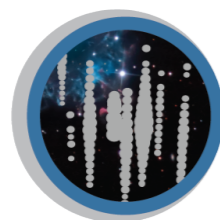


The High-Altitude Water Cherenkov Gamma-Ray Observatory

Segev BenZvi

WIPAC, UW-Madison

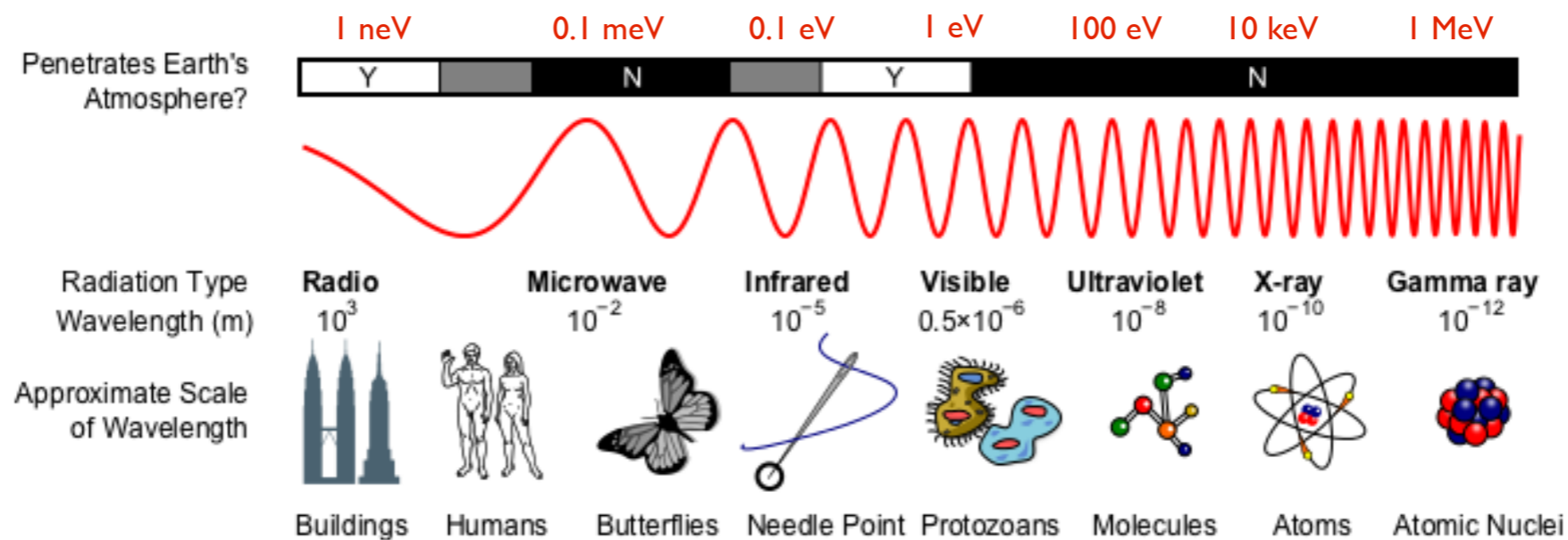
High Altitude Water Cherenkov
Gamma-Ray Observatory



ICECUBE MASTERCLASS
AN AUTHENTIC ASTROPHYSICS RESEARCH EXPERIENCE

Multiwavelength Astronomy

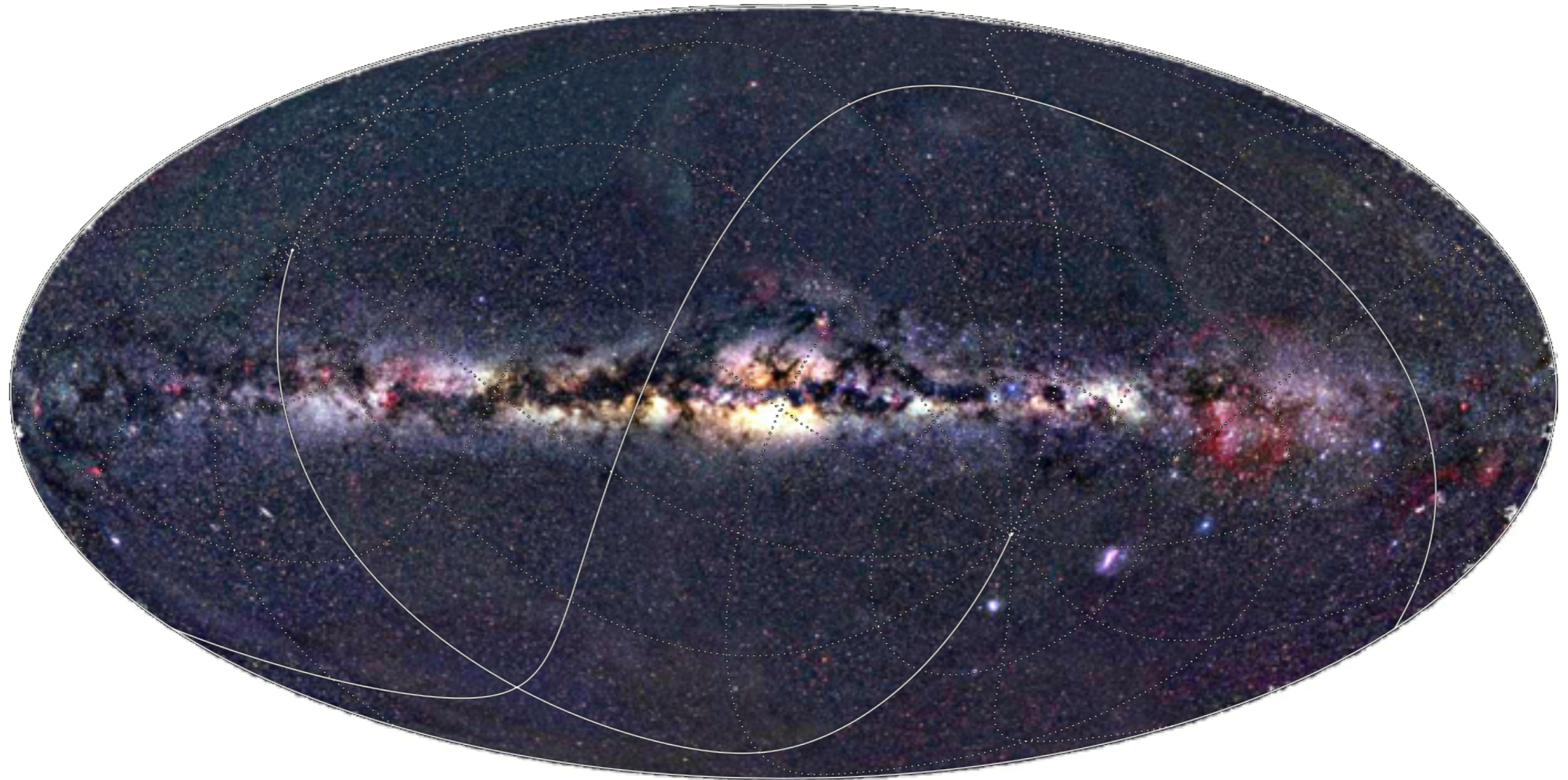
- ▶ Astronomy using **TeV radiation** (wavelength $\lambda = 10^{-18}$ meters)



- ▶ Why try to detect gamma rays?
 - Learn about the highest energy particles in the universe
 - Study very high energy acceleration
 - Probe the structure of the universe (cosmology)

