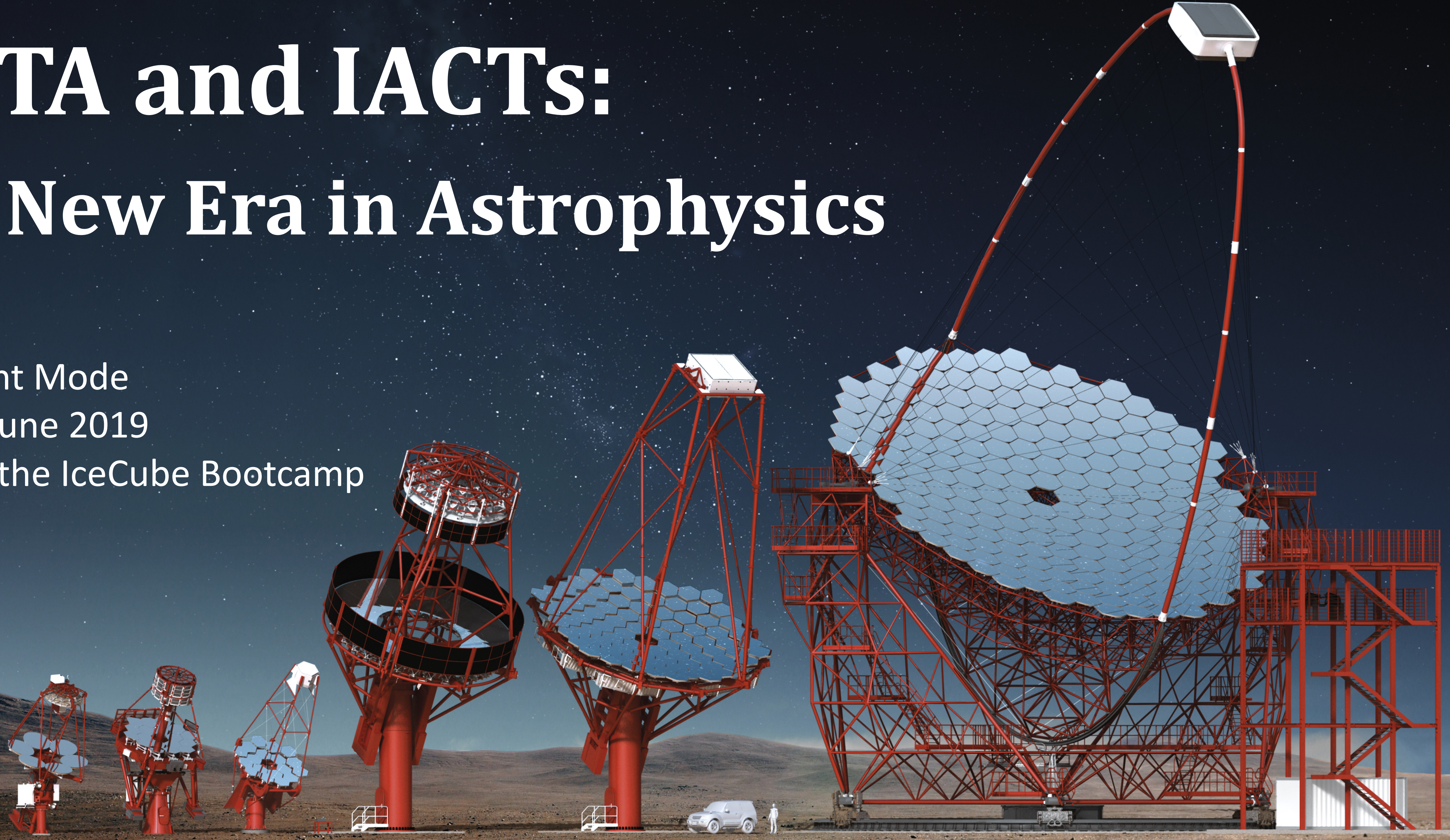
CTA and IACTs:
A New Era in Astrophysics

Brent Mode
12 June 2019
For the IceCube Bootcamp



Motivations for TeV Gamma Ray Astronomy

Astroparticle Physics and Gamma Rays

10^{3} 10^{1} 10^{-1} 10^{-3} 10^{-5} 10^{-7} 10^{-9} 10^{-11}

radio microwave infrared optical UV X-ray

Astroparticle physics over 13 orders of magnitude

Gamma rays over 9 orders of magnitude

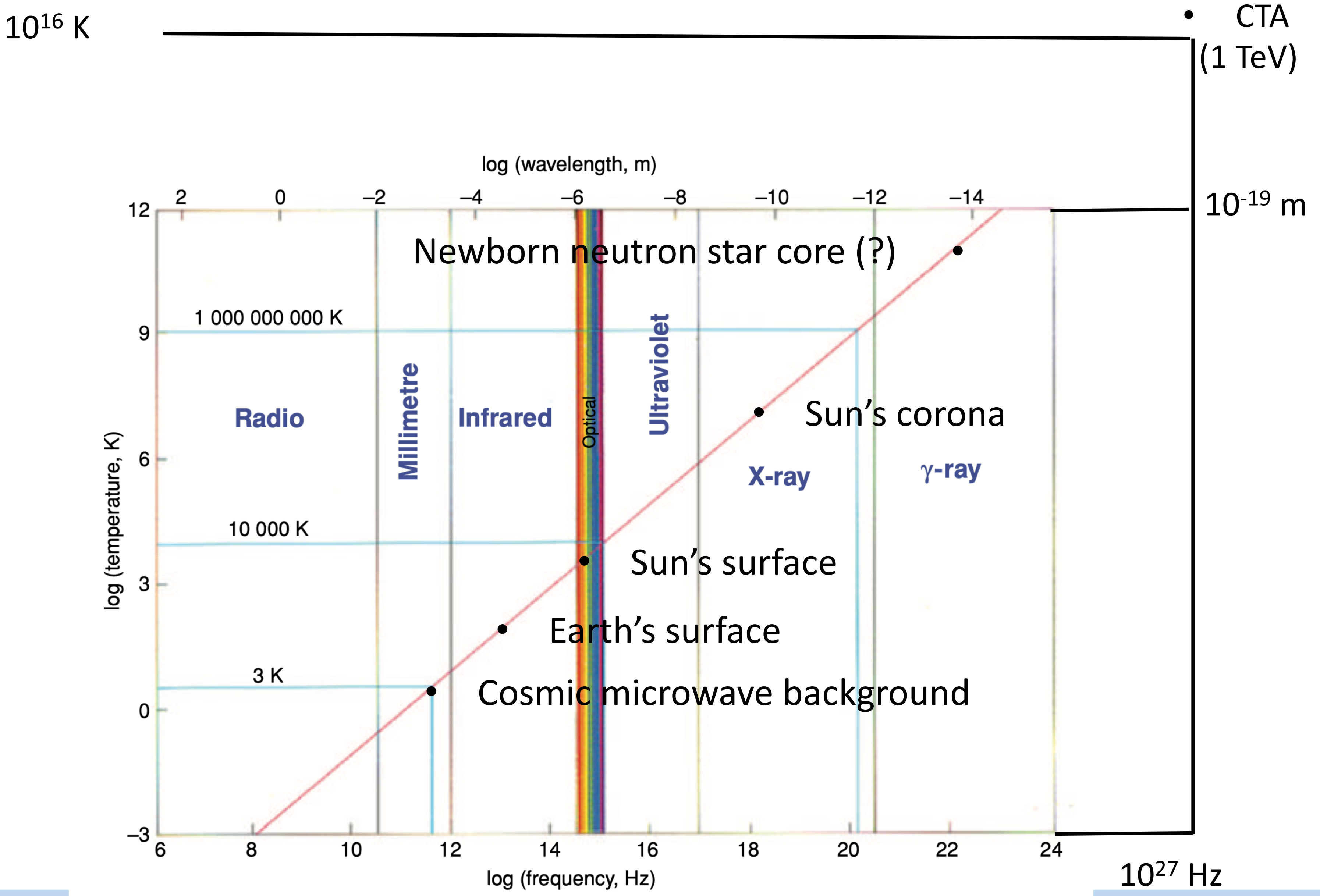
10^{-12} 10^{-14} 10^{-16} 10^{-18} 10^{-20} 10^{-22} 10^{-24} meters

Fermi CTA HAWC IceCube ARA

0.1 MeV 1 EeV

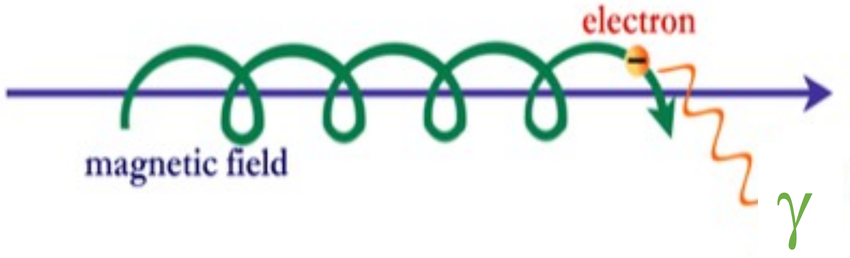
The Thermal v. Non-Thermal Universe

- Black body radiation is responsible for much of the low energy light in the universe
- Even some gamma rays can come from very high energy thermal events
- Most gamma rays will come from non-thermal processes, as the associated black body temperature peaked at 1 TeV is 10 quadrillion K

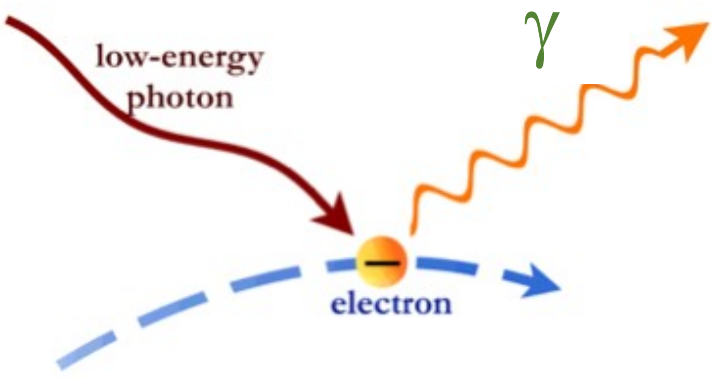


Non-thermal Mechanisms of Gamma Ray Production

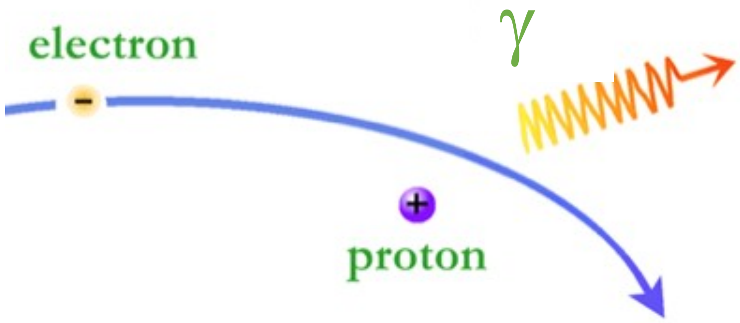
- Production of gamma rays in particle physics can occur through a variety of mechanisms
- Each of these processes can create gamma rays in astrophysical sources
- Inverse Compton scattering is a particularly important source of astrophysical gamma rays



