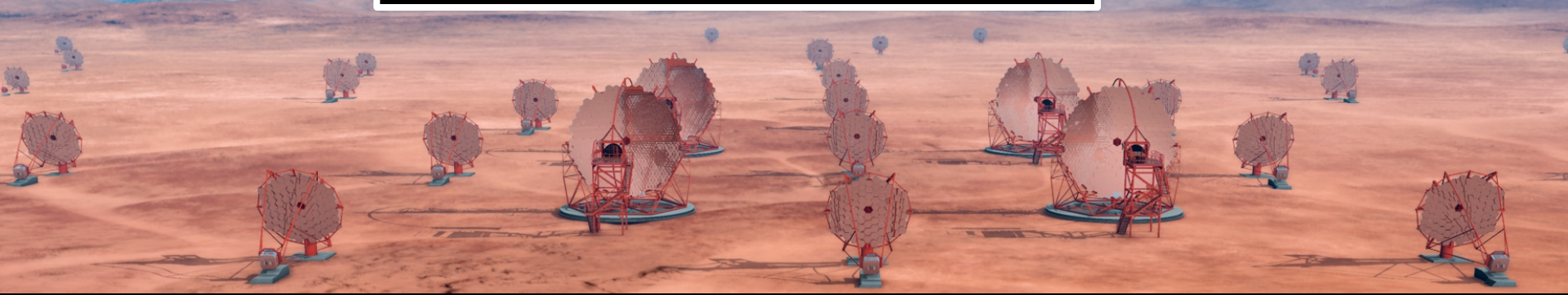
# The Status and Future of Cherenkov Telescope Arrays

Jim Hinton

University of Leicester

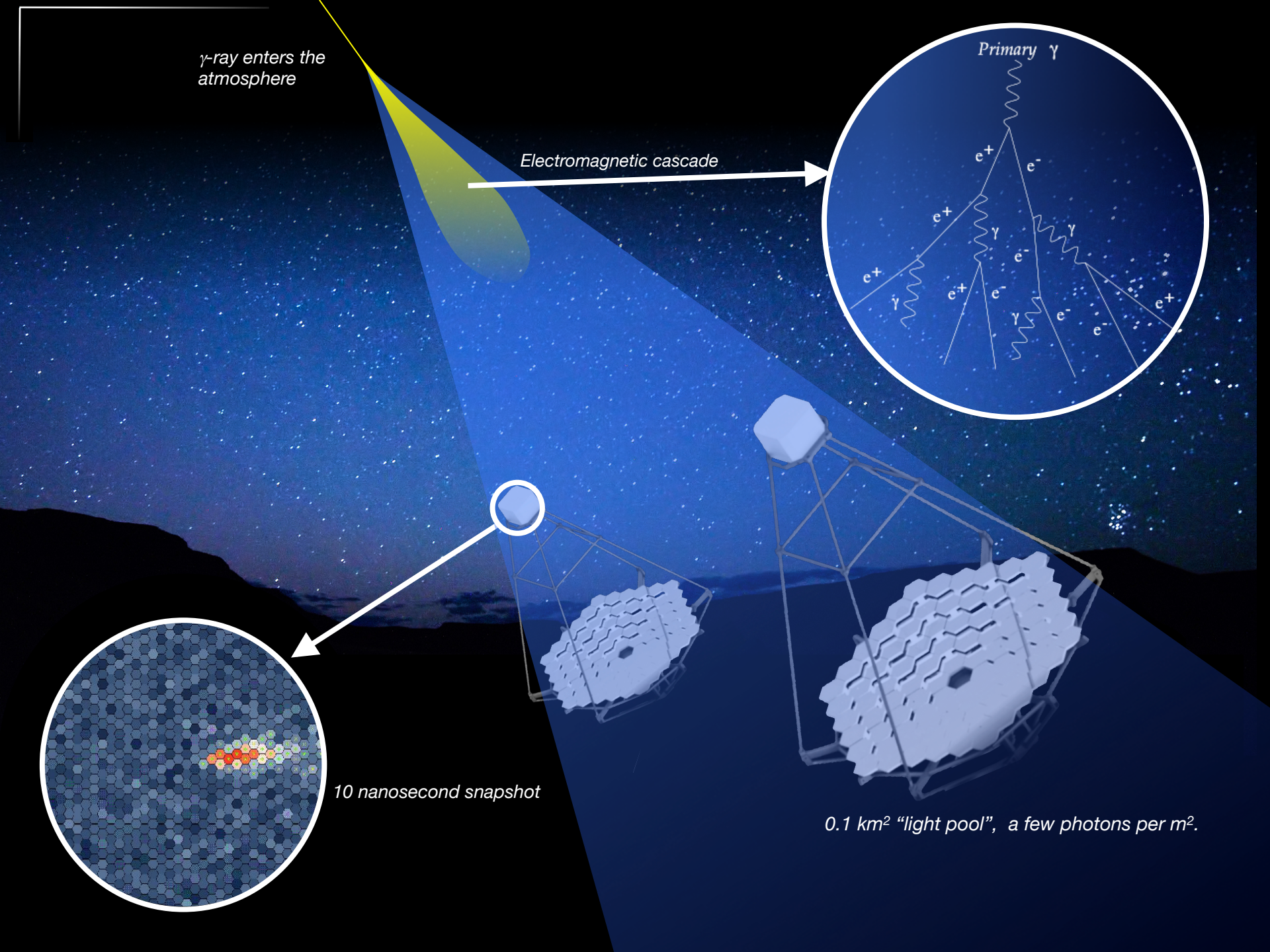
ASTROPARTICLE PHYSICS 2014

A joint TeVPA/IDM conference



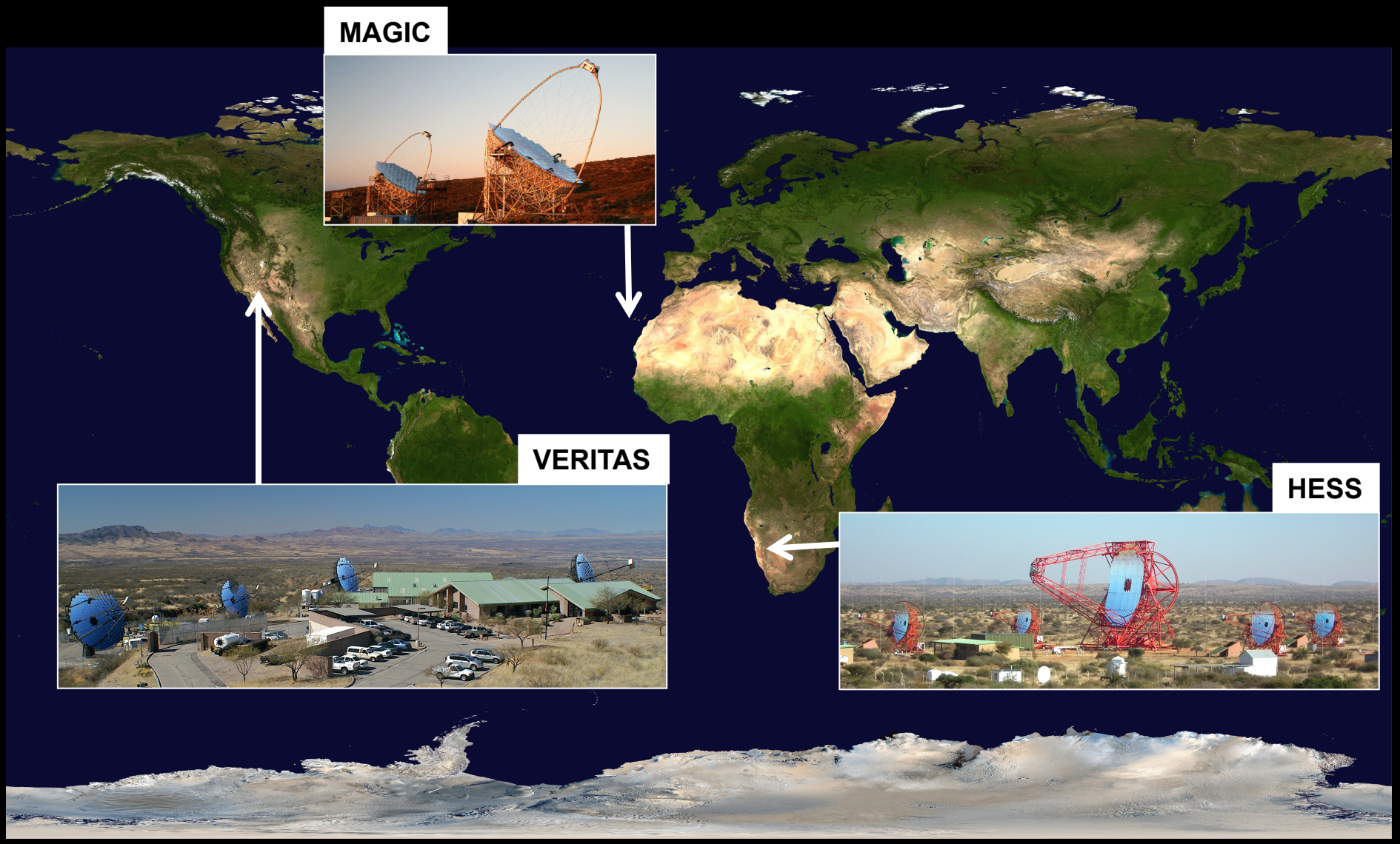

Trevor Weekes

Eckart Lorenz


γ-ray enters the atmosphere
Electromagnetic cascade
Primary γ
e+
e-
γ
10 nanosecond snapshot
0.1 km² "light pool", a few photons per m².

# Why Cherenkov Telescopes?

- Gamma-ray astronomy
  - In general big advantages over other methods of probing high energy particles (probes hadrons + leptons, photon cross-section, ….)
- Advantages to satellites
  - Only way to build sensitive >TeV instruments
  - High statistics /short timescales
    - Large collection areas O($km^2$)
- Advantages to ground particle detectors
  - Superior energy/angular resolution
  - Superior background rejection
- Limitations?
  - Smallish duty cycle, smallish field of view

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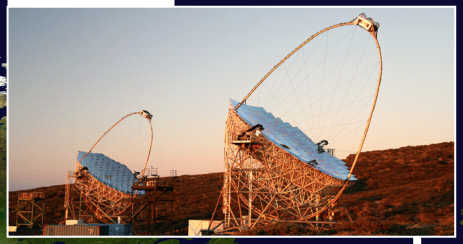
MAGIC



- 2 - 5 Telescopes
- 500-2000 pixel cameras
- 3.5 - 5.0° FoV
- ~0.1° angular res.
- ~15% energy res.
- Sensitivity <1% Crab
- ~30 GeV < E < ~50 TeV

VERITAS

HESS

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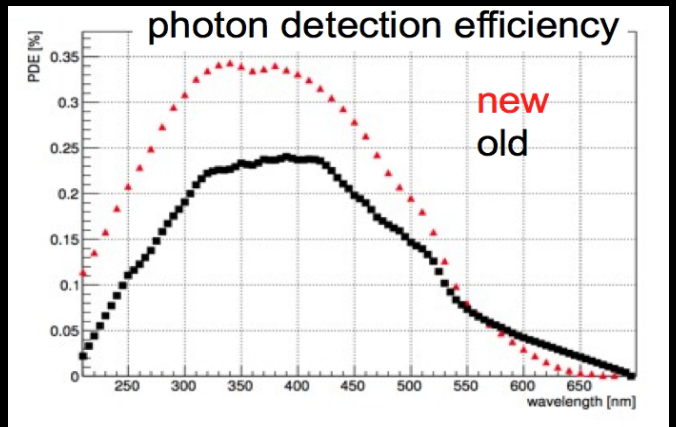
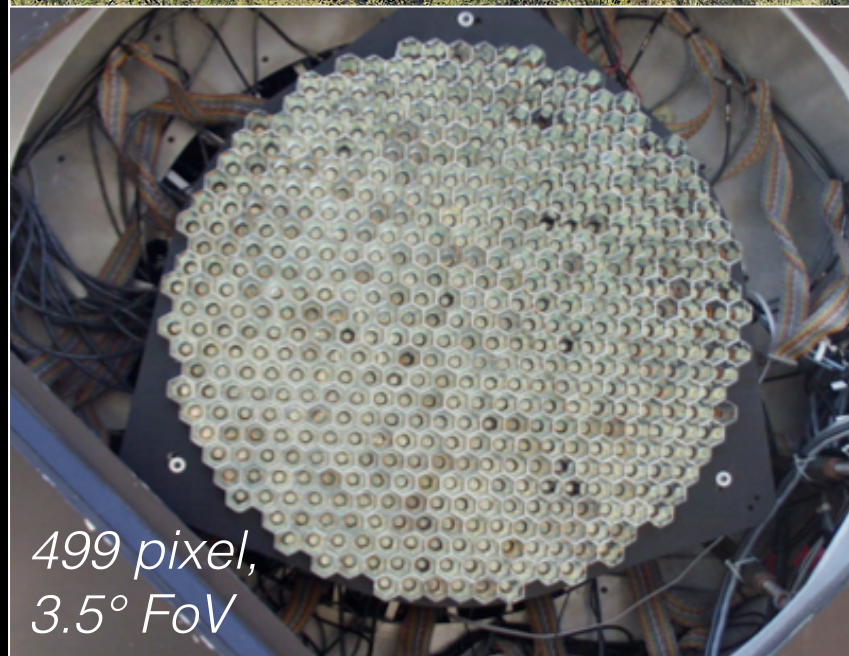
# VERITAS

- Four telescope system at Whipple Observatory (1270 m alt.) in Arizona, USA
- Completed 2007
  - 2009 telescope move
- Cameras upgraded 2012
  - Much higher quantum efficiency PMTs
  - Improved trigger

