Gamma radiation from rapidly rotating black holes

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NCTS Summer School on Astrophysics 2018

- Accretion and Emission of Accreting Black Holes

§1　Why gamma-rays?

Why high-energy (HE; 10 MeV-10GeV) & very-high-energy (VHE; 10GeV-100TeV) gamma-rays?

Interpreting γ-rays should be less ambiguous compared to reprocessed, lower-energy photons.

Thus, HE and VHE γ-rays are important as direct signatures of non-thermal plasma processes.

→ Explore nature's accelerators.

Chapter 1

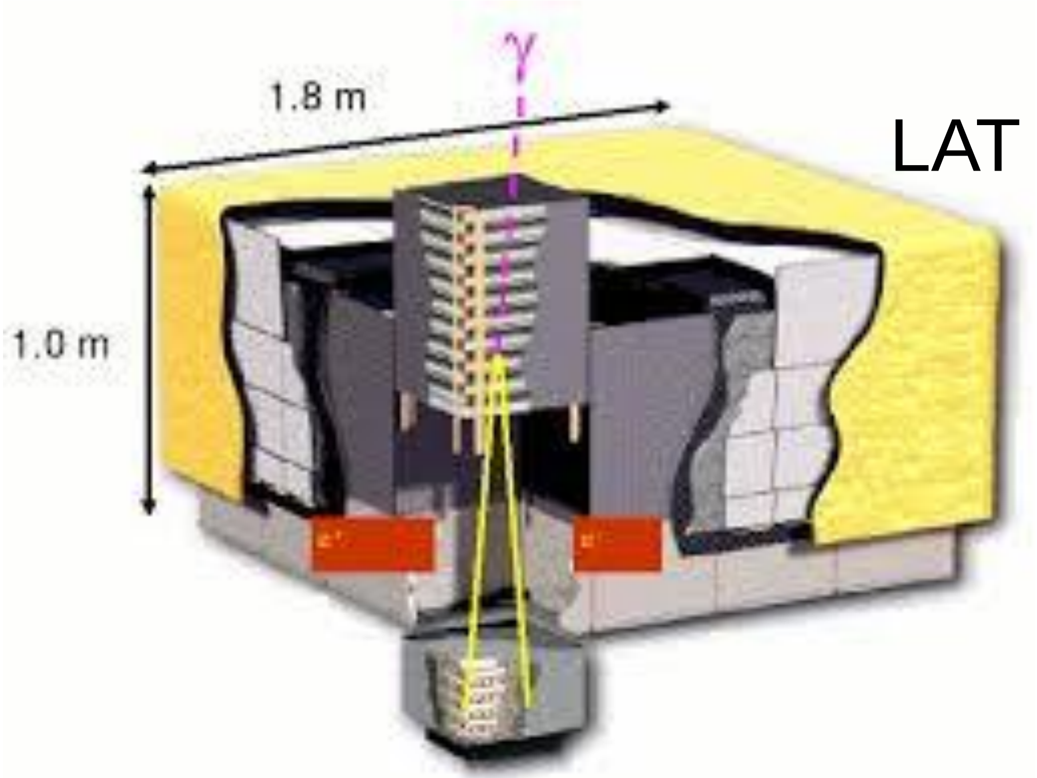
Quick review of γ-ray observations

§1 High-energy (HE) γ-rays

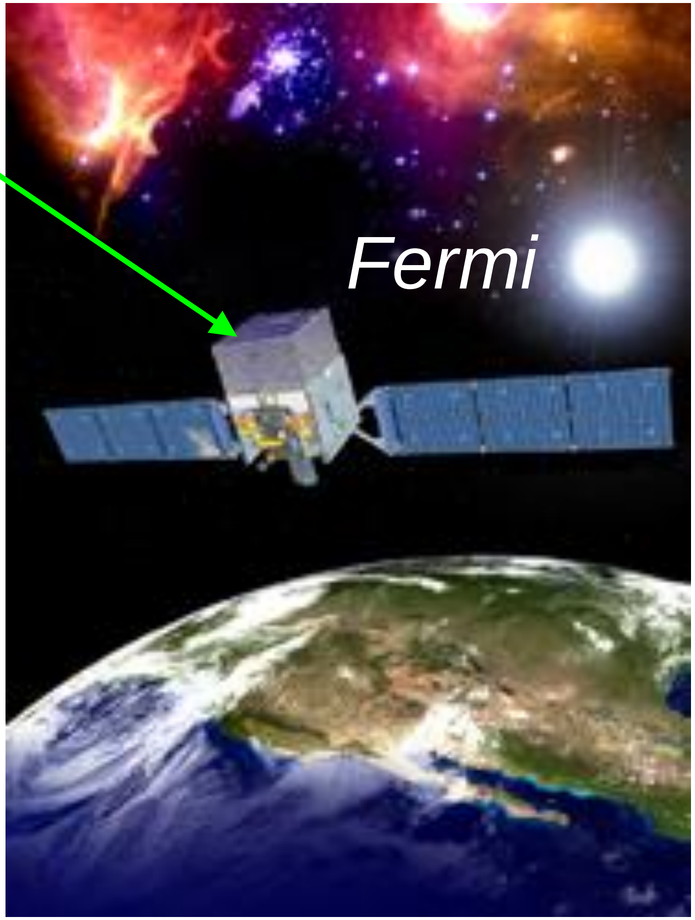
§2 Very-high-energy (VHE) γ-rays

§1 HE γ-ray observations (0.1 – 30 GeV)

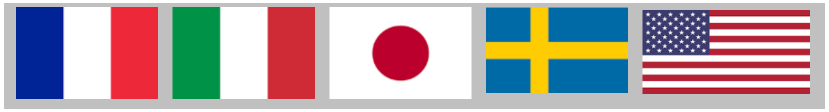
The Large Area Telescope (LAT) is the principal instrument on the *Fermi* Gamma-ray Space Telescope, which was launched on June 11, 2008.