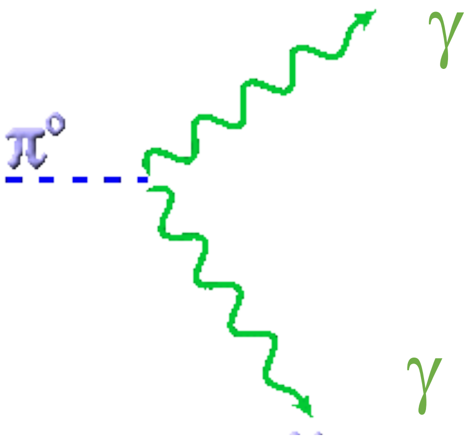
(1) Synchrotron (electromagnetic)



(2) Inverse Compton (electromagnetic)



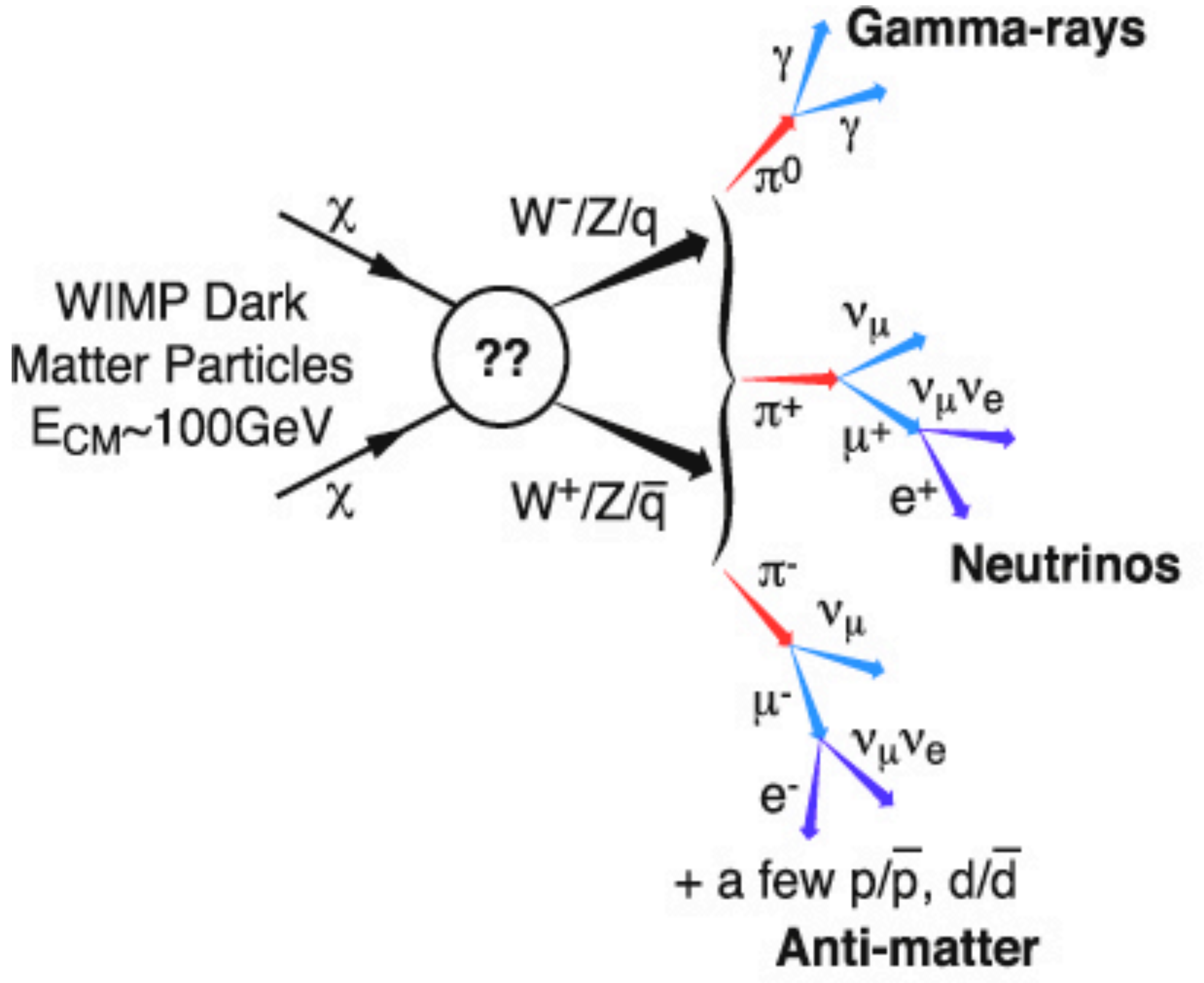
(3) Bremsstrahlung (electromagnetic)



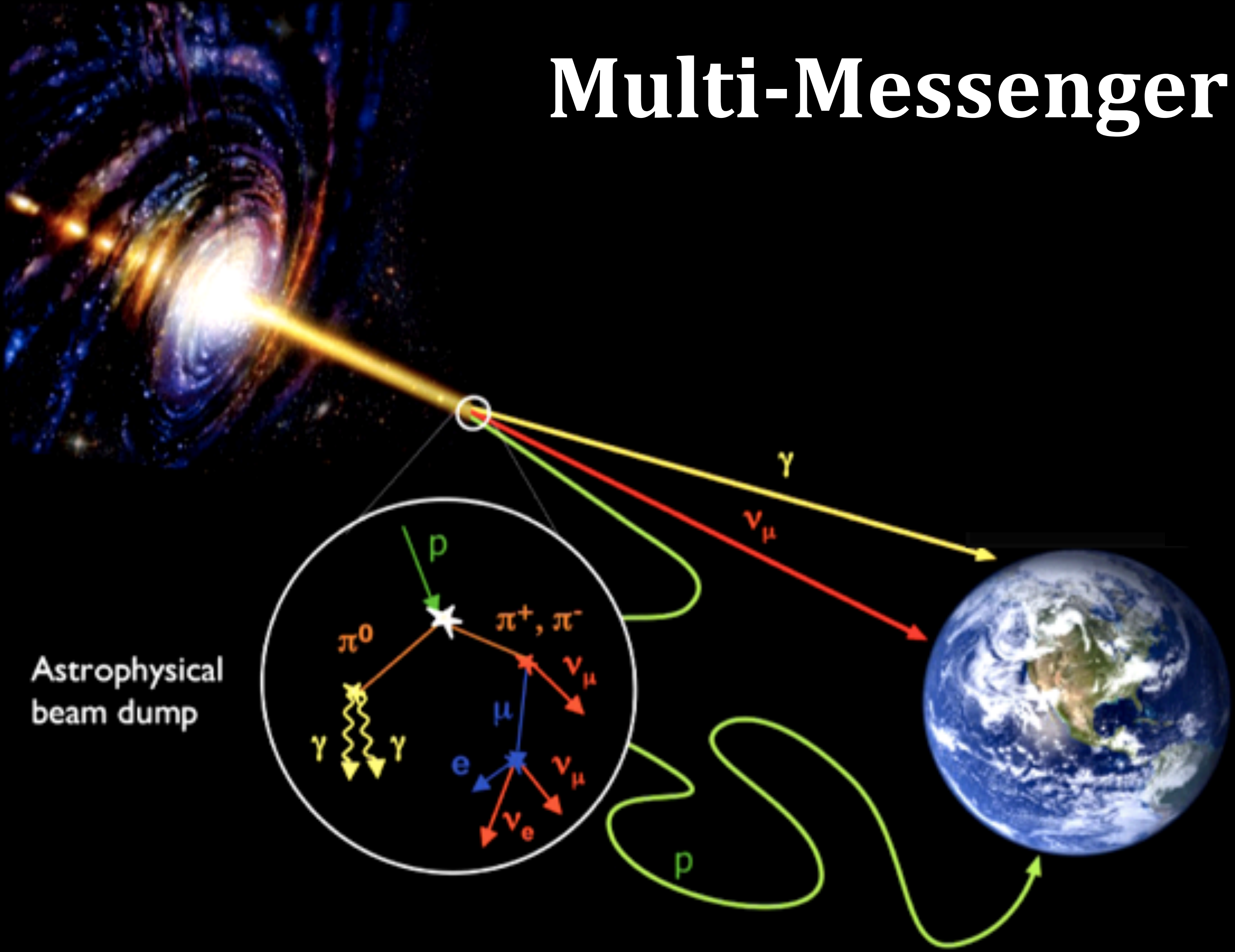
(4) Pion decay (hadronic)

Possible Gamma Ray Production from Dark Matter

- A possible fifth non-thermal source of gamma rays is exotic particle decay or interaction, like dark matter
- This gives rise to the indirect detection sector of the dark matter search
- It is complementary with the direct detection and accelerator production approaches
- This approach has the benefit of being potentially sensitive to more than one broad class of dark matter models

