

Intro to (Ultra-High Energy) Cosmic Rays



It all started in 1911...





Scott starting point (preserved)



14.12.1911 / 11.01.1912

- “Yes, the Pole. But under much different circumstances than we had imagined.”



McMurdo & Scott cairn



Ernest
Shackleton,
(picture from
first expedition)



Endurance Expedition

- Dec 5, 1914 - set sail for Antarctica from South Georgia Island
- Jan 18, 1915 - Endurance trapped in pack ice just one day from planned landing site on Antarctic shore.
- Oct 27, 1915 - Ship is crushed by ice after drifting with pack ice.



July, 1915



October, 1915



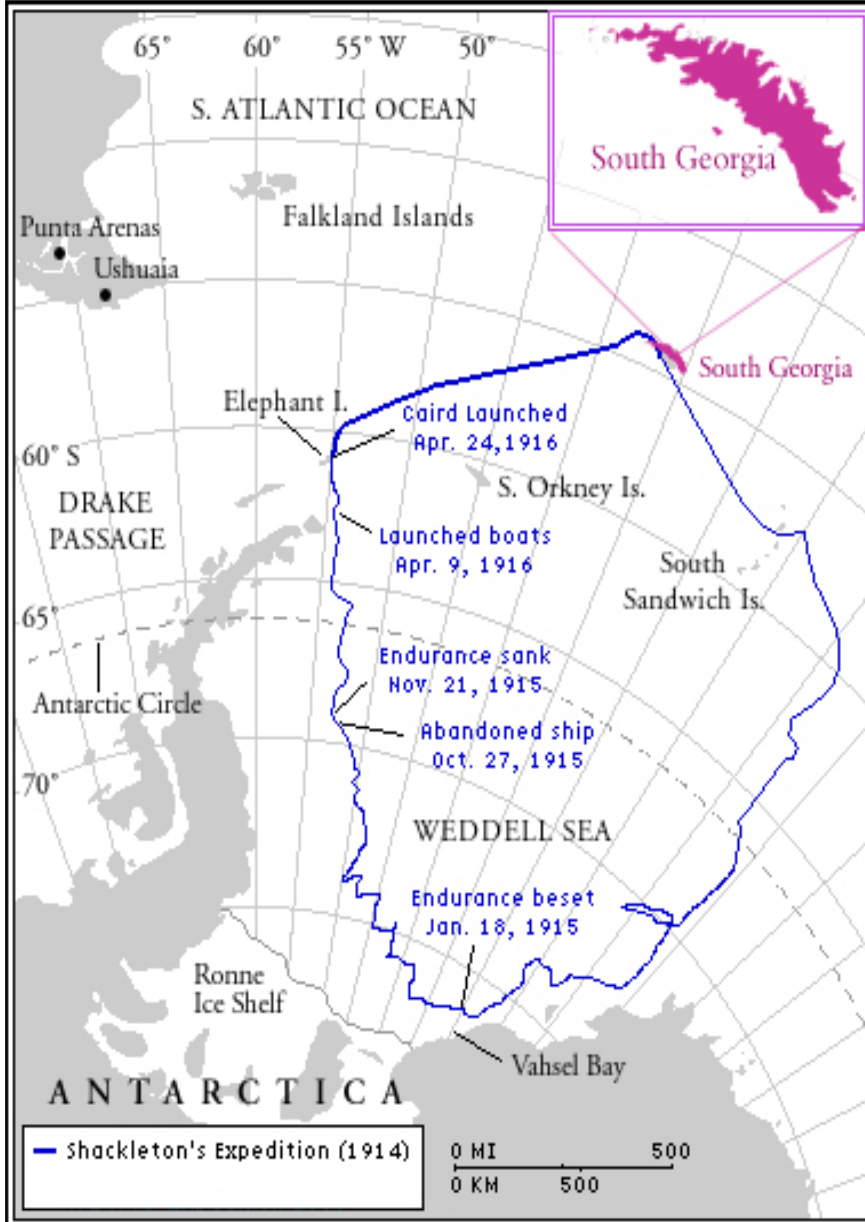
Endurance Expedition

- April 9, 1916 - Launch of 3 lifeboats because ice floes are breaking up. Later they land on Elephant Island.
- April 24, 1916 - Shackleton sets sail in one 22 1/2 foot lifeboat with 5 companions on 800 mile voyage to seek help on South Georgia Island for men left behind. Selects 2 to accompany him for trek across the island.