LAT



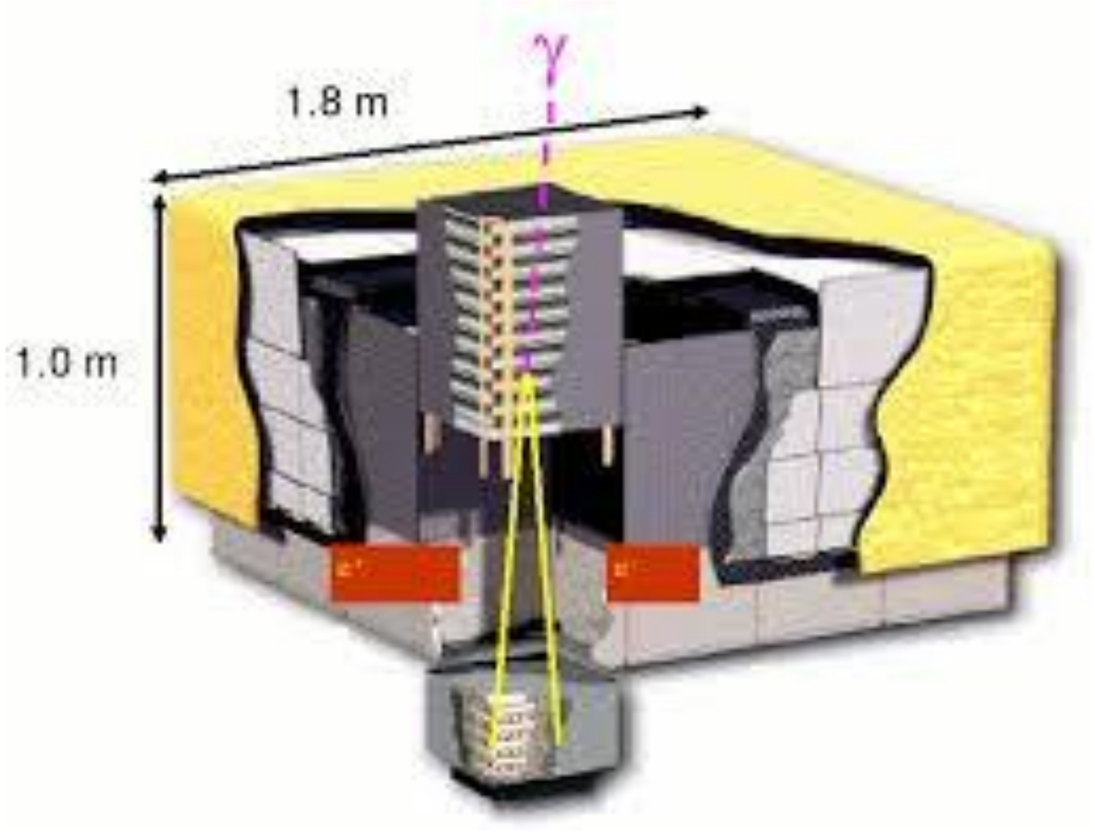
http://www-glast.stanford.edu/mission.html



§1 HE γ-ray observations (0.1 – 30 GeV)

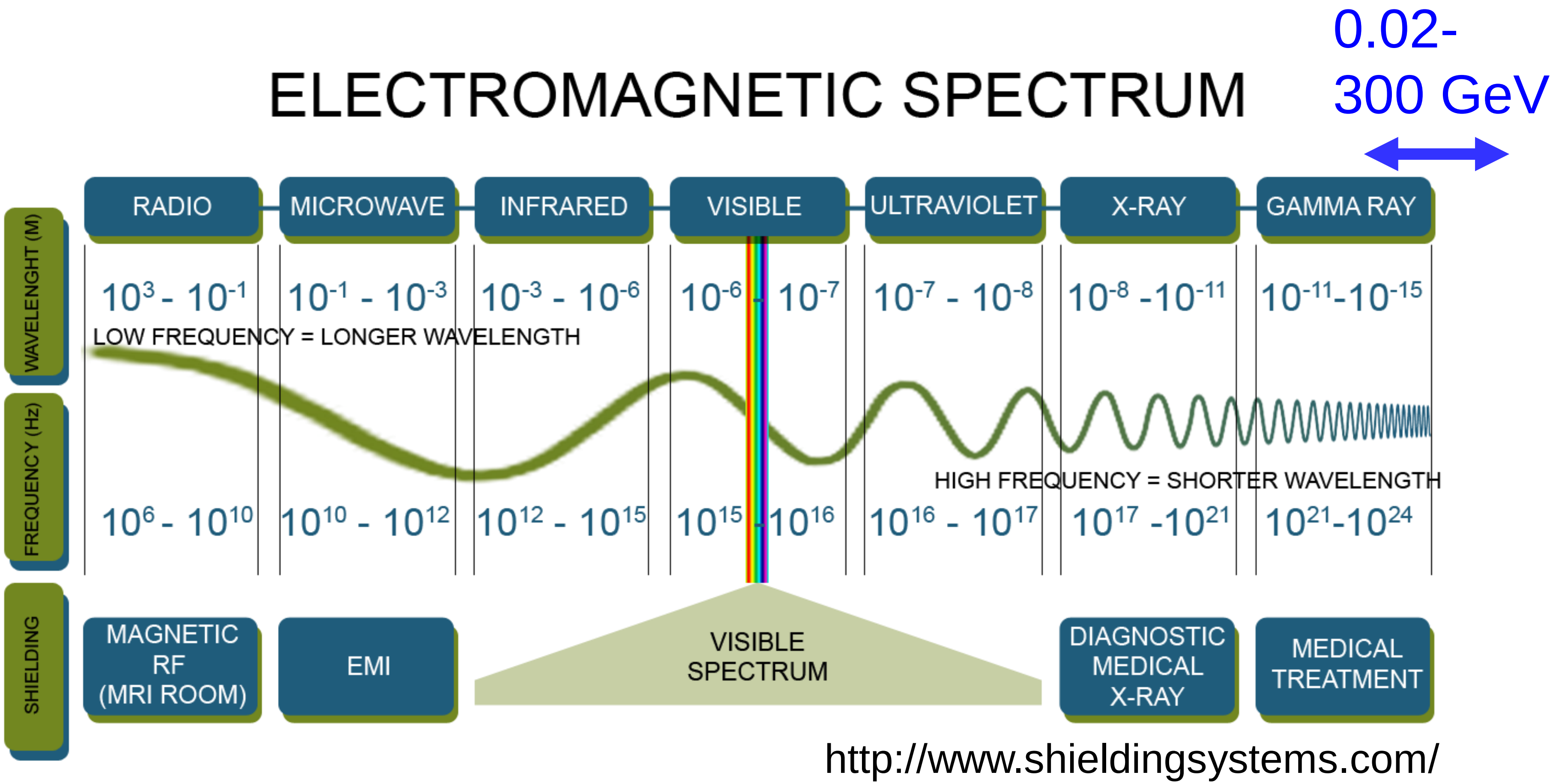
The Large Area Telescope (LAT) is the principal instrument on the *Fermi* Gamma-ray Space Telescope, which was launched on June 11, 2008.

LAT is an imaging HE gamma-ray telescope.