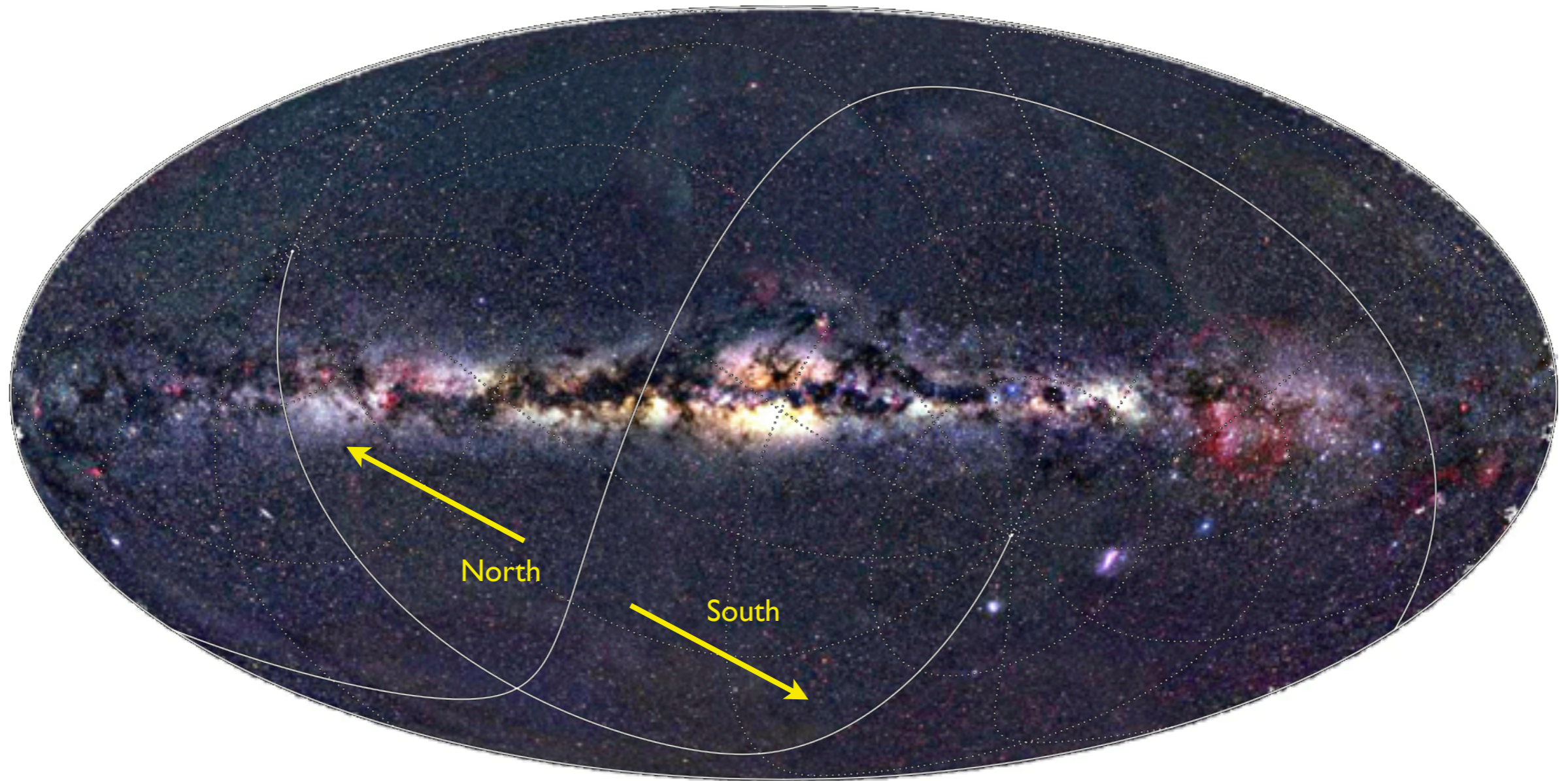
Optical Astronomy

- ▶ The **optical** universe: 400 - 750 nm, or 1.5 - 3 eV



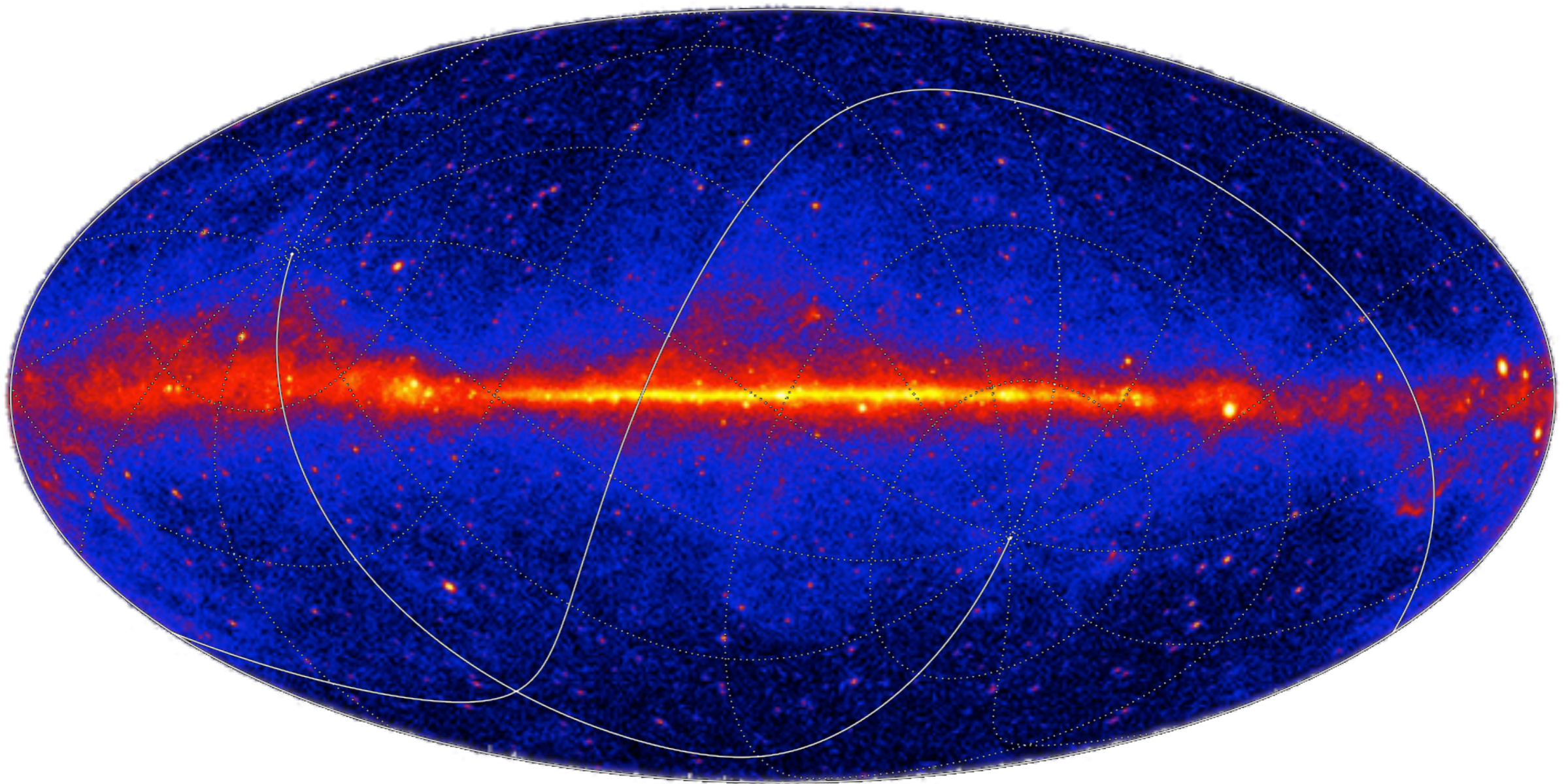
Optical Astronomy

- ▶ The **optical** universe: 400 - 750 nm, or 1.5 - 3 eV

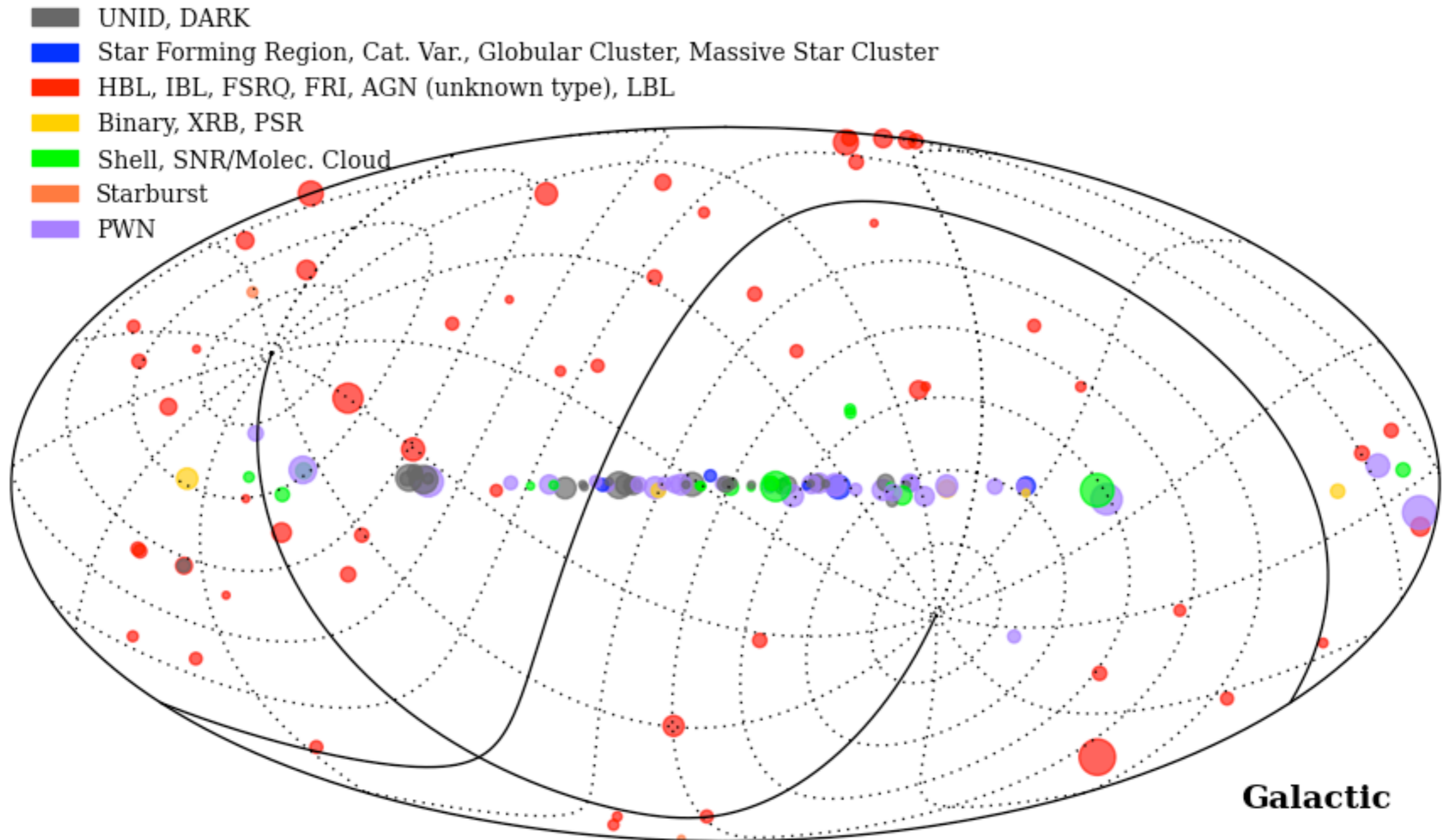


GeV Gamma-Ray Astronomy

- ▶ GeV band: **100 MeV - 100 GeV**, or 10^{-17} - 10^{-14} m

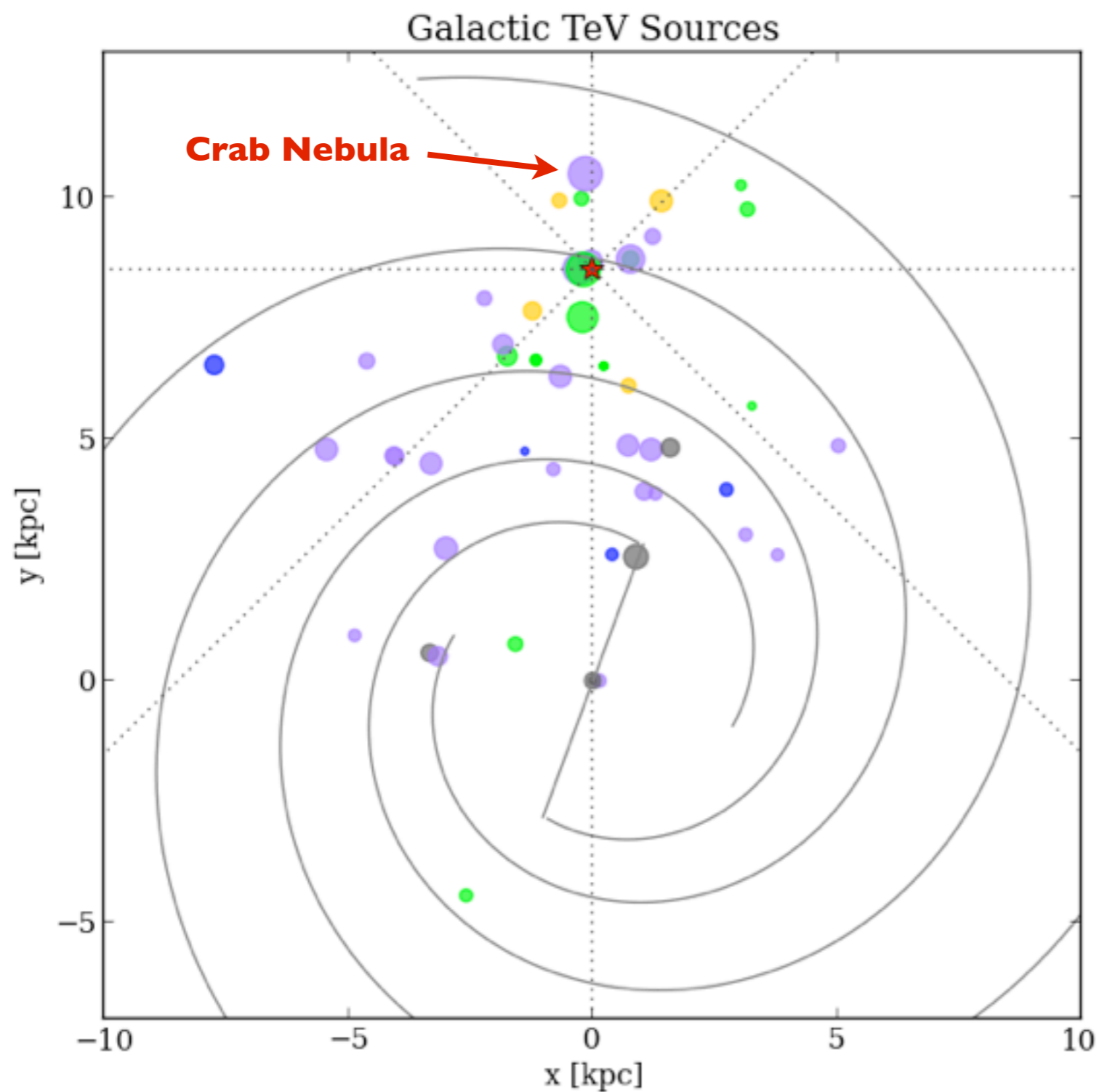


TeV Gamma-Ray Astronomy

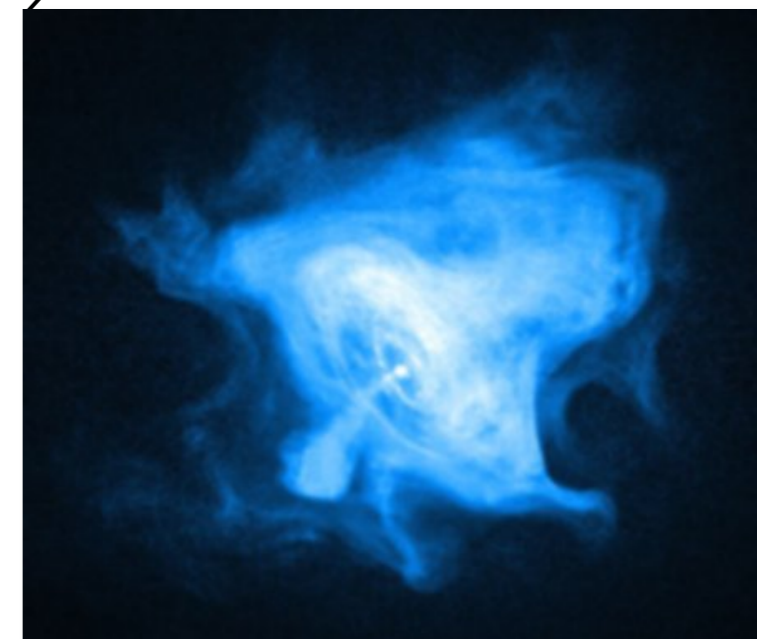
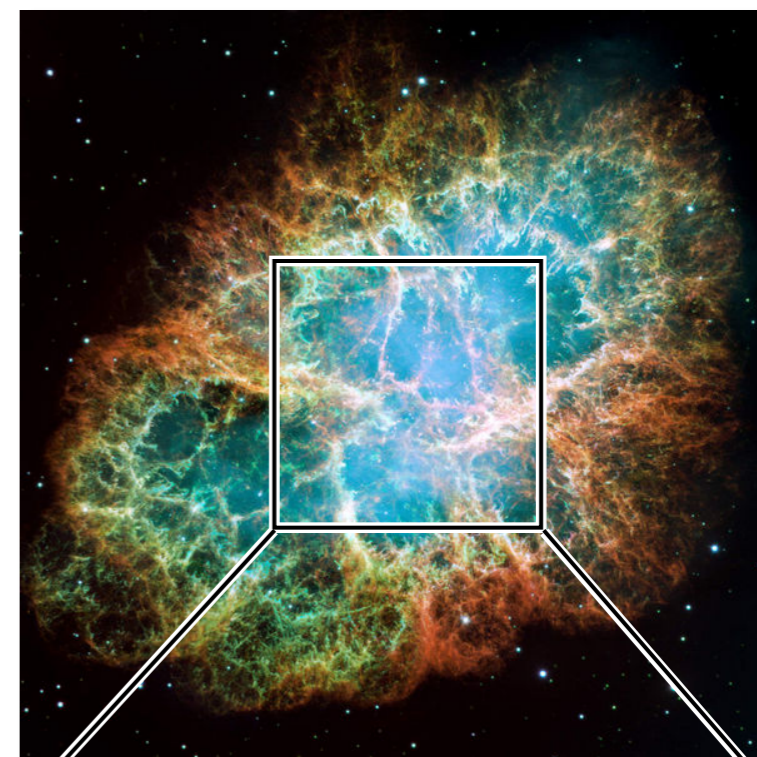


► TeV band: **100 GeV - 100 TeV**, or 10^{-20} - 10^{-17} m

Galactic Gamma-Ray Sources

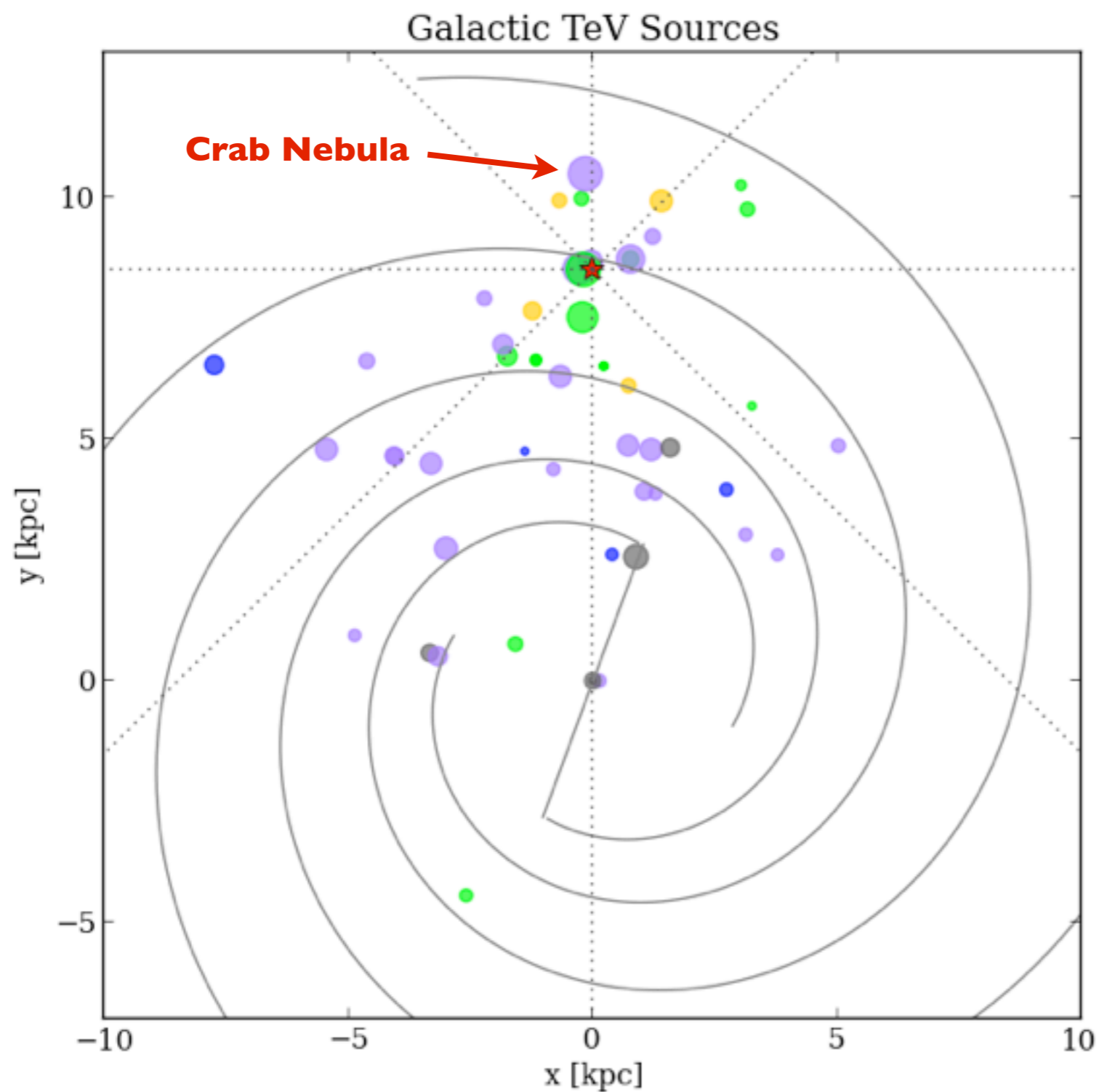


Crab Nebula: Hubble

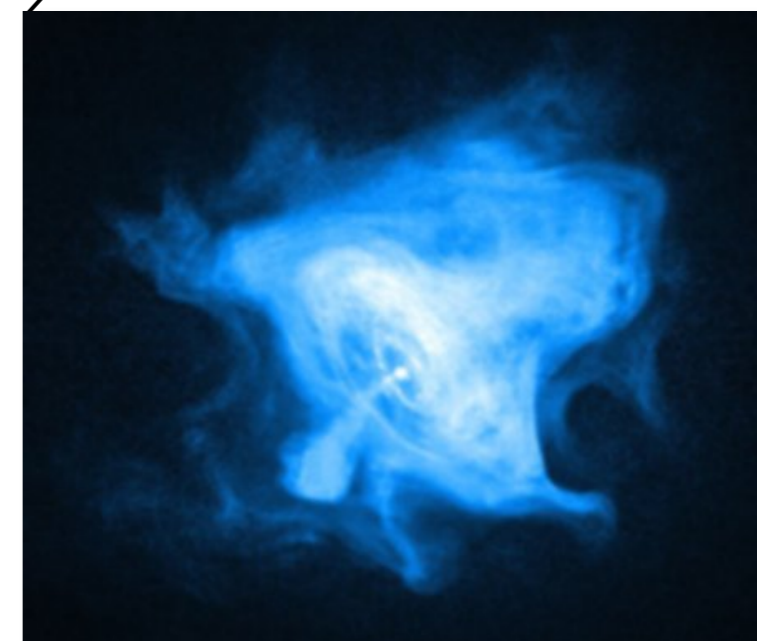
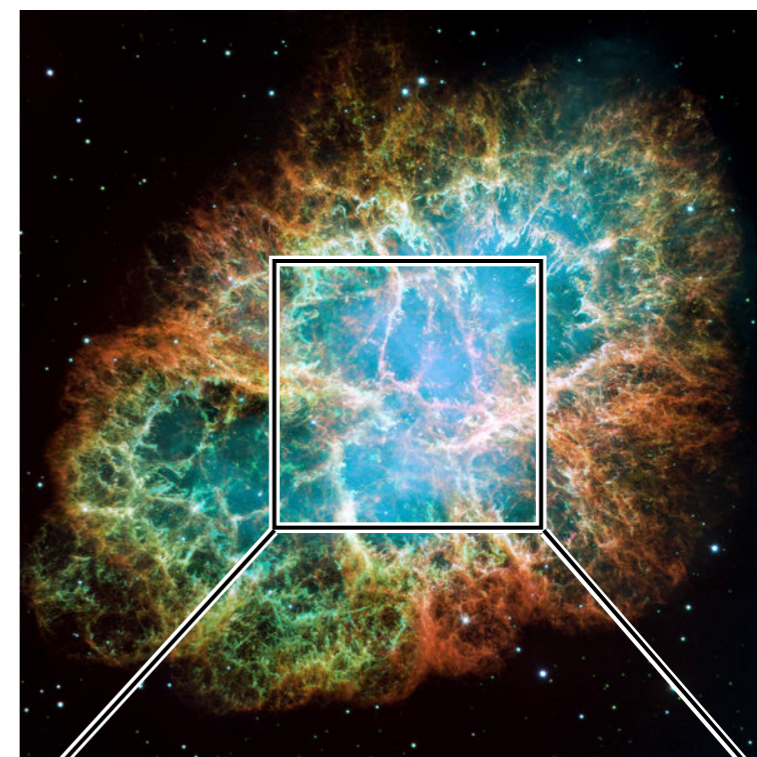