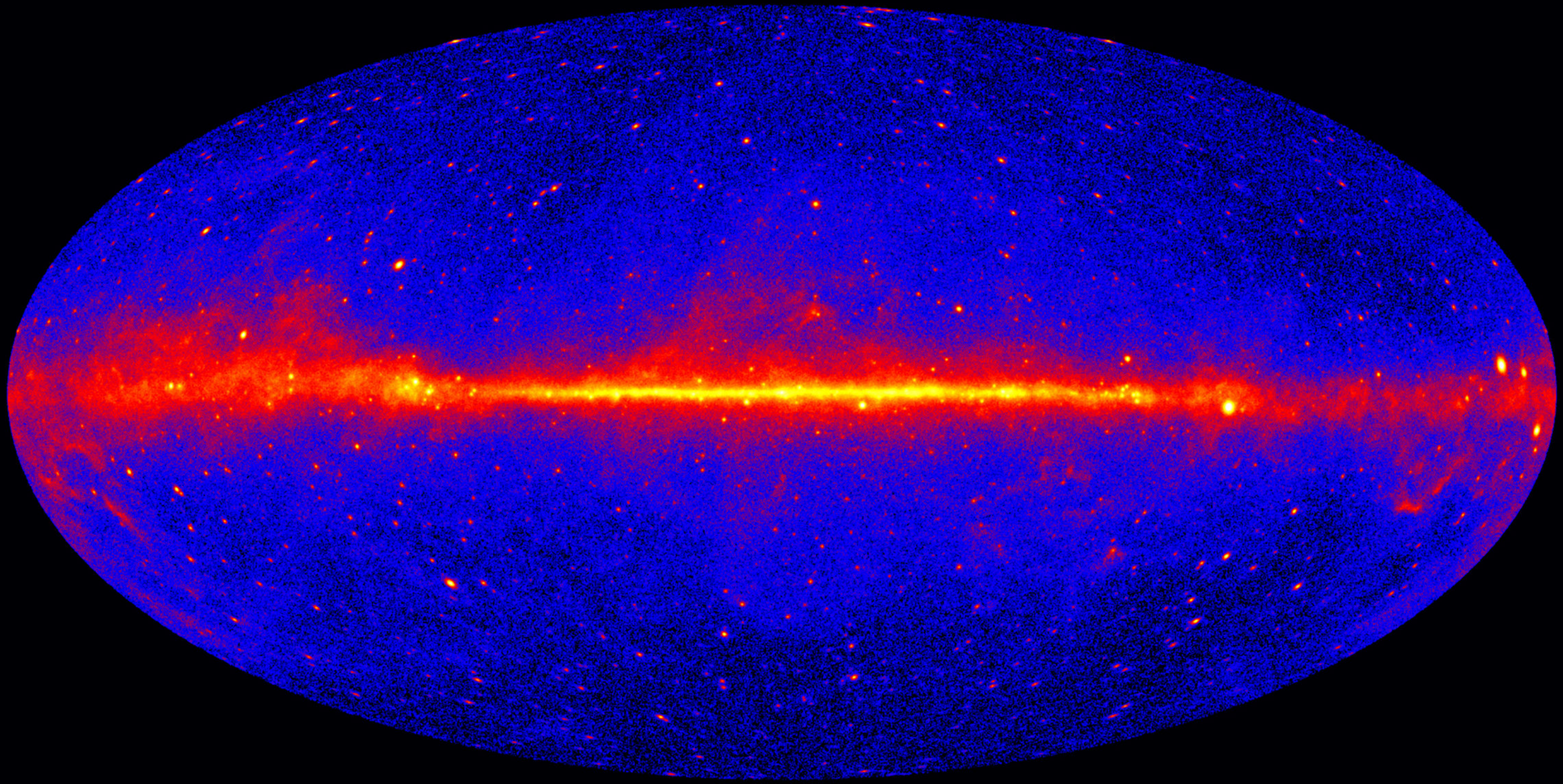


Multi-Messenger Astronomy



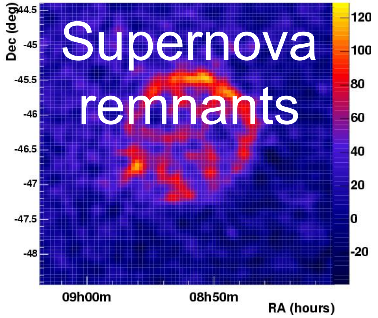
- Using photons, neutrinos, cosmic rays, and gravitational waves, we can study astrophysical sources and transient objects much more thoroughly than ever before
- Different astrophysical sources emit different particles and at different energies, allowing for multi-instrument, coordinated observations

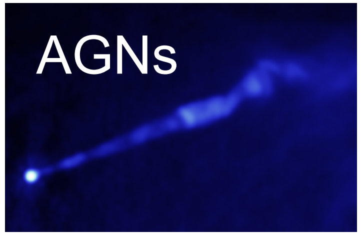
The Universe in >1 GeV Gamma Rays

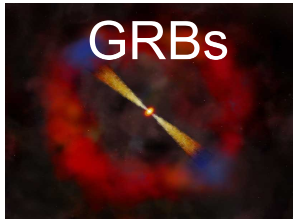


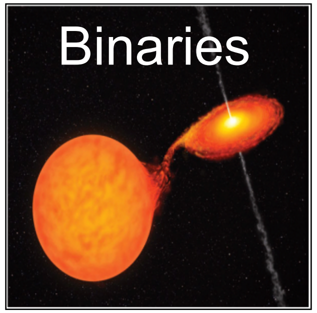
Fermi Large Area Telescope

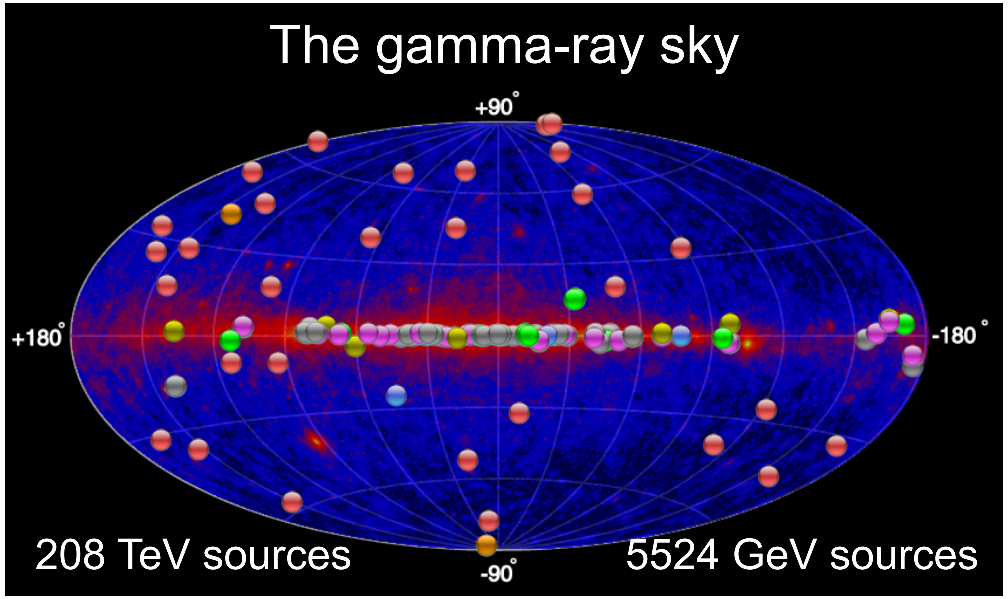
Physics with TeV Gamma Ray Telescopes

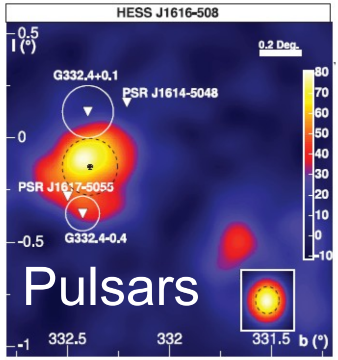


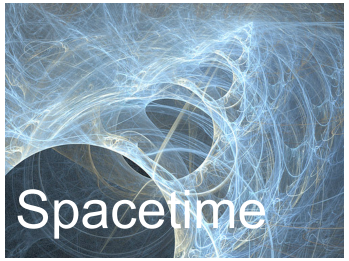




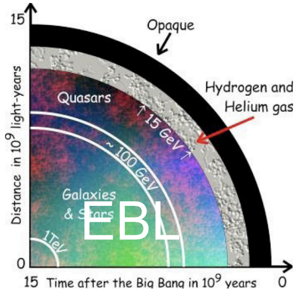








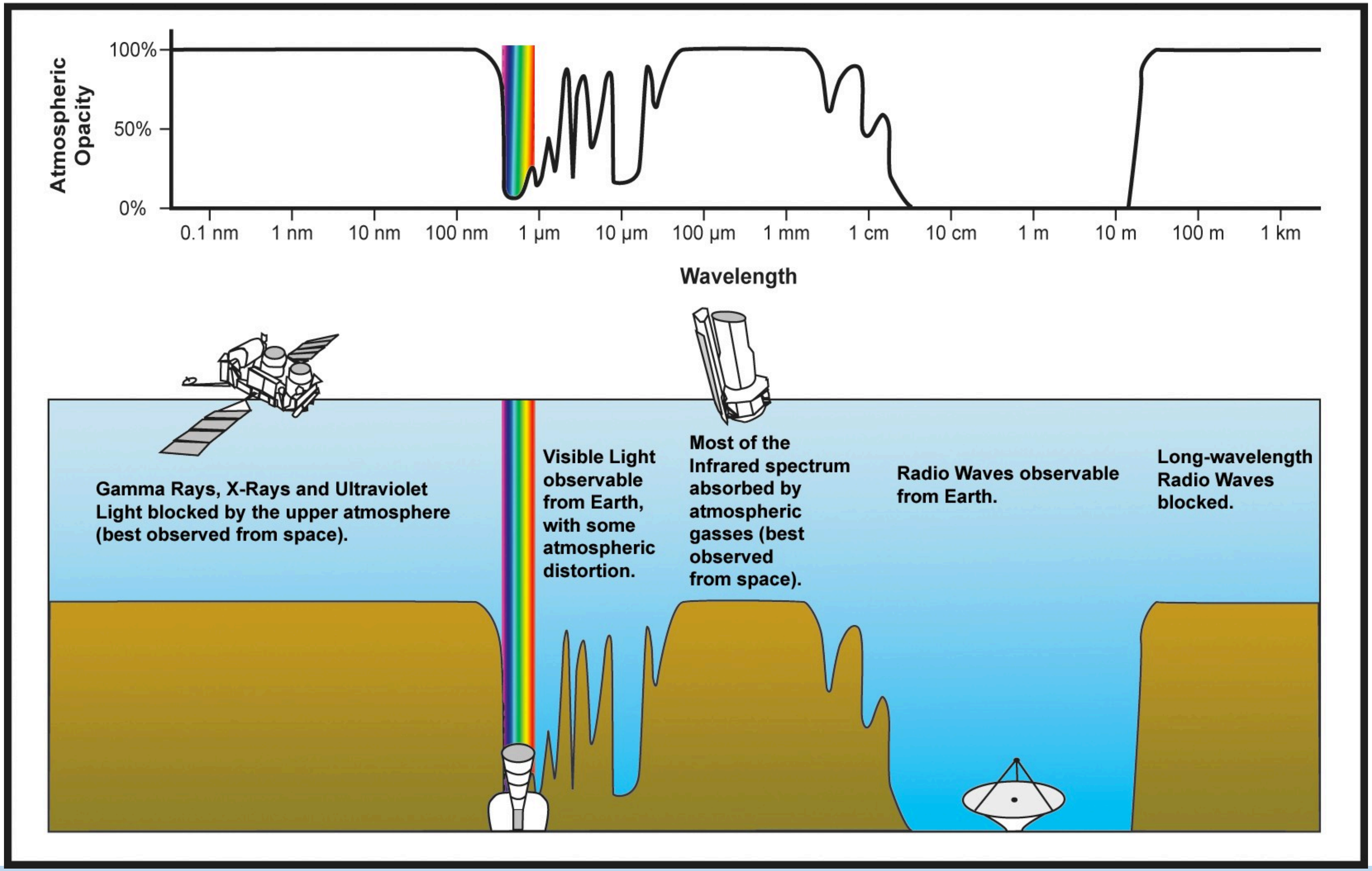
Axions, …



Imaging Atmospheric Cherenkov Telescopes:

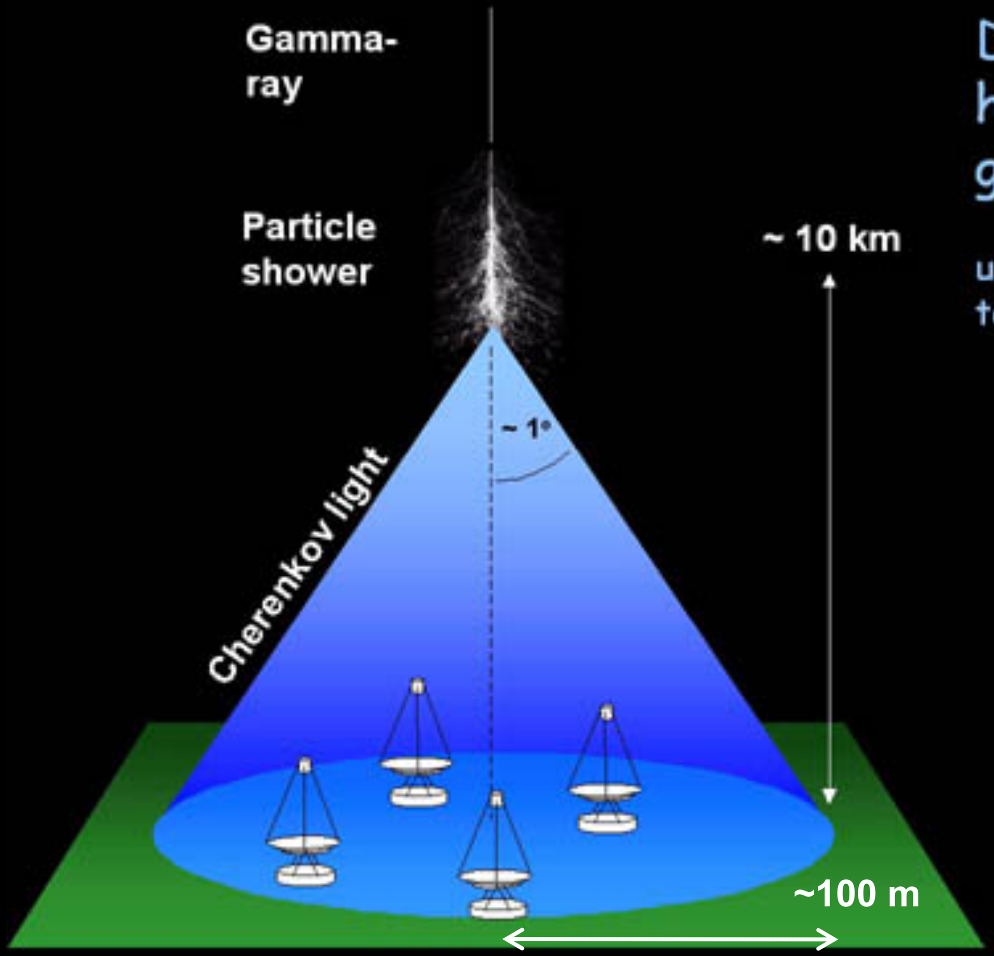
A technique for TeV gamma-ray astronomy

The Atmosphere is Opaque to Gamma Rays



Atmospheric Cherenkov Radiation

- Optical frequency (blue) light
- Very short (few ns) exposure to limit night sky background
- Cherenkov cone very narrow, ~1°:
- $\theta = \arccos \frac{1}{n\beta}$
- 1000-1500 hours per year (dark, good weather)

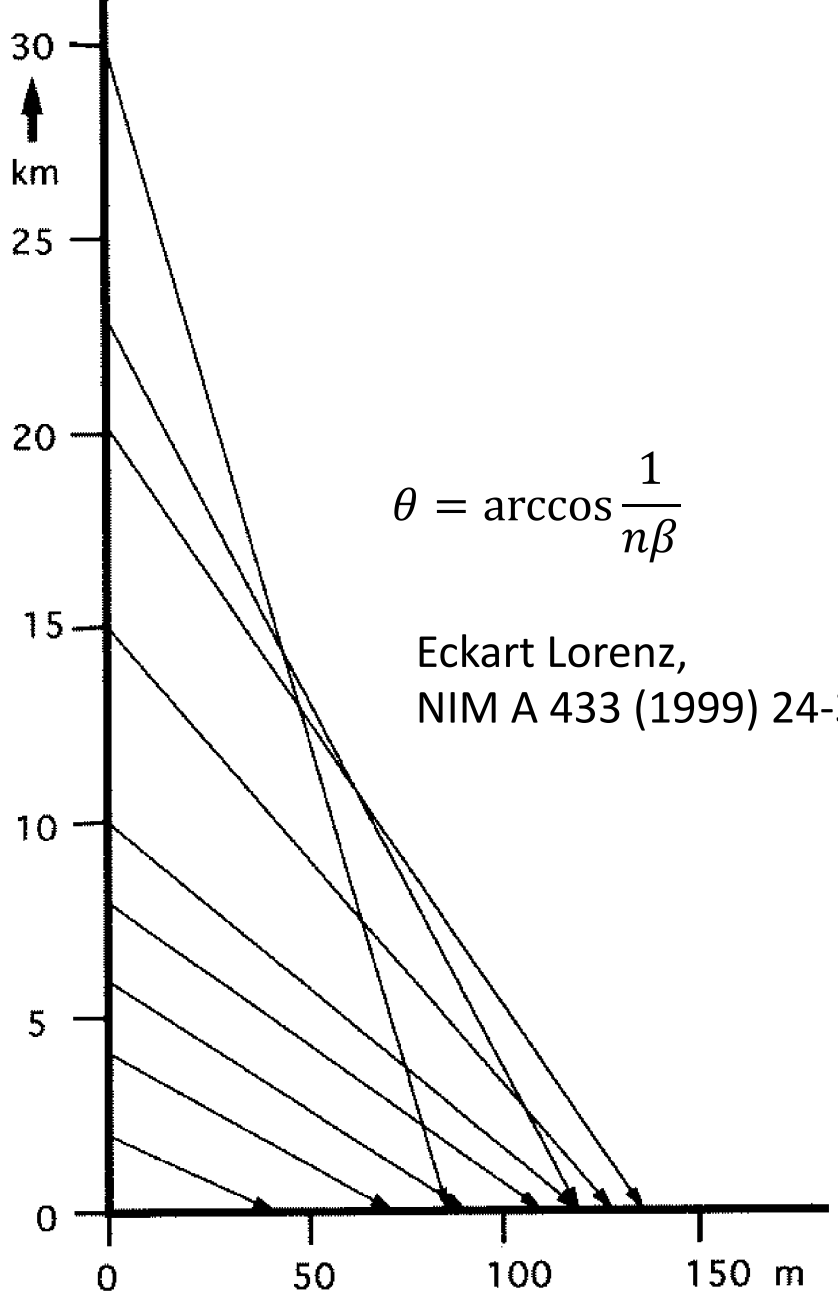


Detection of high-energy gamma rays

using Cherenkov telescopes

Cherenkov Light Pool from Vertical Shower

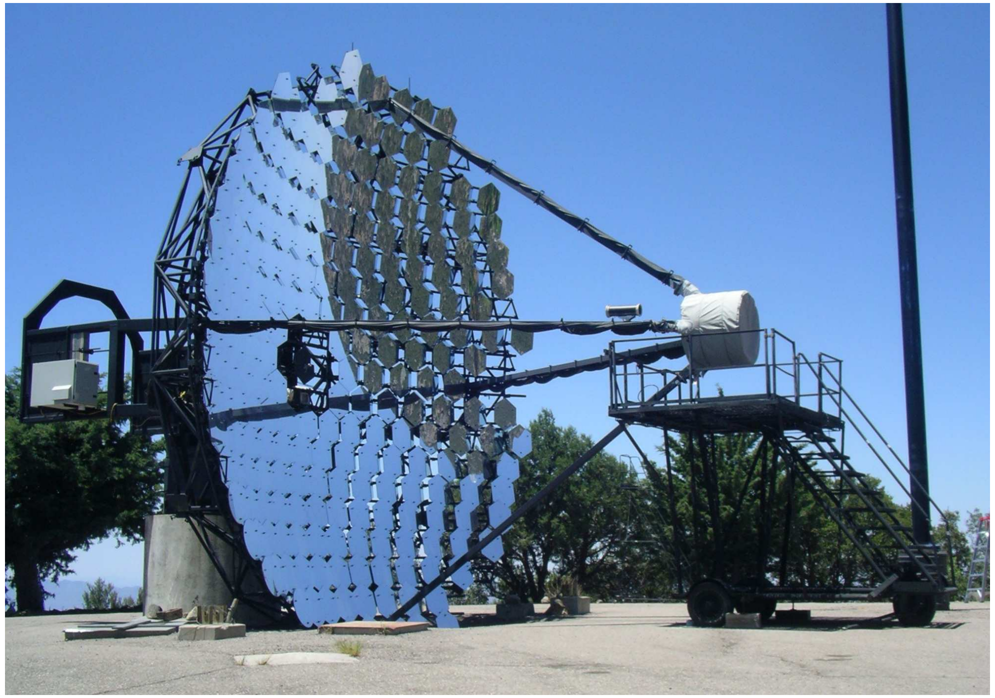
- At high altitude, density is small, index of refraction is close to 1, and Cherenkov angle is small
- Towards ground level, each of these increases
- Light pool of radius ~120-140 m on ground