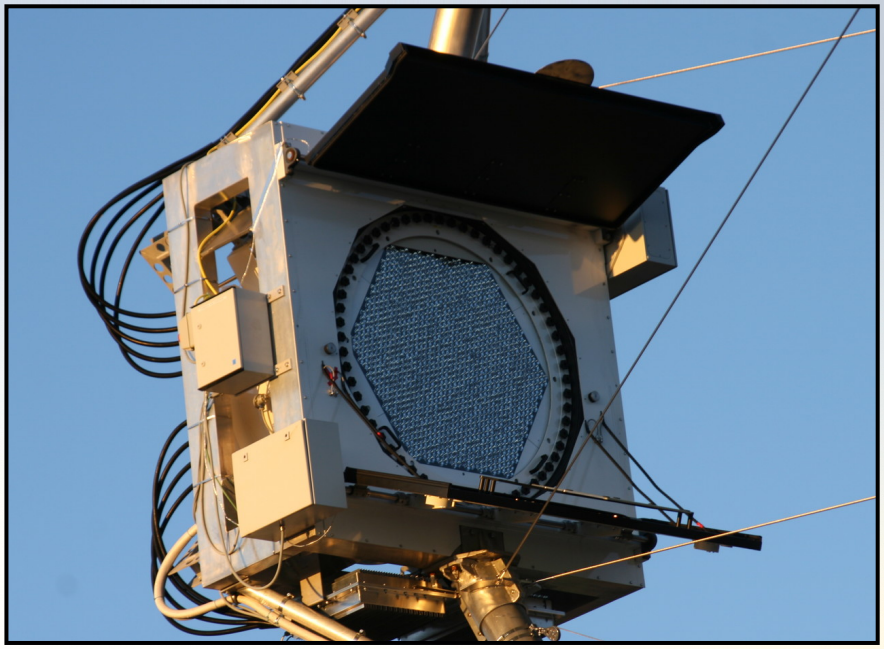






# MAGIC

- Two large telescopes on La Palma (2200 m alt.)
- First telescope
  - completed 2004
- Second telescope
  - operational 2009
- Upgrade
  - of original camera 2012

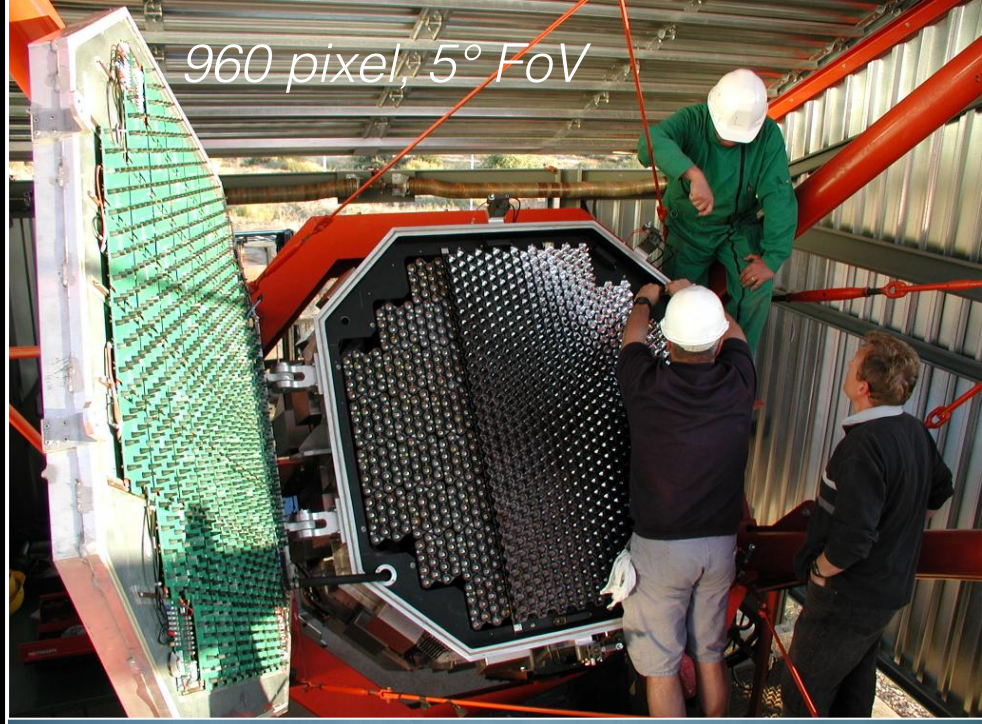


*1039 pixel, 3.5° FoV*

*2× 17m ⌀*

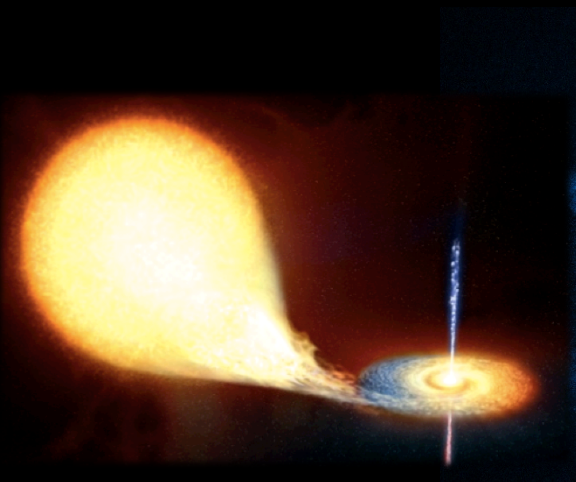
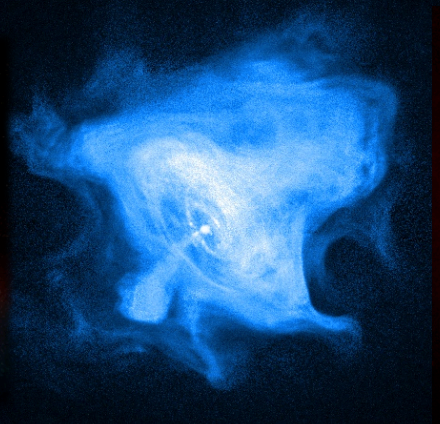
# H.E.S.S.

- Khomas Highlands of Namibia (1800 m alt.)
- Phase 1
  - Four 12 m telescope system completed 2004
- Phase 2
  - Addition of a 28 m telescope in 2012
  - 0.07° pixels, 3.5° FoV
- Upgrade underway
  - Of original cameras
  - Completed 2016
  - Reduced deadtime / improved reliability



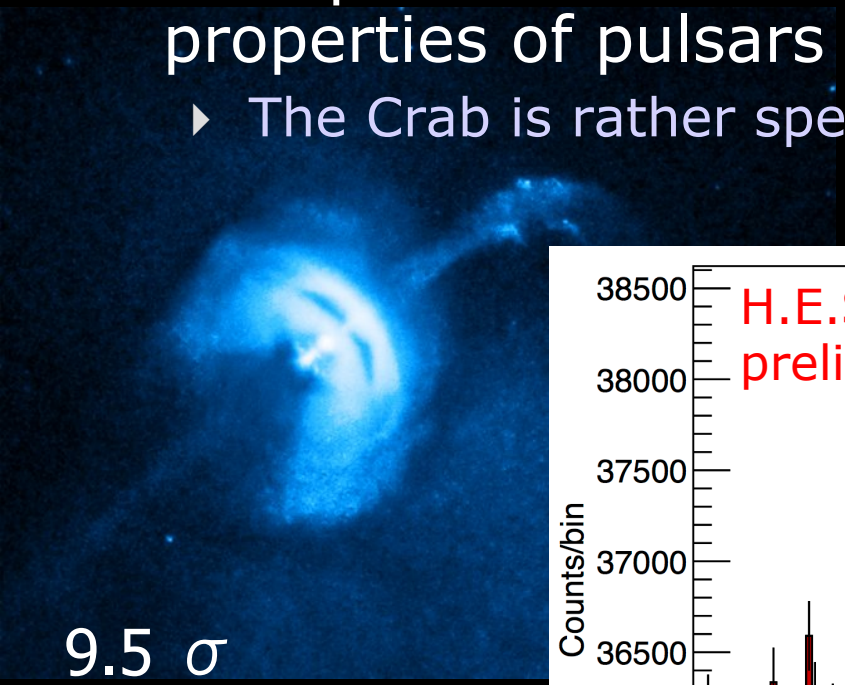

# Scientific Highlights

- Imaging of cosmic particle acceleration sites
- Physics of pulsars and pulsar winds
- Galactic surveys
- Probing the extragalactic background light
- Extreme variability of AGN
- Limits on dark matter and new physics
- 17 papers in Science/Nature/PRL
- **Major contributions from <u>all</u> current CTAs**

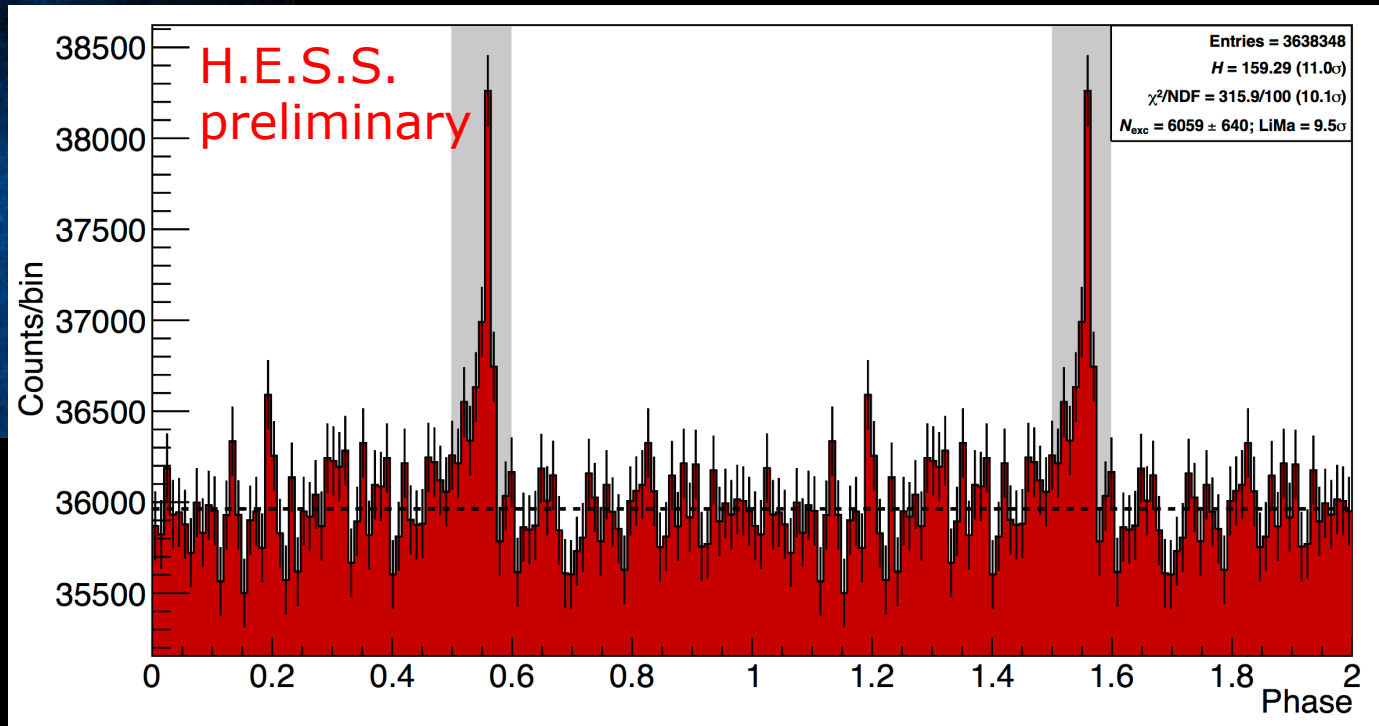



# The Vela Pulsar

- 2nd pulsar detectable from the ground (high statistics and high energies)
- A step towards understanding the high energy properties of pulsars in general
  - The Crab is rather special – need more objects!

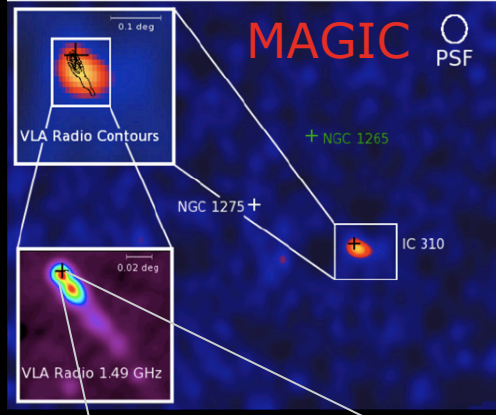


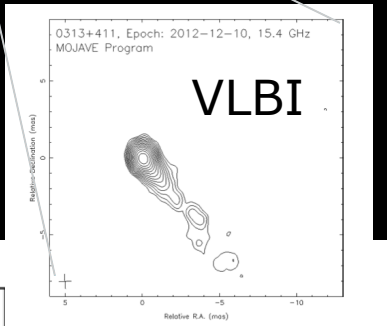
9.5 σ
17 hours
<E> = 40 GeV

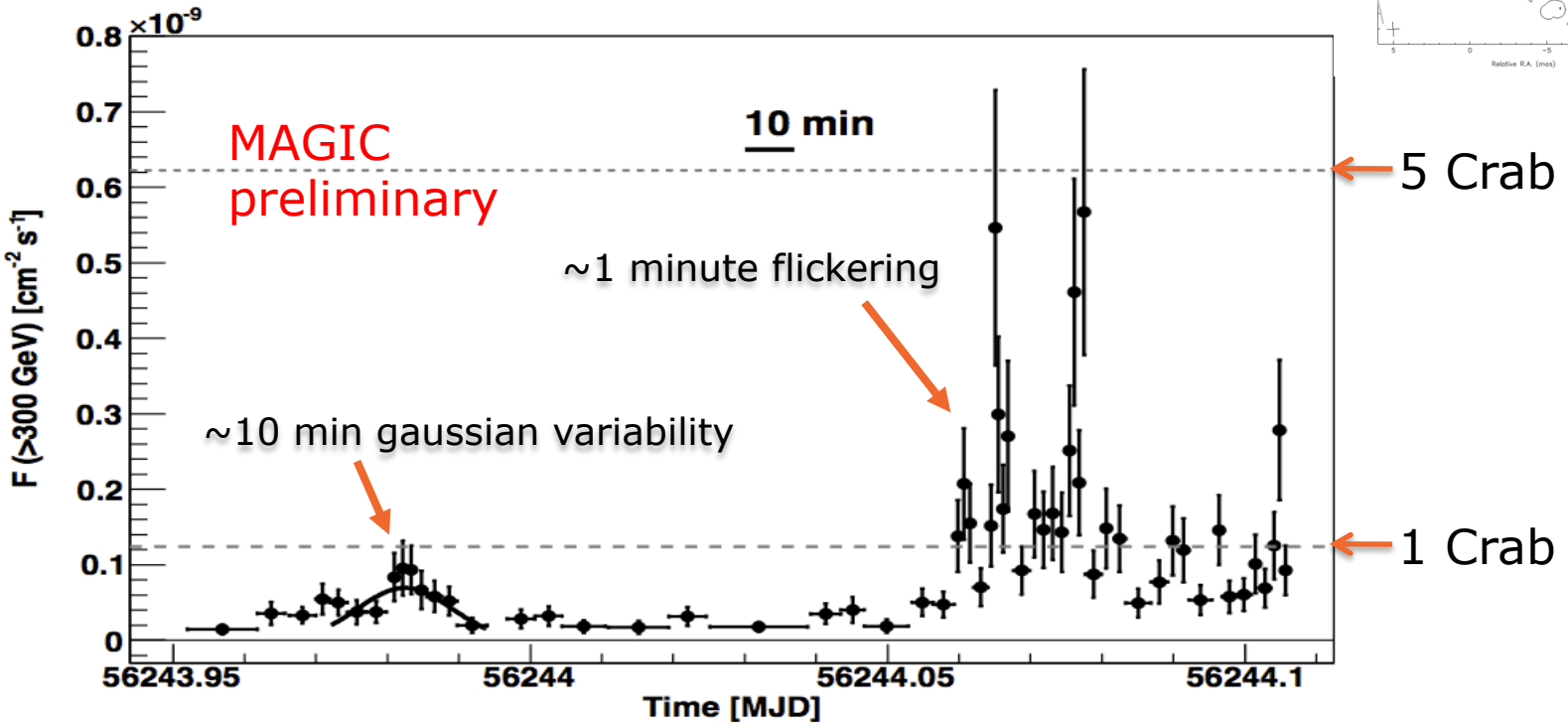


# IC 310

- The **closest blazar** (z=0.019)
  - Previously thought to be a (large viewing angle) radio galaxy, new: VLBI jet
- Extreme variability seen with MAGIC
  - Despite larger jet viewing angle ~15°