Crab Pulsar: Chandra

Galactic Gamma-Ray Sources

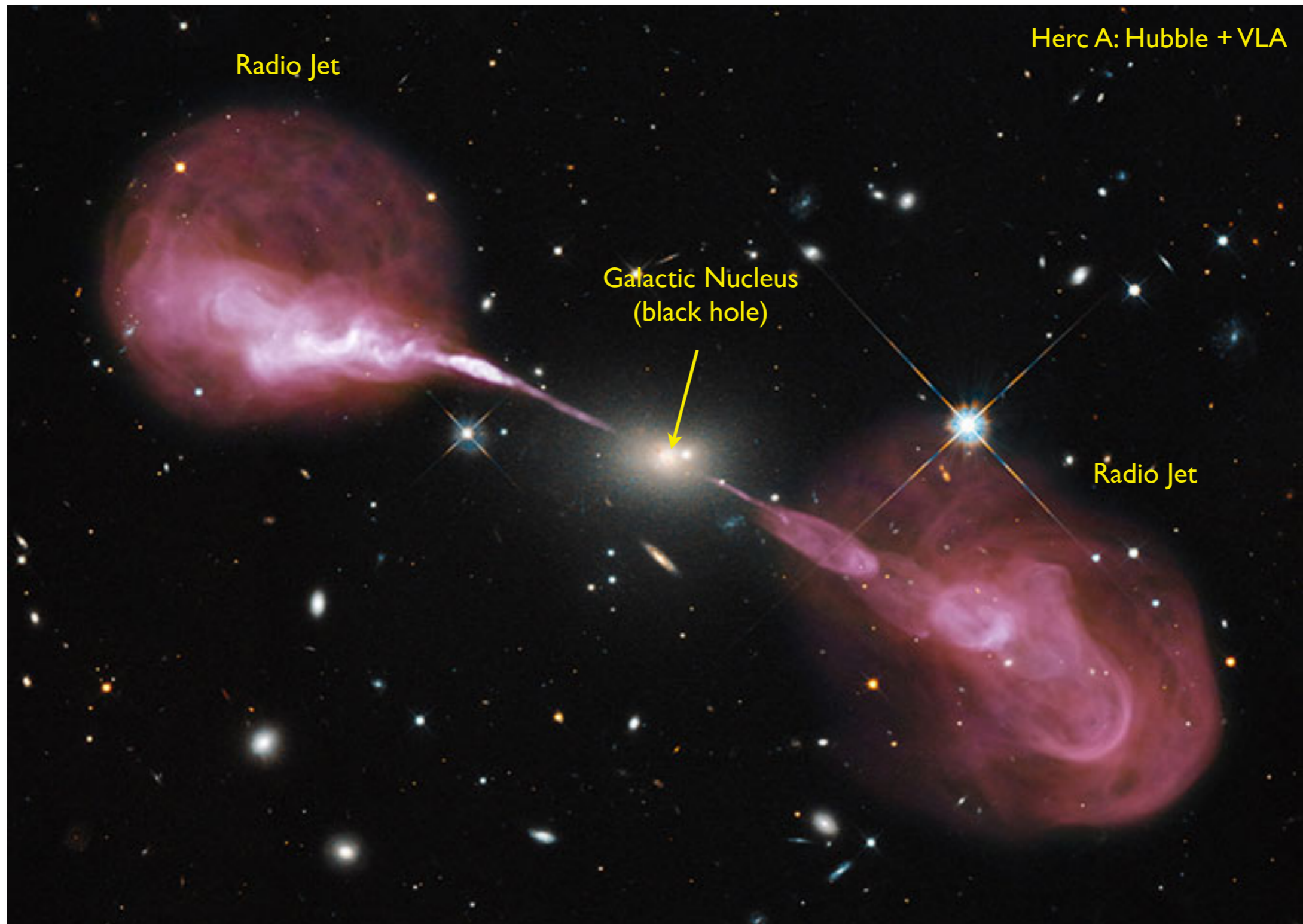


Crab Nebula: Hubble

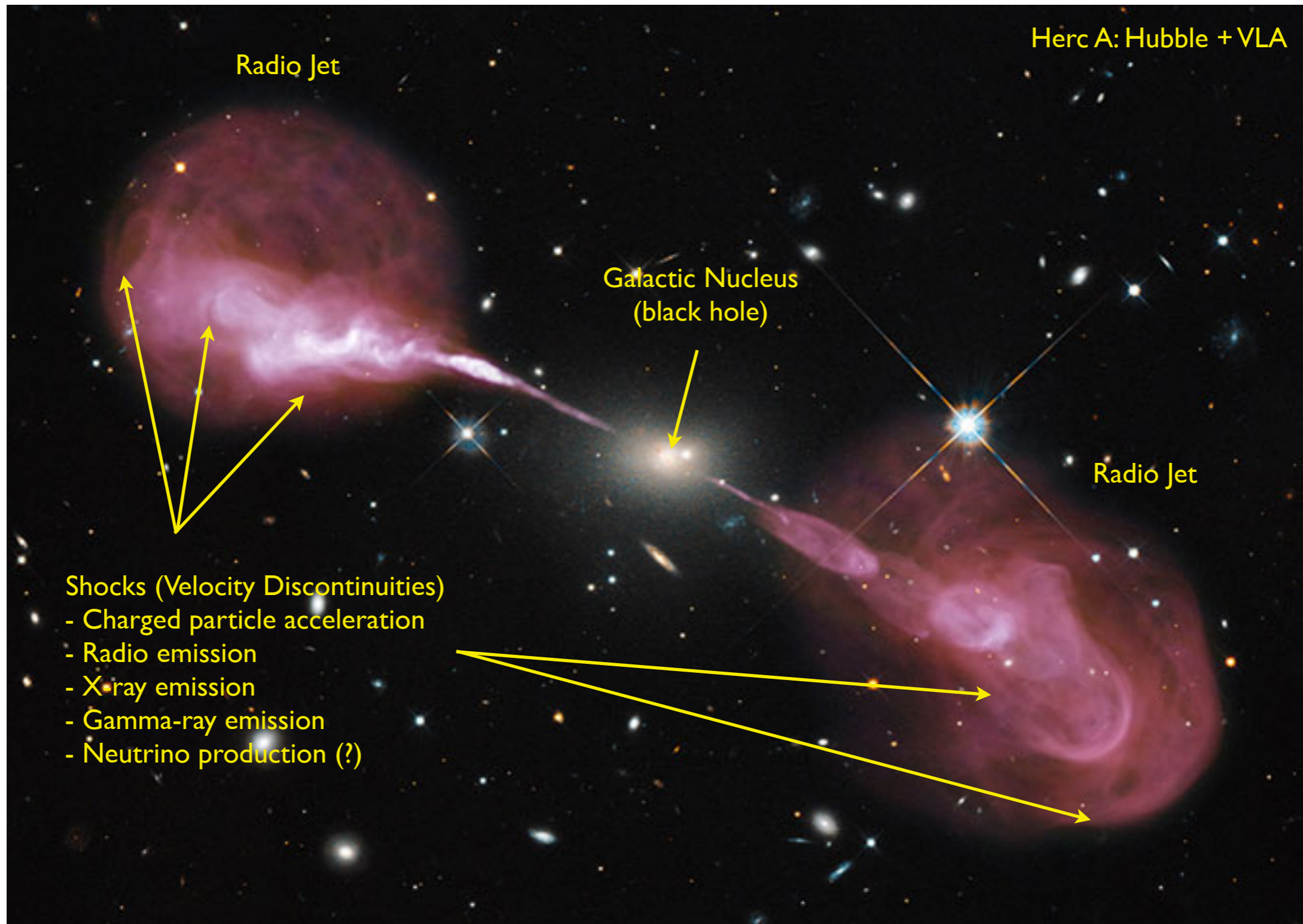


Crab Pulsar: Chandra

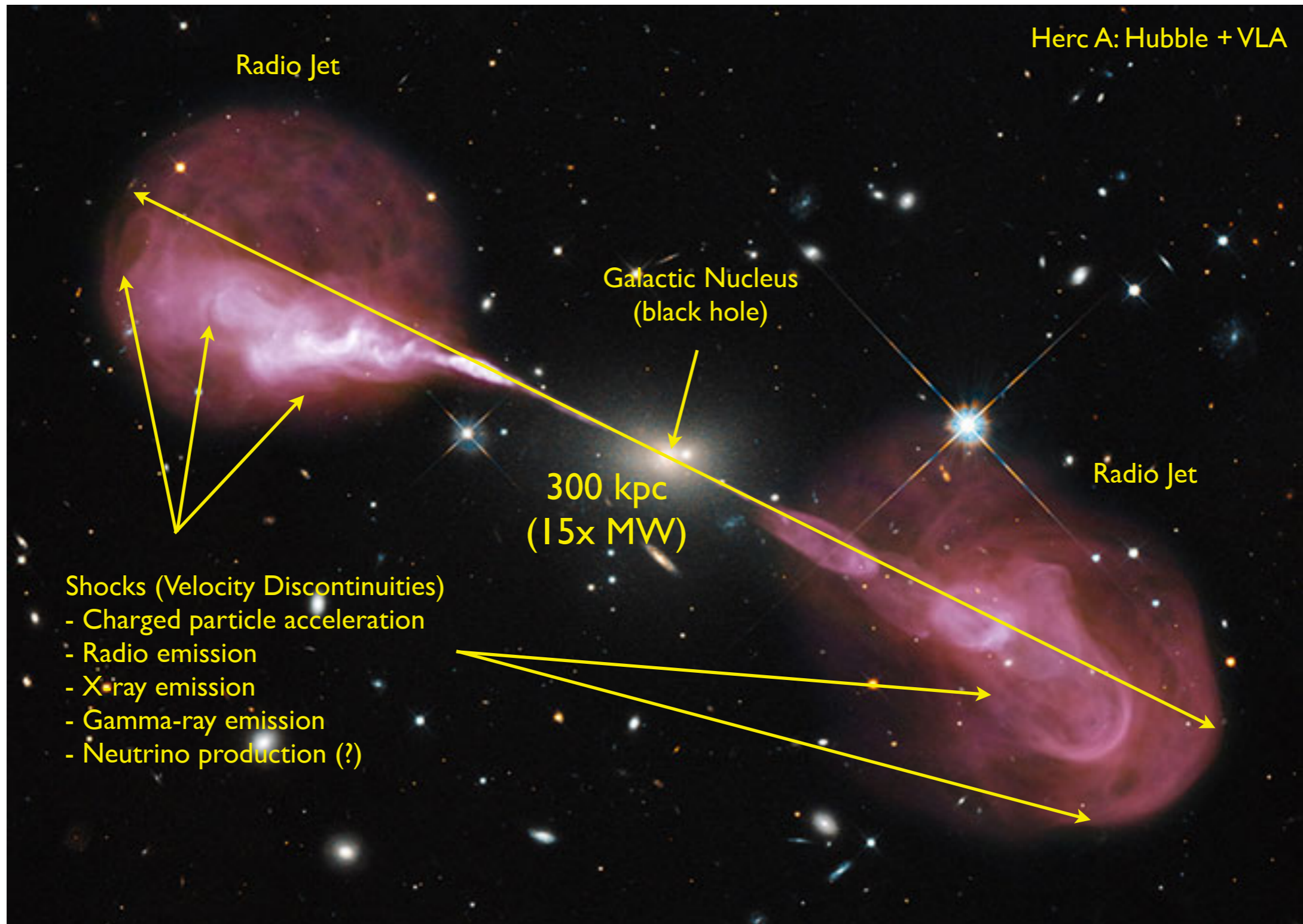
Extragalactic Source (AGN)



Extragalactic Source (AGN)

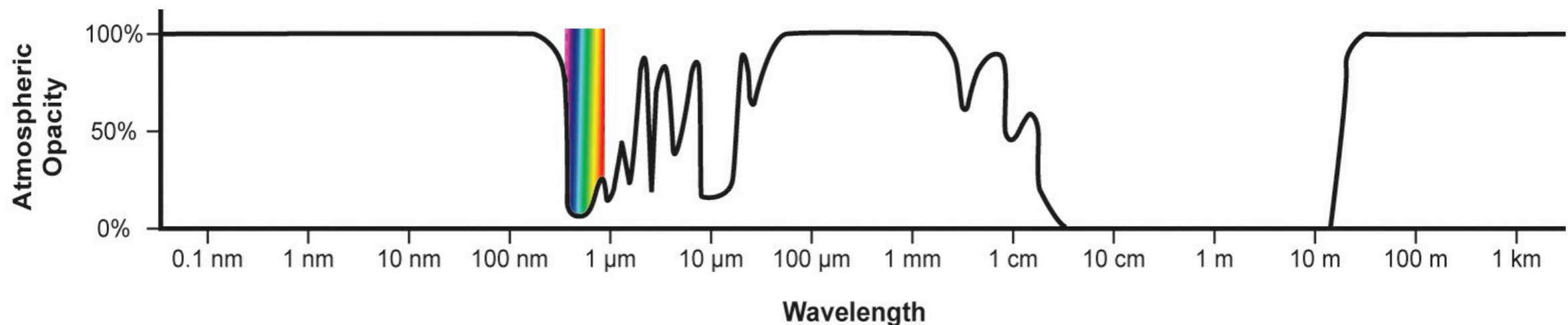


Extragalactic Source (AGN)



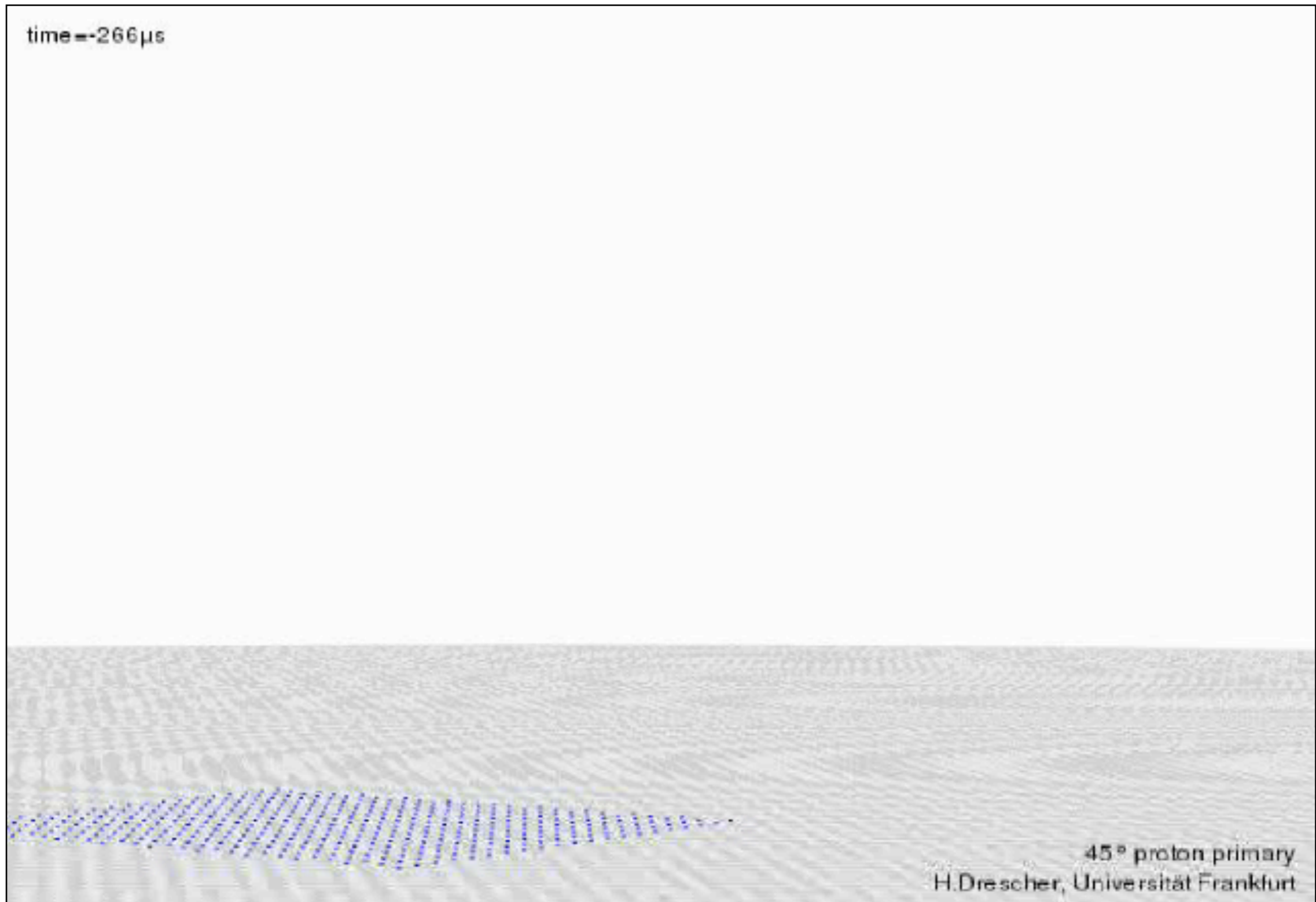
Detecting TeV Gamma Rays

- ▶ Flux of TeV gamma rays at Earth is **1 particle/day in 1 m x 1 m area**. Too small to use a satellite!