§1 HE γ-ray observations (0.1 – 30 GeV)

Energy range: 20 MeV - 300 GeV.



Such γ-rays can be emitted only by ultra-relativistic particles.

§1 HE γ-ray observations (0.1 – 30 GeV)

Energy range: 20 MeV - 300 GeV.

Field of view: ~2.5 ster (entire sky covered every 3 hrs.)

Angular resolution:
The point spread function has a 68% containment radius of about 3° at 100 MeV and 0.04° at 100 GeV.

Effective area: ~7000 cm^2 at 1 GeV, decreasing at lower and higher energy.

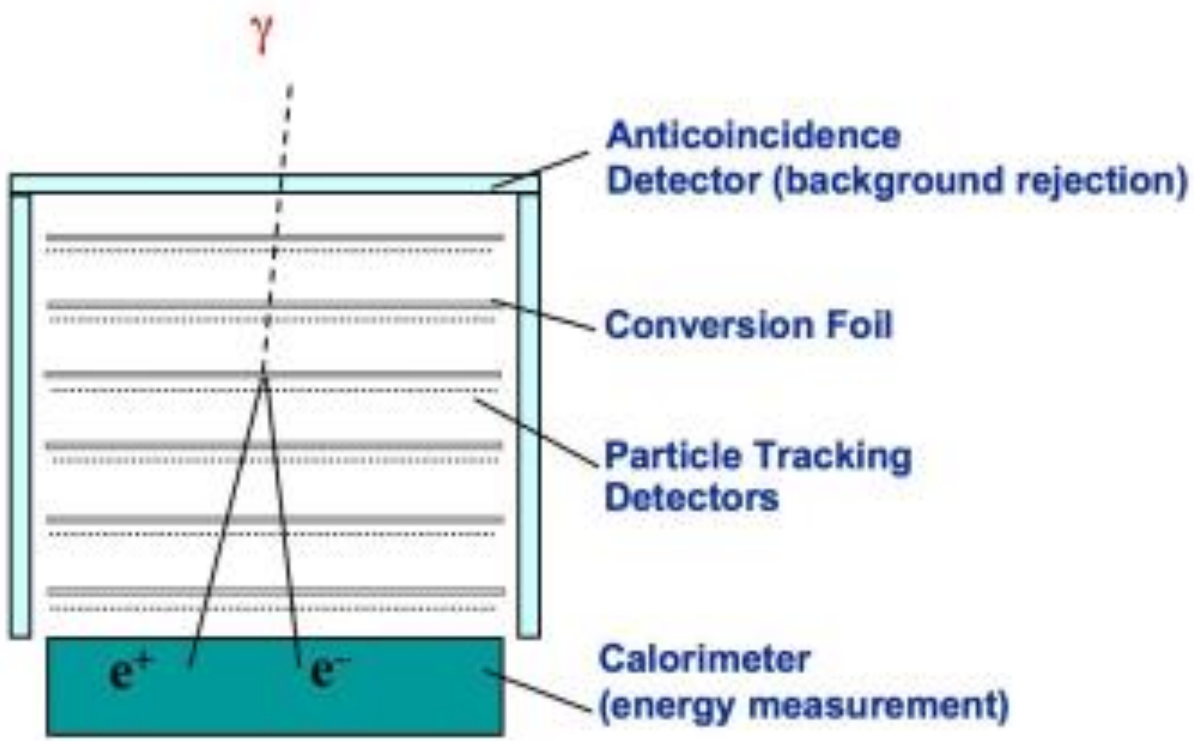
§1 HE γ-ray observations (0.1 – 30 GeV)

The Fermi LAT instrument

A γ-ray passes through the anticoincidence detector. It proceeds until it interacts with an atom in a tungsten foil to materialize as an $e^{\pm}$ pair.

SKIP

Please ask Hsiang-Kuang for details.



http://www-glast.stanford.edu/instrument.html

The Fermi LAT instrument

The pairs create ions in silicon strip detectors, allowing the progress of the particles to be tracked. Finally the particles are stopped by a calorimeter.

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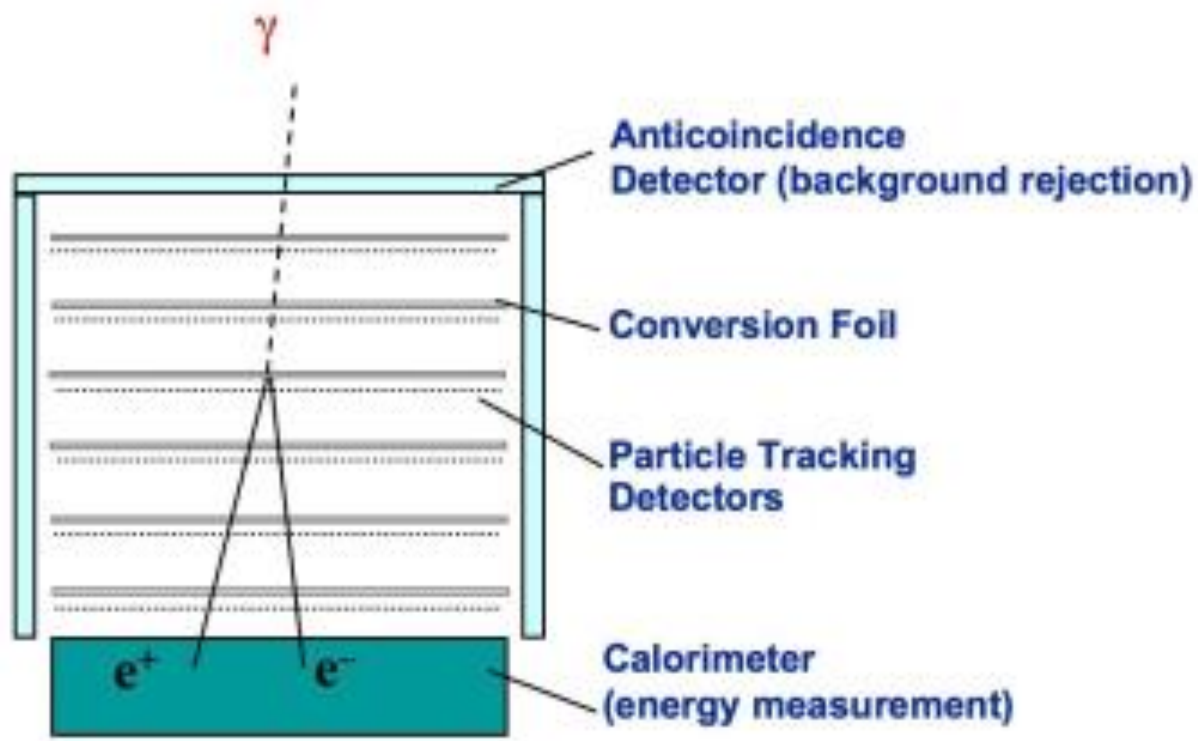

http://www-glast.stanford.edu/instrument.html

The Fermi LAT instrument

The information from the anticoincidence detector, tracker and calorimeter is combined to estimate the energy and direction of the gamma ray.