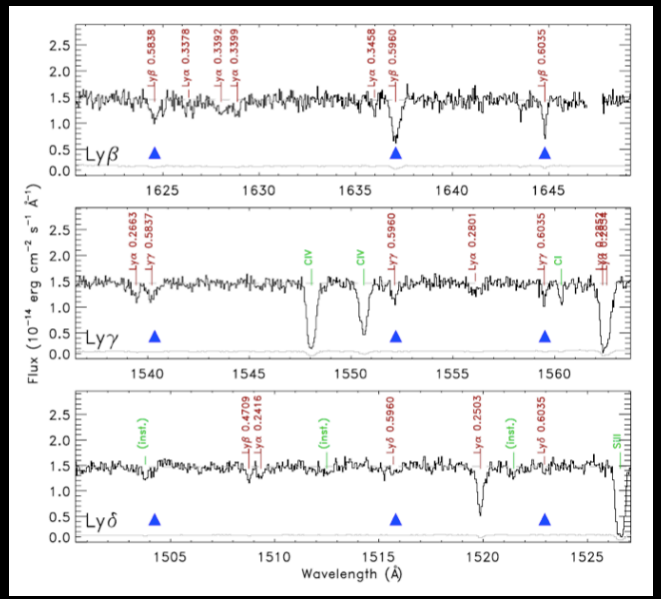


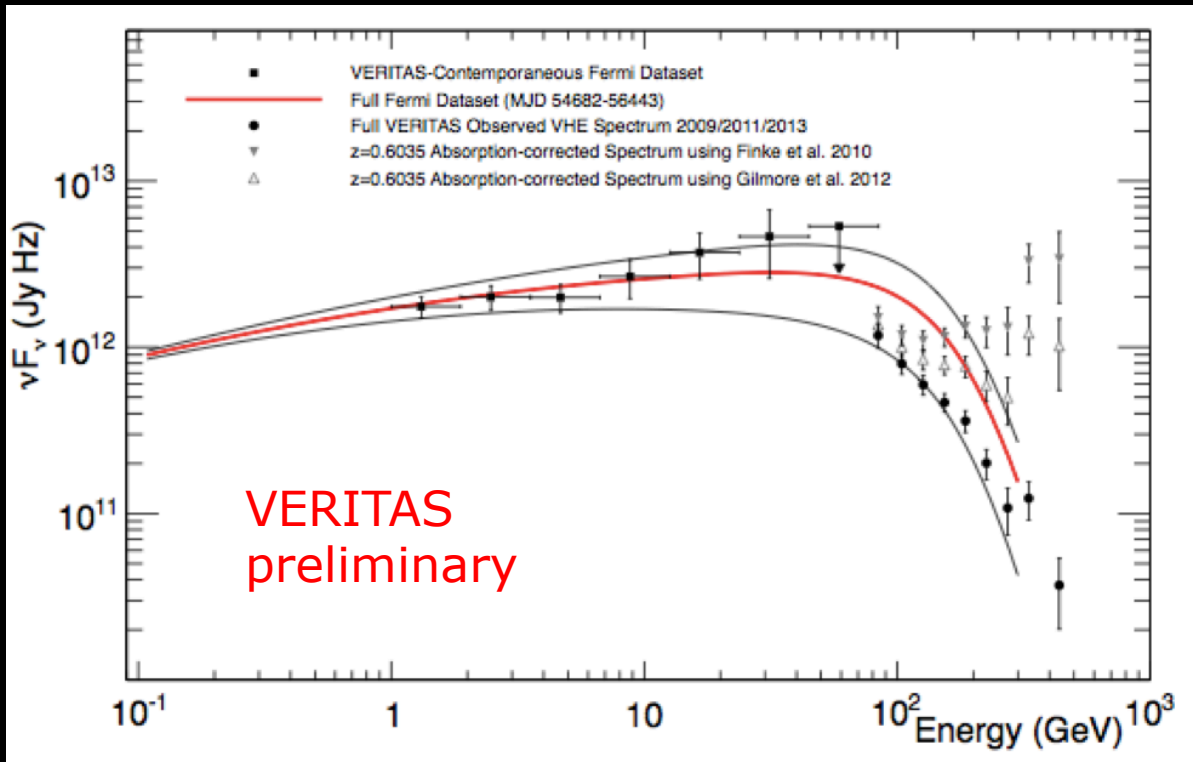



# PKS 1424+240

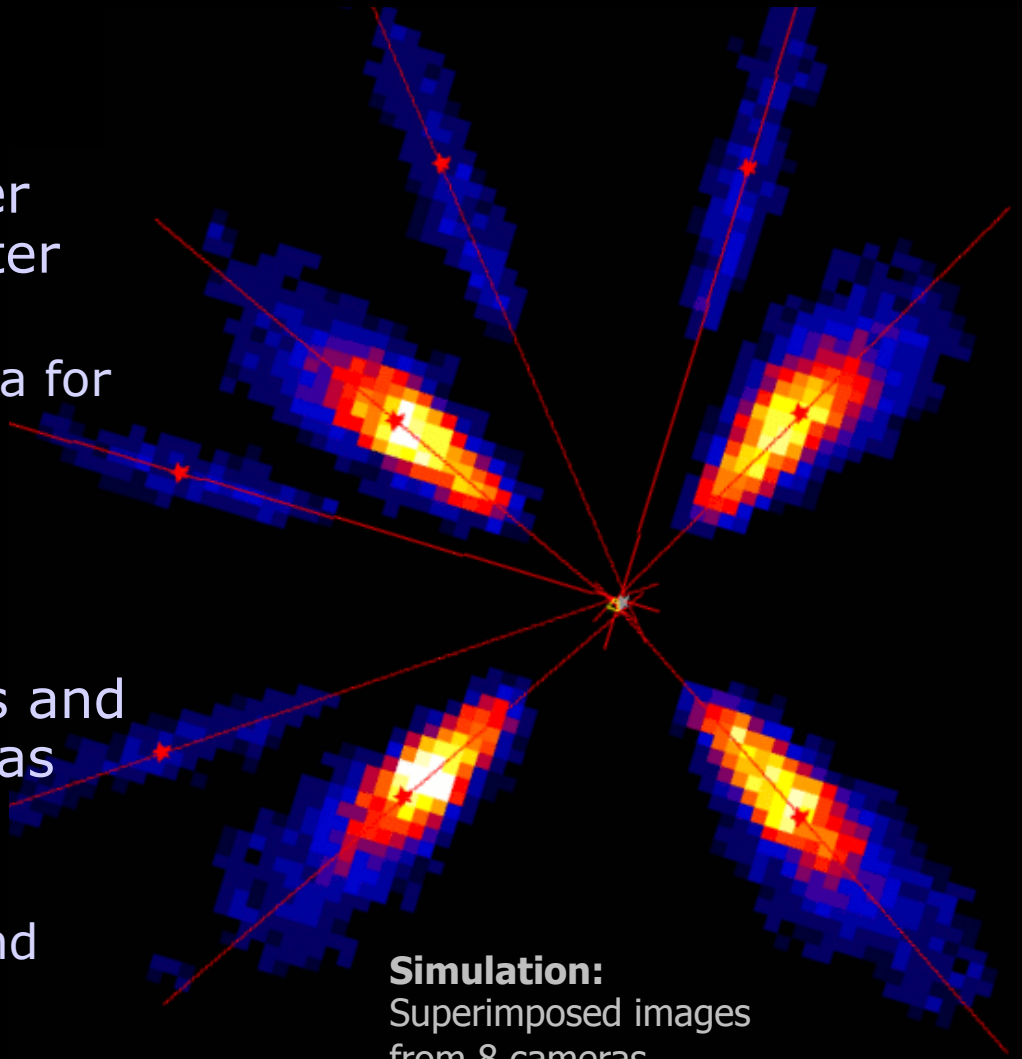
- **The most distant** blazar
  - Very solid lower limit z>0.63 from absorption lines in optical spectrum
- Well measured spectrum to several hundred GeV
- Implied **upturn** in intrinsic spectrum



# How to do better with IACT arrays?

- More events
  - More photons = better spectra, images, fainter sources
    - › Larger collection area for gamma-rays
- Better events
  - More precise measurements of atmospheric cascades and hence primary gammas
    - › Improved angular resolution
    - › Improved background rejection power
- ☛ More telescopes!



**Simulation:**
Superimposed images from 8 cameras

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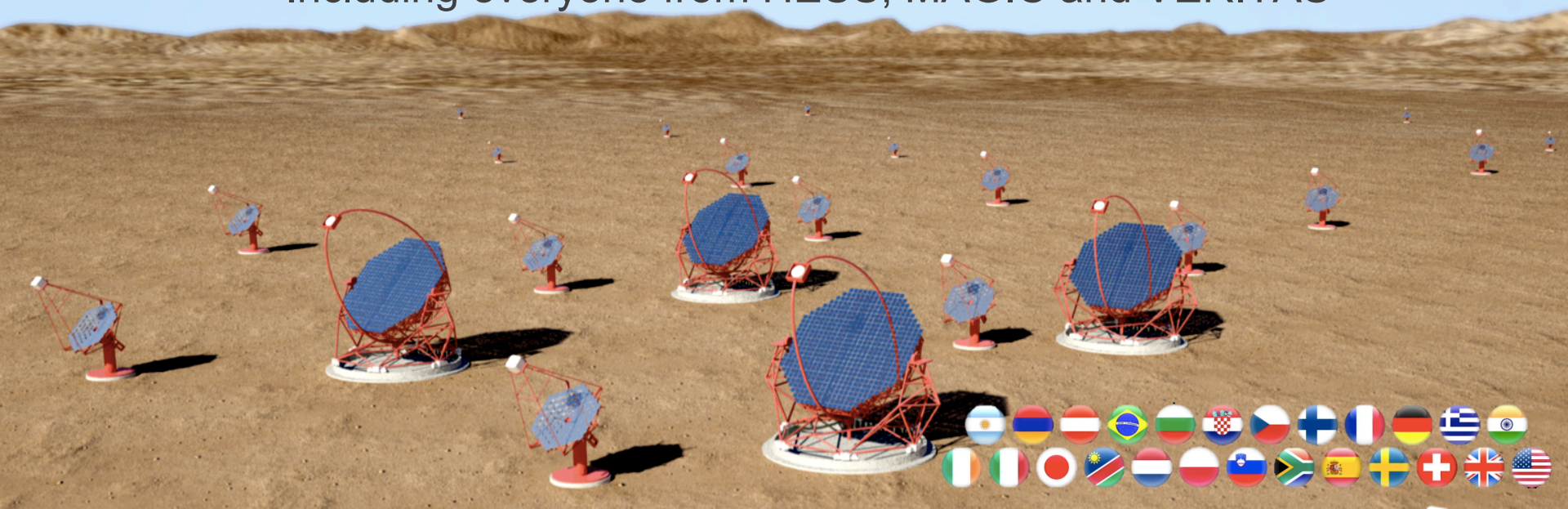
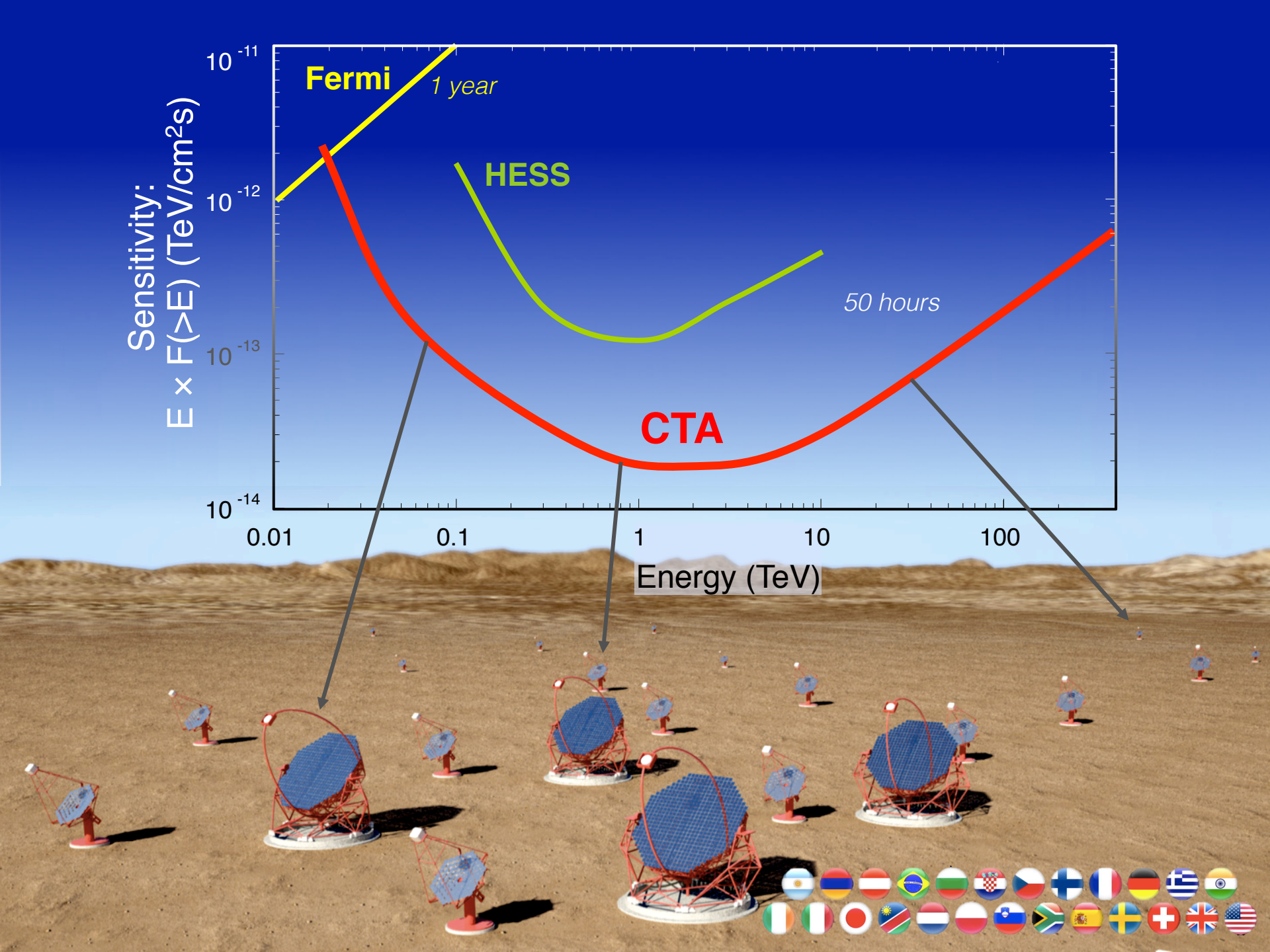
# The Cherenkov Telescope Array