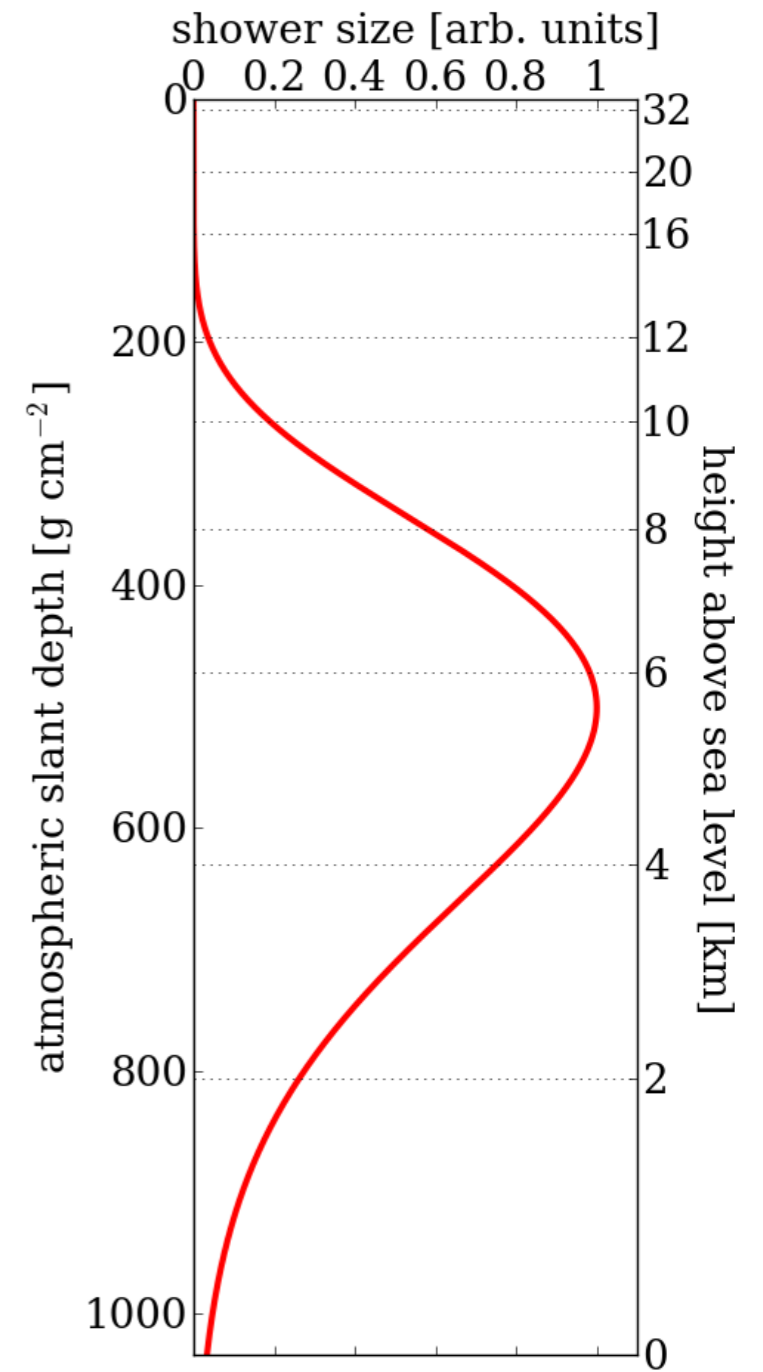
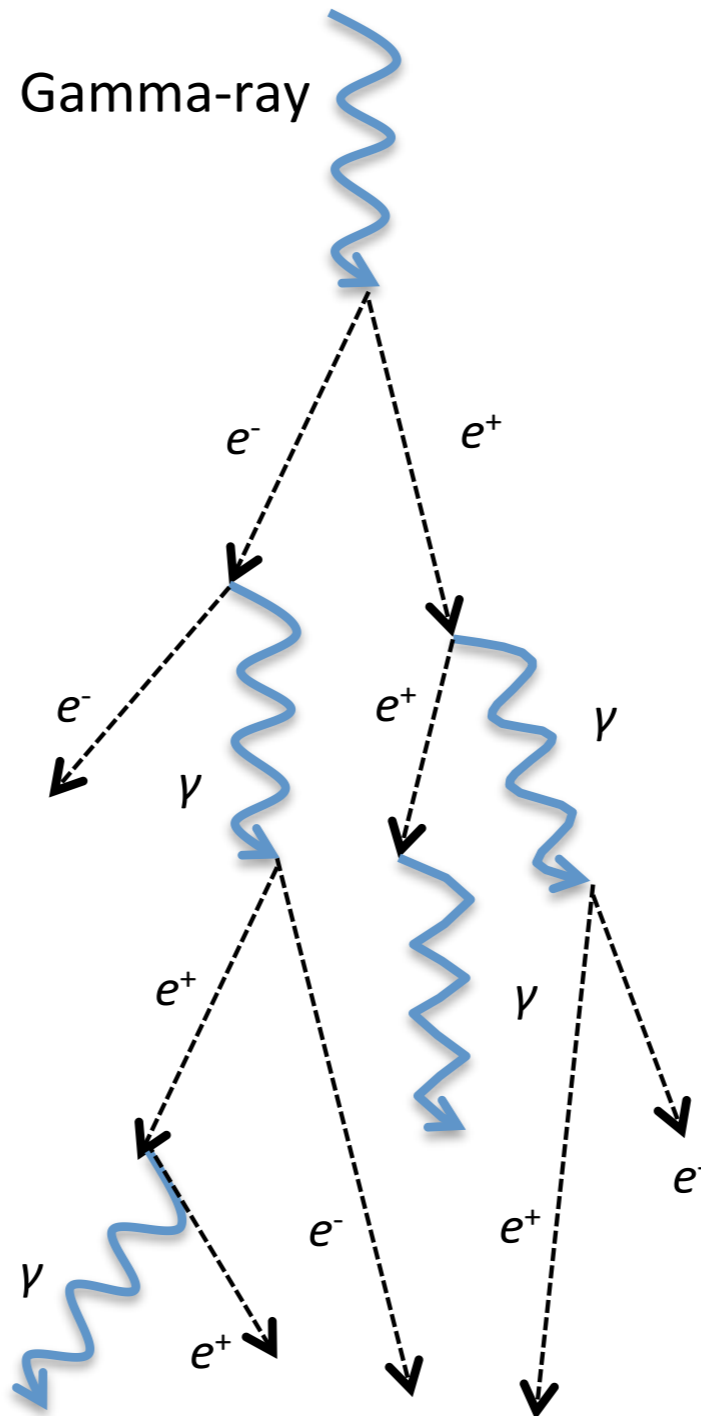
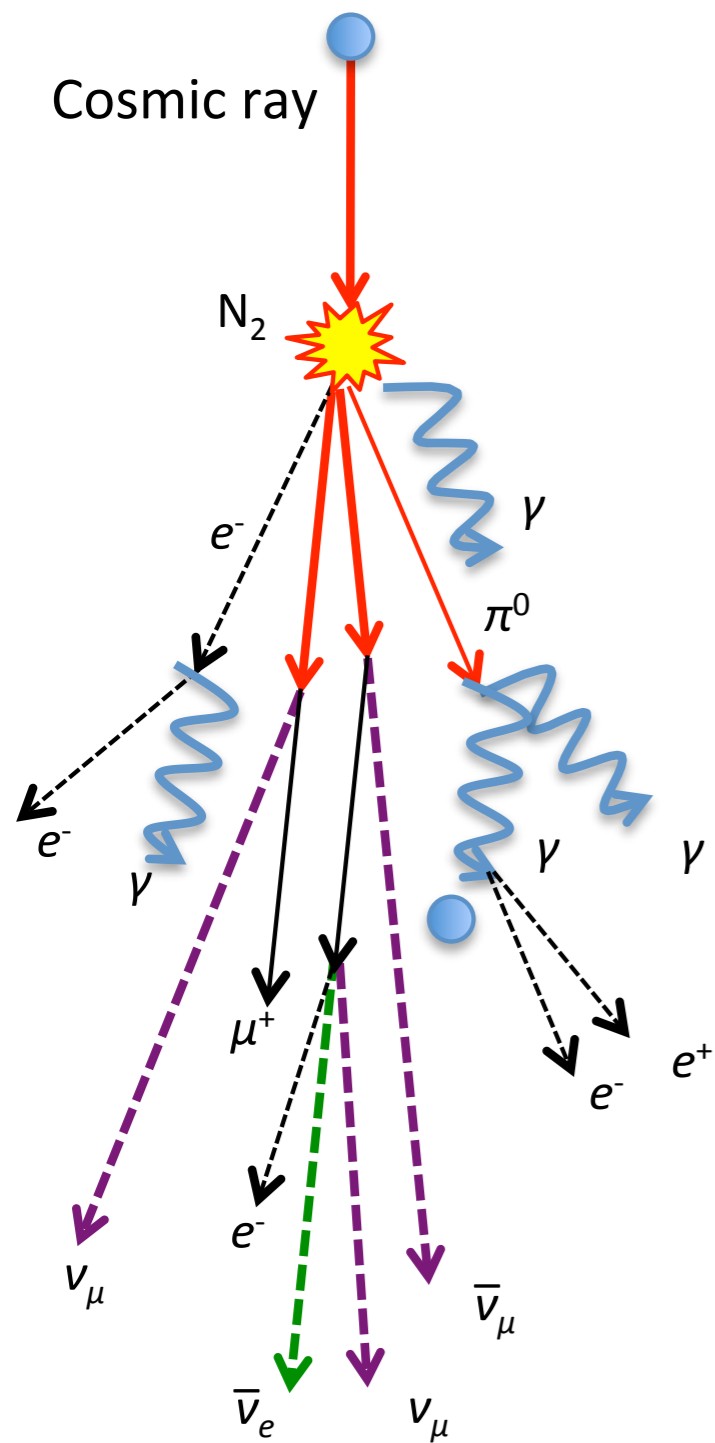


- ▶ But, the atmosphere is opaque to TeV gamma rays
- ▶ They produce **air showers** which we can observe

Cosmic Ray Air Shower (Proton)



Air Shower Development

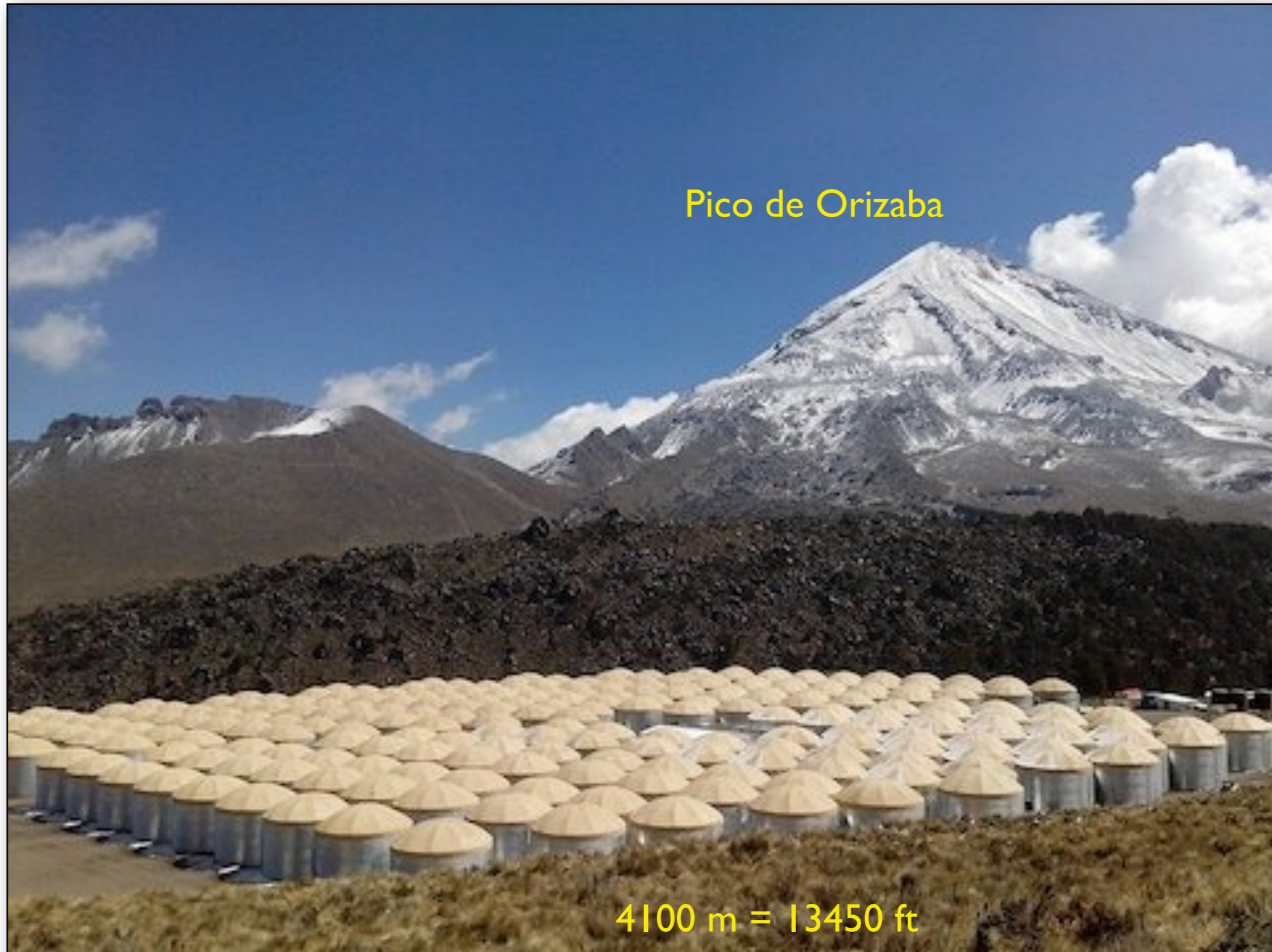


HAWC Gamma-Ray Observatory

- ▶ The **H**igh-**A**ltitude **W**ater **C**herenkov Observatory is under construction near Puebla, Mexico
- ▶ Goals: observe **gamma rays** and **cosmic rays** from half the sky each day
- ▶ Statistics:
 - 4100 m above sea level
 - 19° N latitude
 - 300 water tanks
 - 1/6th of sky in FOV
 - Covers 100 GeV to 100 TeV

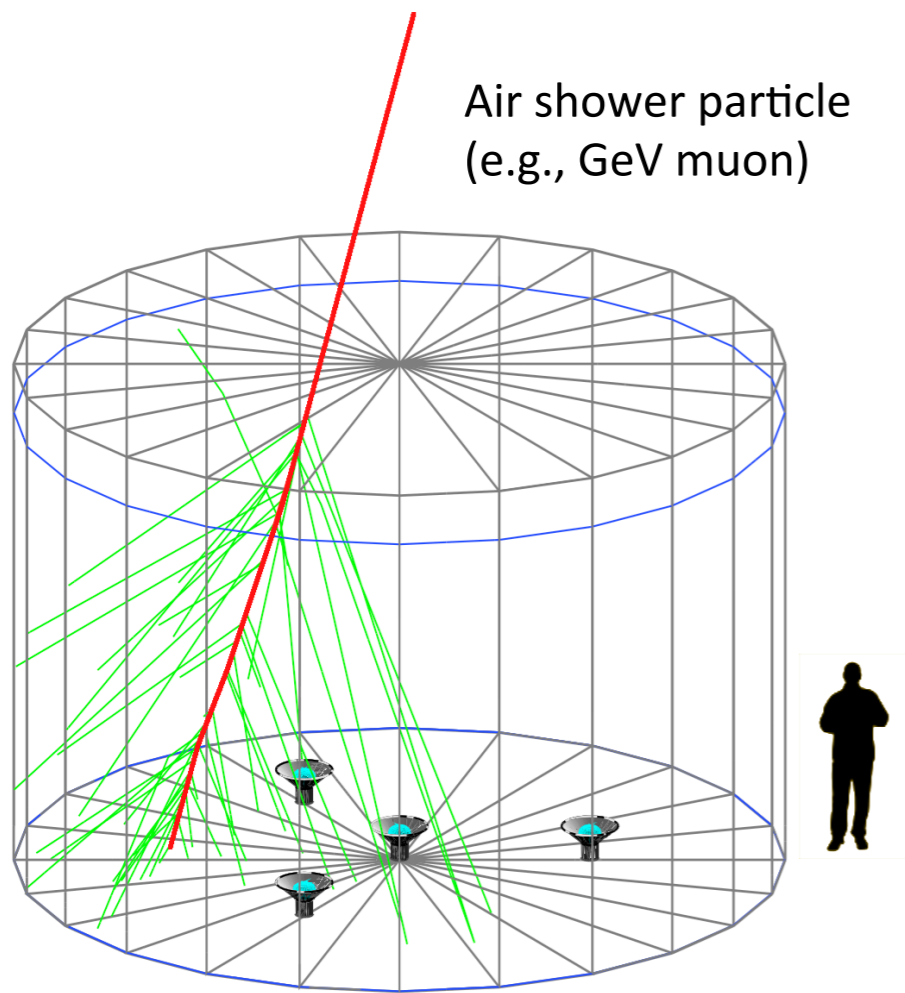


HAWC Observatory



Water Cherenkov Detectors

- ▶ Array of 300 water tanks: 7.3 m diameter, 5 m height
- ▶ 200,000 L water per tank, 4 phototubes observe Cherenkov light from shower particles