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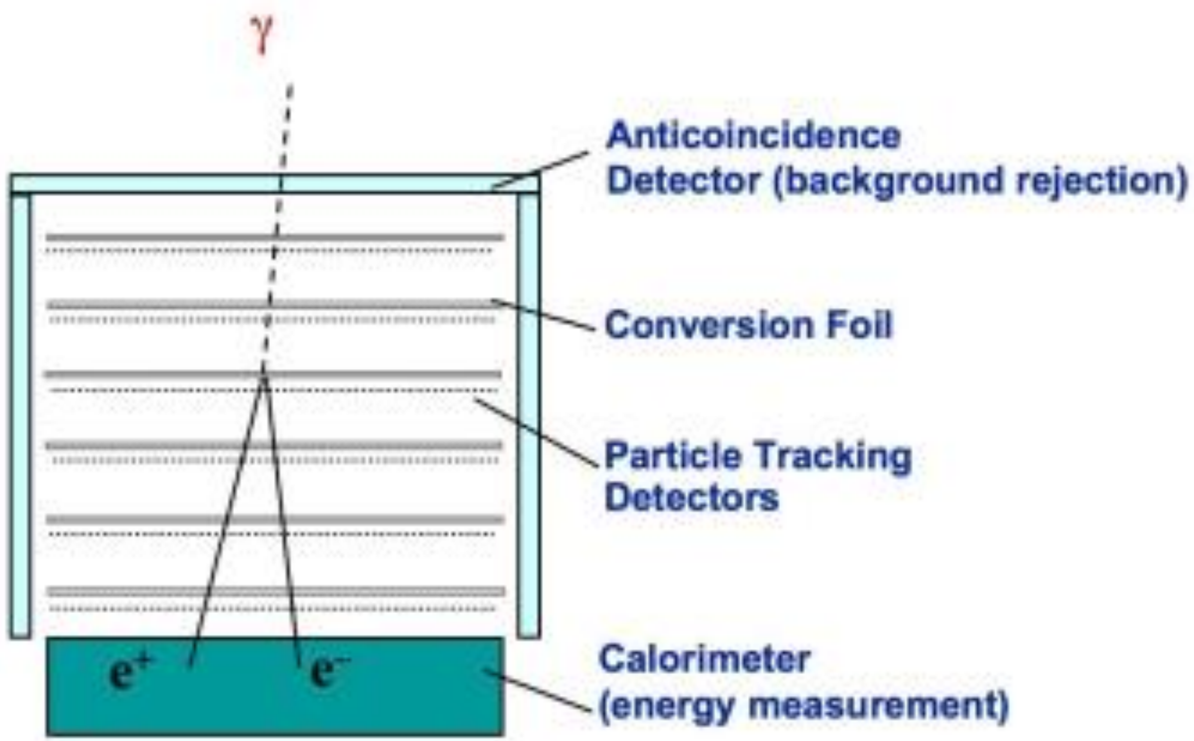

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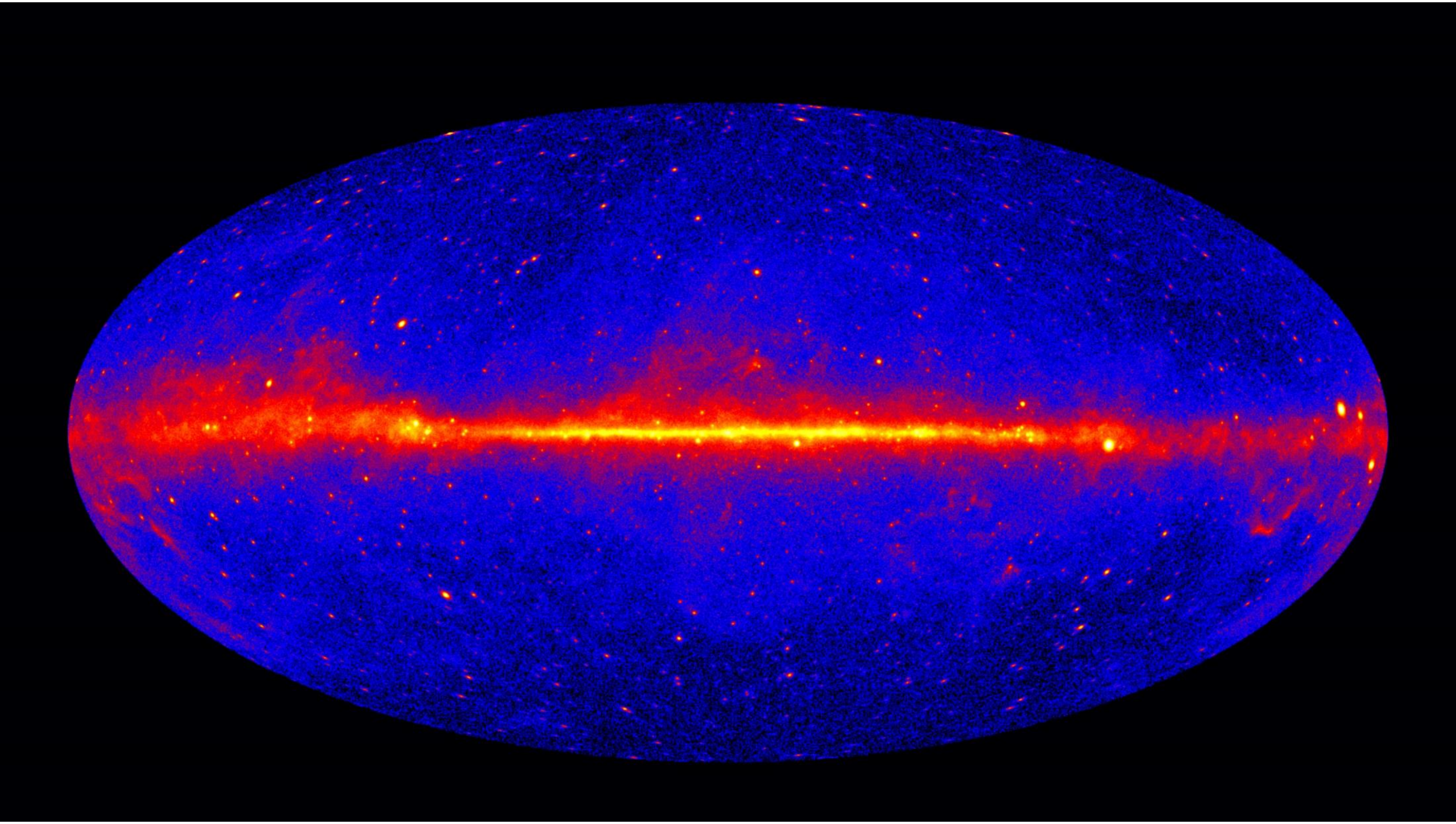
Please ask Hsiang-Kuang for details.