- A huge improvement in all aspects of performance
  - A factor ~10 in sensitivity, much wider energy coverage, much better resolution, field-of-view, full sky, …
- A user facility / proposal-driven observatory
  - With two sites with a total of >100 telescopes
- A 27 nation ~€200M project
  - Including everyone from HESS, MAGIC and VERITAS




Fermi
1 year
HESS
50 hours
CTA
Sensitivity:
E x F(>E) (TeV/cm²s)
10 -11
10 -12
10 -13
10 -14
0.01
0.1
1
10
100
Energy (TeV)

# Large-Sized Telescope

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**

# Medium-Sized Telescope

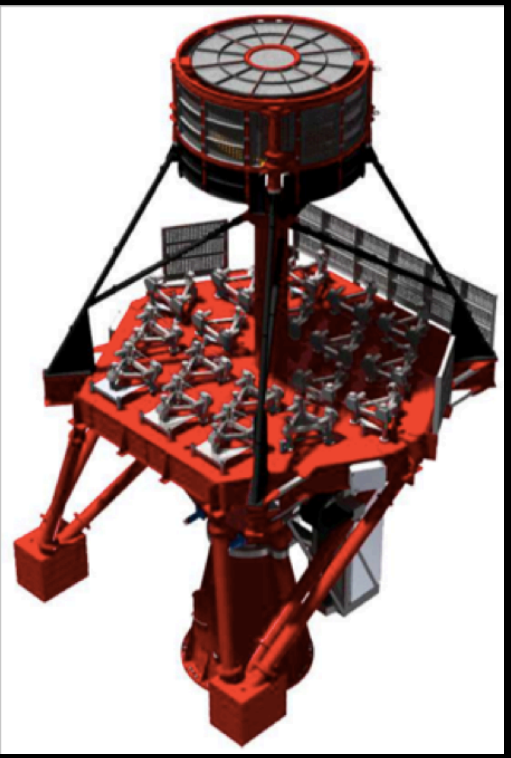
100 $m^2$ dish area
16 m focal length
1.2 m  mirror facets

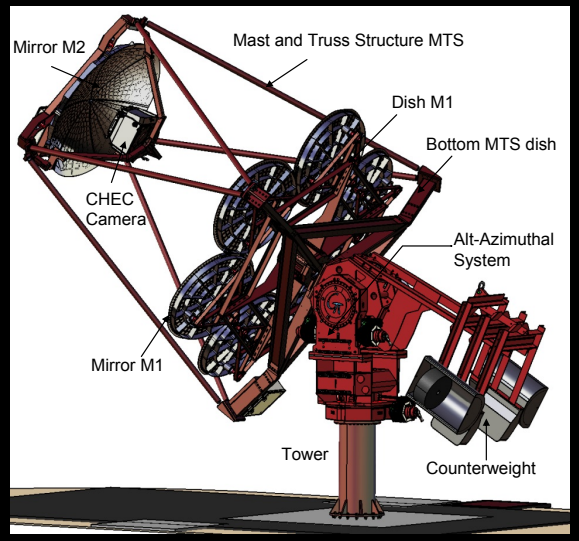
7.5$^o$ field of view
~2000 x 0.18$^o$ pixels

**25 MSTs on South site**
**15 MSTs on North site**

*Berlin*
*MST prototype*

# Small-sized Telescopes

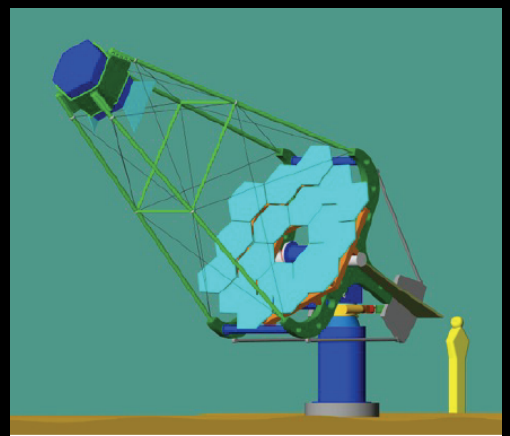





~8 $m^2$ dish area

9° field of view
~0.2° pixels

**70 SSTs on South site**



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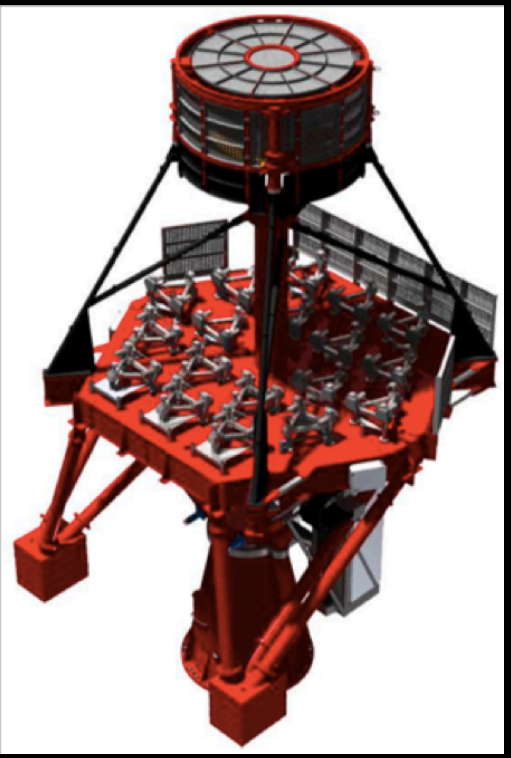
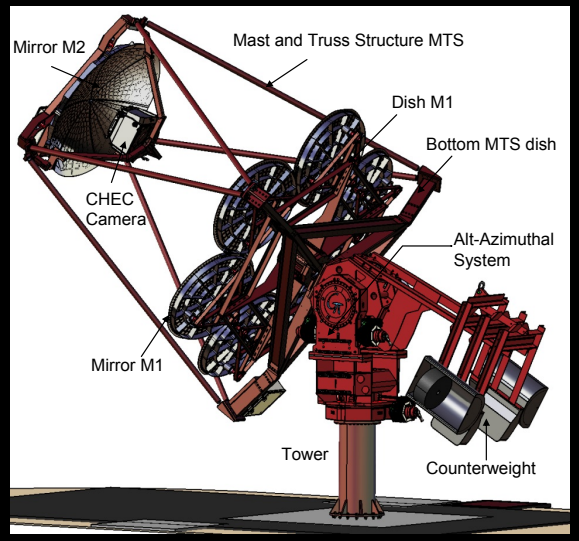
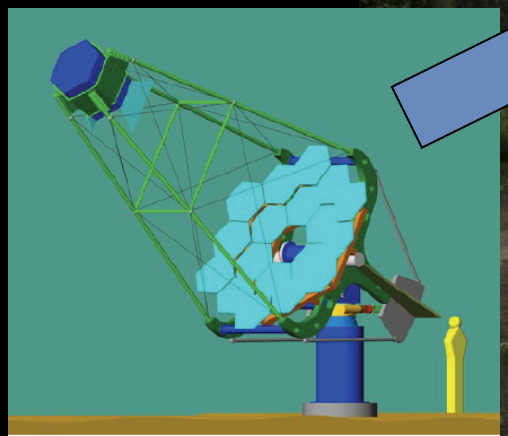
# Small-sized Telescopes