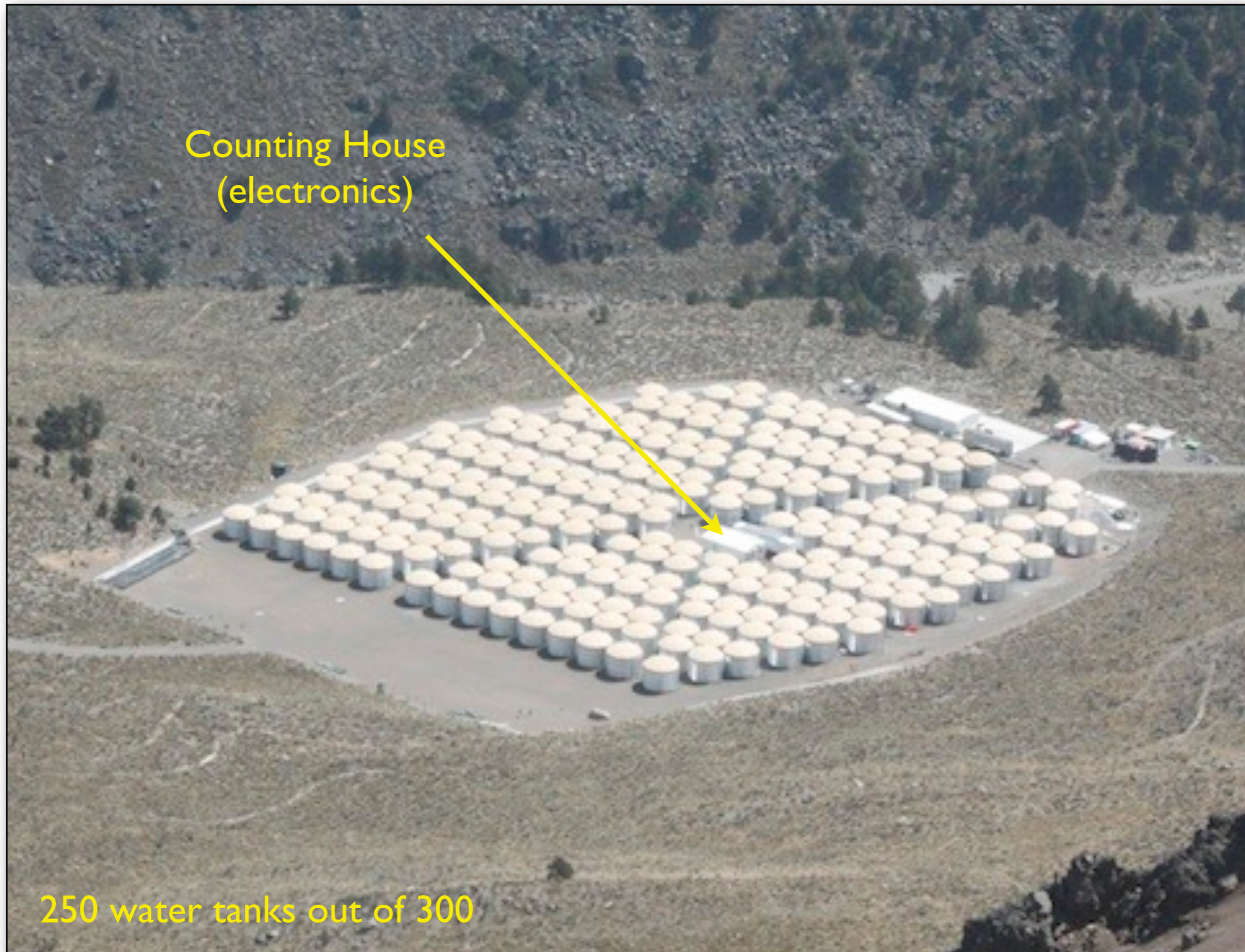


HAWC: May 2014

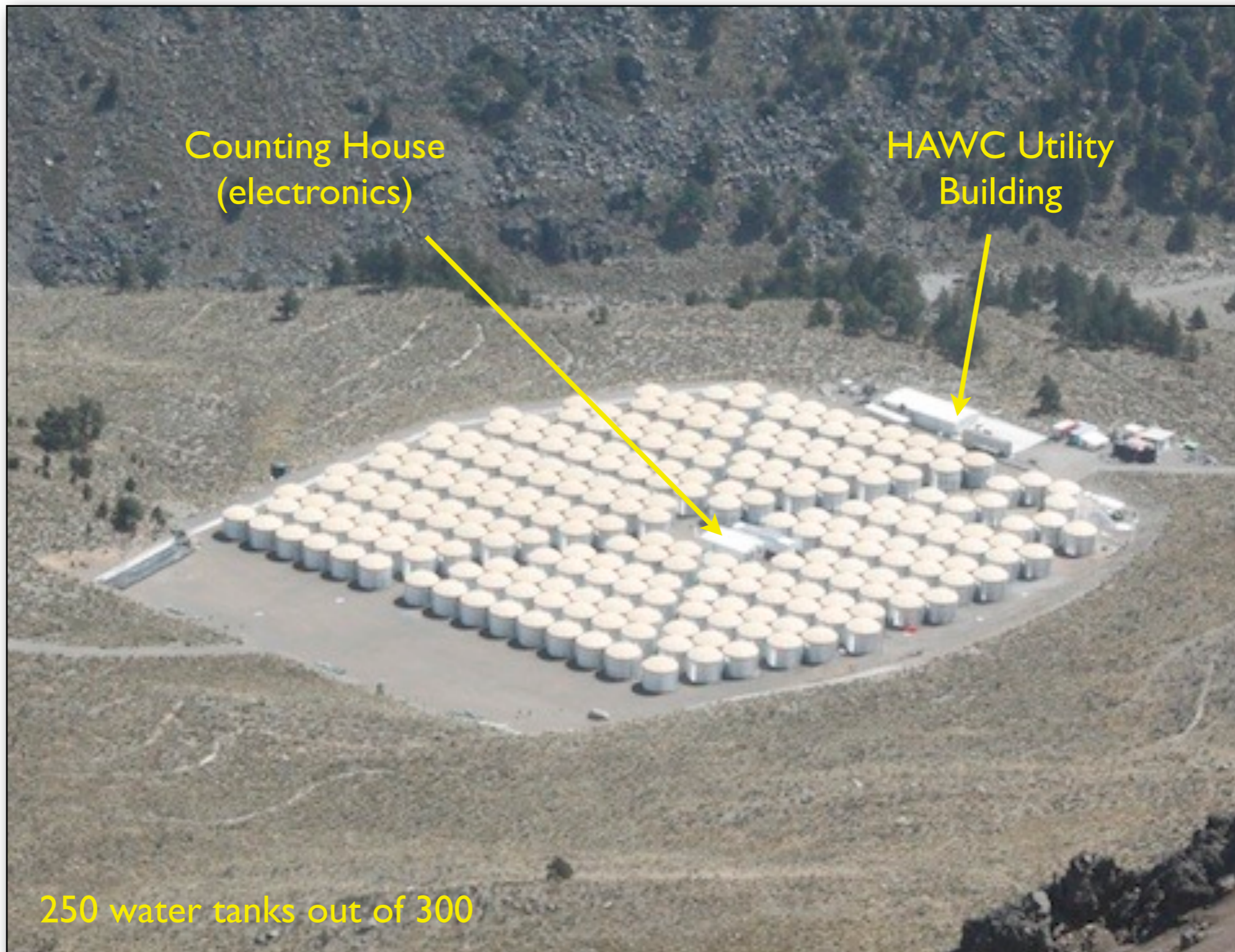


250 water tanks out of 300

HAWC: May 2014



HAWC: May 2014



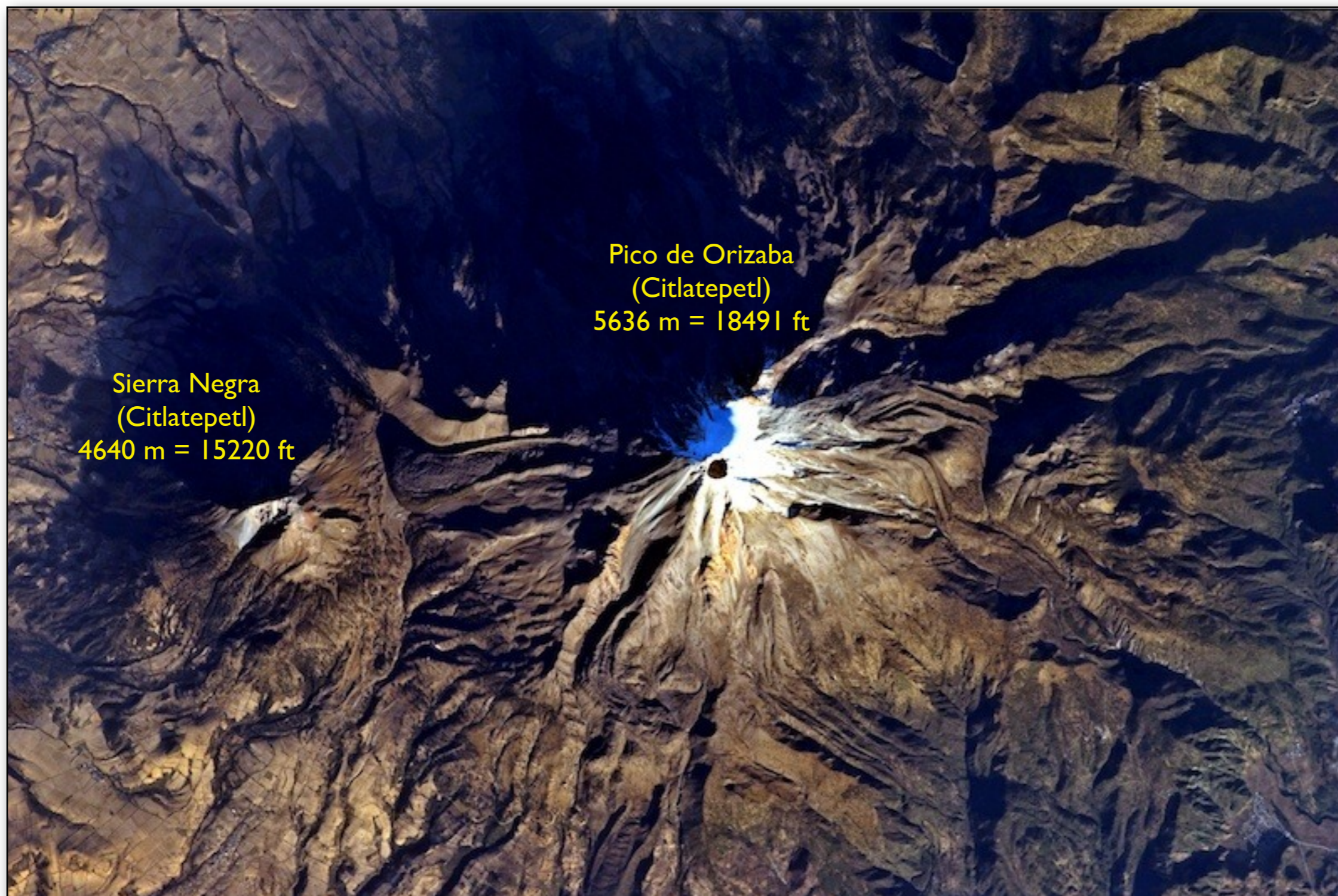
HAWC Site

NASA Earth Observatory



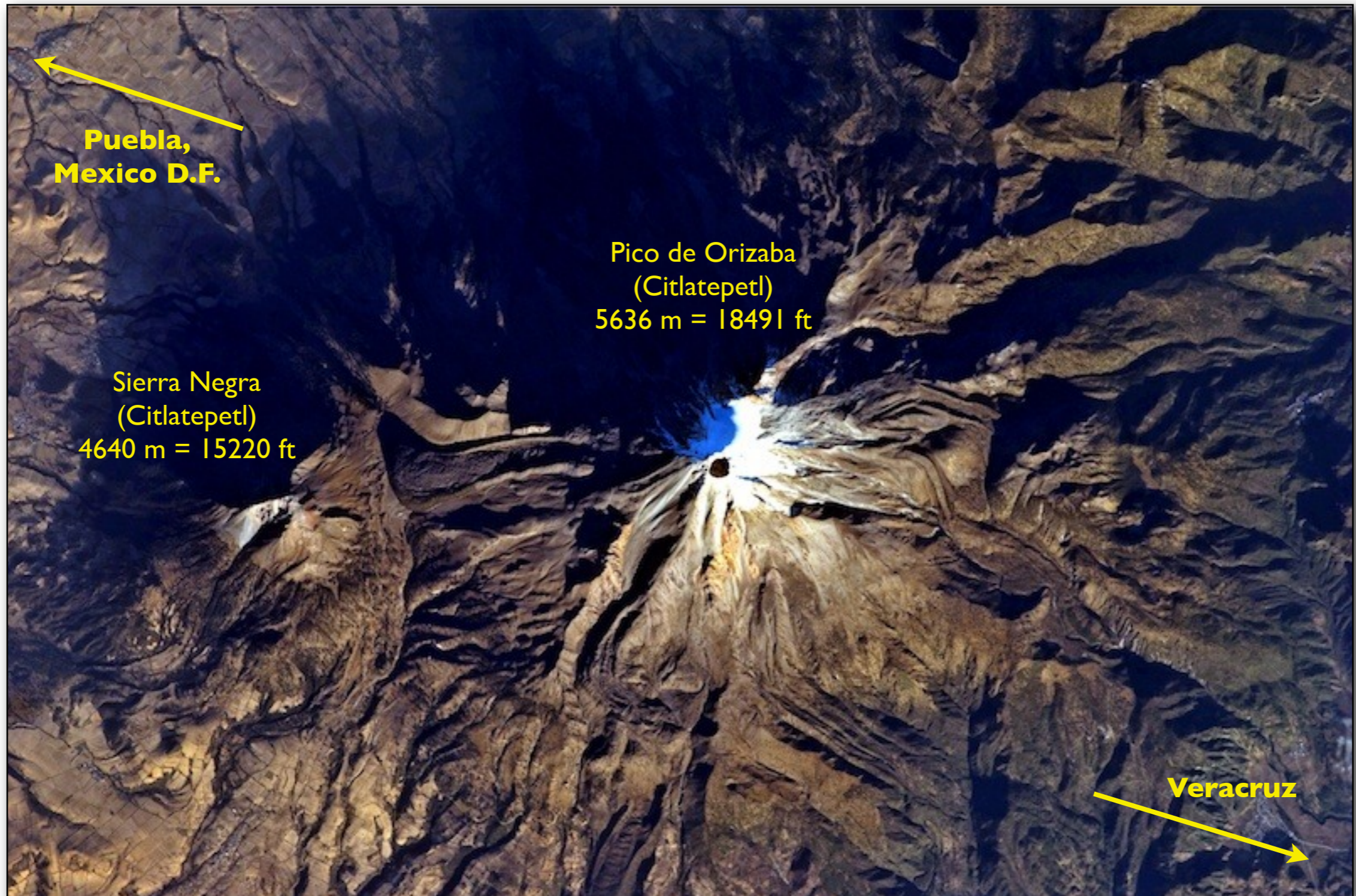
HAWC Site

NASA Earth Observatory



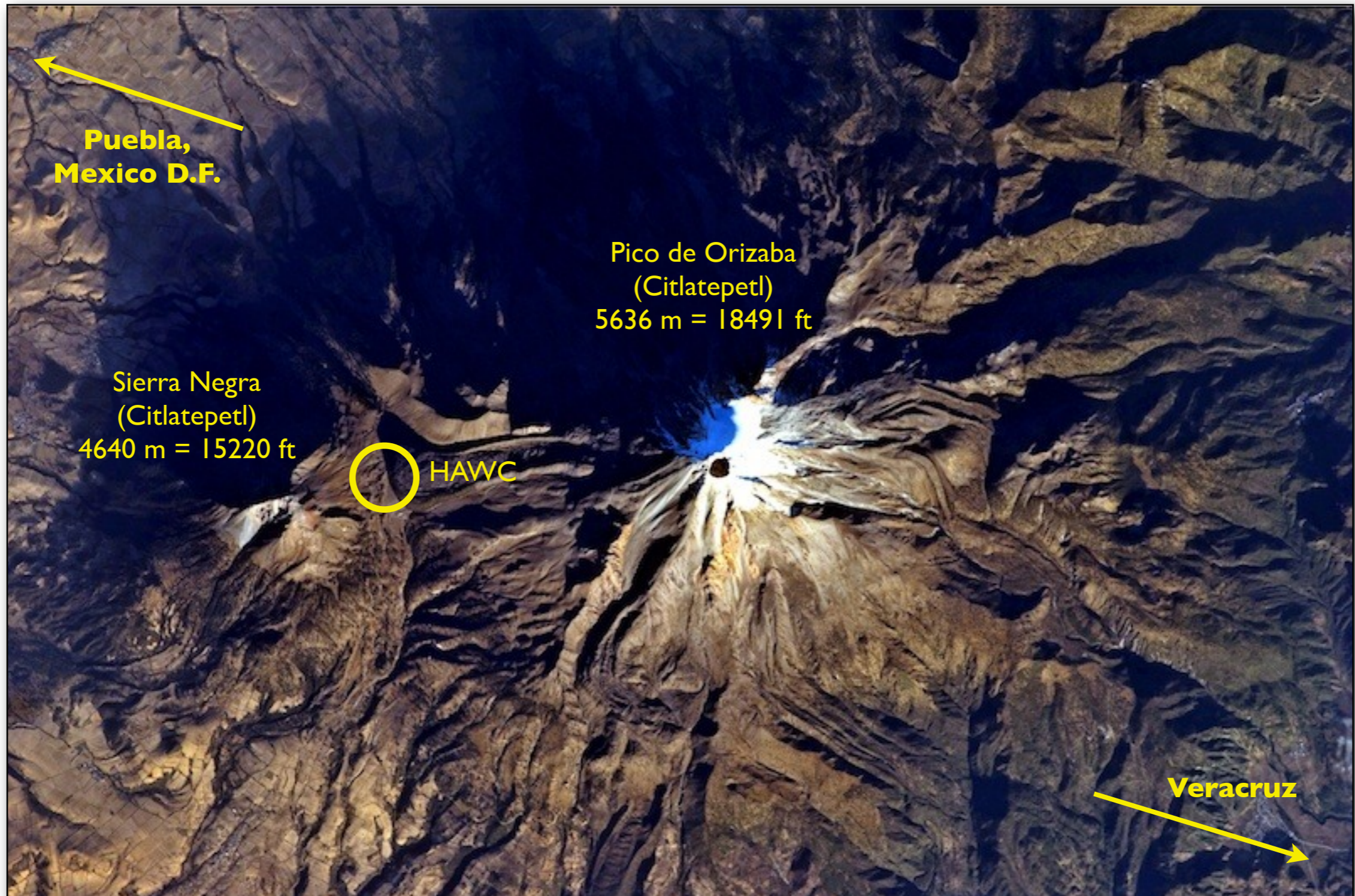
HAWC Site

NASA Earth Observatory



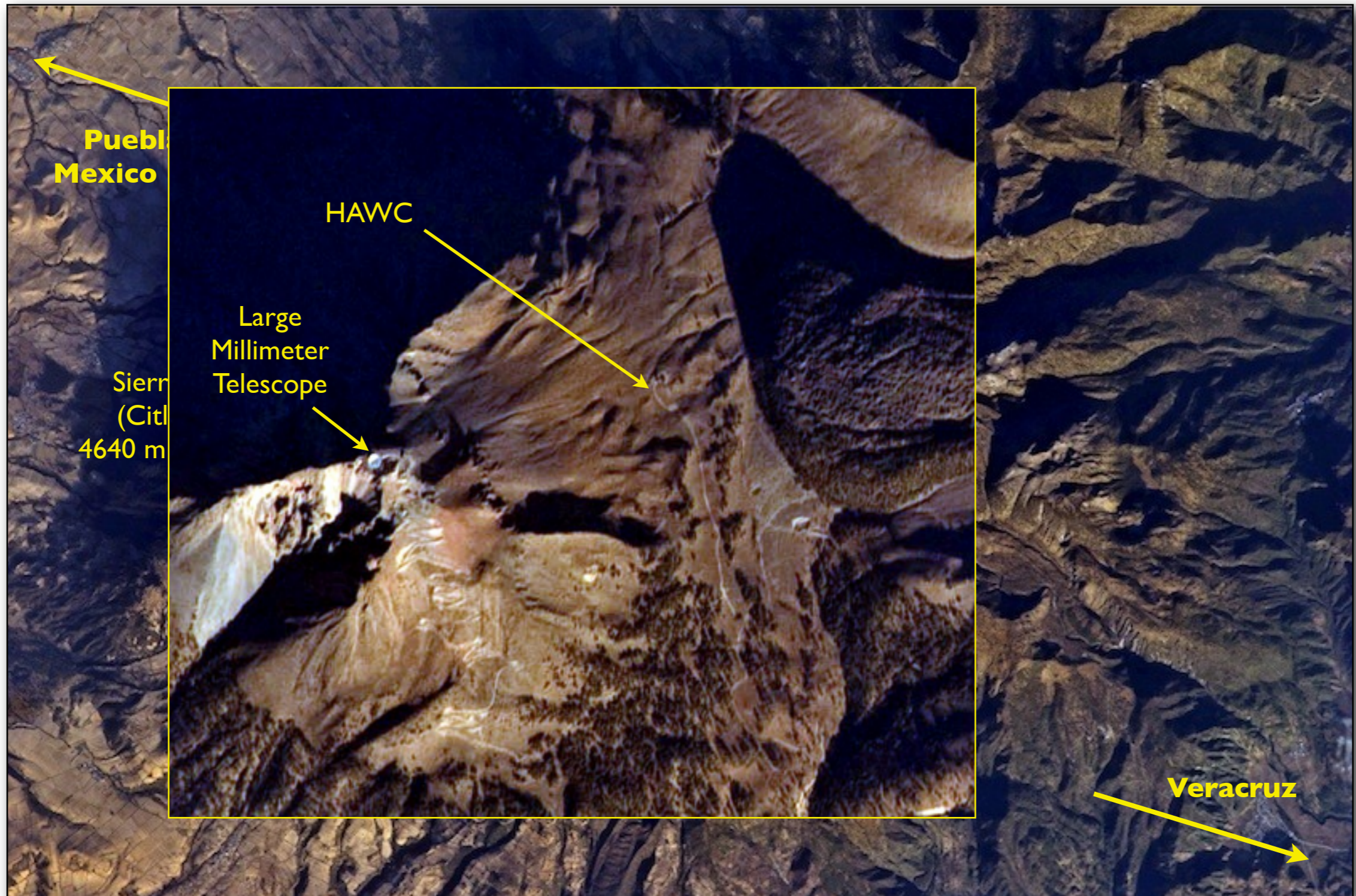
HAWC Site

NASA Earth Observatory



HAWC Site