"WE PULLED THE THREE BOATS A LITTLE HIGHER ON THE BEACH"

Photograph by F. Haden



Endurance Expedition

- May 10, 1916 - arrived South Georgia Island. Had to cross impassable frozen mountain range to reach the whaling station.
 - 40 km / 36 hours
- http://www.condorjourneys-adventures.com/antarctica_cruise4.asp
- Immediately turned around to rescue remaining crew on Elephant Island - 4 months more to complete rescue.



South Georgia
Island

Trek from landing site
at King Haakon Bay to
Stromness Bay for
rescue

Endurance Expedition

- <http://www.kodak.com/US/en/corp/features/endurance/>

That was all of tangible things; but in memories we were rich. We had pierced the veneer of outside things. We had "suffered, starved and triumphed, groveled down yet grasped at glory, grown bigger in the bigness of the whole. We had seen God in His splendours, heard the text that Nature renders." We had reached the naked soul of man.

South, published 1919. In this extract, Shackleton was paraphrasing 'The Call of the Wild' by [Robert Service](#), published in 1907.



Discovering the Rewards of CR Physics



More rewards (2)

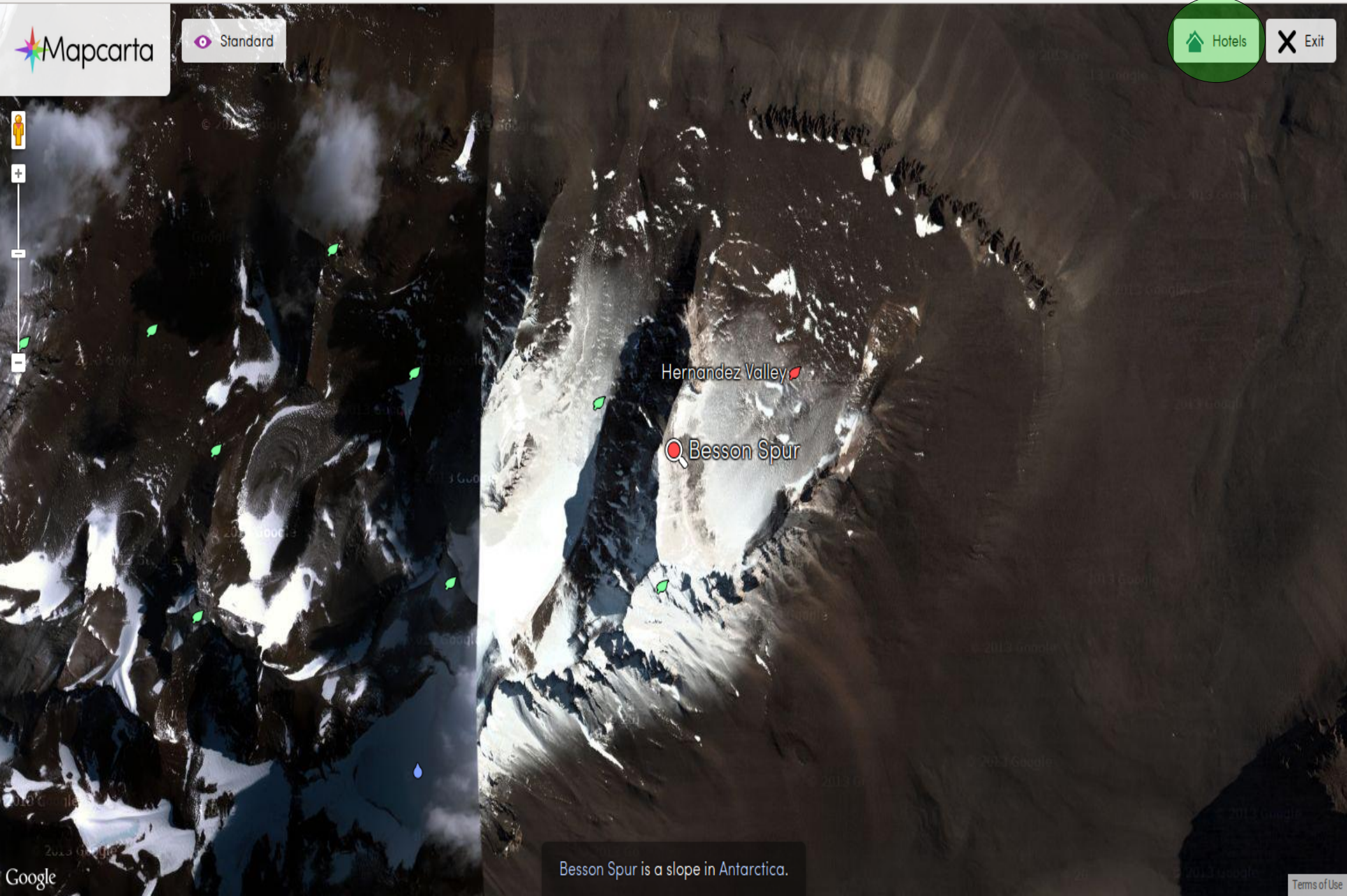
Most Visited ▾ Getting Started b1 Runs echo vesti