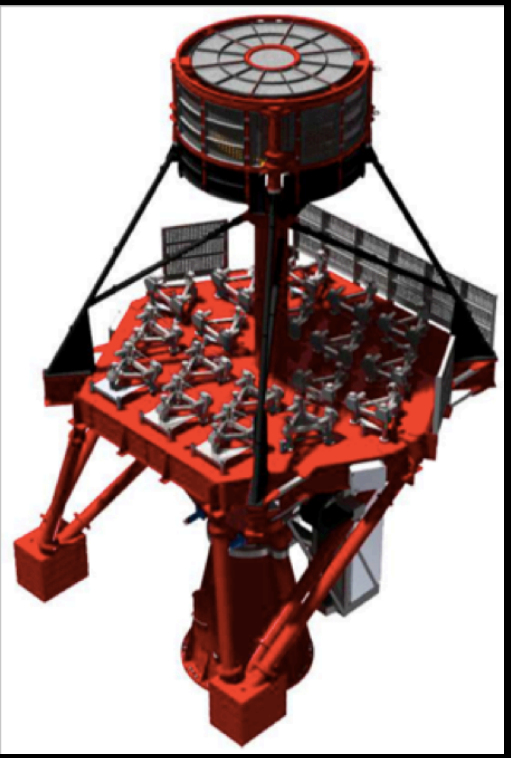
~8 $m^2$ dish area

9° field of view
~0.2° pixels

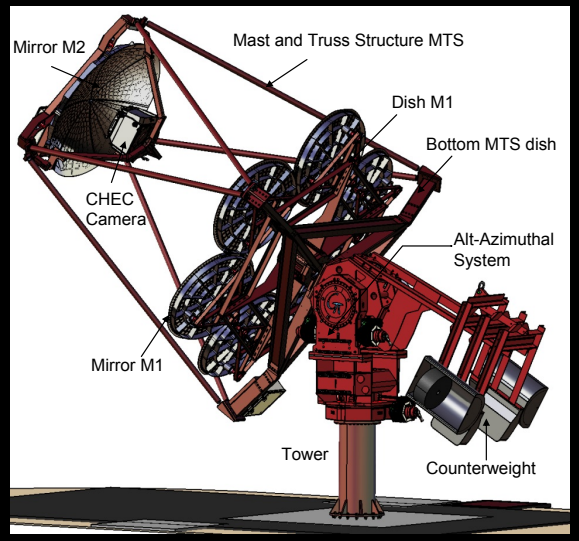
**70 SSTs on South site**

- SST-1M Prototype in Cracow

# Small-sized Telescopes



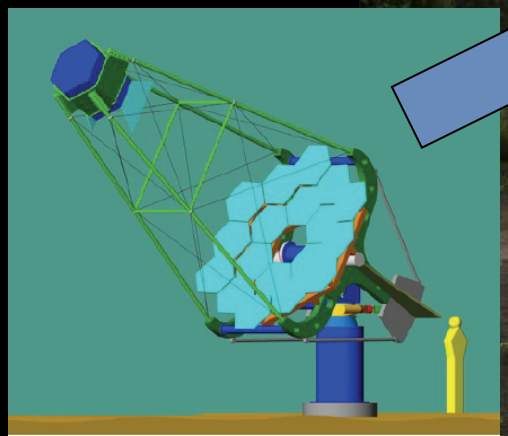
- SST-2M Prototypes by Autumn




~8 $m^2$ dish area

9° field of view
~0.2° pixels

**70 SSTs on South site**



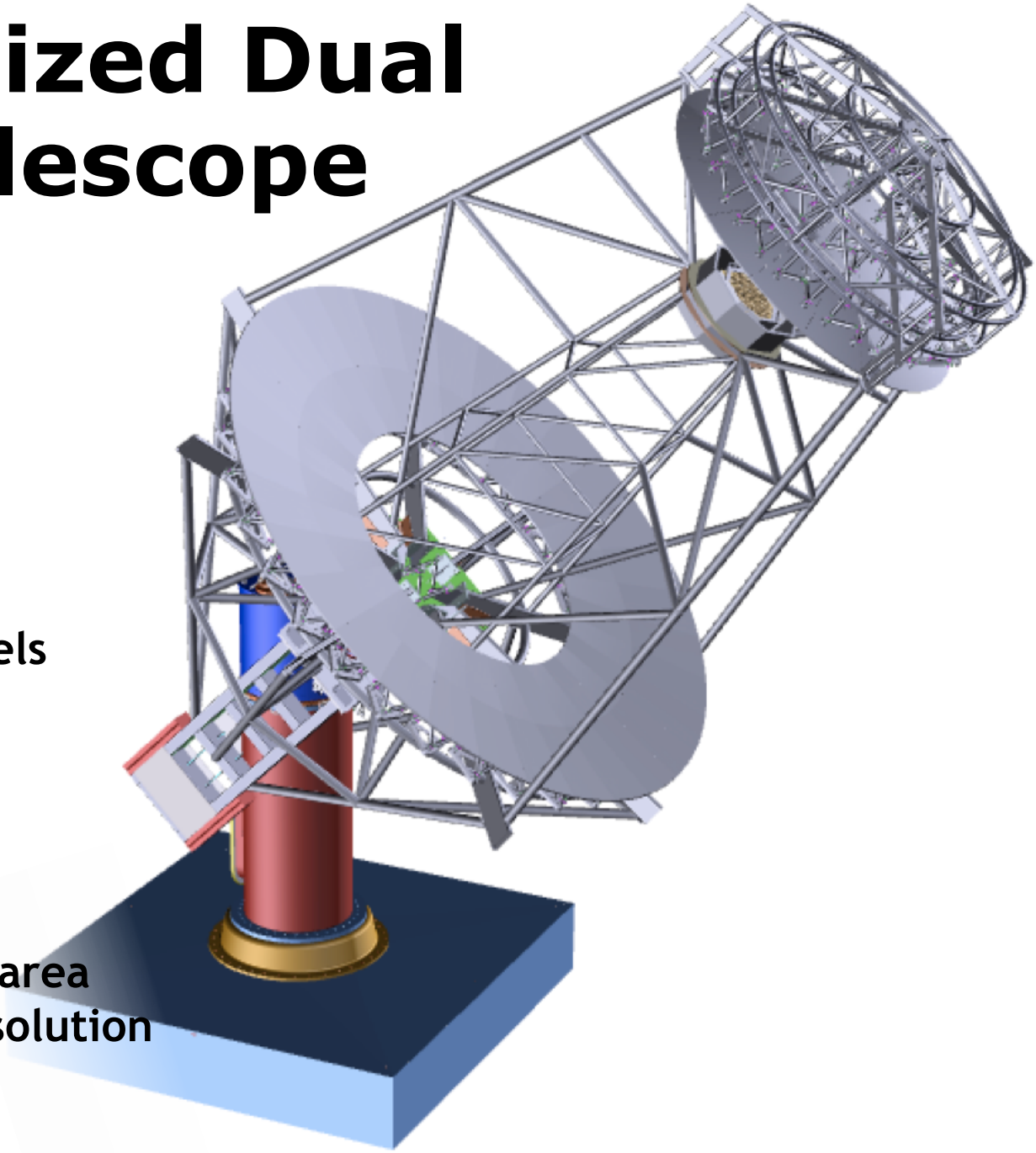
- SST-1M Prototype in Cracow

# Medium-sized Dual Mirror telescope

9.7 m primary
5.4 m secondary
5.6 m focal length, f/0.58
40 $m^2$ eff. coll. area
PSF < 4.5' over FoV
$8^o$ field of view
**11328 x $0.07^o$ SiPM pixels**
Target readout ASIC

**Extend South array by adding 24 SCTs**

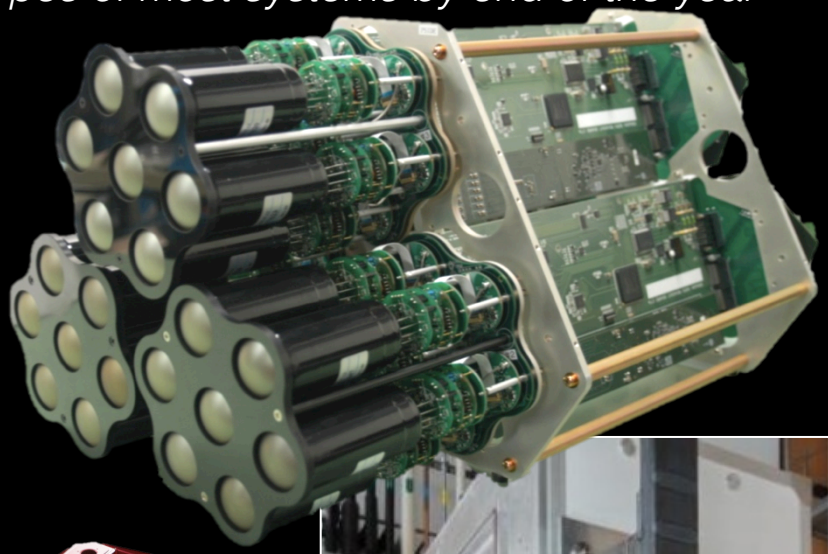
**➜ increased collection area**
**➜ improved angular resolution**

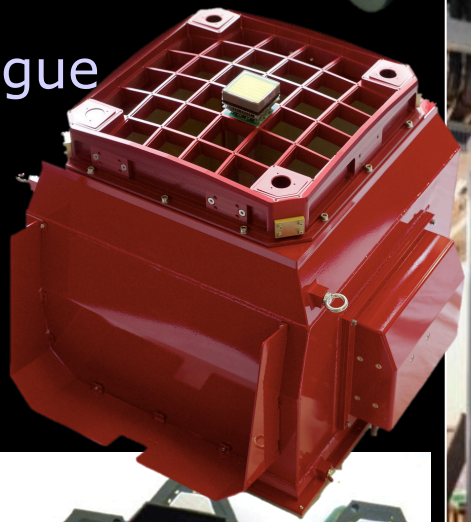


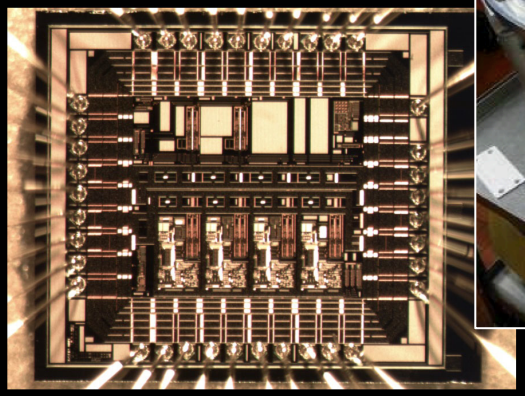
*Full camera prototypes of most systems by end of the year*

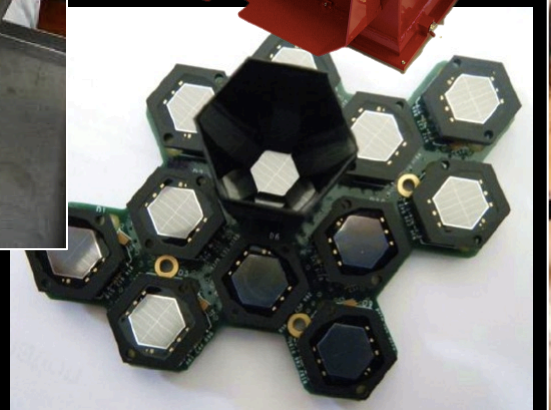
# Cameras

- Photosensors
  - PMTs for LST/MST
  - Silicon PMs (or MAPMs) for SST +SCTs (smaller plate scales)
- Electronics
  - Both fully digital and analogue pipelines being prototyped



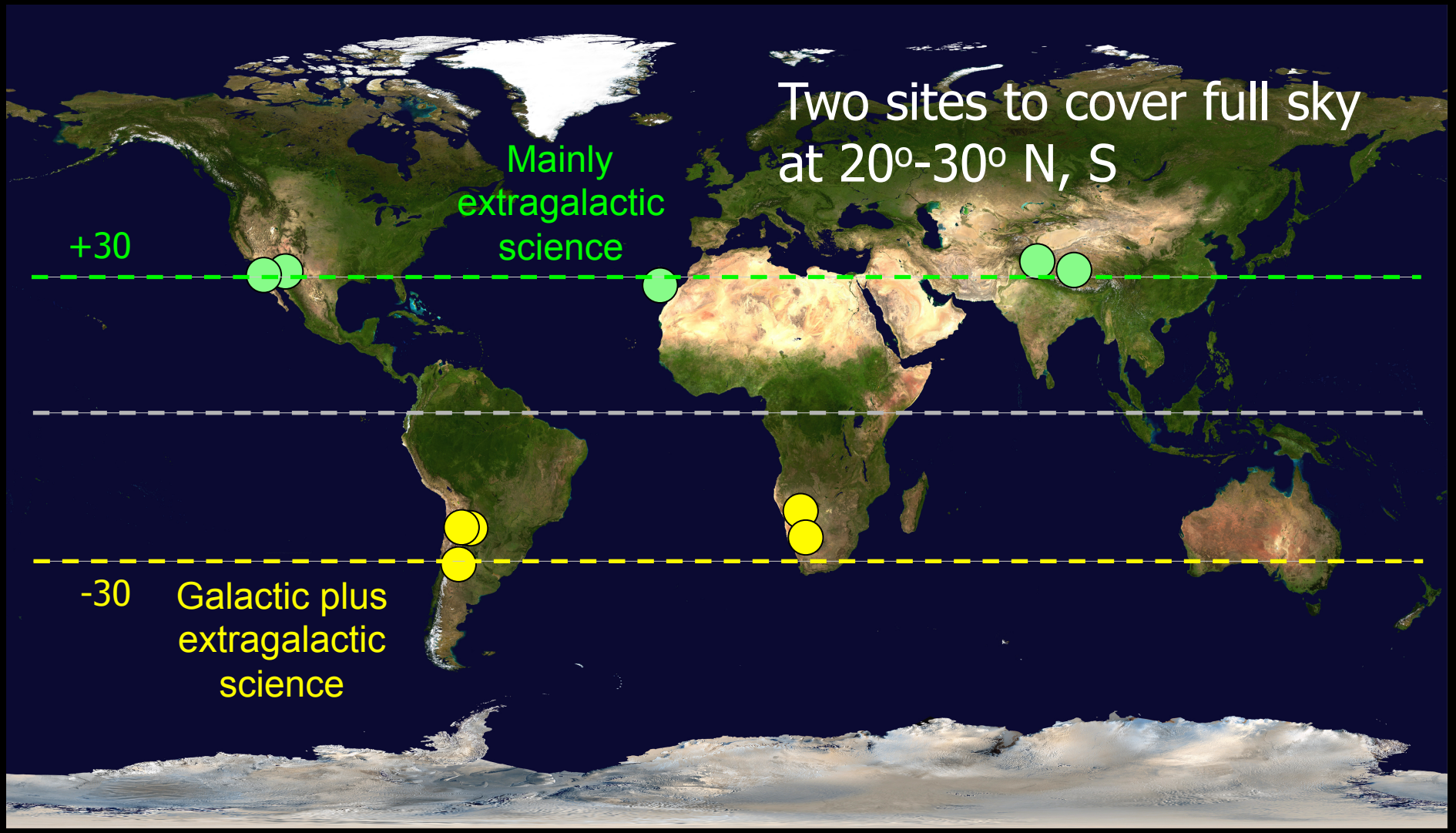






Signal processing ASIC for the NECTAr project.

# CTA Sites


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

# Sites: Candidates

+additional lower priority candidates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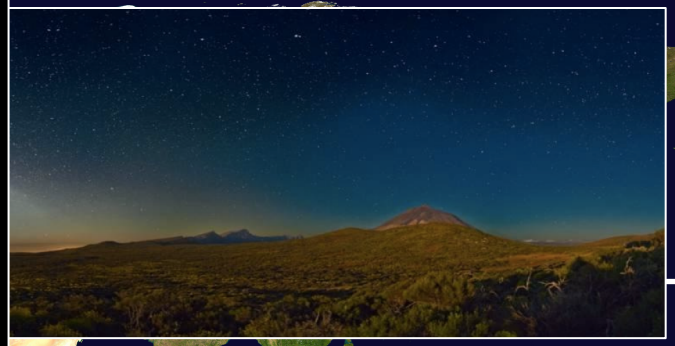
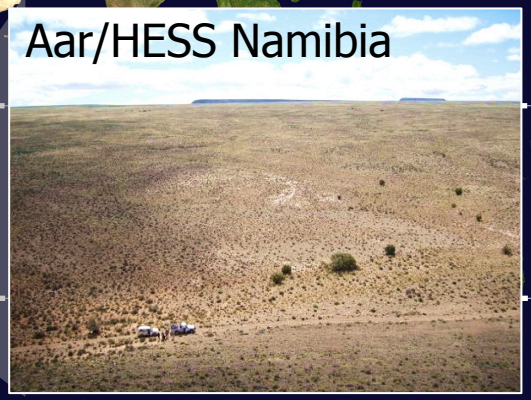
# Sites: Candidates

+additional lower priority candidates


- South
  - **Negotiations starting** with Namibia and Chile ➔ Decision by November 2014
- North
  - Mexico, US and Spain still all under consideration ➔ Decision early 2015
- Site development 2015+





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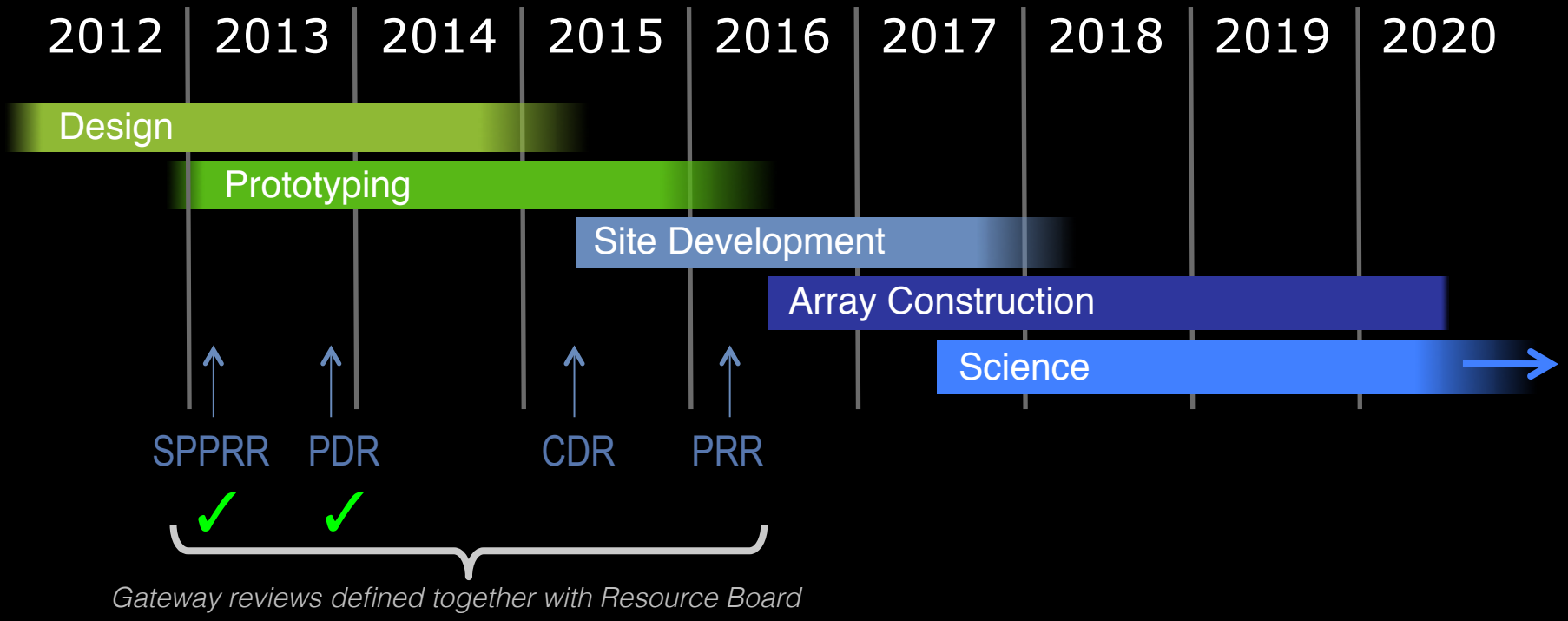
# CTA Timeline




