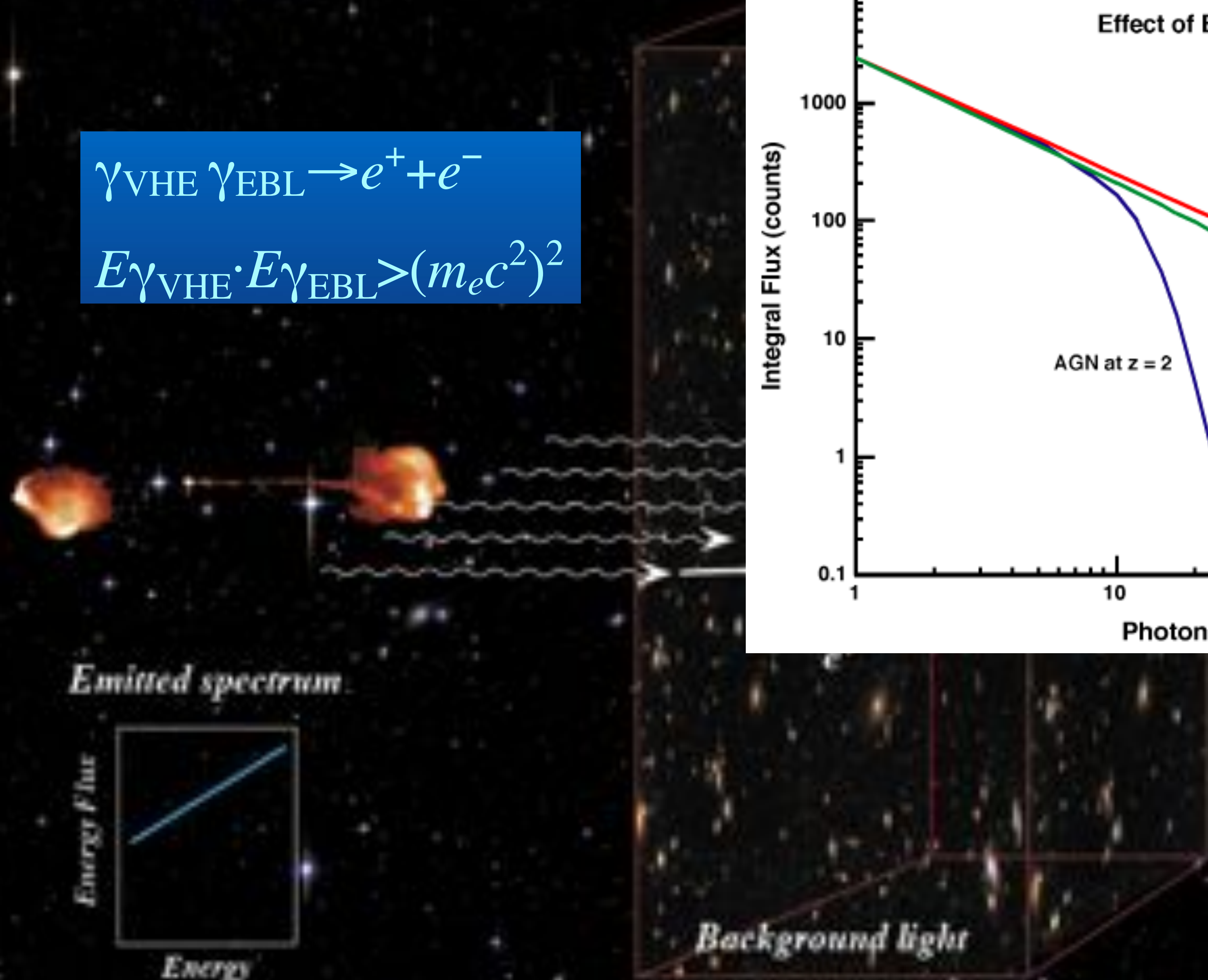


EXTRAGALACTIC BACKGROUND LIGHT

$$\gamma_{VHE}\,\gamma_{EBL} \rightarrow e^{+} + e^{-}$$

$$E\gamma_{VHE} \cdot E\gamma_{EBL} > (m_e c^2)^2$$



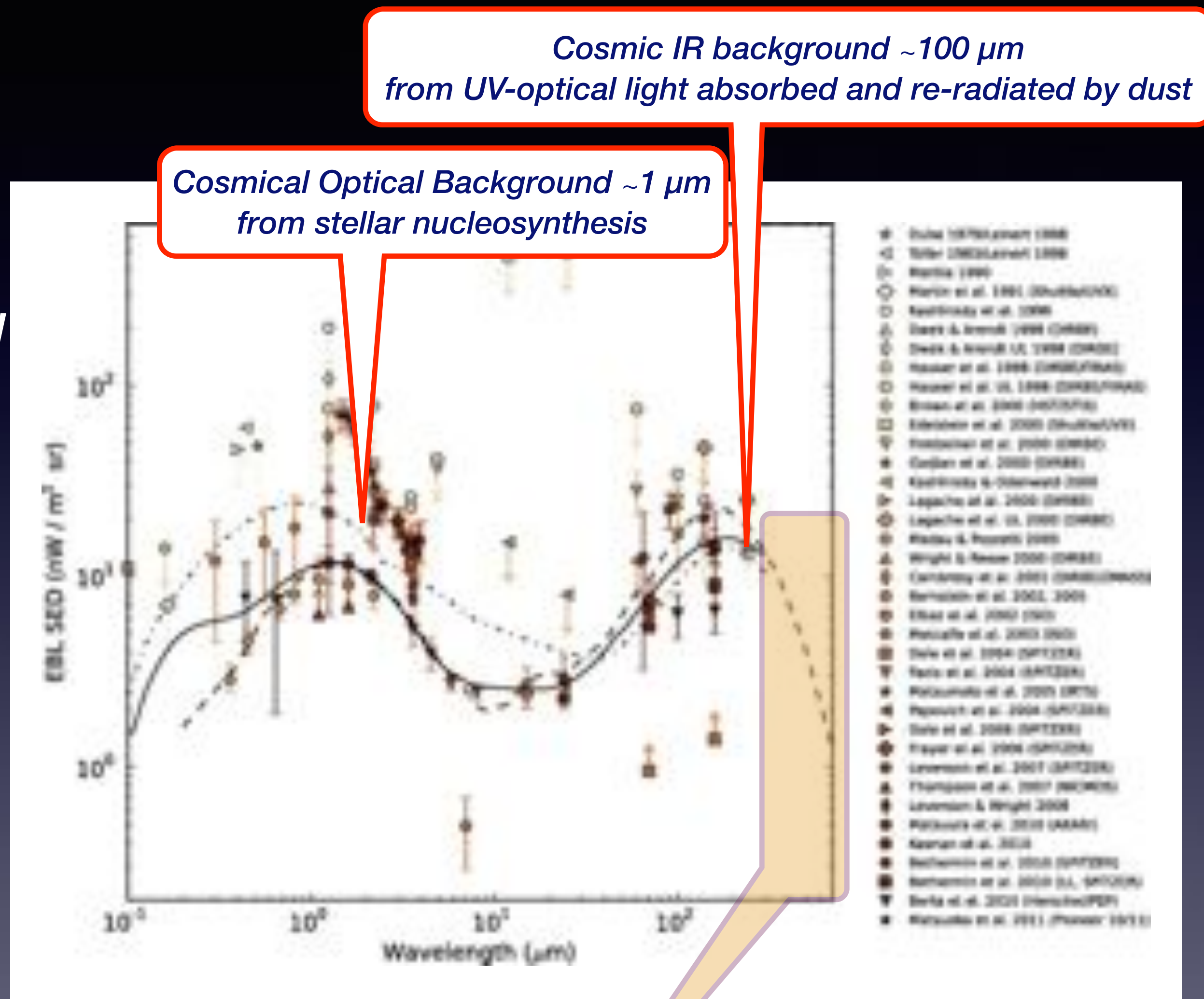


$$\Phi_{obs}(E_\gamma, z) = e^{-\tau(E\gamma, z)} \times \Phi_{int}(E_\gamma).$$

http://arxiv.org/abs/1303.7124

EXTRAGALACTIC BACKGROUND LIGHT

- *Largest second background light after CMB which preserves information on structure of the universe at the decoupling between matter and radiation following the Big Bang (z ~1000)*
- *EBL contains information on the Stellar Formation Rate Density*
- *integral measurement of radiation emitted during the star formation*



CTA can probe full energy range.
For first time energy above 10 TeV can be probed

cta cherenkov telescope array

CONCLUSIONS

CTA has

- improved sensitivity by a factor 10
- Huge physics potential
    - Cosmic Particle Acceleration
    - Probing Extreme
    - Physics Frontiers – beyond the SM
- Approval/construction
    - Aim for site preparation in mid-2016
    - Estimate 3-5 year construction period
    - Early operation of partial arrays
    - Investment cost ~200 M€;
    - CDR this semester

Eckart Lorenz (1938-2014)

Thank You for your attention and thanks Eckart!