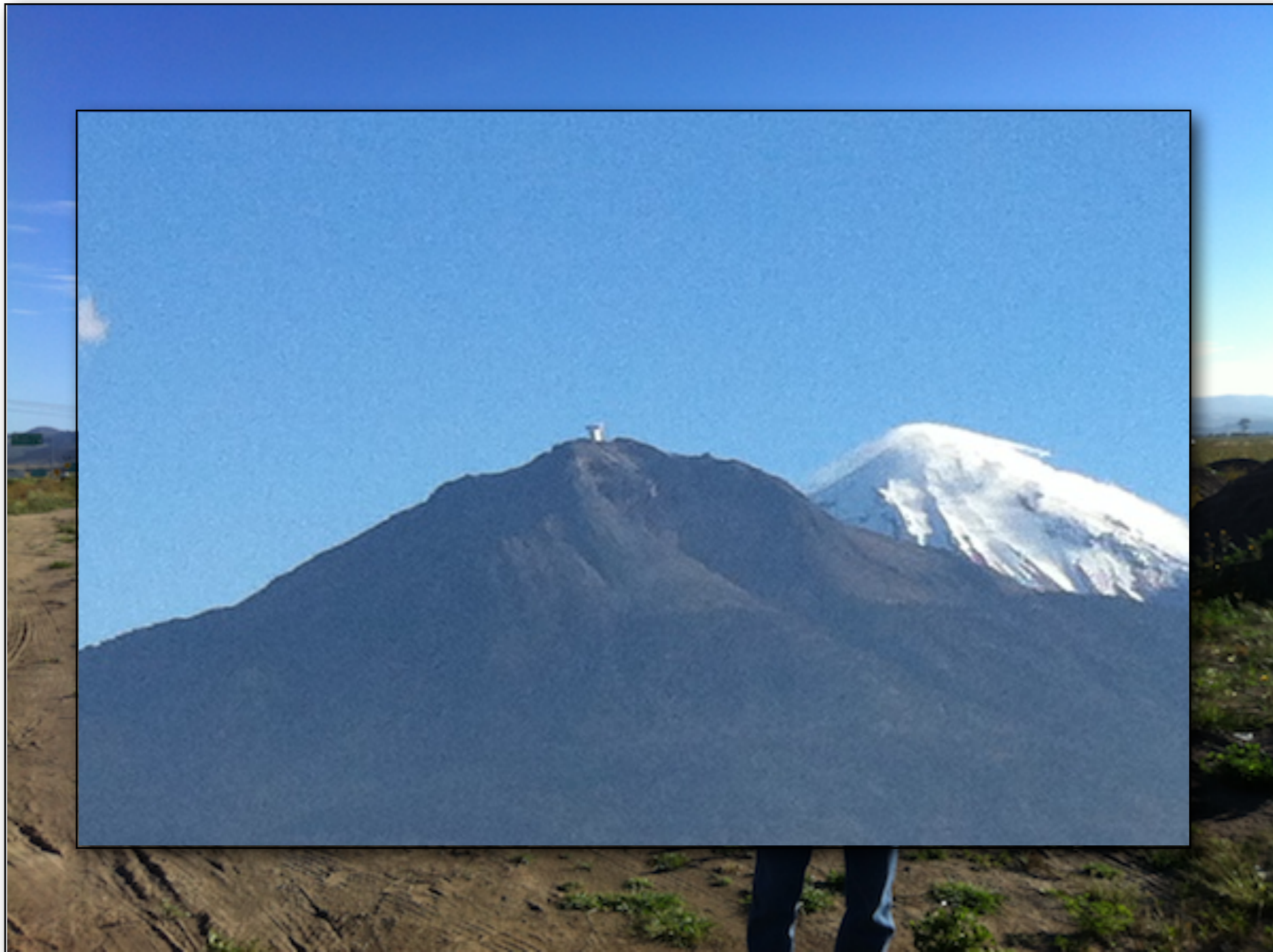
NASA Earth Observatory



Going Up the Mountain



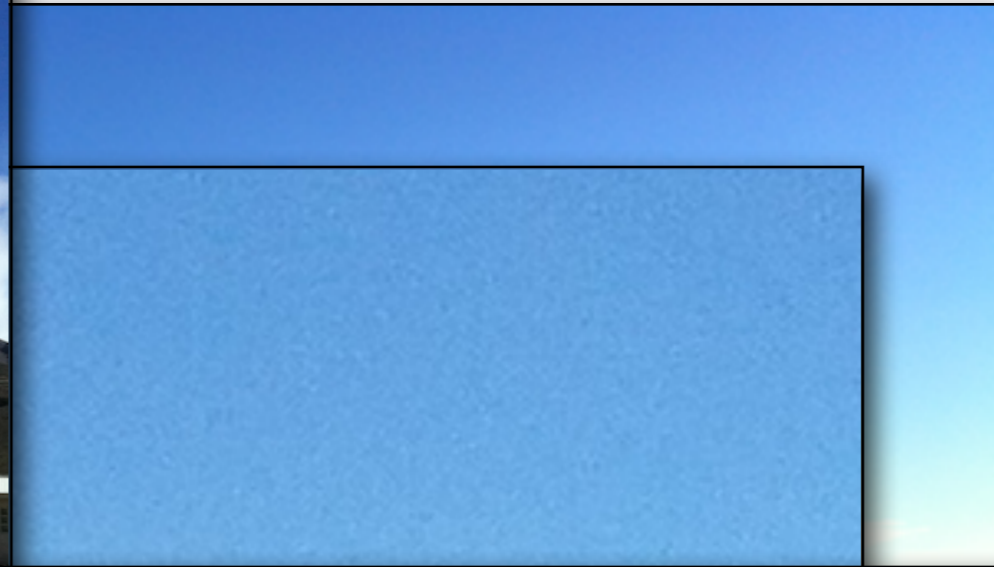
Going Up the Mountain



Going Up the Mountain



Going Up the Mountain



Life Near the Site

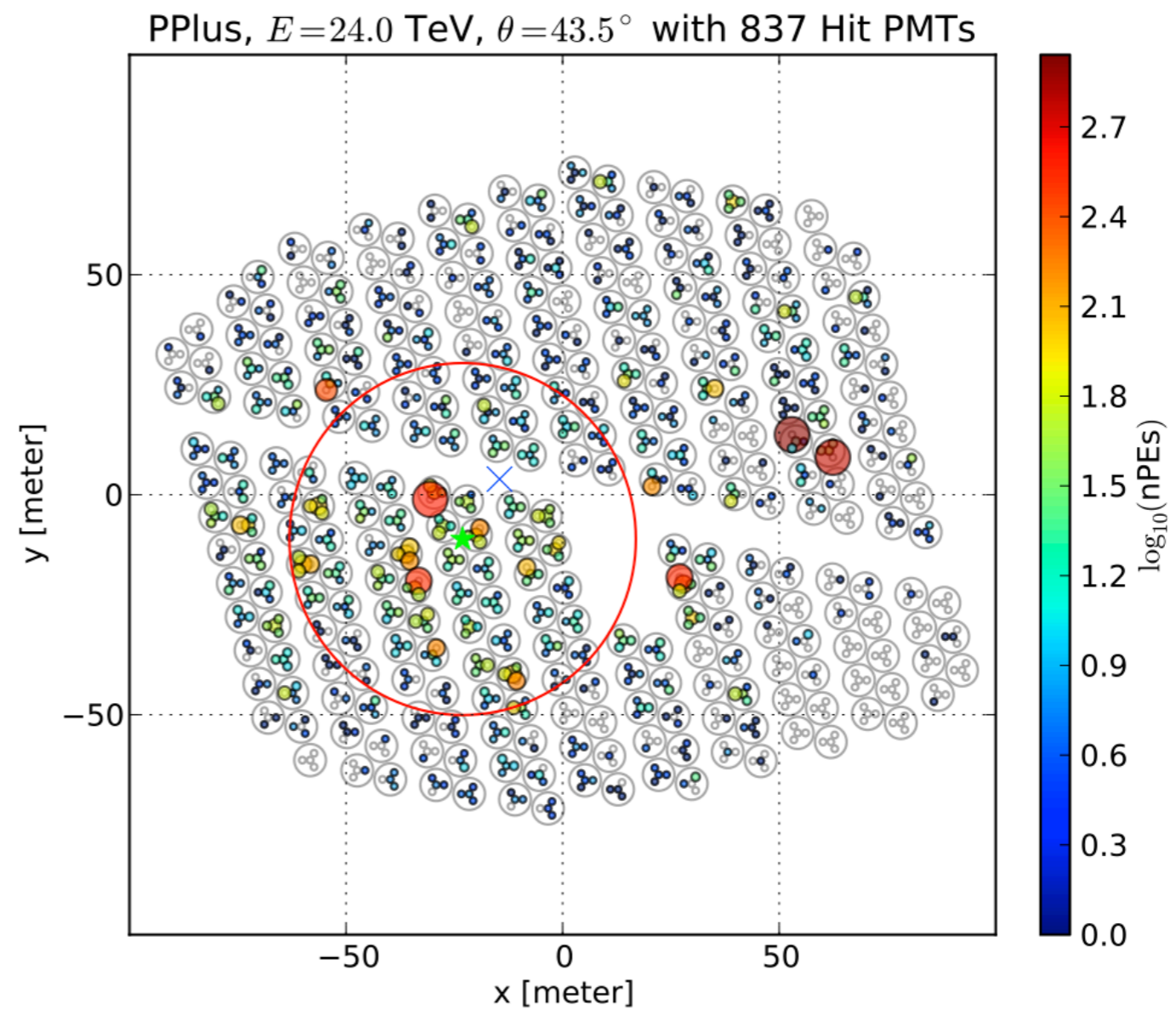
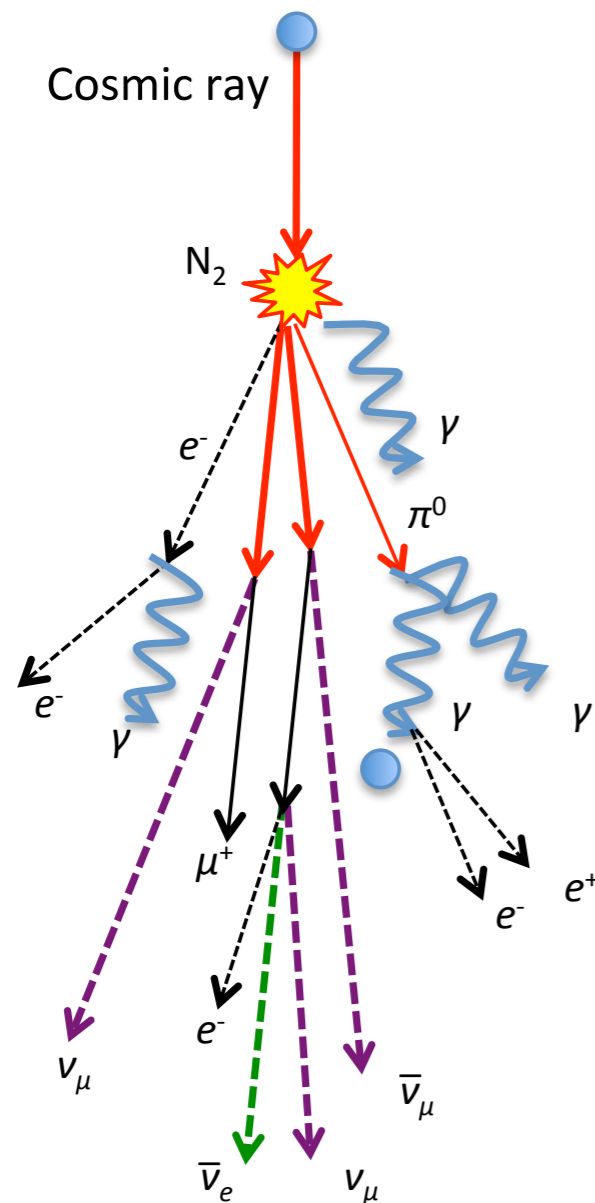


Life Near the Site



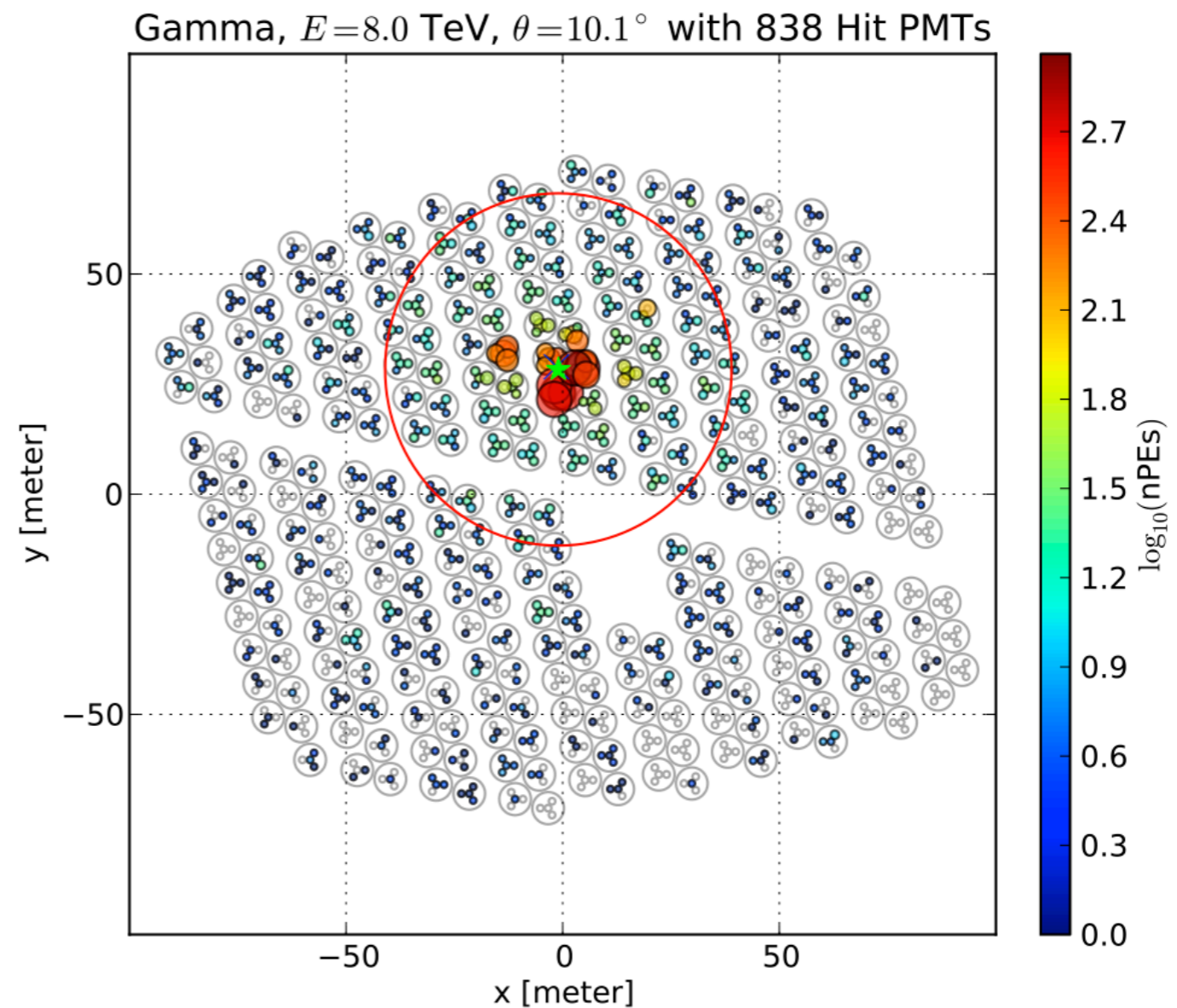
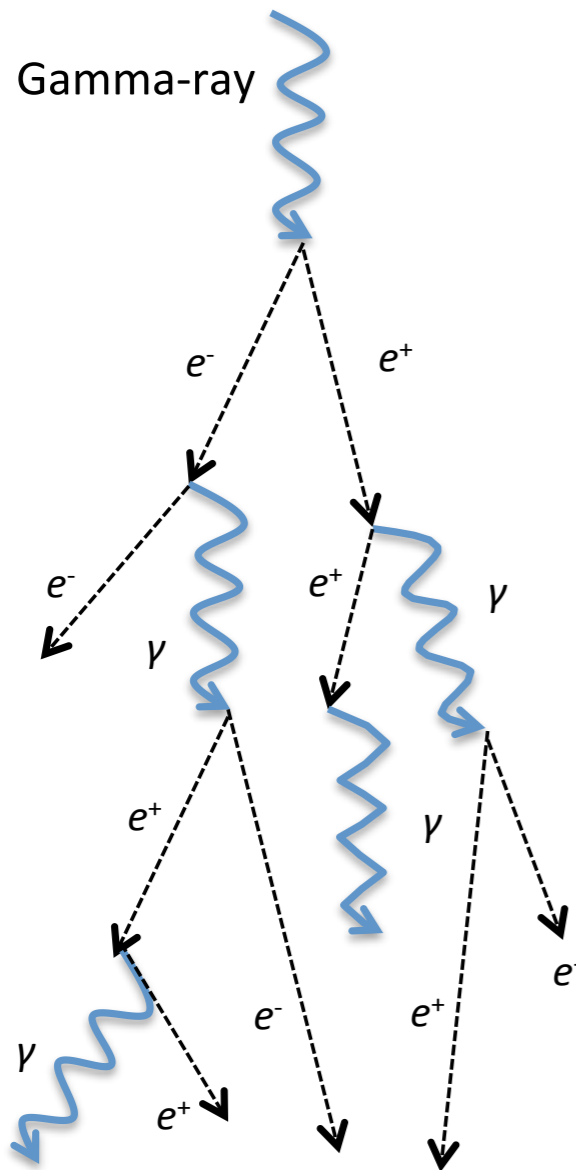
Background Rejection: Proton Tagging

- ▶ Look for large hits far from shower core (99% rejection at 10 TeV)