§1 HE γ-ray observations (0.1 – 30 GeV)

Fermi/LAT sky map above 10 GeV



https://svs.gsfc.nasa.gov/11342

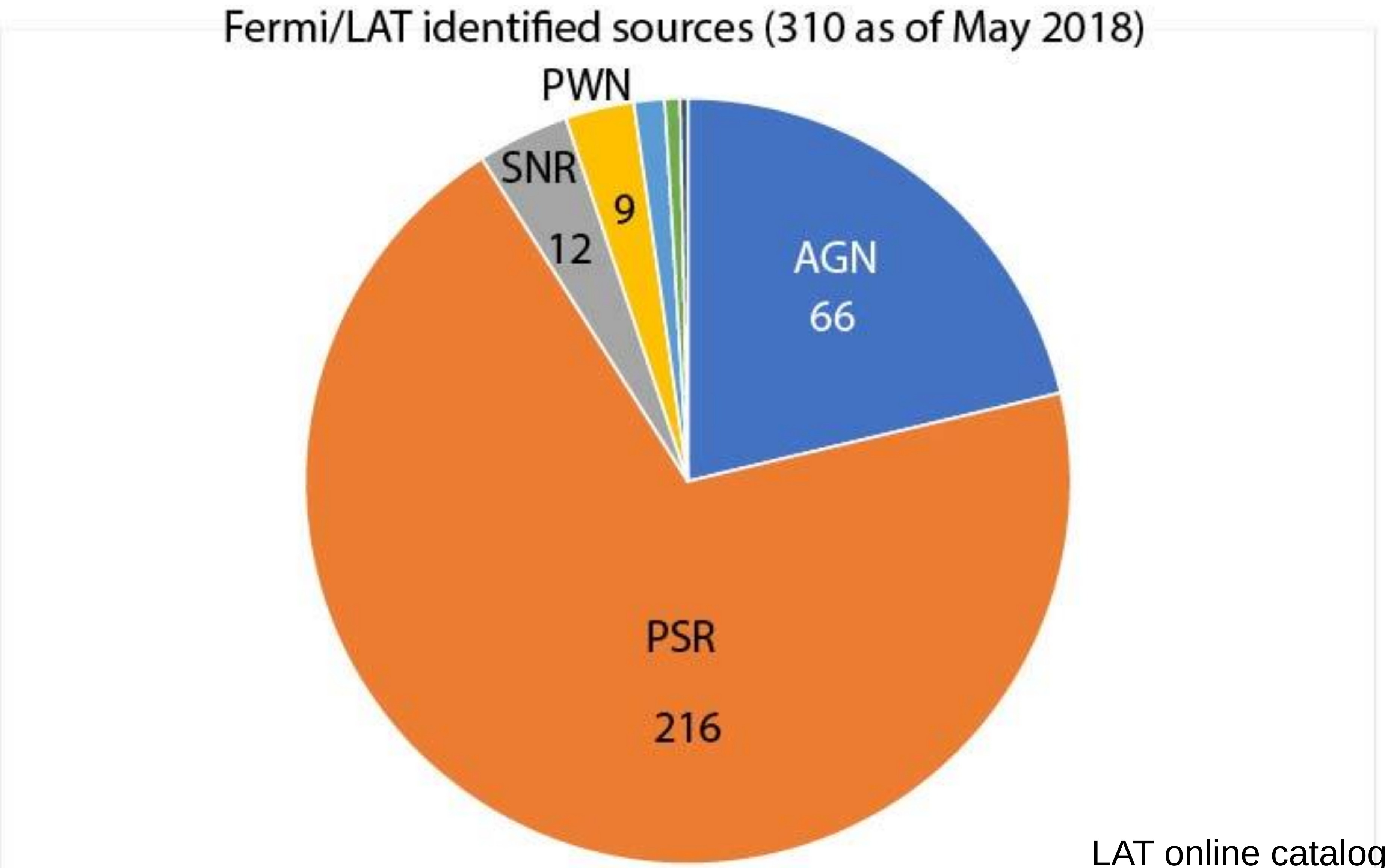
§1 HE γ-ray observations (0.1 – 30 GeV)

Fermi detected sources:

Rotation-powered pulsars:	216
Active galactic nuclei (AGNs):	66
Supernova remnants (SNRs):	12
Pulsar wind nebulae (PWNe):	9
Binaries:	4
Normal galaxies:	2
Star-forming region (SFR):	1

LAT online catalog
https://fermi.gsfc.nasa.gov/ssc/data/access/lat/

§1 HE γ-ray observations (0.1 – 30 GeV)



LAT online catalog
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§1 HE γ-ray observations (0.1 – 30 GeV)

Pulsars	Young, radio-selected:	55
	Young, gamma-selected:	57
	Young, X-ray selected:	5
	MSP, radio-selected:	96
	MSP, gamma-selected:	3
		216 (total)
AGNs	BL Lac type of blazers:	18
	FSRQ type of blazers:	38
	Radio galaxies:	3
	Blazer candidates:	5
	Narrow-line Seyfert 1:	2
		66 (total)

§1 *HE γ-ray observations (0.1 – 30 GeV)*

Fermi/LAT highlights (from extra-galactic to galactic)

Gamma-ray bursts

Compact mergers (NS-NS,NS-BH)

Collapsers (rapidly spinning stellar core collapses w/ jets)

Active galactic nuclei

Blazers (HBL, FSRQ), and other types of active galaxies

Fermi bubble (of the Milky Way galaxy)

Pulsars

Rotation-powered young pulsars ($\tau = 10^{3\text{-}6}$ yrs)