Standard

Hotels

Exit



Hernandez Valley

Besson Spur

Besson Spur is a slope in Antarctica.

Google

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In the beginning (while RF Scott et al were ice-locked in a tent)



Victor Hess (April, 1912, Austrian [Fordham U, 1938]): 1) Ionization increases with altitude 2) Ascent during solar eclipse shows that sun is not source

Measure discharge of Wulf Electroscope

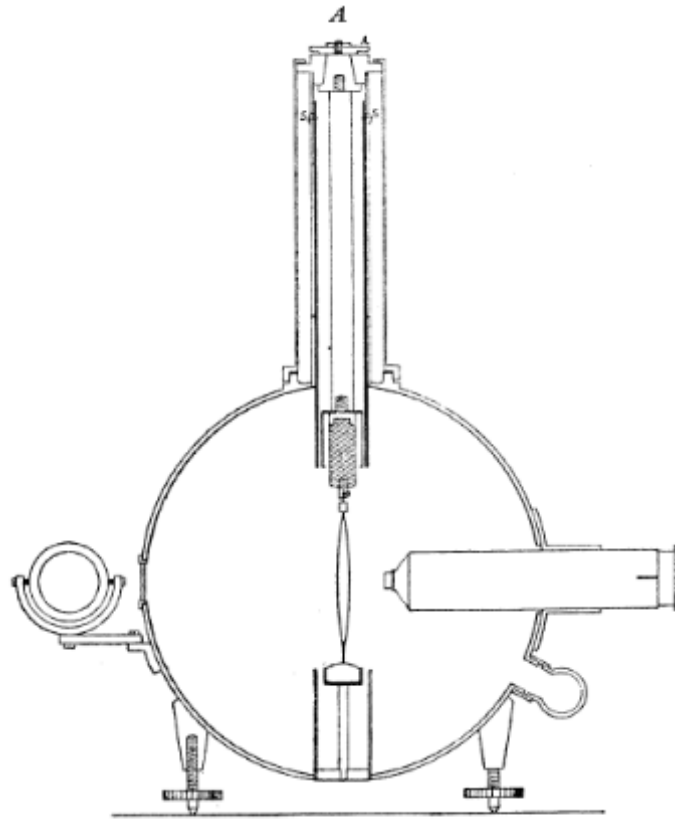
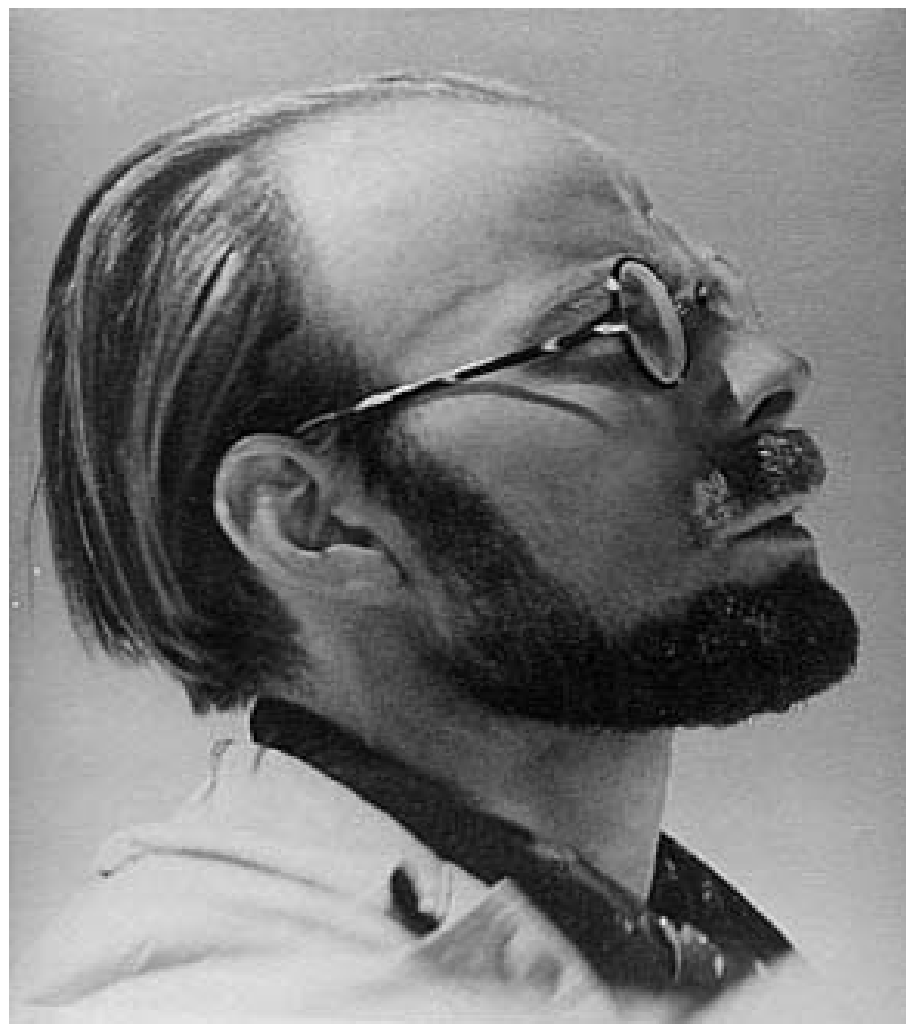