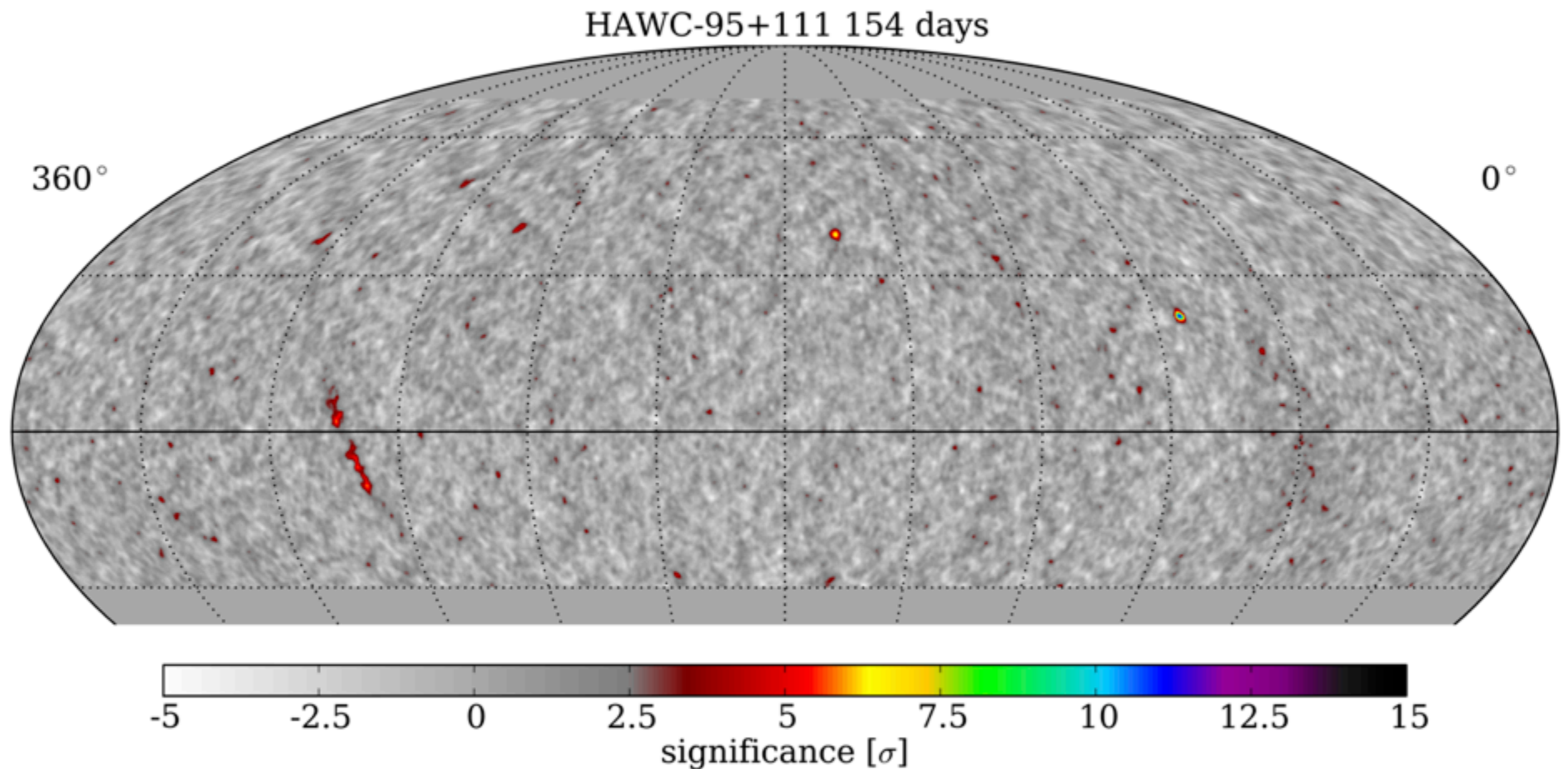
Signal: Gamma-Ray Tagging

- ▶ No large hits far from core: probably a gamma-ray



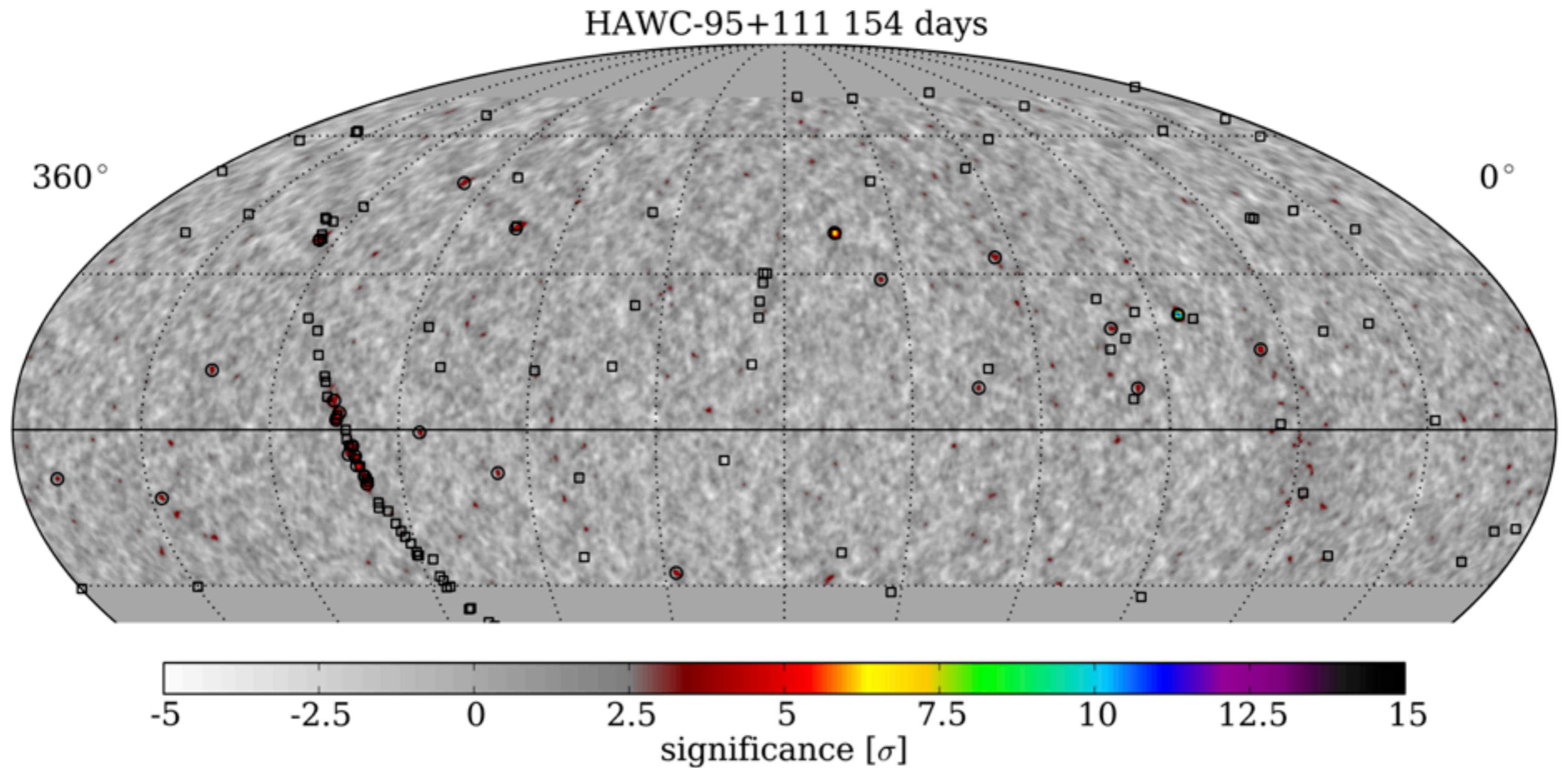
Data: Galactic Survey

- ▶ 5 months of HAWC-95+111 data (June-Nov 2013)



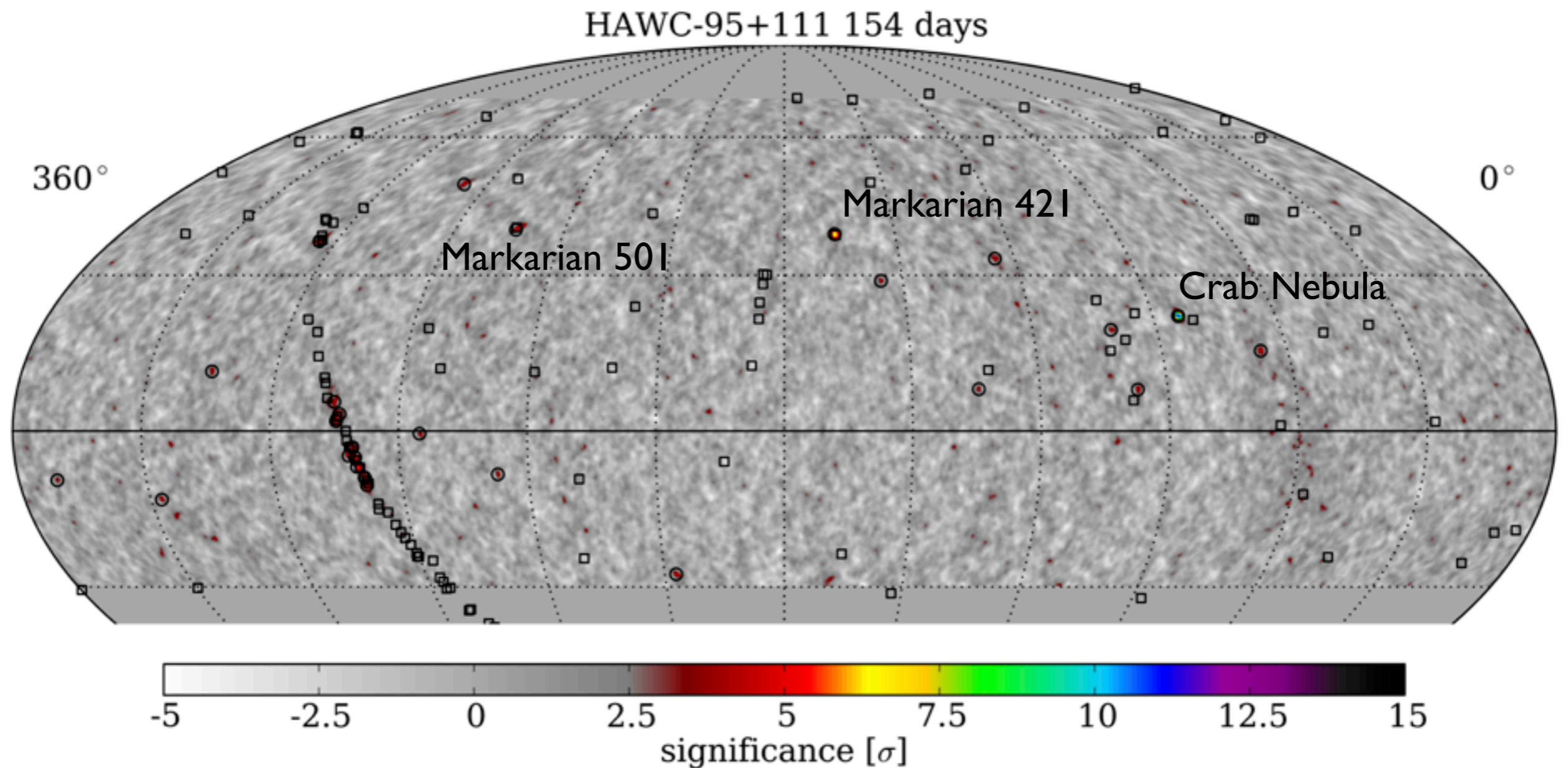
Data: Galactic Survey

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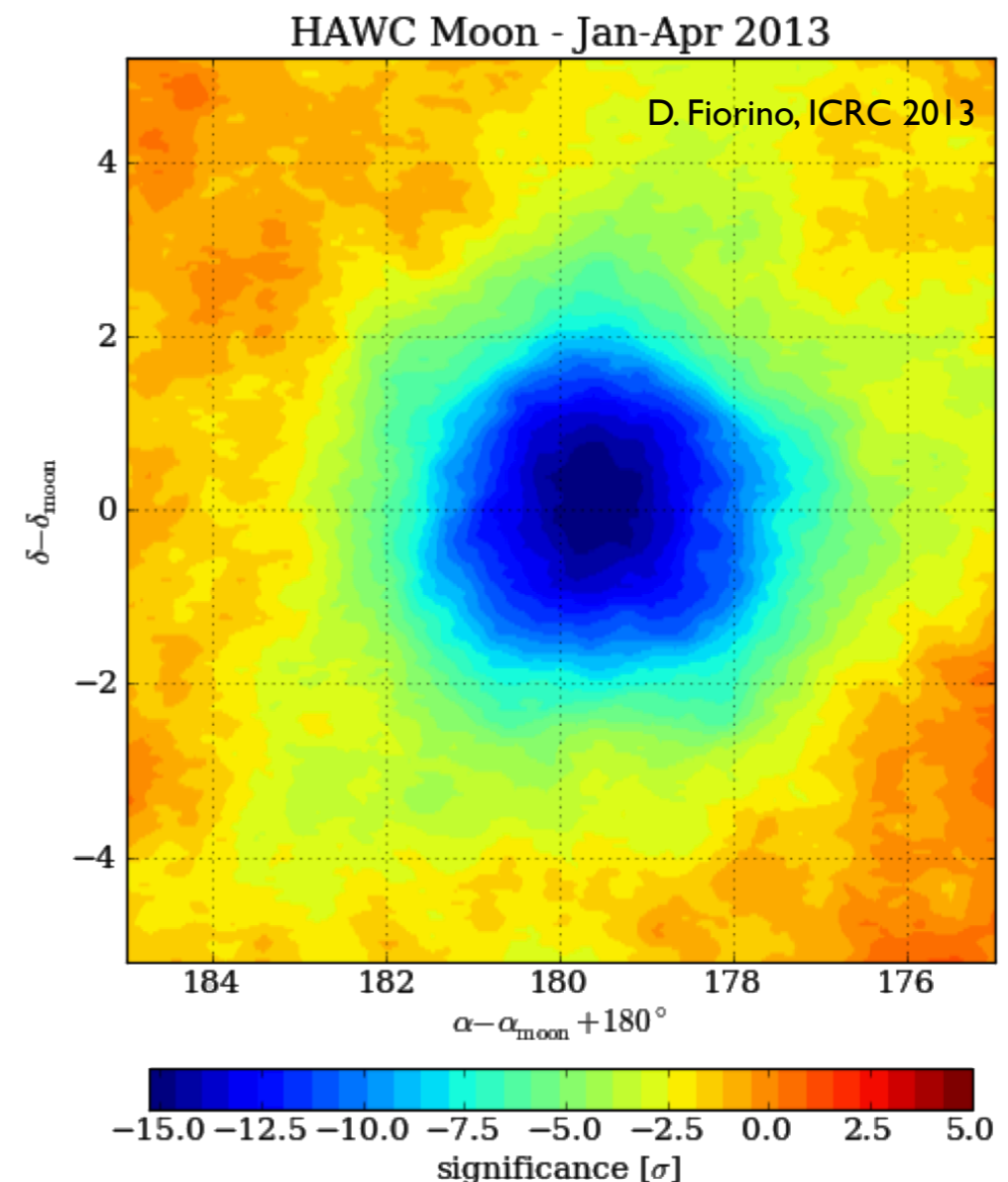
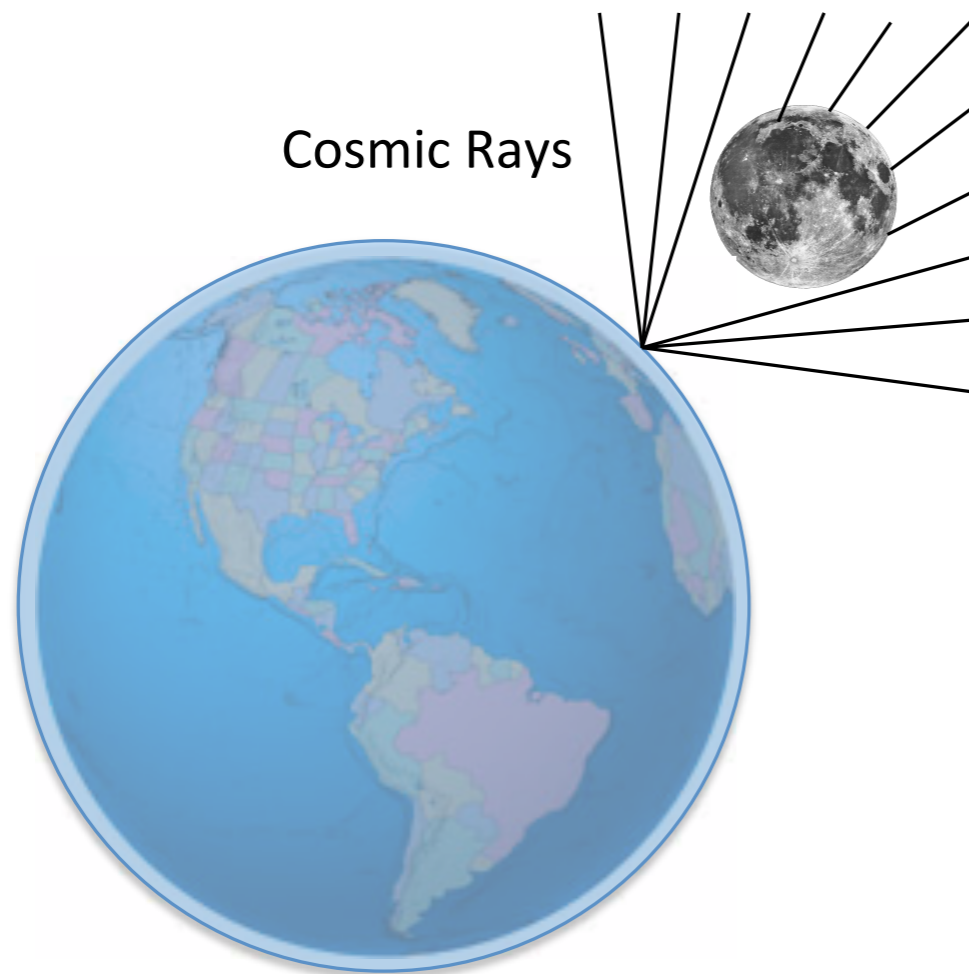