$$\theta = \arccos \frac{1}{n\beta}$$

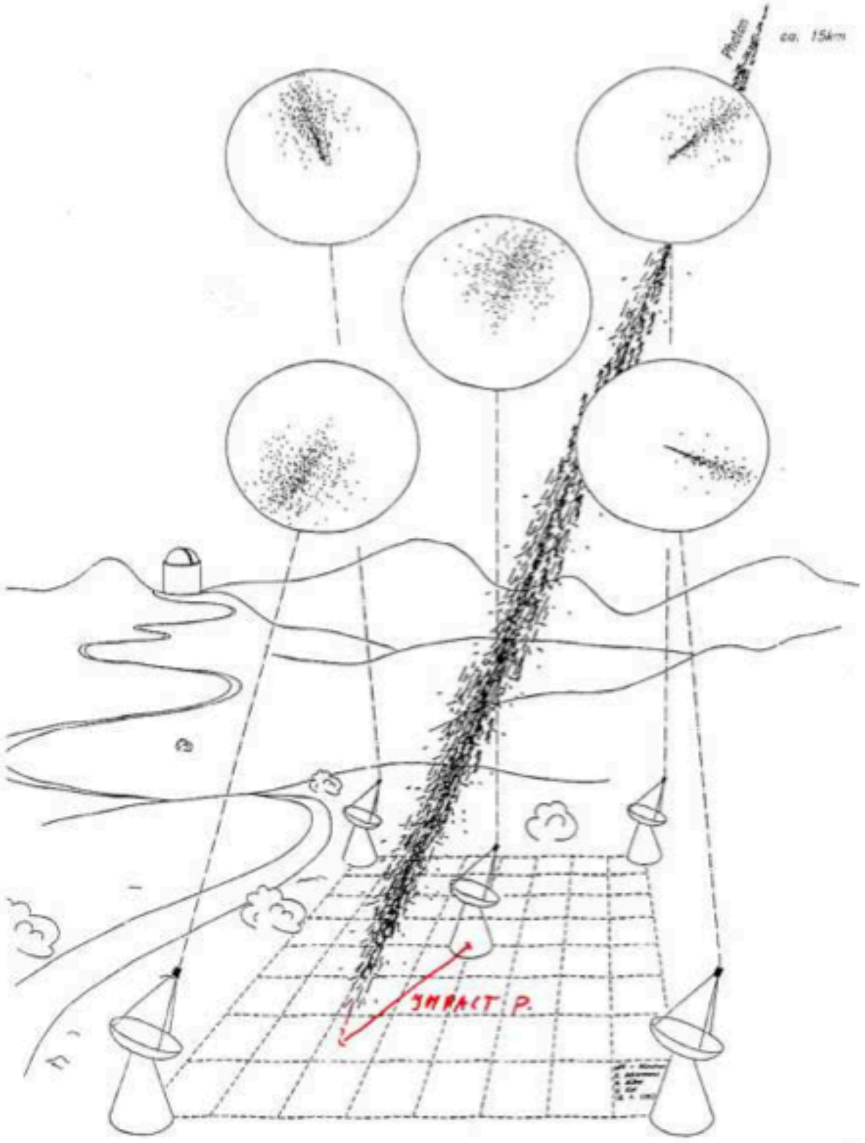
Eckart Lorenz,
NIM A 433 (1999) 24-33

First IACT: Whipple 10 m Telescope at FLWO

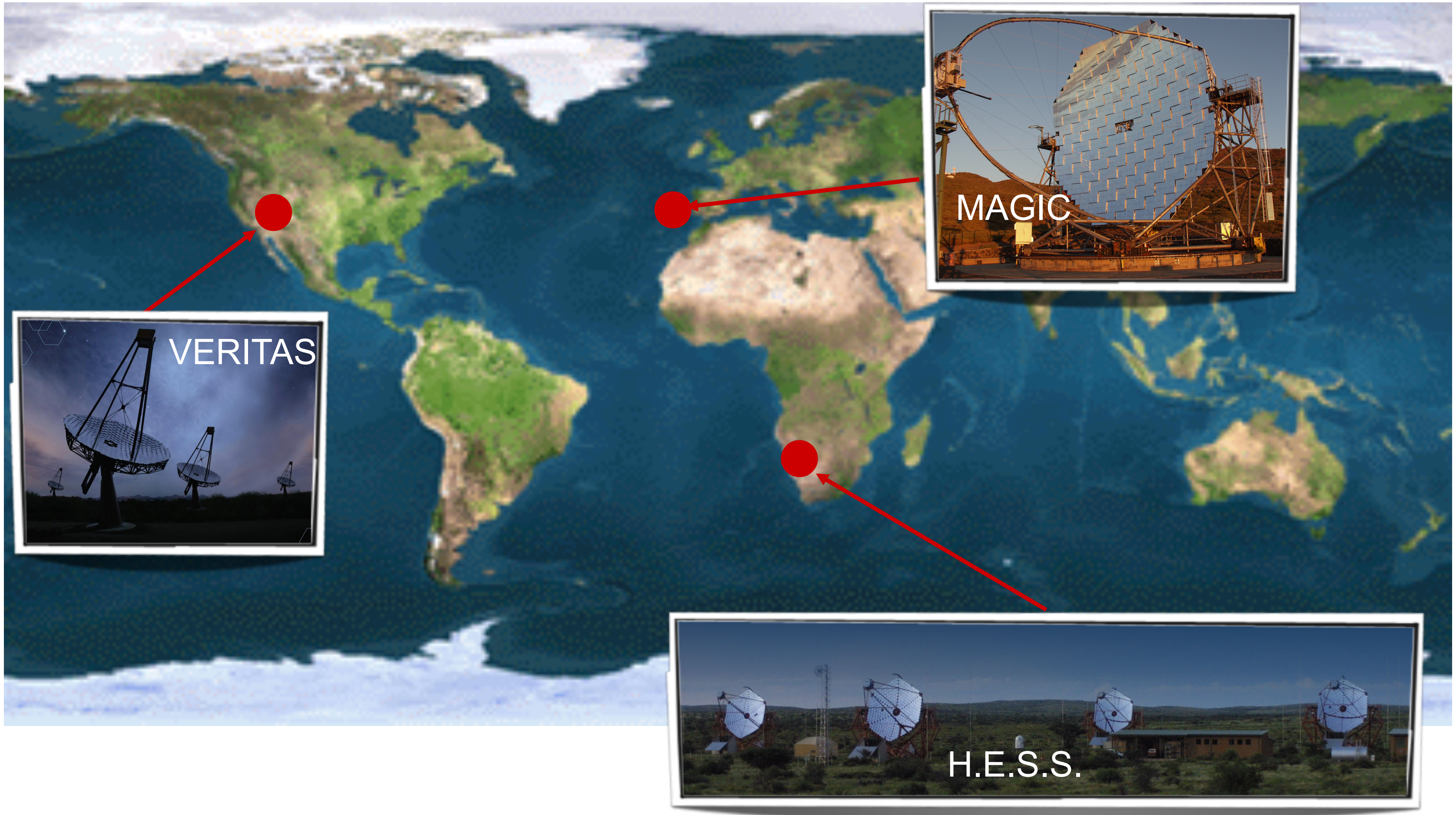


- Pioneer imaging atmospheric Cherenkov telescope
- Discovered the first very-high energy (TeV) astronomical sources
    - Crab Nebula: 1989
    - Markarian 421 (1992): a nearby blazar
    - Markarian 501 (1997): another nearby blazar

Two Telescopes are Better Than One



Current Generation of Stereo IACTs




View from MAGIC


H.E.S.S.