Rotation-powered MSPs

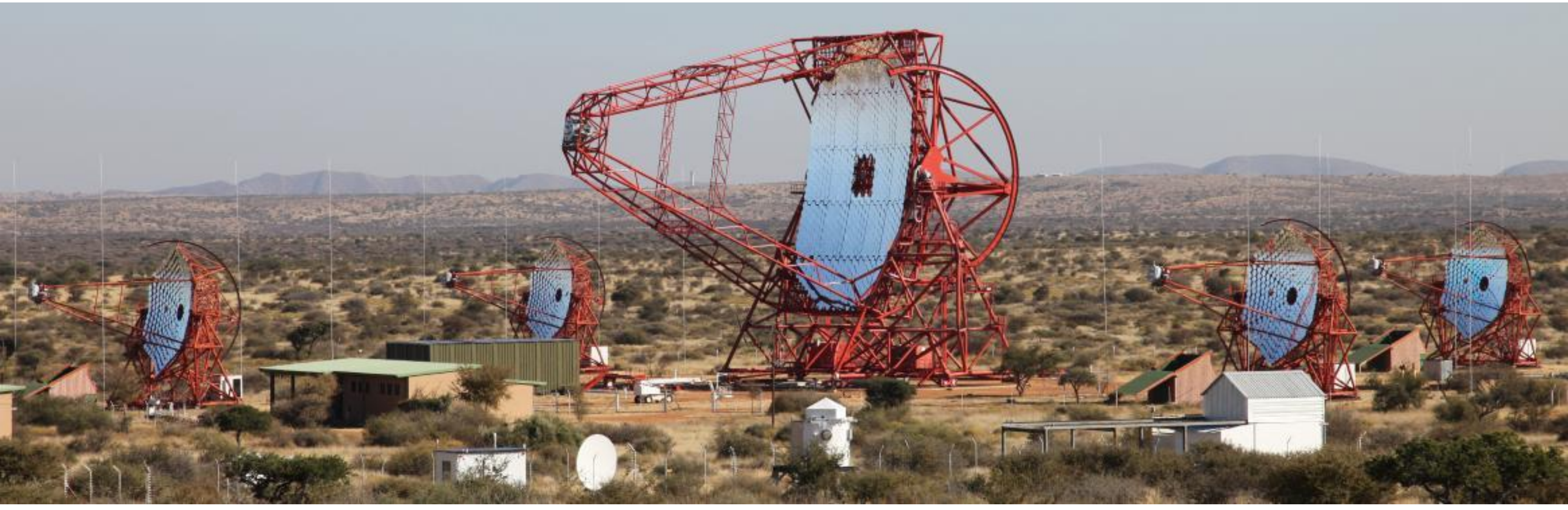
Transitional MSPs (accreting/non-accreting states)

§2 VHE γ-ray observations (30 GeV – 100 TeV)

Imaging Atmospheric Cherenkov Telescopes (IACTs)

High Energy Stereoscopic System (H.E.S.S)

- Four 12-m & one 28-m diameter telescopes.
- Operational: Summer 2002 – present
- Located in Nambia.
- Sensitive in 100GeV-10TeV



§2 *VHE γ-ray observations (30 GeV – 100 TeV)*

Imaging Atmospheric Cherenkov Telescopes (IACTs)

Major Atmospheric Gamma Imaging Cherenkov (MAGIC)

Two 17-m telescopes.

Operational: 2004 – present

Located in La Palma, Canary islands, Spain.

Sensitive in 30GeV-100TeV

§2 VHE γ-ray observations (30 GeV – 100 TeV)

Imaging Atmospheric Cherenkov Telescopes (IACTs)

Very Energetic Radiation Imaging Telescope Array System (VERITAS)

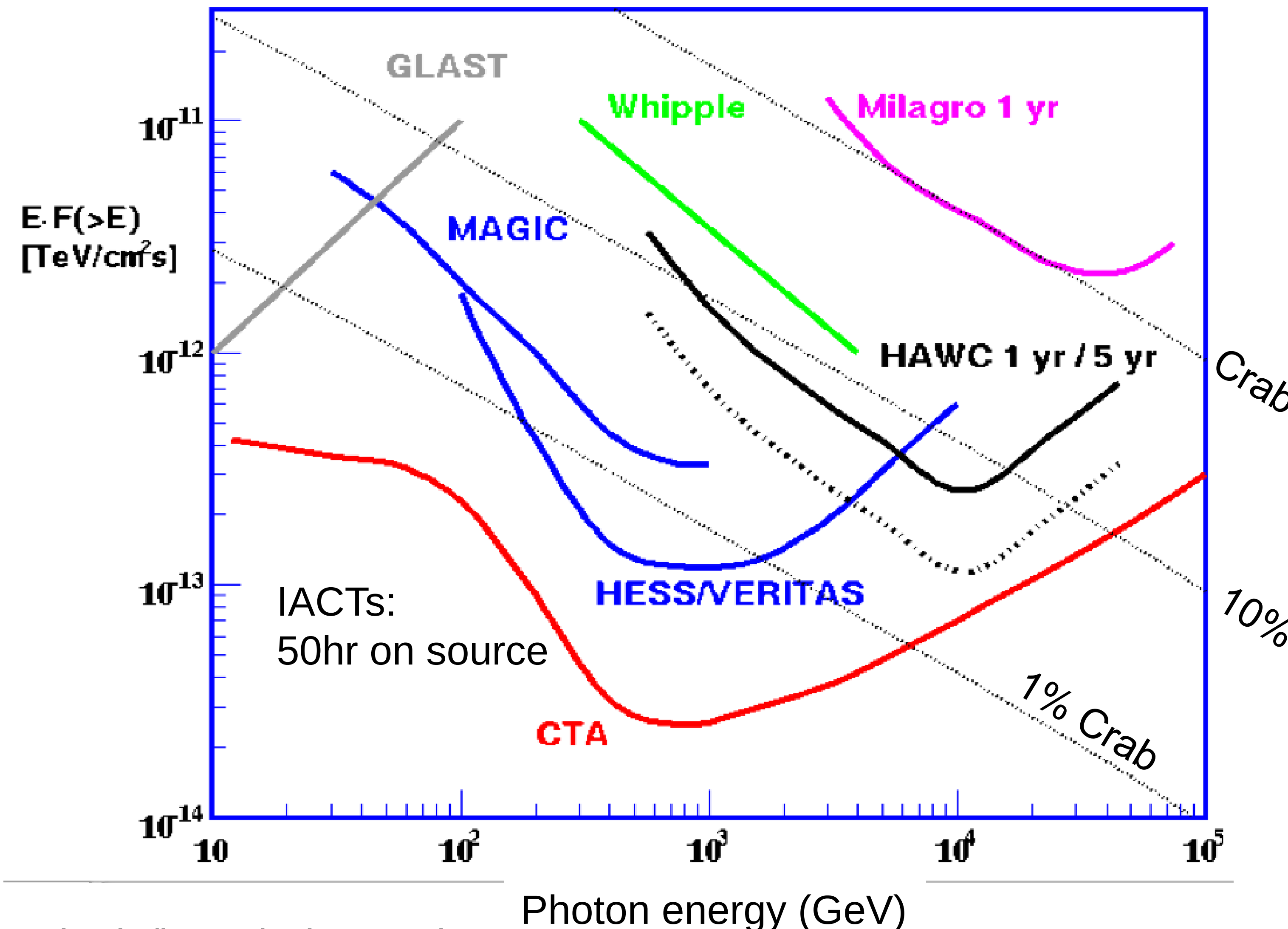
Four 12-m diameter telescopes.