- CTAO Public Limited Company founded v. soon
  - Interim legal entity for the CTA Observatory
  - Taking over from (partly) FP7 funded Prep. Phase
- Aiming for **project approval** mid 2015

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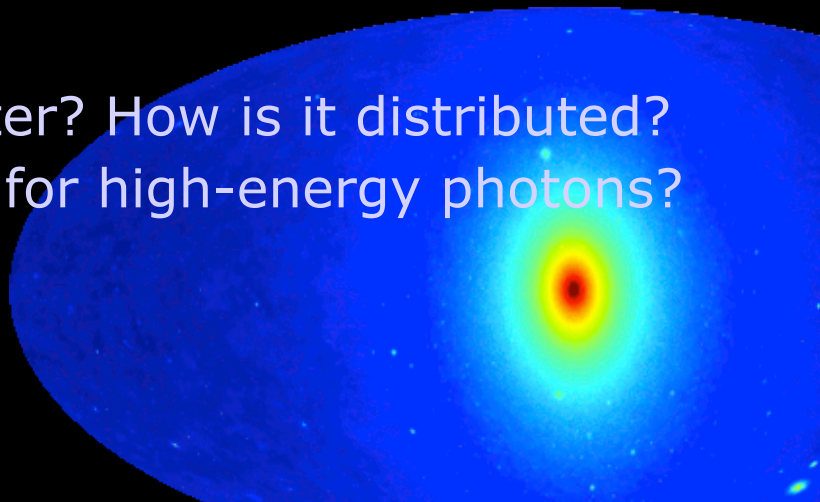
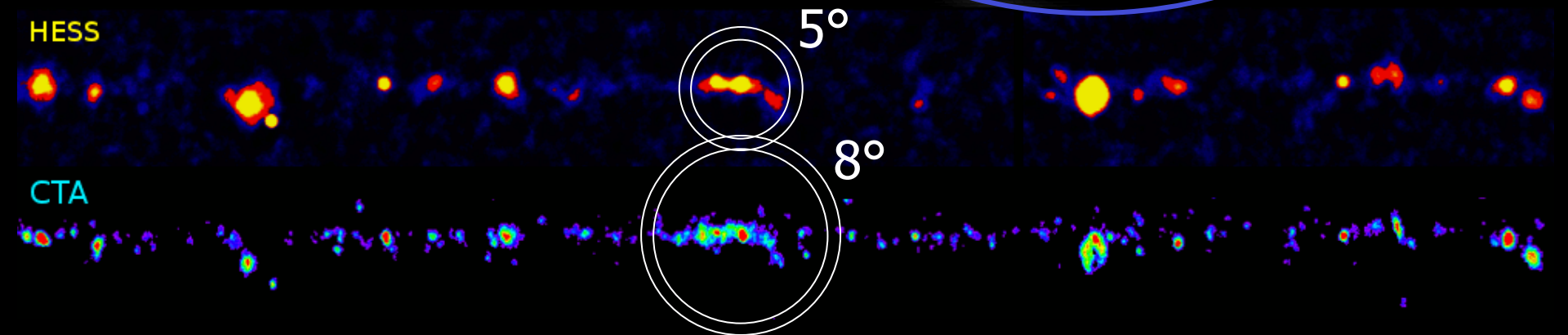
# CTA Science

- **Cosmic Particle Acceleration, Propagation and Impact**
  - Mechanisms for particle acceleration, galactic CR acceleration and Pevatrons, acceleration in jets and lobes of AGN, cosmic ray transport, …
  - What role do accelerated particles play in feedback on star formation and galaxy evolution?
- **Probing Extreme Environments**
  - Neutron stars and black holes, relativistic jets, winds and explosions, the contents of cosmic voids, …
- **Physics Frontiers**
  - 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?

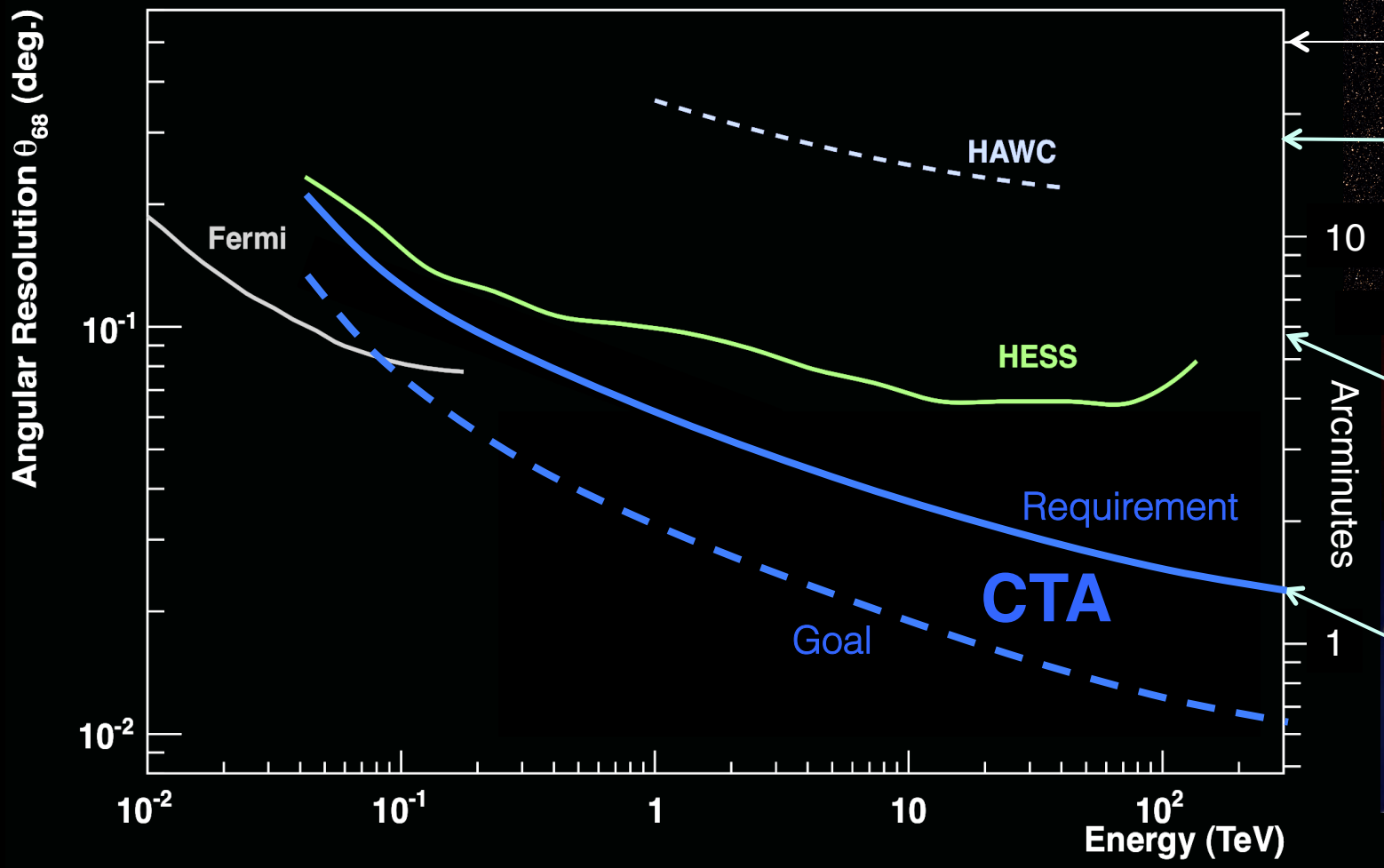


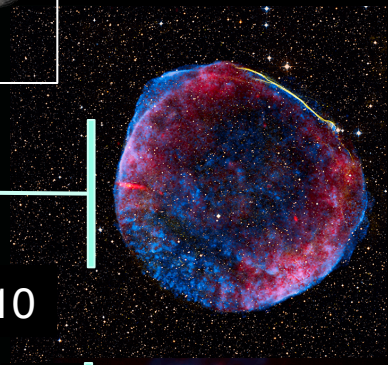
# CTA Reach

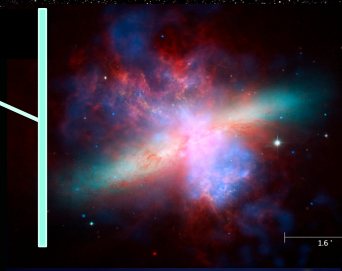
- Galactic objects
  - Newly born pulsars and the supernova remnants
    - have typical brightness such that HESS etc can see only relatively local (typically at a few kpc) objects
  - CTA will see **whole** Galaxy
- Field of view + sens.
  - Survey speed ~300×HESS

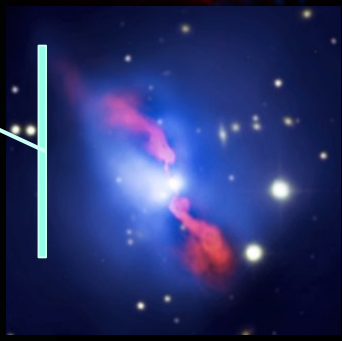


# CTA Resolution







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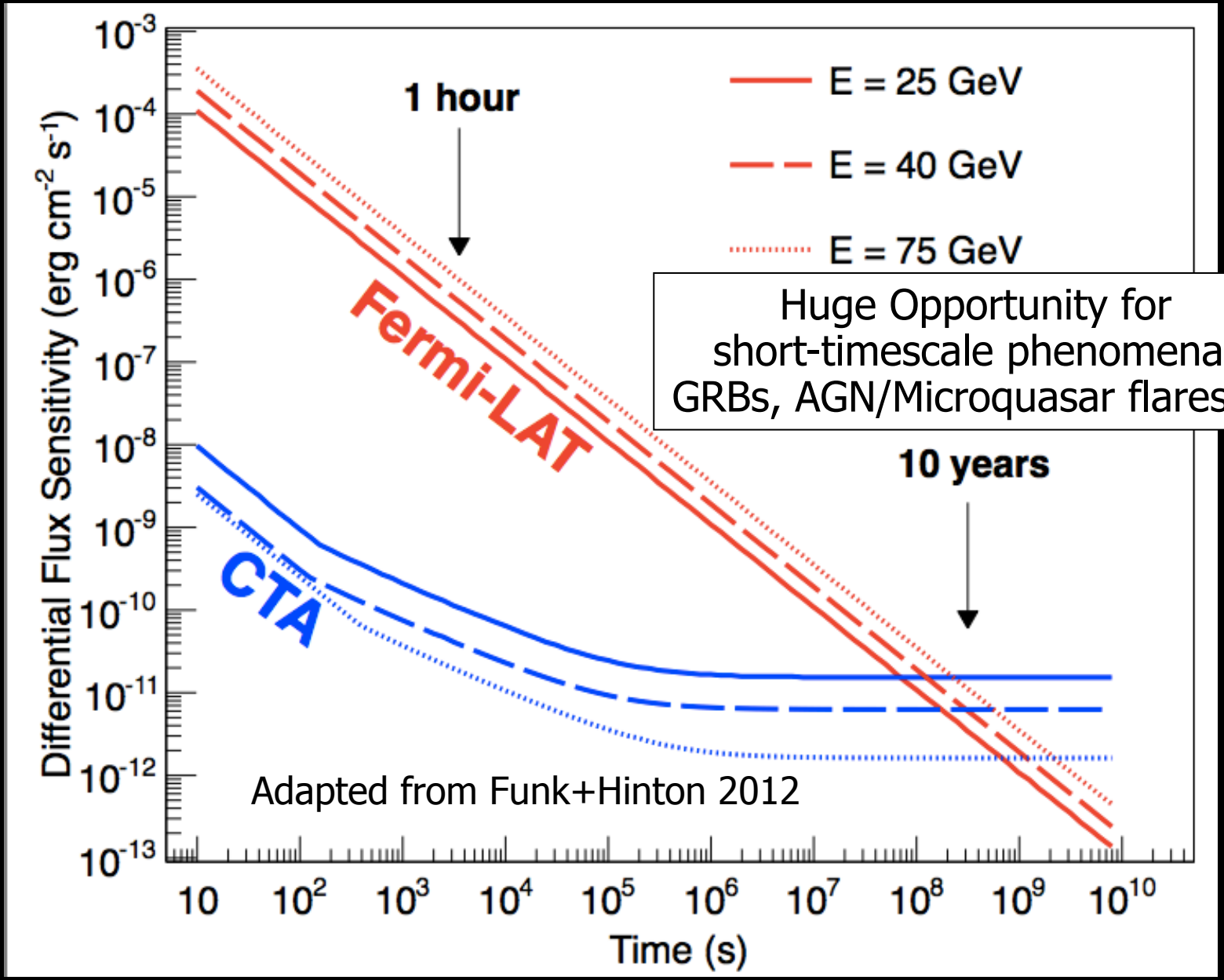
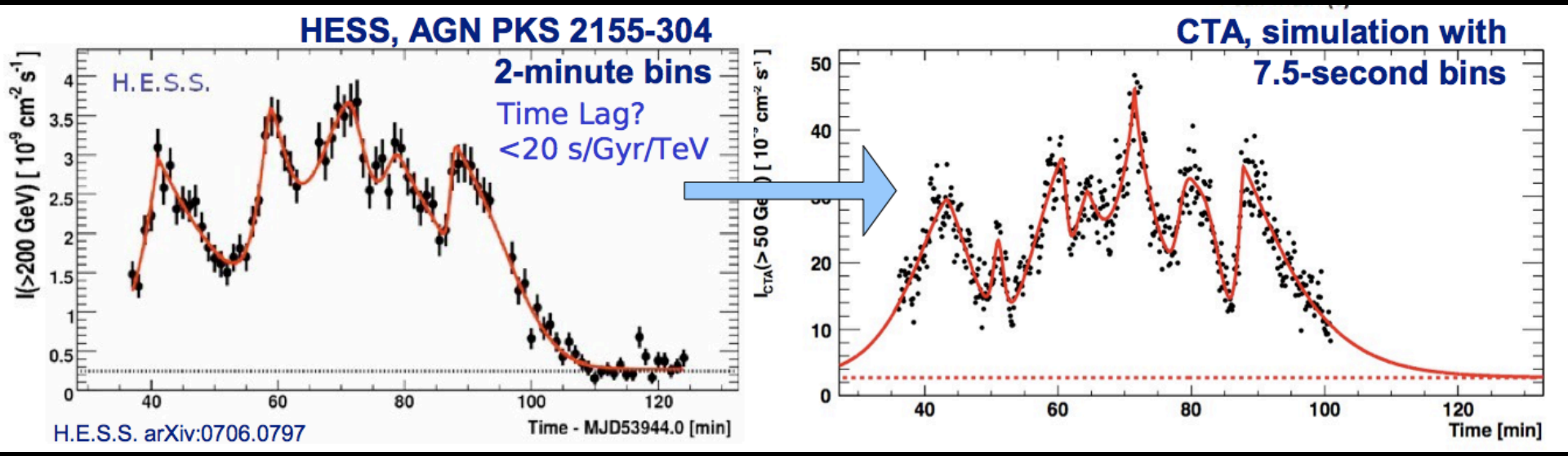
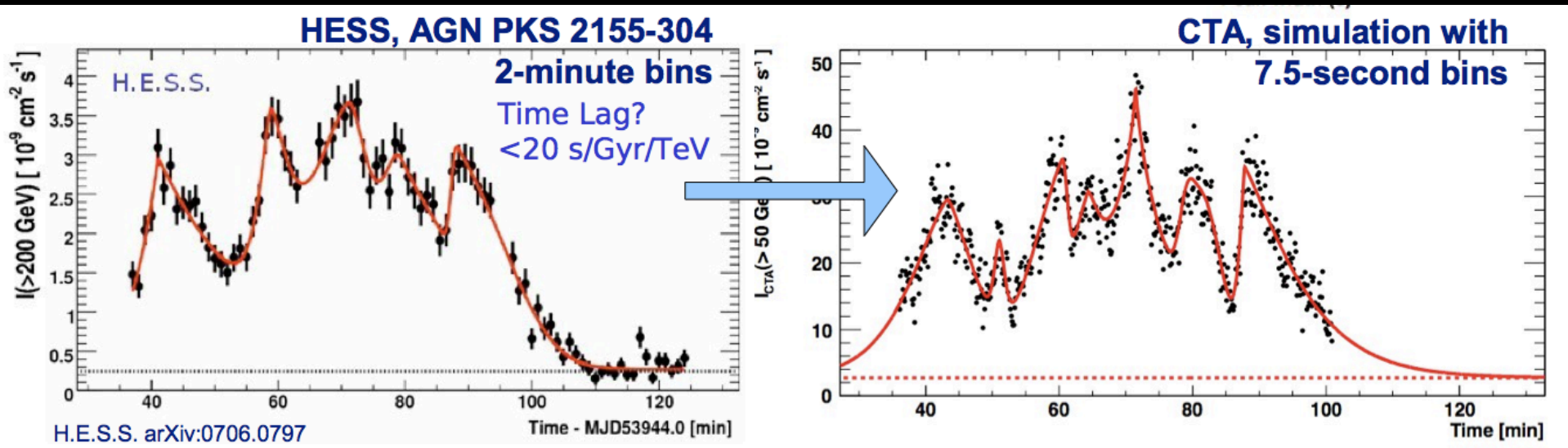
# Variability with CTA