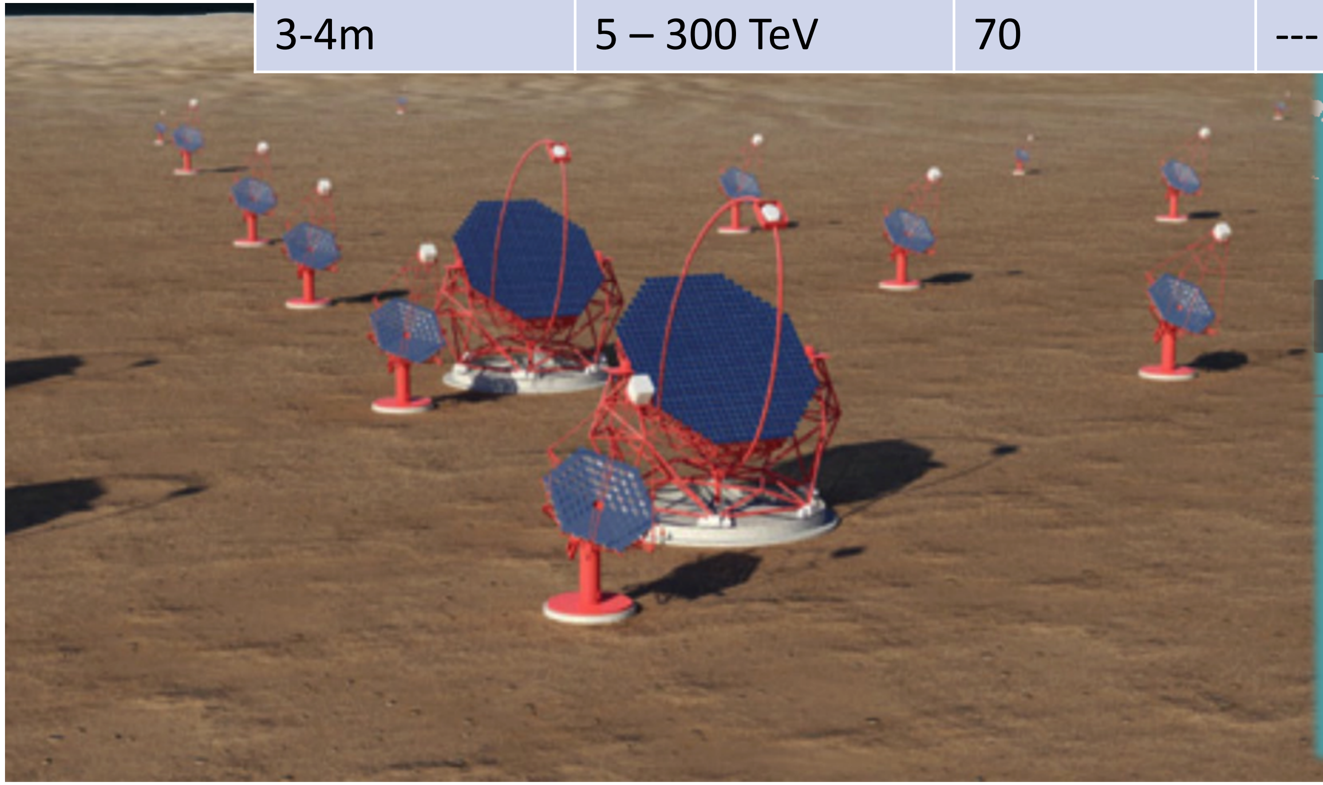

VERITAS

The Cherenkov Telescope Array

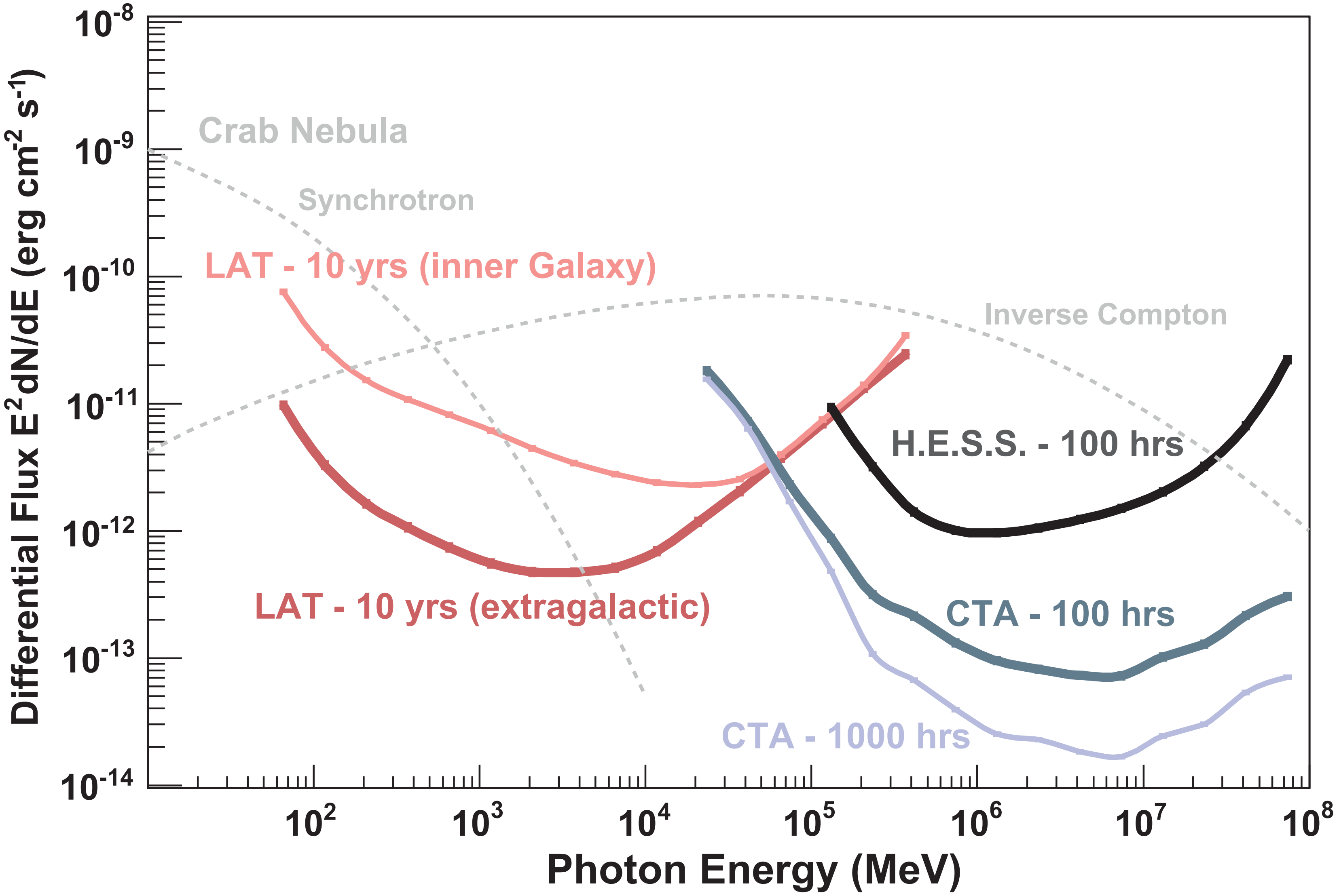
Cherenkov Telescope Array

Telescope size	Energy range	South array	North array
23m	20GeV – 1 TeV	4	4
9-12m	100Gev – 10TeV	25	15
3-4m	5 – 300 TeV	70	---

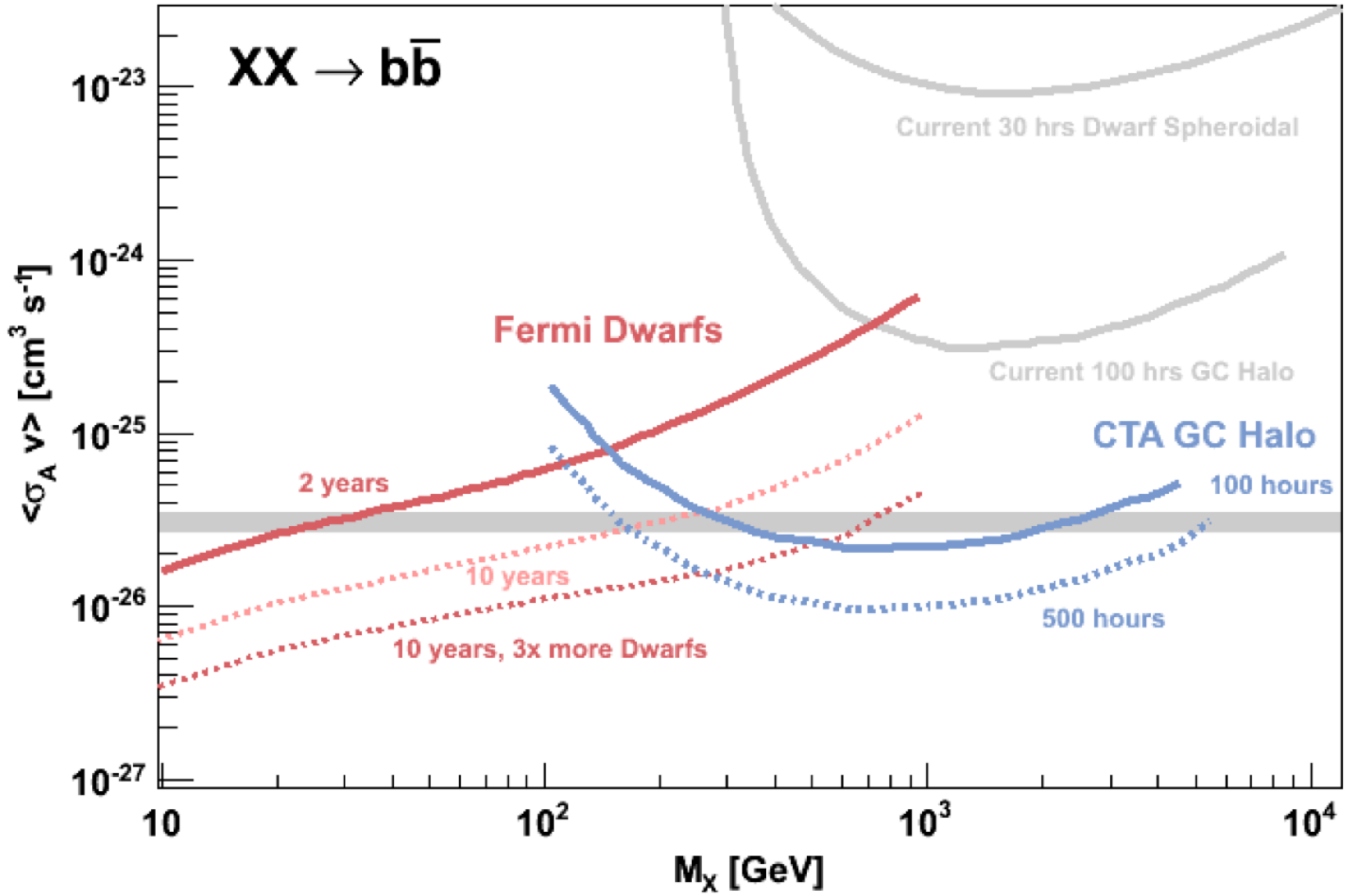
2 arrays of differently sized telescopes looking for gamma ray induced air showers



CTA v. Fermi LAT

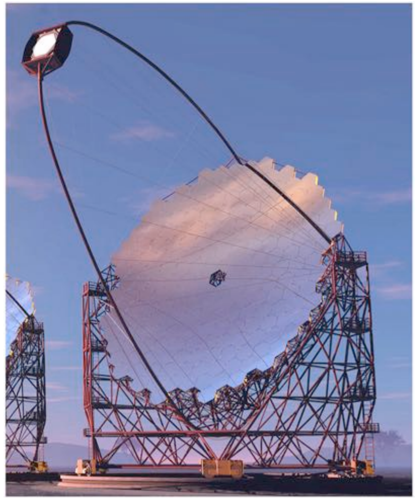


Fermi Dwarfs and CTA GC Will Cover Entire WIMP Mass Range Down to Thermal Cross Section



Prototype CTA Telescopes Underway

Large, Canary Islands



Medium (1 mirror), Berlin

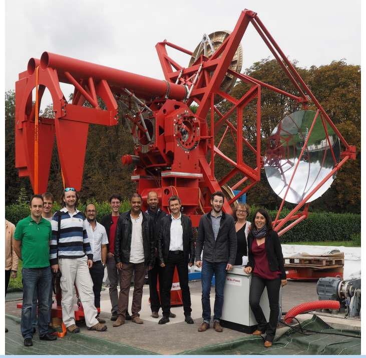
Medium (2 mirror), Arizona

Small:

1 mirror, Krakow

2 mirror, Sicily

2 mirror, Paris



CTA @ WIPAC:
Developing the pSCT Camera

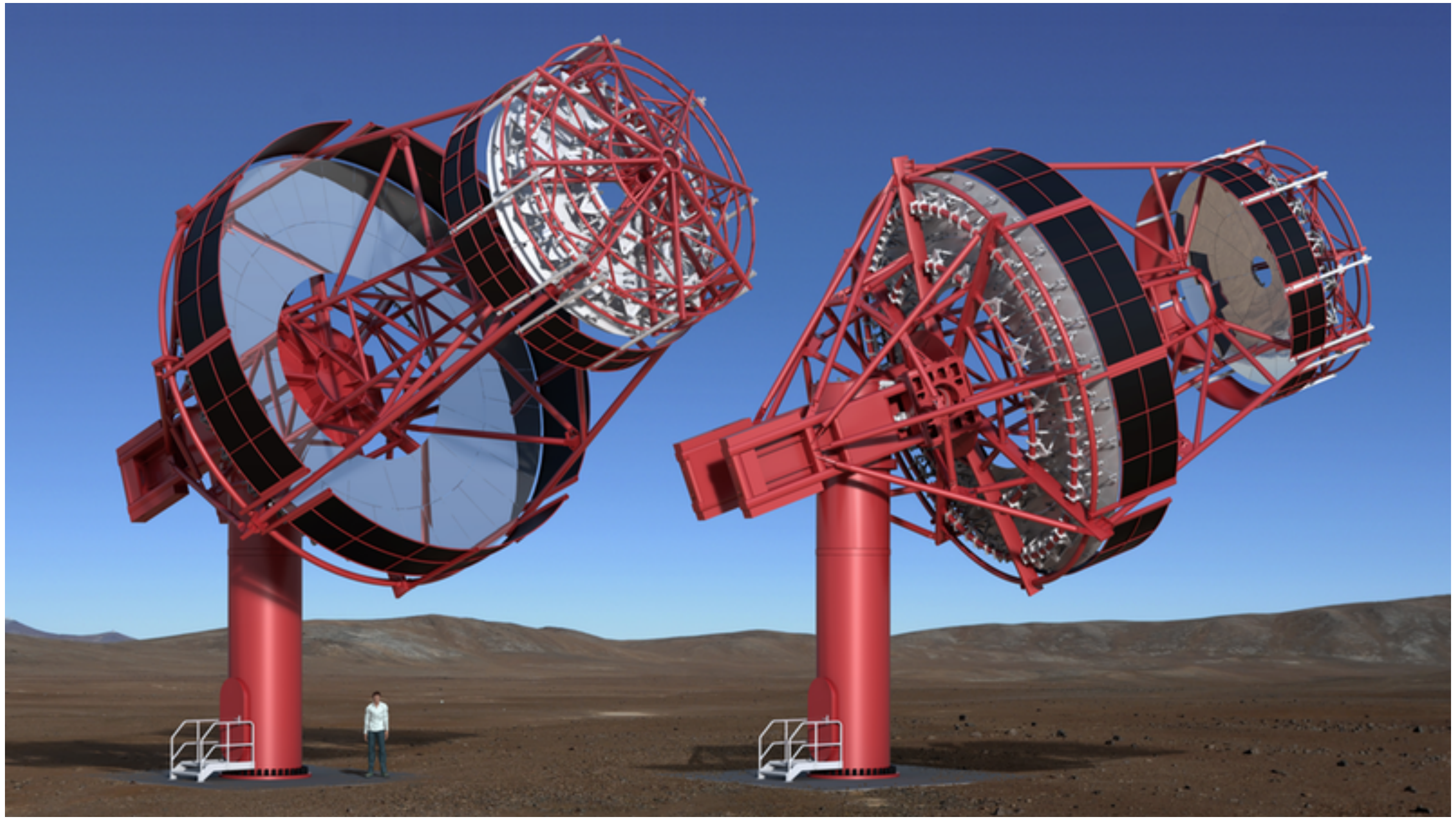
pSCT: Prototype Schwarzschild-Couder Telescope

Use two mirrors instead of one:

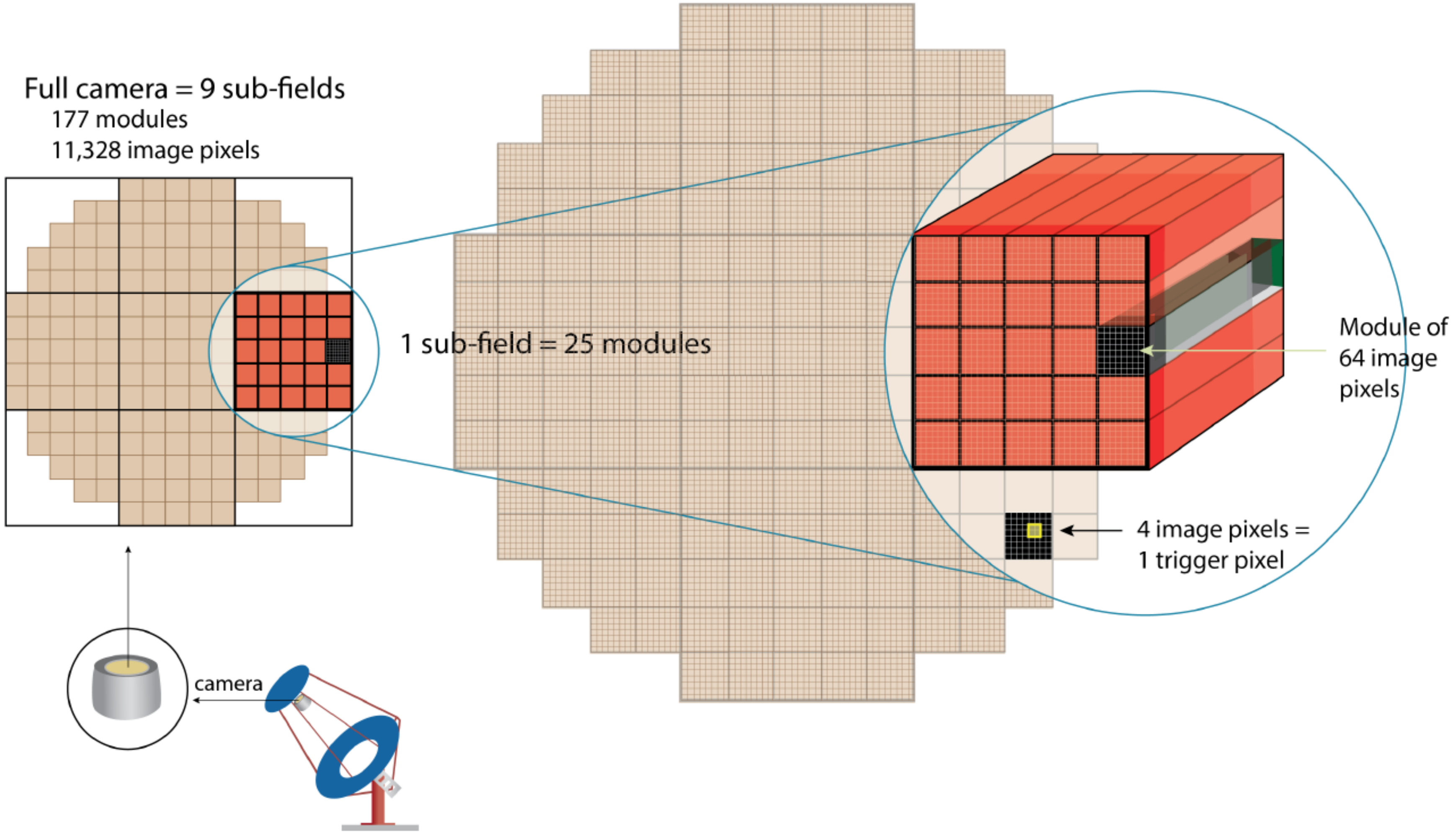
- Advantages:
  - Telescope can be more compact
  - Has wider field of view
  - Better resolution

- Need special technique for a-spherical mirror shaping:
  - optimized for maximum resolution and field of view

- Need fast high resolution camera:
  - possible through new developments in SiPM and ASIC technology