Operational: 2007 – present

Located in Arizona, USA.

Sensitive in 50GeV-50TeV

Sensitivity of IACTs and other missions



http://umdgrb.umd.edu/hawc/science.php

§1 HE γ-ray observations (0.1 – 30 GeV)

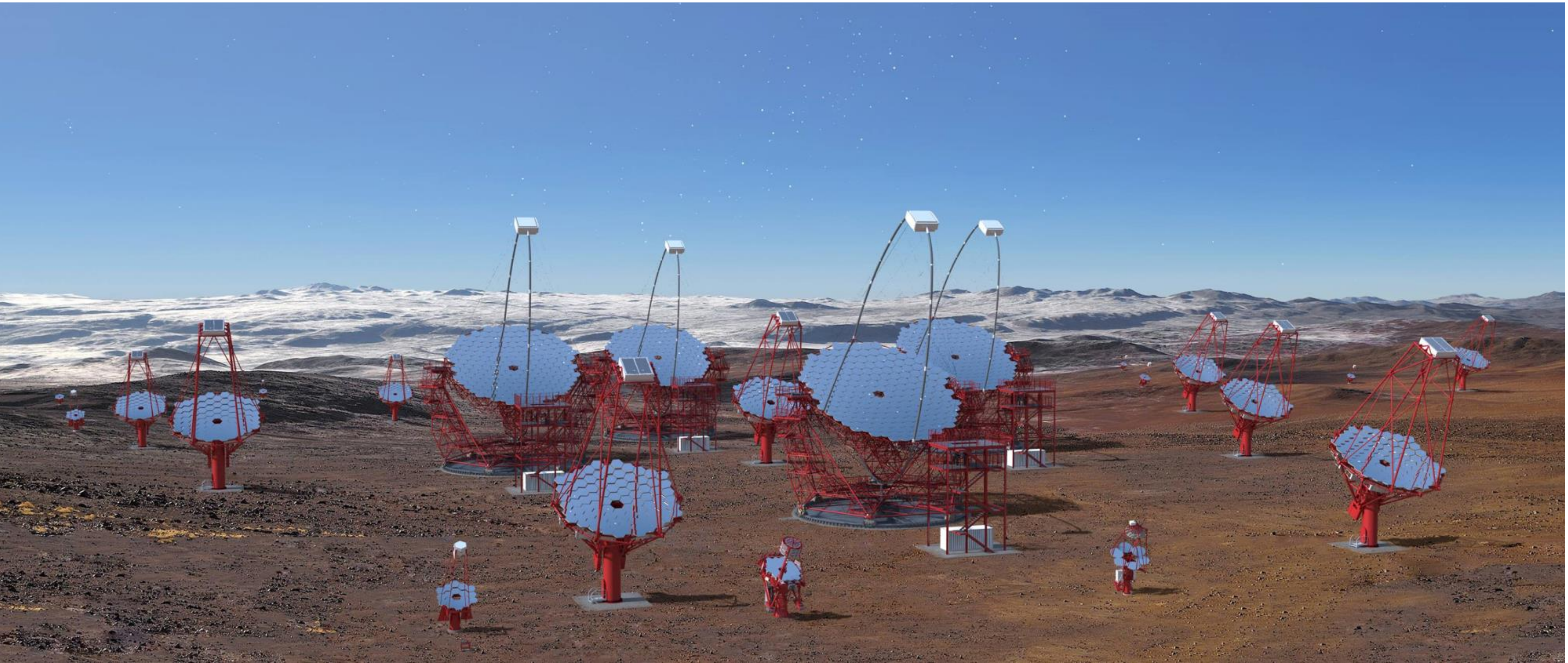
Cherenkov Telescope Array (CTA)

>100 telescopes.

Operational: near future

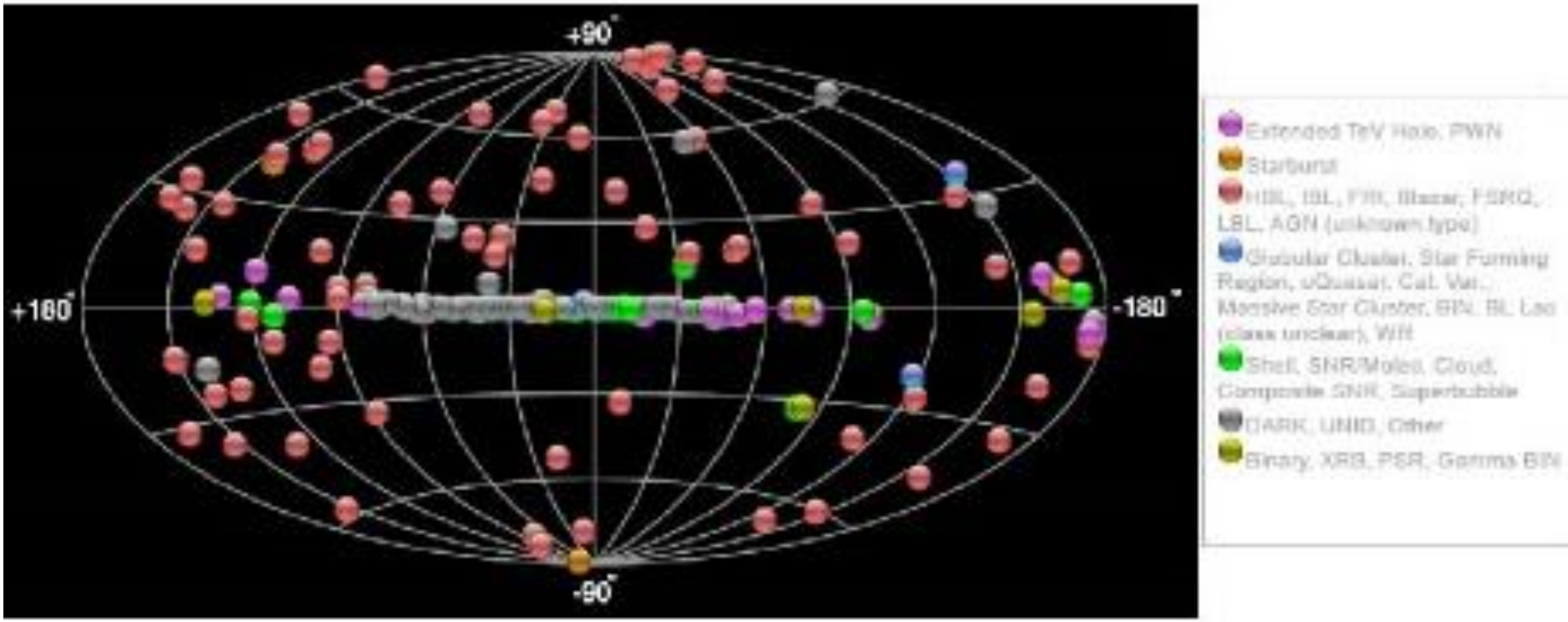
Located in La Palma & Chili (i.e., N/S hemispheres).