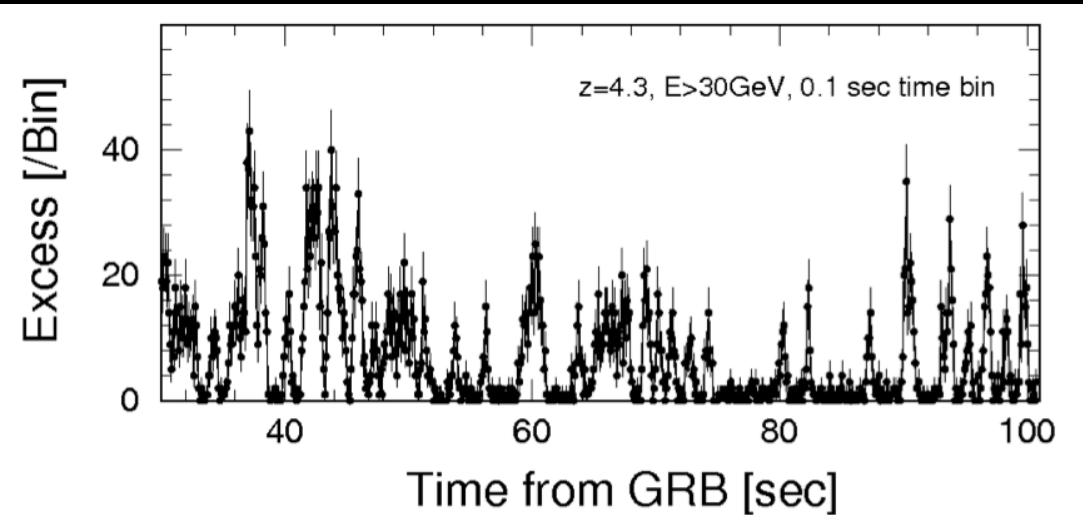


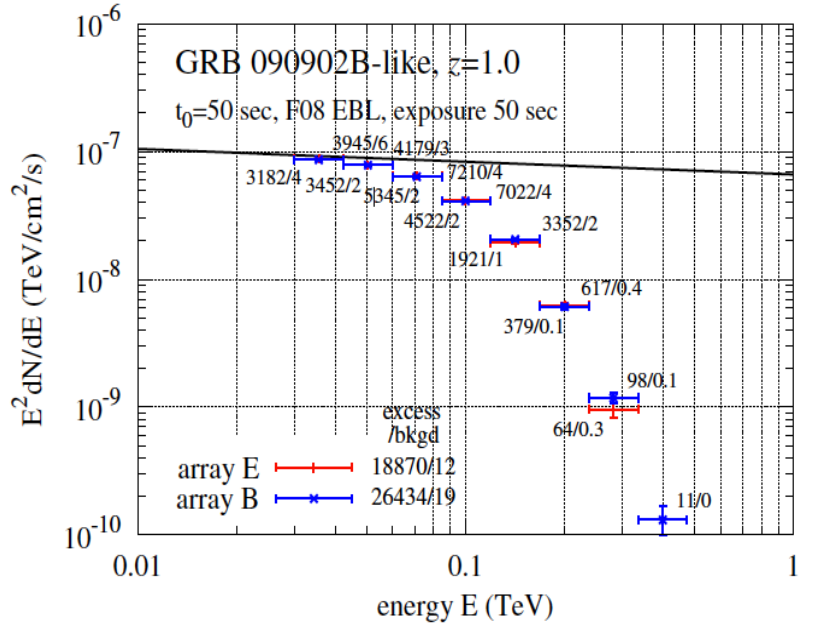
# Variability with CTA



# Variability with CTA



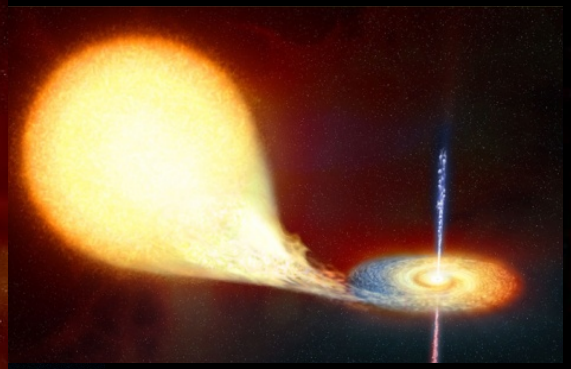



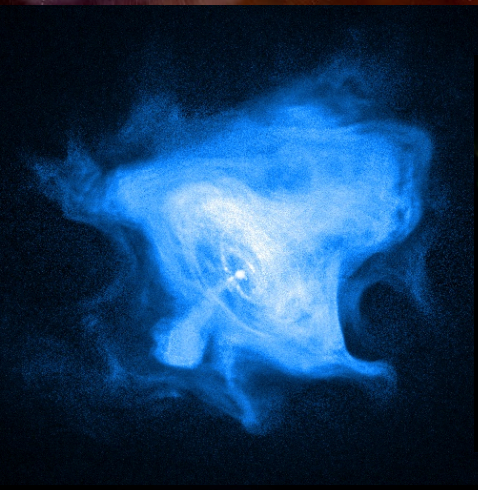
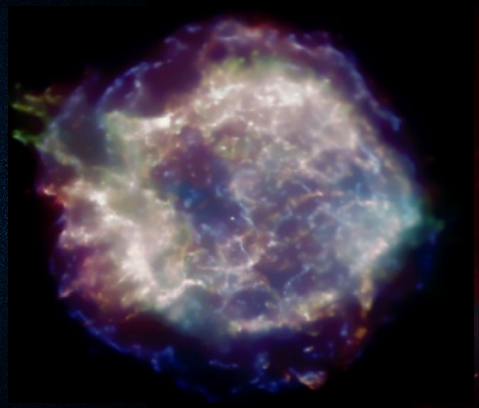



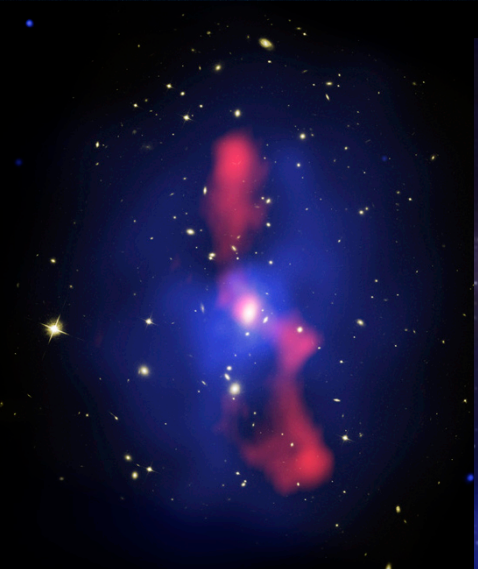

*See special issue of APh on CTA*

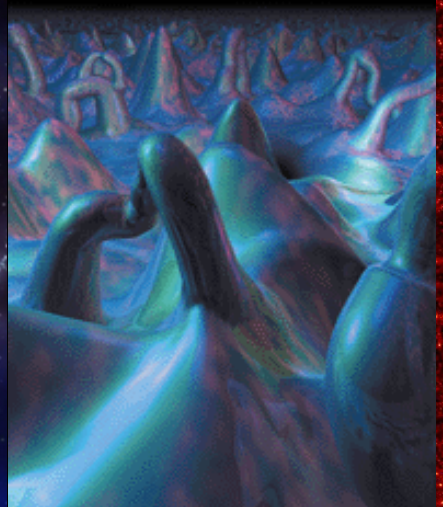
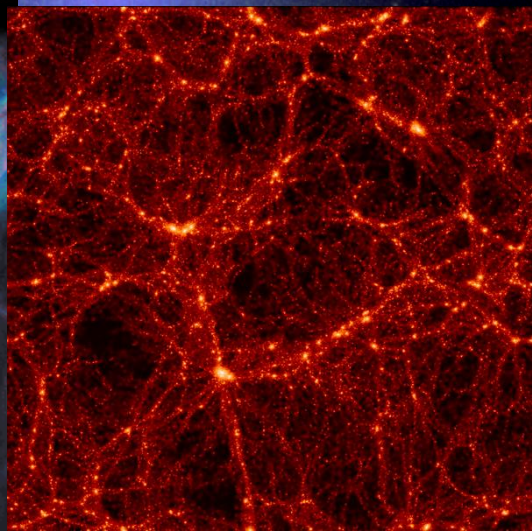
# Conclusions

- Current Cherenkov Telescope Arrays still delivering
  - All with (fairly) recent upgrades and recent important results → watch this space!
- **CTA**
  - Major recent progress towards realising the observatory
  - On track for completion ~2020 (1st science much earlier)
  - Will open up VHE astronomy to a wide community
- NB Ground-based future is not just IACTs
  - Also HAWC (now!) and LHAASO (on CTA timescale)