Other Weird Things We Can Do with HAWC

High Altitude Water Cherenkov
Gamma-Ray Observatory

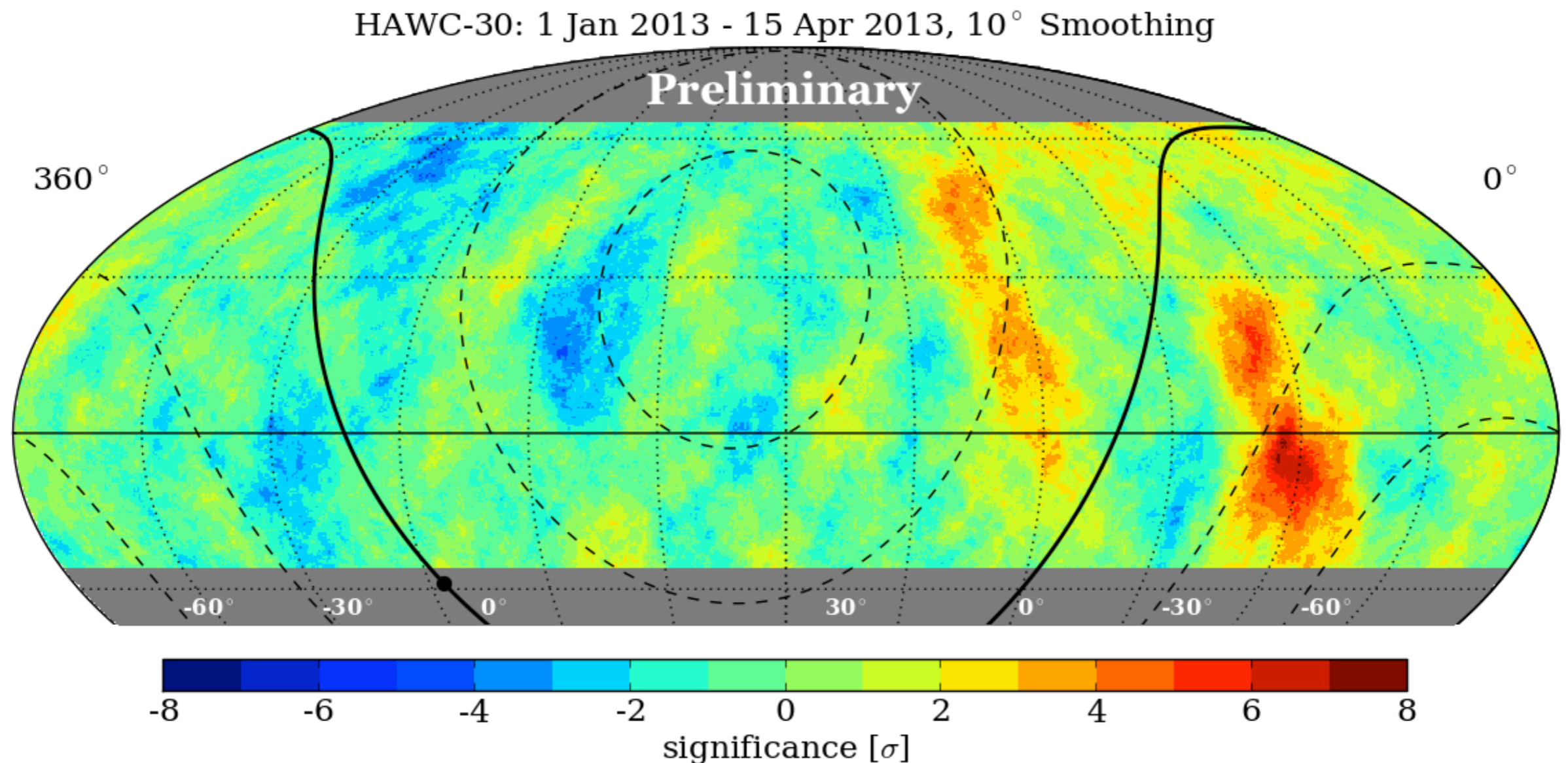
Data: Moon Shadow

- ▶ Cosmic rays are blocked by the moon
- ▶ We can see a “shadow” in direction of moon; use this to **calibrate** detector



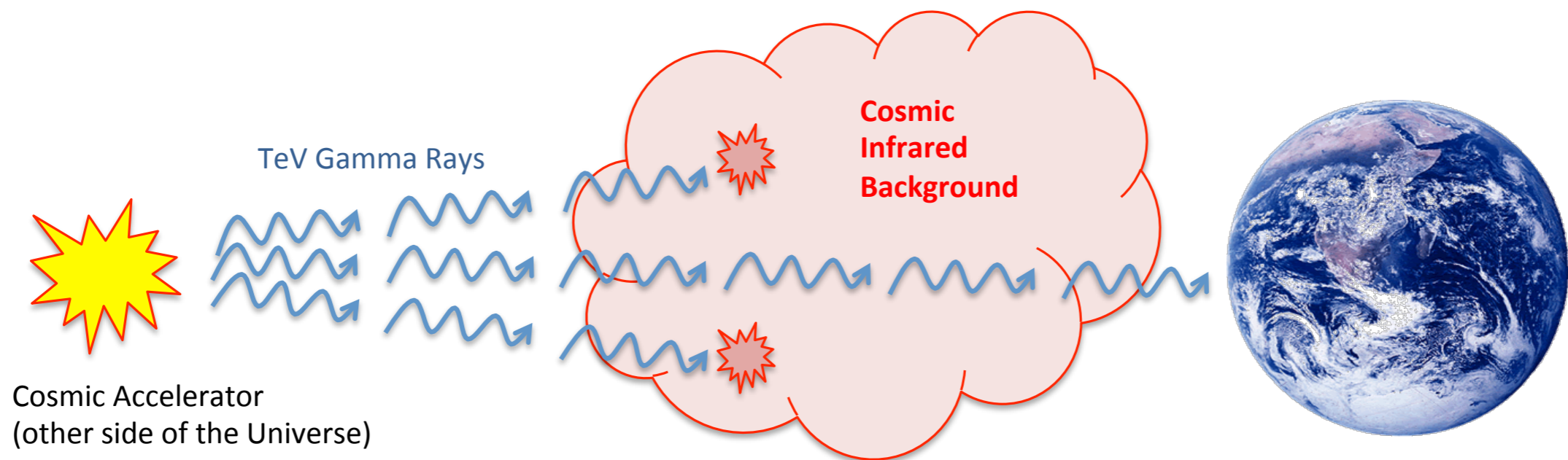
Cosmic Ray Anisotropy

- ▶ Galactic cosmic rays (H + He) are slightly anisotropic when they arrive at Earth. Effect is small: **0.1%**



Cosmology: IR Background

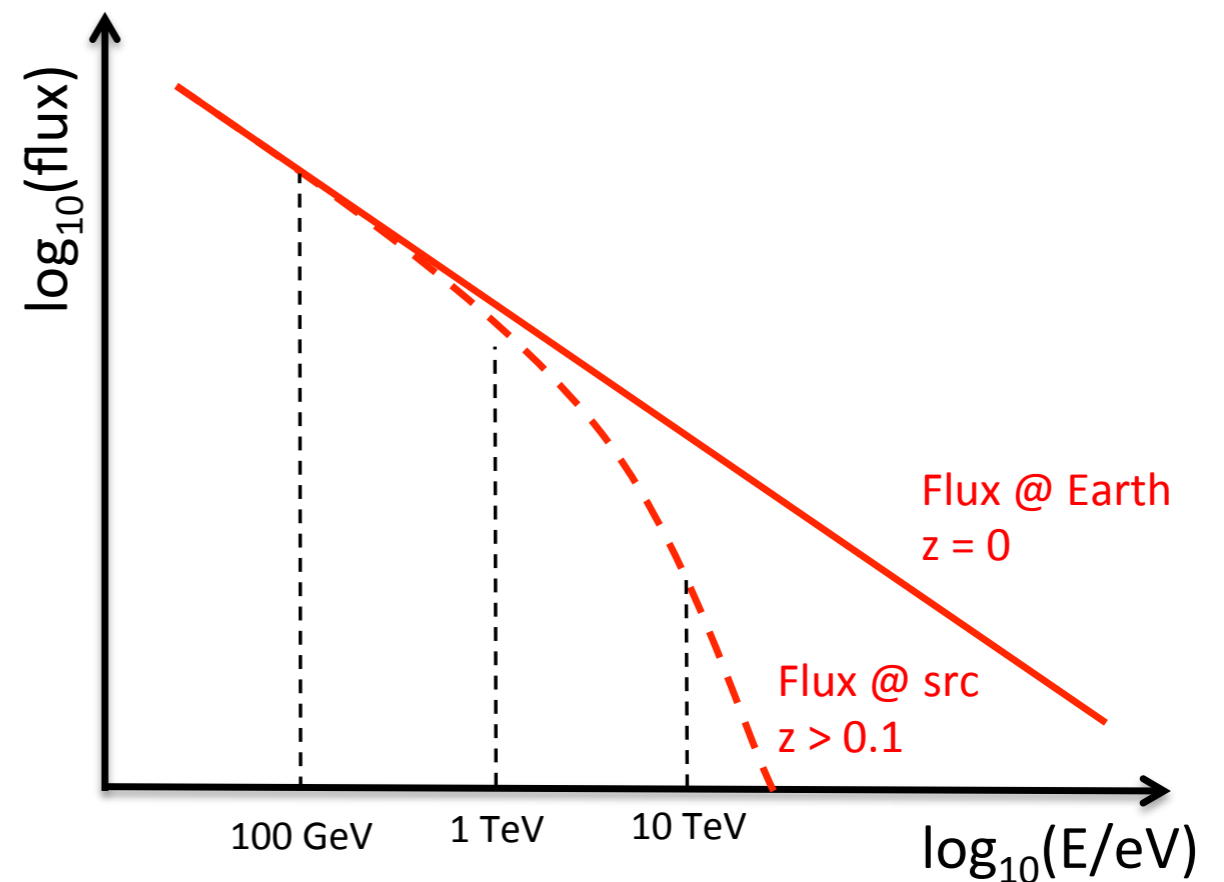
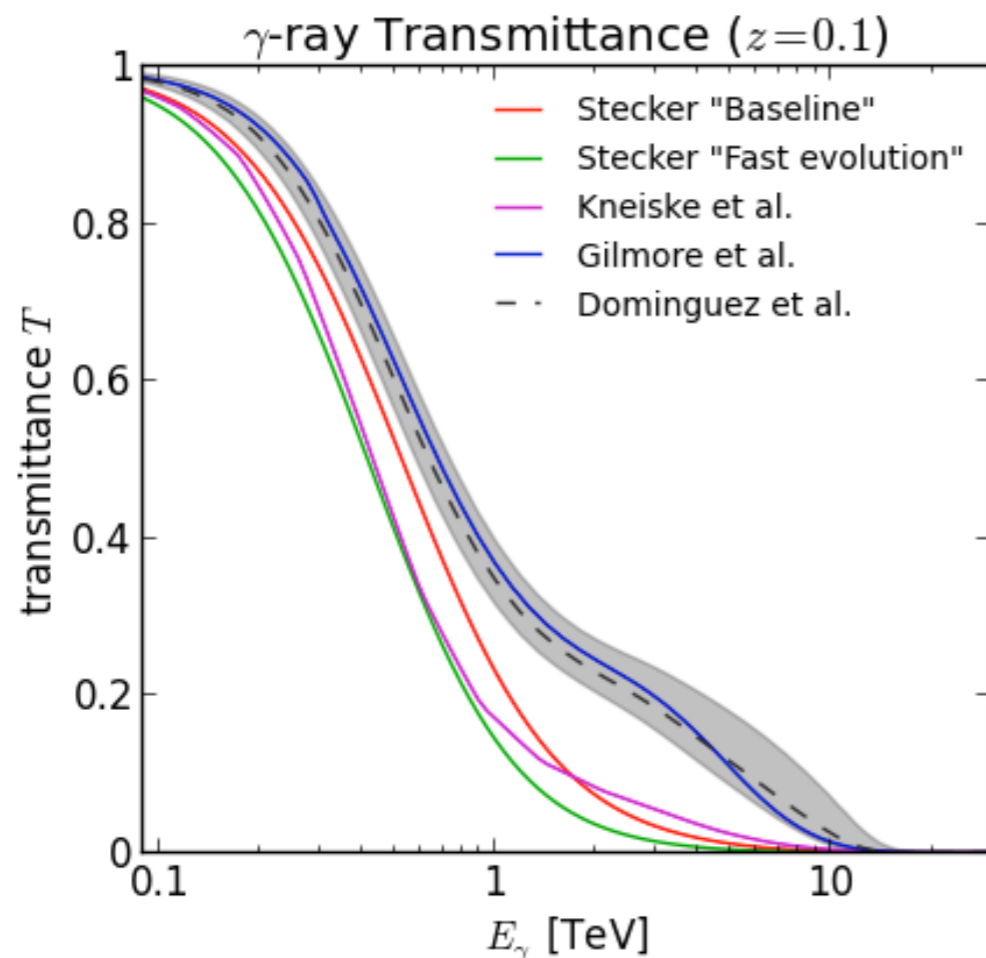
- ▶ TeV gamma rays are absorbed by the **cosmic infrared background**



- ▶ This is redshifted light from the first stars; very important for models of evolution of universe

Detecting the IR Background

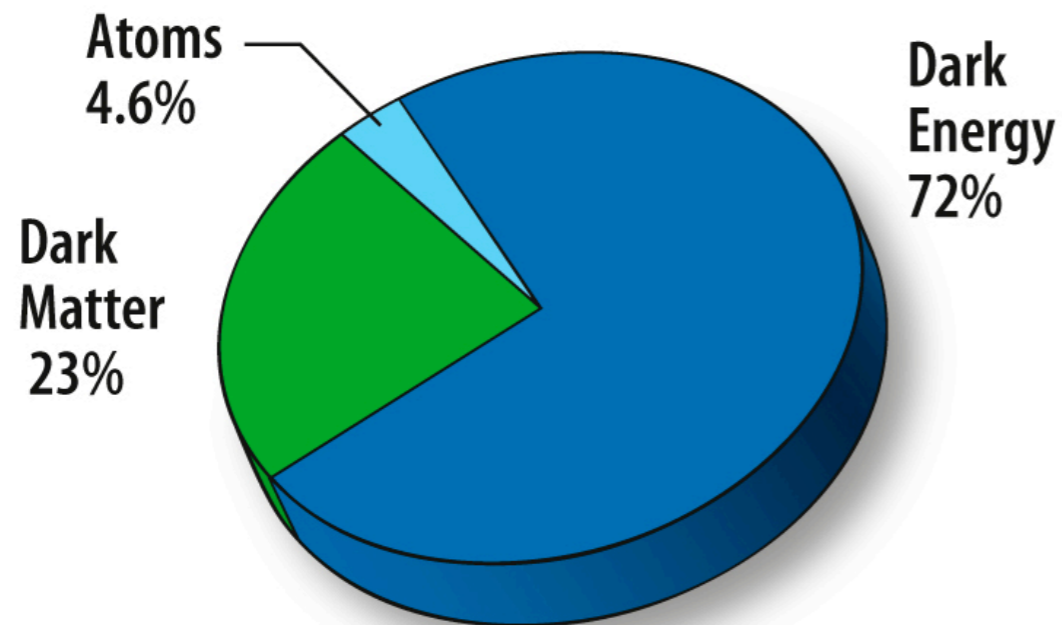
- ▶ Due to absorption, energy spectra of distant sources “cut off” more than they would w/o IR background



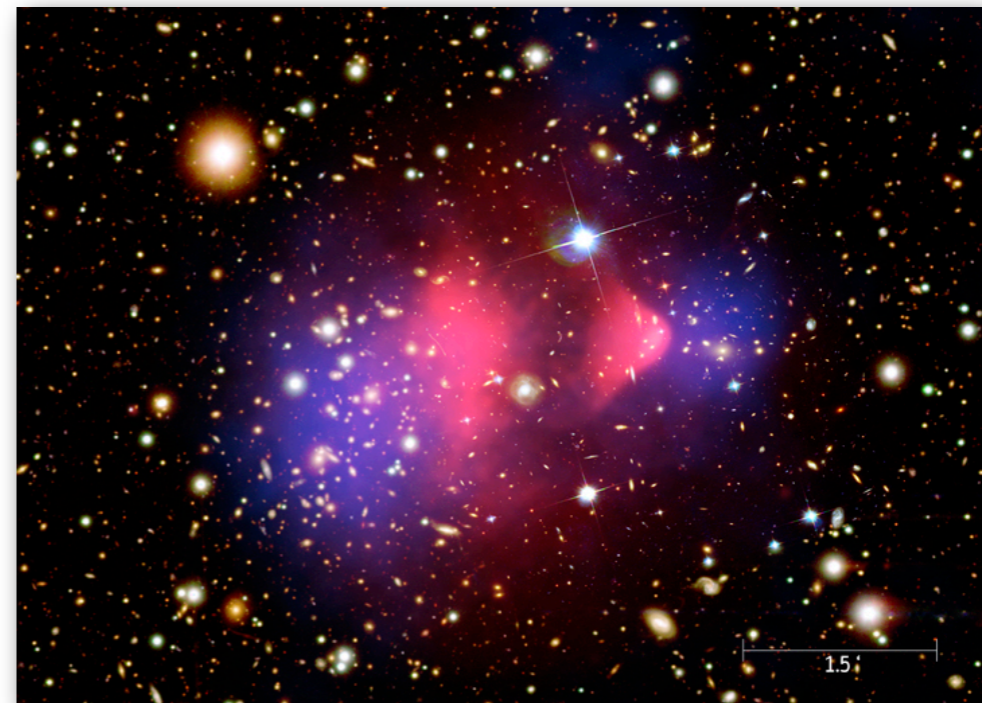
- ▶ Try to “de-absorb” spectra and estimate **IR flux**

Dark Matter Detection

- ▶ Dark matter: unknown **gravitationally-bound, non-baryonic** component of the universe



Bullet Cluster (Hubble + Chandra)



- ▶ Could be massive particles which decay to gamma rays
- ▶ Strategy: look for astrophysical objects with low luminosity, look for anomalous gamma-ray emission

Lorentz Invariance Violation

- ▶ Is the speed of light **constant**?
- ▶ Or does it change as photon energy increases?
- ▶ Search transient signals in X-rays, gamma rays, etc.
- ▶ See if signals **align in time**