Figure 1: The Wulf electroscope. The 17 cm diameter cylinder with depth 13 cm was made of Zinc. To the right is the microscope that measured the distance between the two silicon glass wires illuminated using the mirror to the left. The air was kept dry using Sodium in the small container below the microscope. According to Wulf [16], with 1.6 ion pairs per second produced, the tension was reduced by 1 V, the sensitivity of the instrument, as measured by the decrease of the inter-wire distance.

Pierre Auger (1937, French)

Detection of Extensive Air
Showers via coincidence
measurements



JULY-OCTOBER, 1939

REVIEWS OF MODERN PHYSICS

VOLUME 11

Extensive Cosmic-Ray Showers

PIERRE AUGER

In collaboration with

P. EHRENFEST, R. MAZE, J. DAUDIN, ROULEY, A. FRÉON

Paris, France

Reed Richards (1961, USA) – The American approach

BUT, THERE IS TIME ENOUGH TO LEARN OF THE TASK WHICH FACES THE FANTASTIC FOUR! FIRST, LET US DISCOVER MORE ABOUT THEIR ORIGIN-- LET US GO BACK TO THAT MOMENTOUS DAY WHEN AN ANGRY BEN GRIMM CONFRONTED DR. REED RICHARDS...

IF YOU WANT TO FLY TO THE STARS, THEN **YOU** PILOT THE SHIP! COUNT **ME** OUT!

YOU **KNOW** WE HAVEN'T DONE ENOUGH RESEARCH INTO THE EFFECT OF COSMIC RAYS! THEY MIGHT KILL US ALL OUT IN SPACE!

BEN, WE'VE **GOT** TO TAKE THAT CHANCE... I-- I NEVER THOUGHT THAT **YOU** WOULD BE A COWARD!

A COWARD!! NOBODY CALLS ME A COWARD! GET THE SHIP! I'LL FLY HER NO MATTER WHAT HAPPENS!!

AND SO, LED BY A DETERMINED DR. REED RICHARDS, THE LITTLE GROUP SPED TOWARD THE SPACEPORT ON THE OUT-SKIRTS OF TOWN!

SUSAN, BEN AND I **KNOW** WHAT WE'RE DOING... BUT YOU--AND JOHNNY...

DON'T SAY IT, REED! I'M YOUR FIANCEE! WHERE **YOU** GO, I GO!

AND I'M TAGGIN' ALONG WITH SIS--SO IT'S SETTLED!