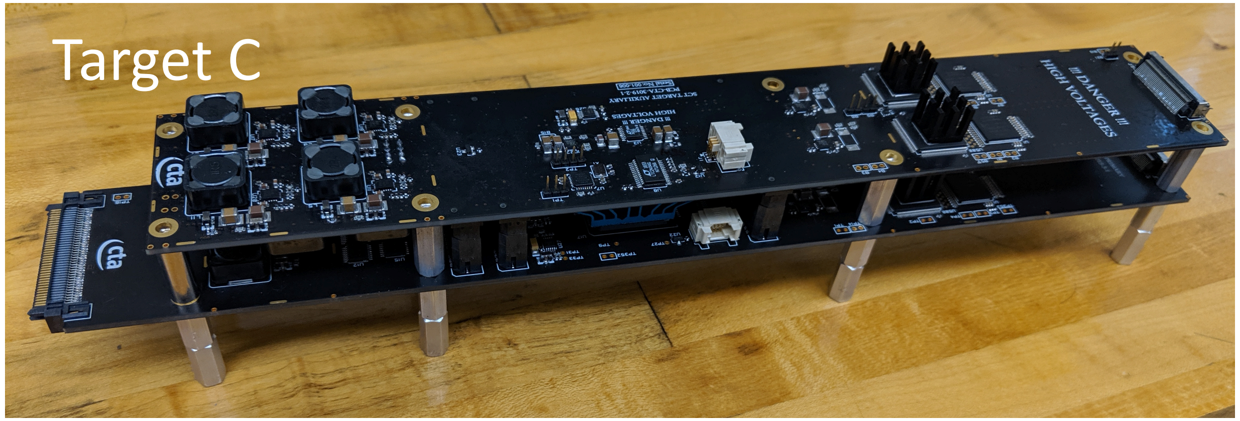


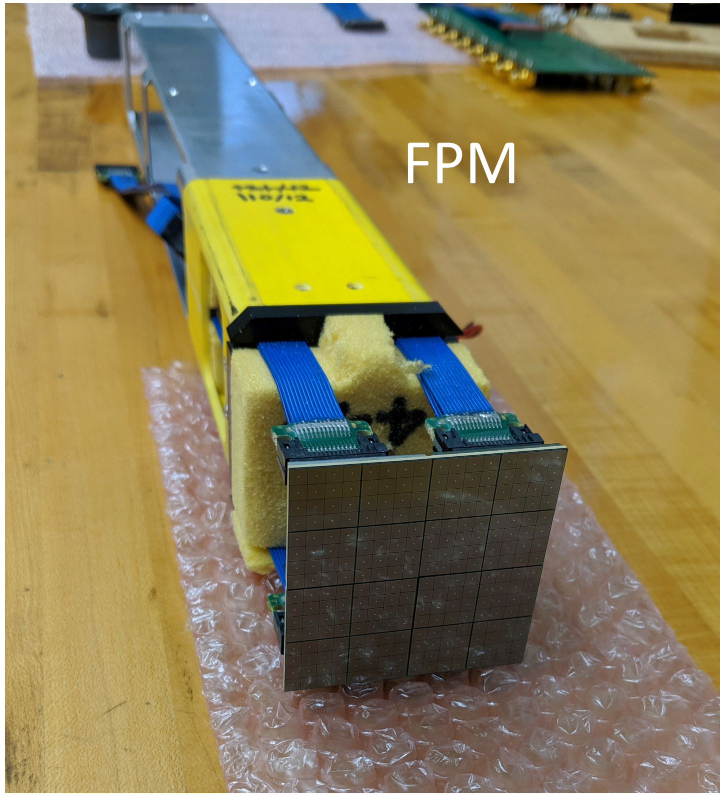
pSCT Camera Organization



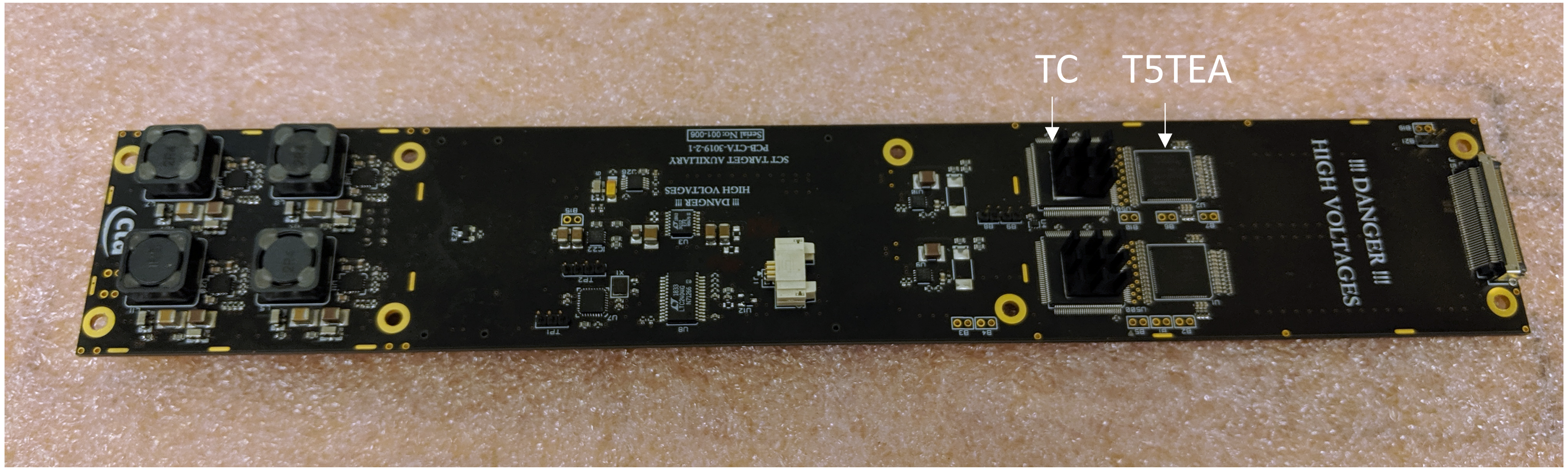
TARGET C and FPM

- In the past, our group has been responsible for various research and development projects for the pSCT camera
- One of our current projects is working on comprehensive testing of the new TARGET C prototype to ensure that it meets rigorous CTA requirements
- We collaborate on this with groups at INFN – Pisa in Italy, FAU in Germany, and Georgia Tech in Atlanta
- The pSCT camera group is a much larger group with members in the US and abroad.
- TeV array readout with GSa/s sampling and event trigger (TARGET)



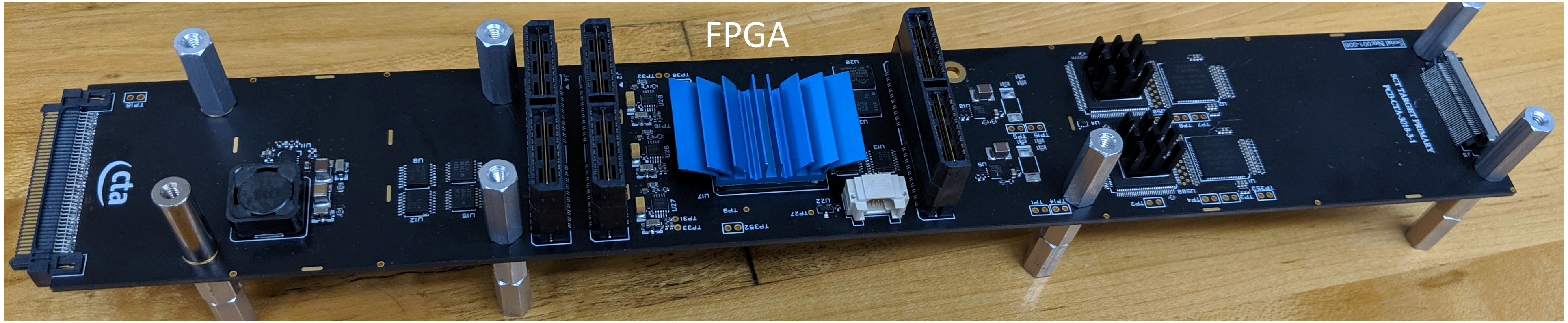


TARGET C Module

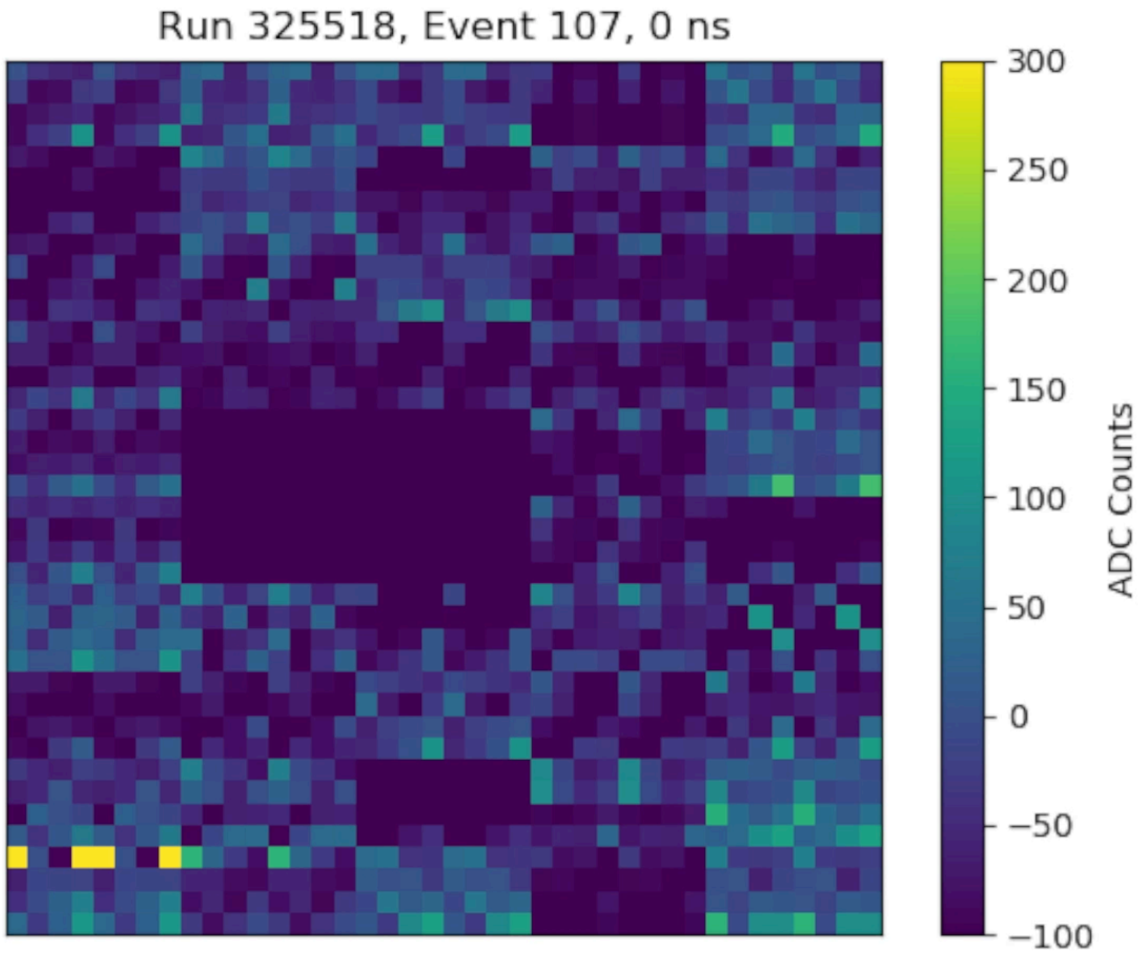


Signal Input

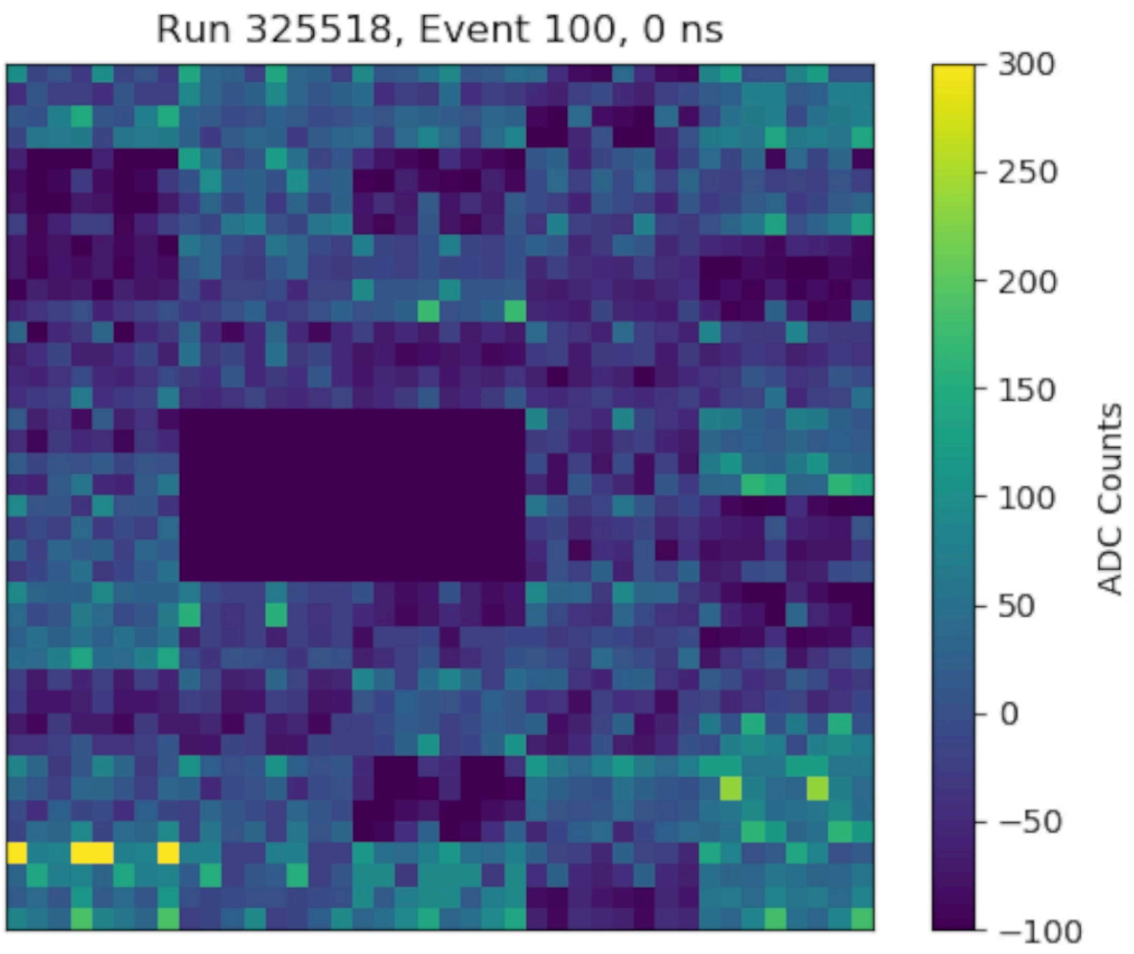
To Backplane



First Light Event



First Light Event



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