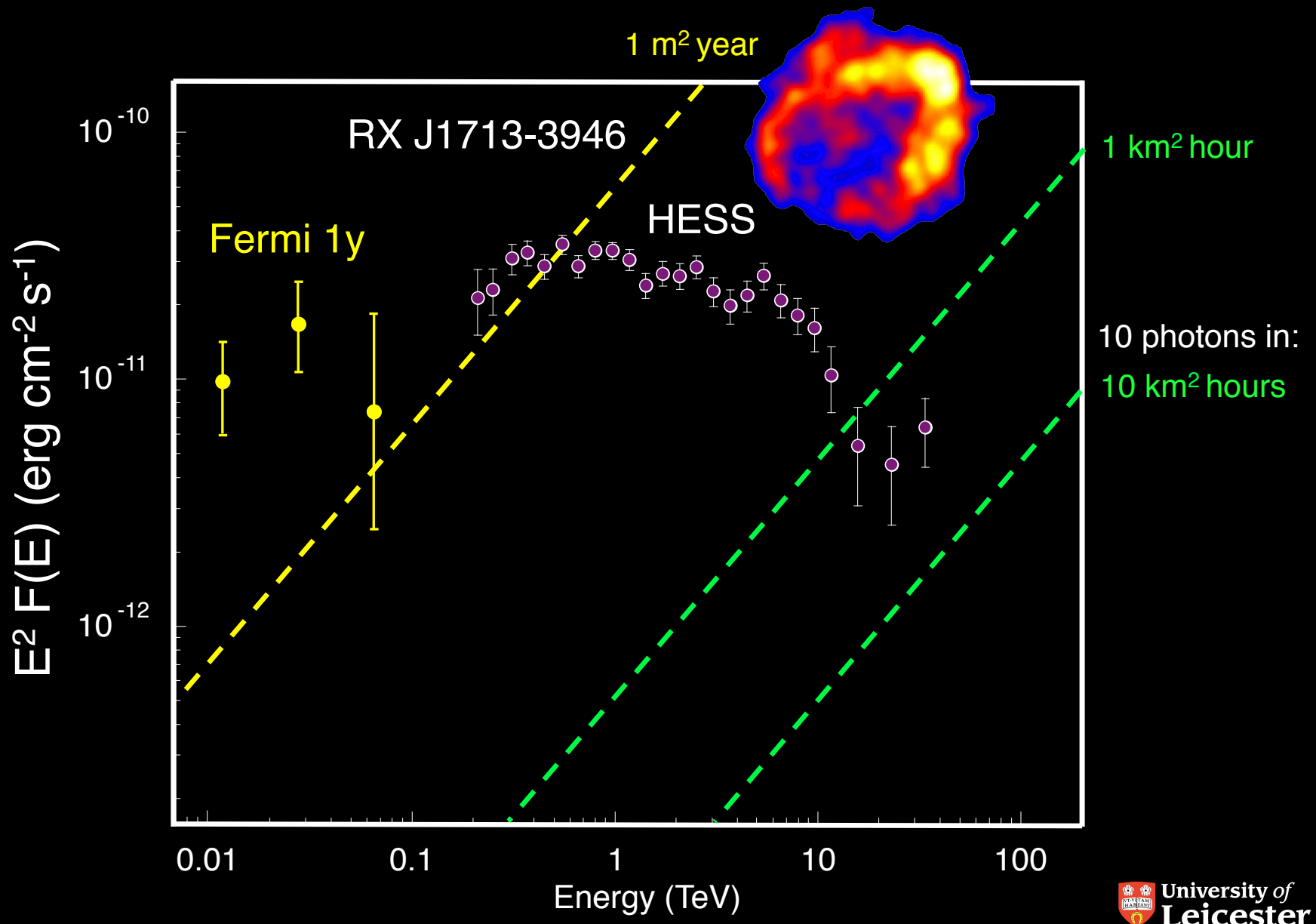



# CTA Area

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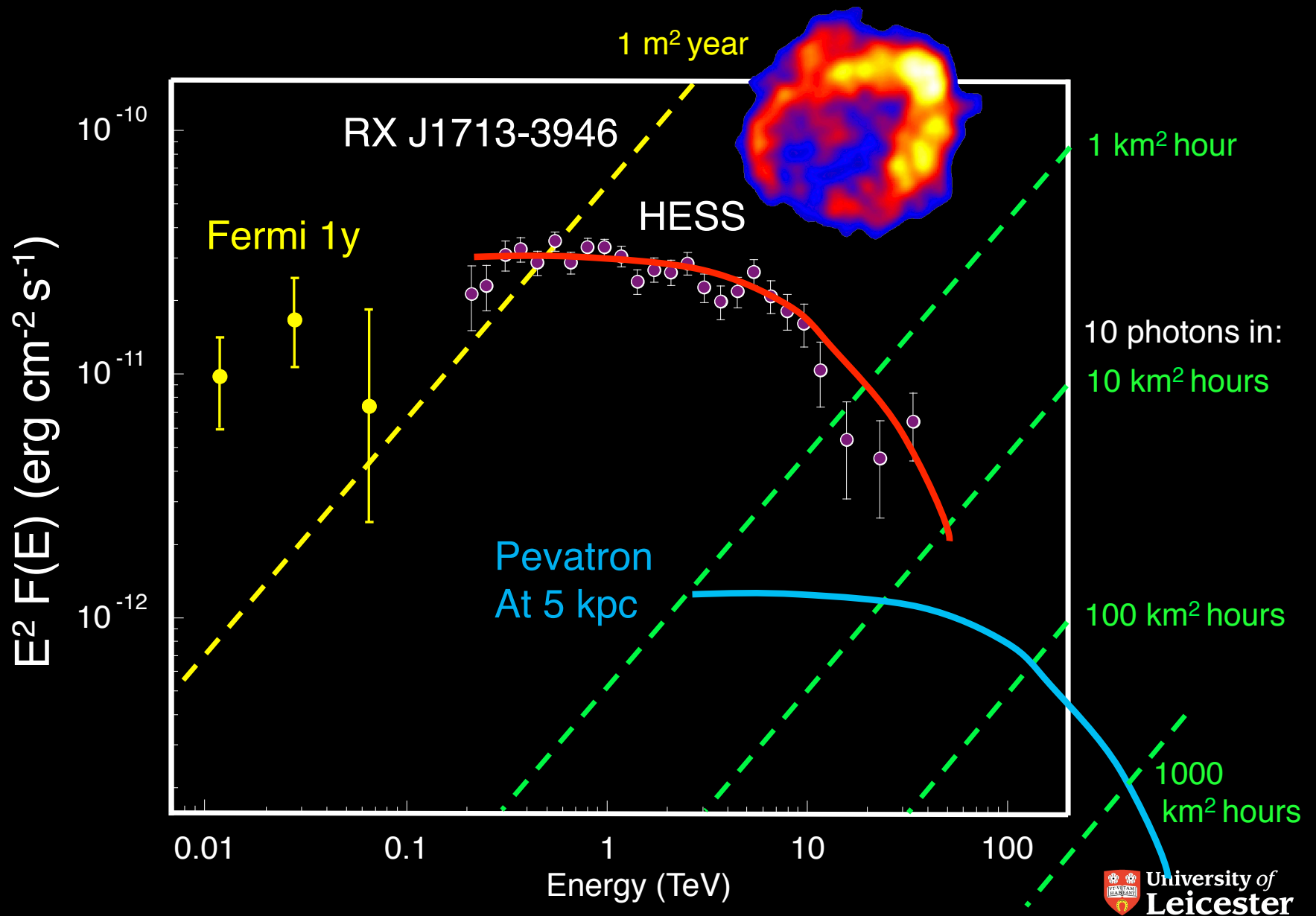
# CTA Area

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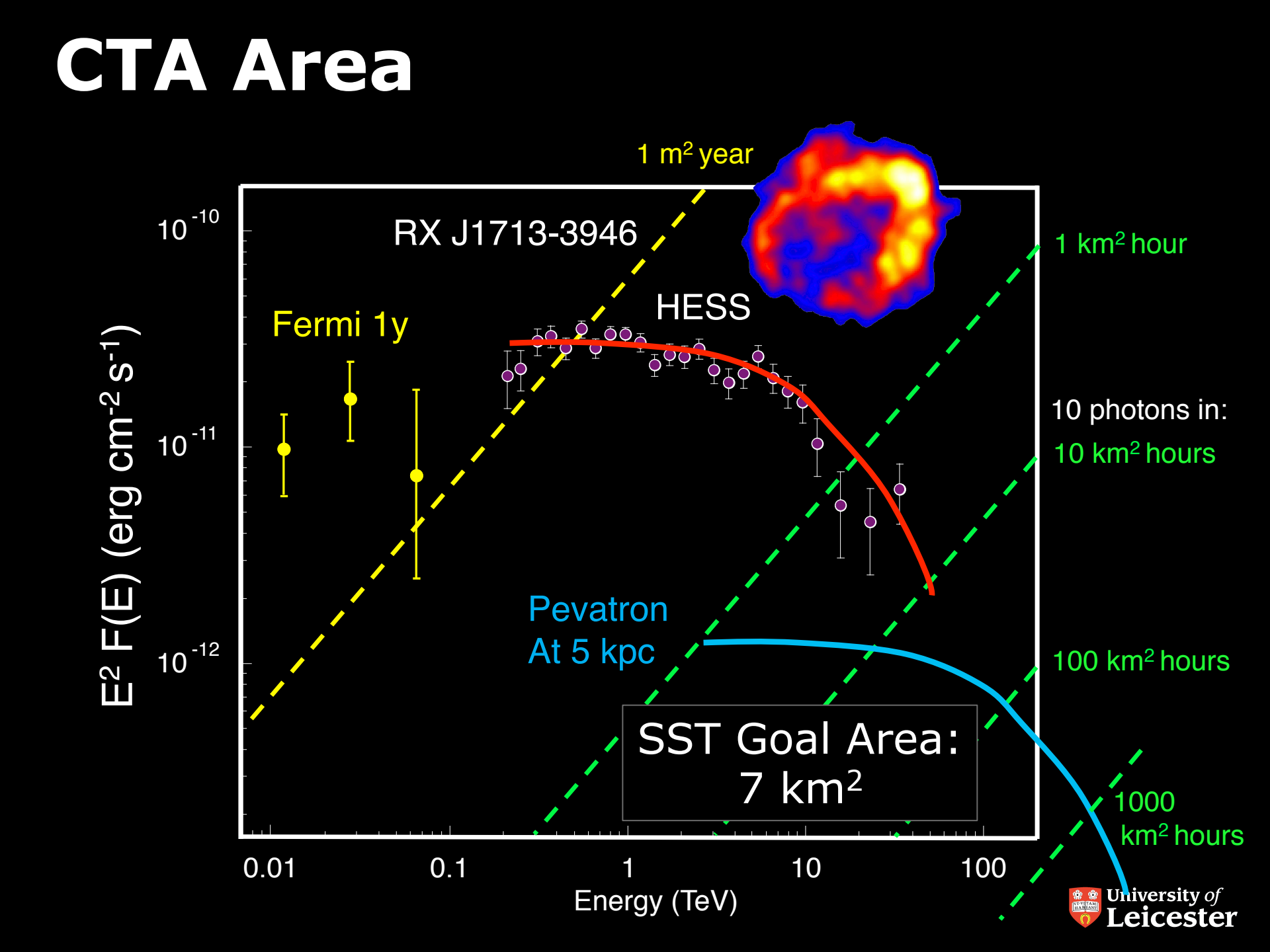
# CTA Area

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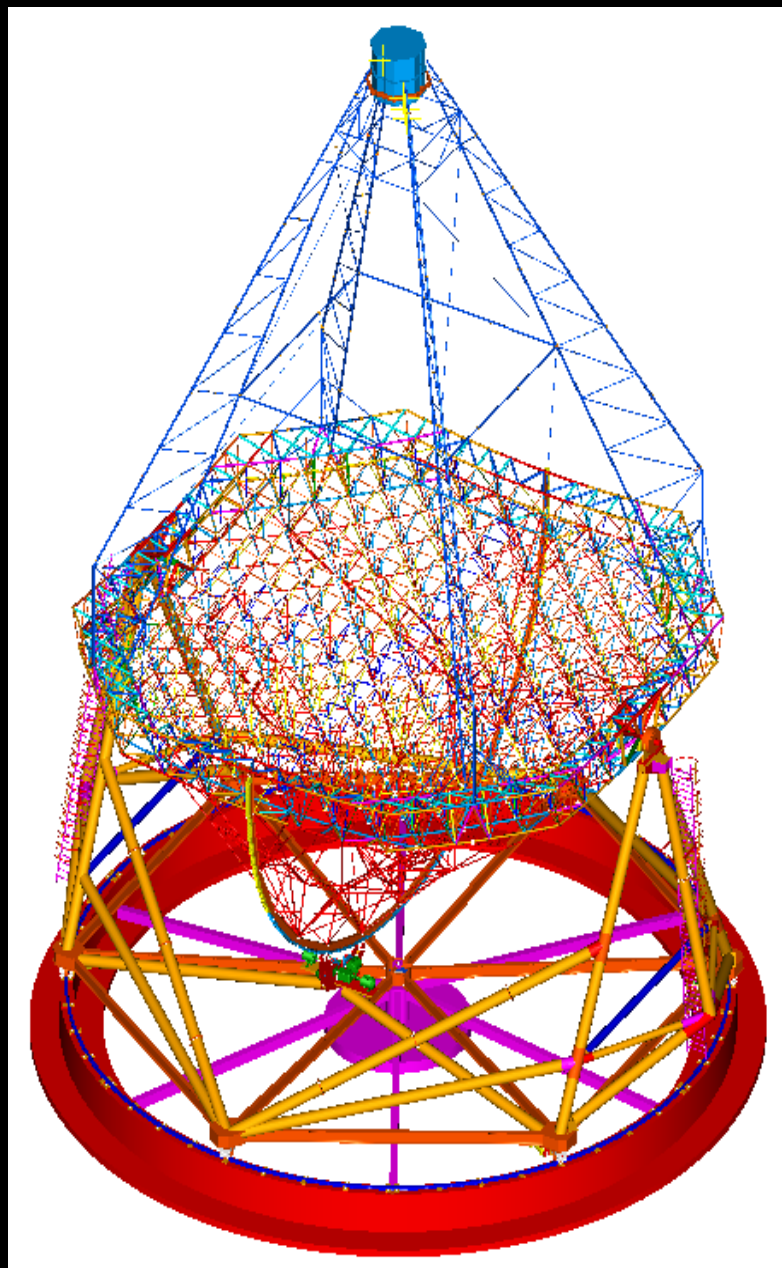
# MACE

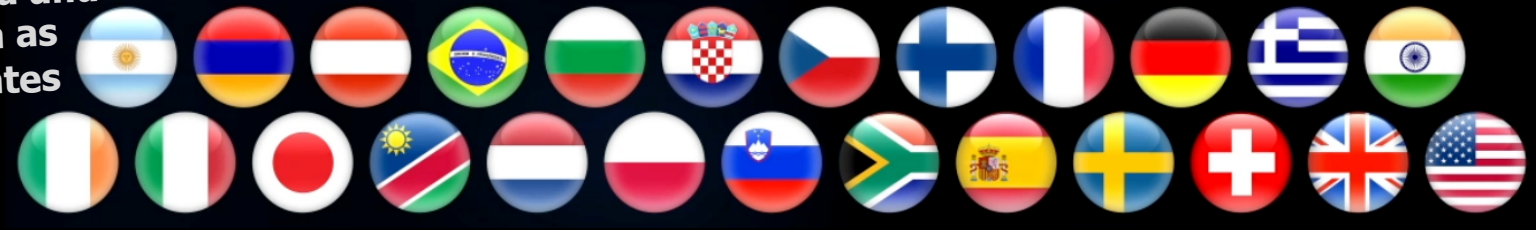
- At Hanle, India, 4200m
- 360 $m^2$ (21 m ∅) mirror
- Threshold ~20 GeV
- 1088 pixel – 4° FoV
- First work on site begun
- Expect 1st results 2013

- Add 3 more tels ~2016



# The CTA Collaboration

+Australia and Canada as associates



>1000 people in 27 countries

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