Sensitive in 20GeV-300TeV



§1 HE γ-ray observations (0.1 – 30 GeV)

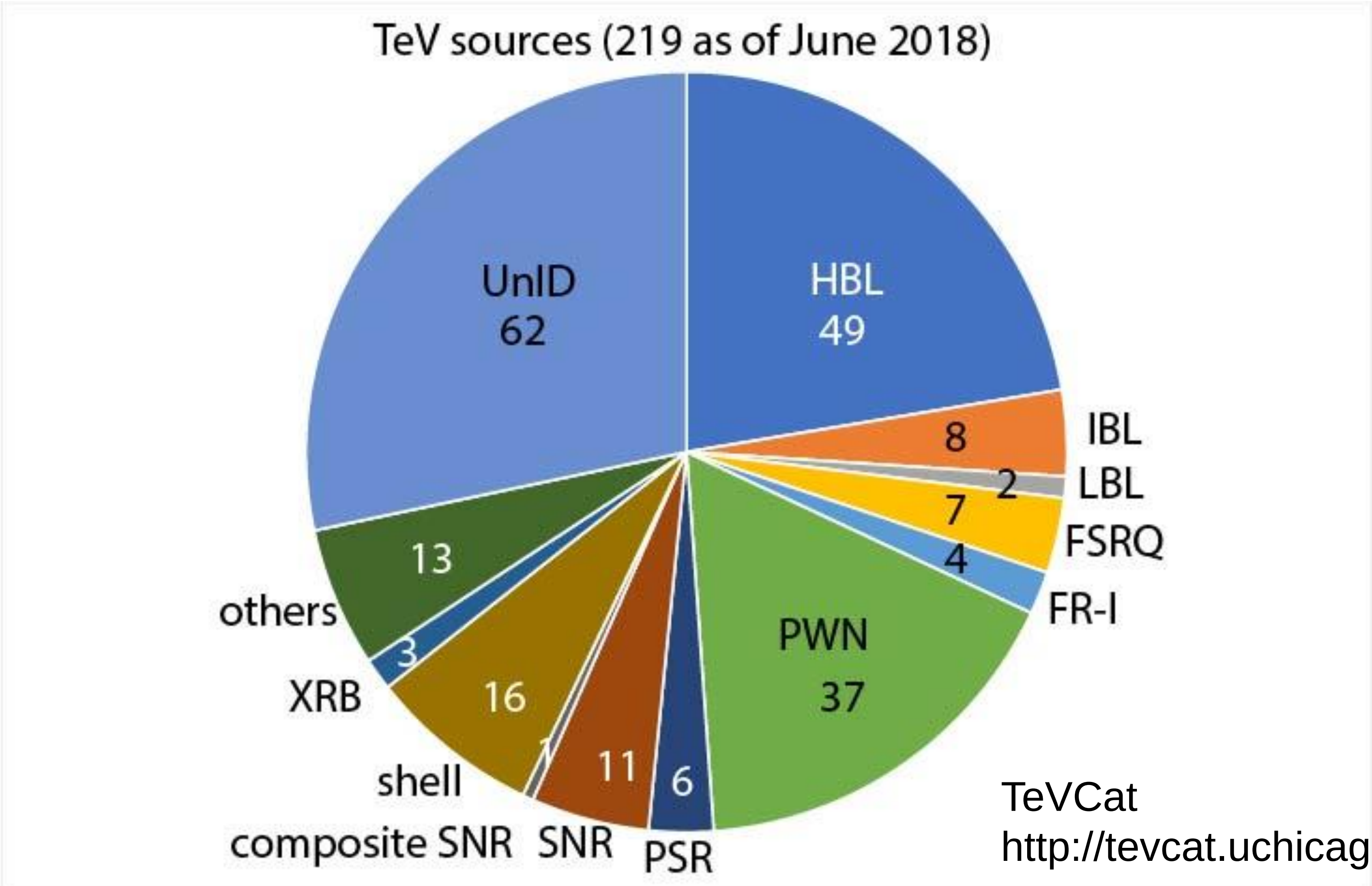
VHE sky map above 100 GeV
w/ H.E.S.S., MAGIC & VERITAS



http://tevcat.uchicago.edu/

§2 VHE γ-ray observations (30 GeV – 100 TeV)

H.E.S.S., MAGIC & VERITAS have detected 219 sources.
157 of them have been identified with other wavelengths.



TeVCat
http://tevcat.uchicago.edu/

§2 VHE γ-ray observations (30 GeV – 100 TeV)

IACTs highlights (Here, limited to BH-related issues only)

Blazers (largest population in TeV sky)

Mrk 501, PKS 2155-304

$\Delta t_{\rm var} = 3 \sim 5$min cf. $G(10^9 M_\odot)/c^3 = 83$ min.

Flares from non-blazers

M87 $\Delta t_{\rm var} \sim 1$ day $\sim 2.7\ GM/c^3$ ($M = 6.4 \times 10^9 M_\odot$)

→ Horizon-scale emission region

Albert + (2008, ApJ 685, L23)

IC 310 $\Delta t_{\rm var} \sim 5$ min $\sim 0.21\ GM/c^3$ ($M = 3 \times 10^8 M_\odot$)

→ Sub-horizon-scale emission region

Aleksic + (2014, Sci 346, 1080)

→ Consider emission from the vicinity of a BH.

END OF CHAPTER 1