NO TIME TO WAIT FOR OFFICIAL CLEARANCE! CONDITIONS ARE RIGHT TONIGHT! **LET'S GO!**

BEFORE THE GUARD CAN STOP THEM, THE MIGHTY SHIP WHICH REED RICHARDS HAD SPENT YEARS CONSTRUCTING IS SOARING INTO THE HEAVENS...TOWARDS OUTER SPACE!

SHE'S BEHAVING LIKE A BABY! EVERYTHING IS PERFECT!

YEAH, EXCEPT THE COSMIC RAYS! NO ONE KNOWS WHAT **THEY'LL** DO...

9

HIGHER AND HIGHER, LIKE A SILVER BULLET, ROARS THE SLEEK SPACE CRAFT...

WE **HAD** TO DO IT!! WE **HAD** TO BE THE FIRST!

BUT WE'RE REACHING THE COSMIC STORM AREA... HANG ON!

RAK TAC TAC TAC TAC

HEAR THAT?? IT'S THE **COSMIC RAYS!!** I--I **WARNED** YOU ABOUT 'EM!!

THEY'RE PENETRATING THE SHIP!! OUR SHIELDING ISN'T STRONG ENOUGH!

BUT I DON'T **FEEL** ANYTHING!

NATURALLY! THEY'RE ONLY RAYS OF LIGHT! YOU CAN'T **FEEL** 'EM-- BUT THEY'LL AFFECT YOU JUST THE SAME!

MY HEAD!! IT--IT'S POUNDING AS THOUGH IT'S ABOUT TO BURST!!

BEN WAS **RIGHT!!** WE SHOULD HAVE **WAITED...** SHOULD HAVE GOTTEN HEAVIER SHIELDING!

JOHNNY! WHAT IS IT? WHAT'S HAPPENING TO YOU?

I DON'T KNOW, SIS! MY BODY FEELS HOT-- LIKE IT'S ON FIRE!! I-I FEEL LIKE I'M BURNING UP!!

UGH!! LISTEN TO ME...

... SOMEBODY **ELSE** TAKE THE CONTROLS... I CAN'T HANDLE THE SHIP ANY MORE! MY-- MY ARMS ARE HEAVY-- TOO HEAVY-- CAN'T MOVE-- TOO HEAVY-- GOT TO LIE DOWN-- CAN'T MOVE!!

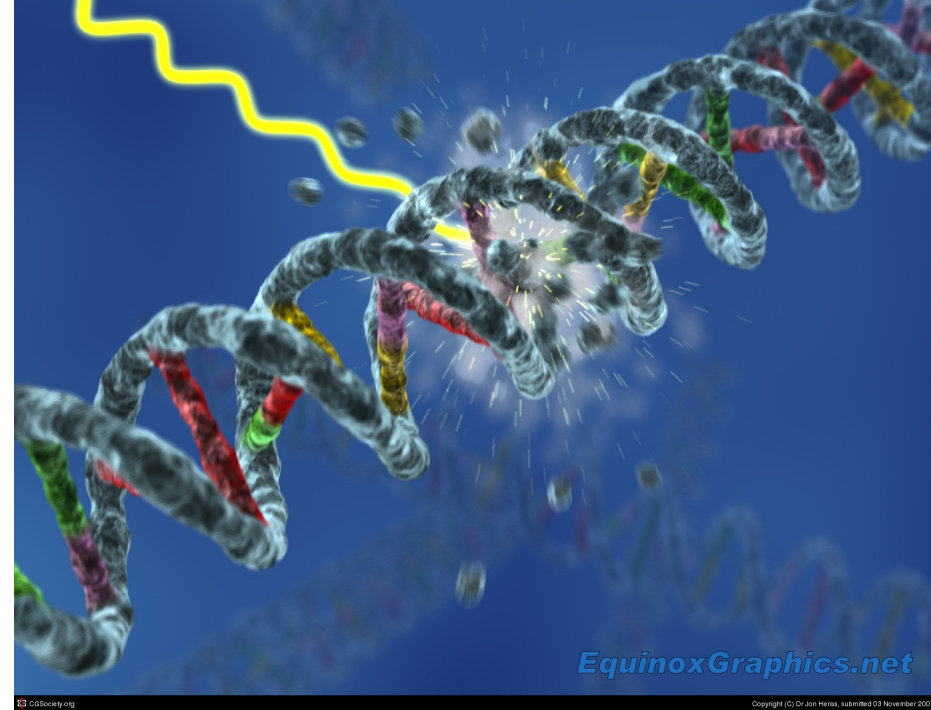
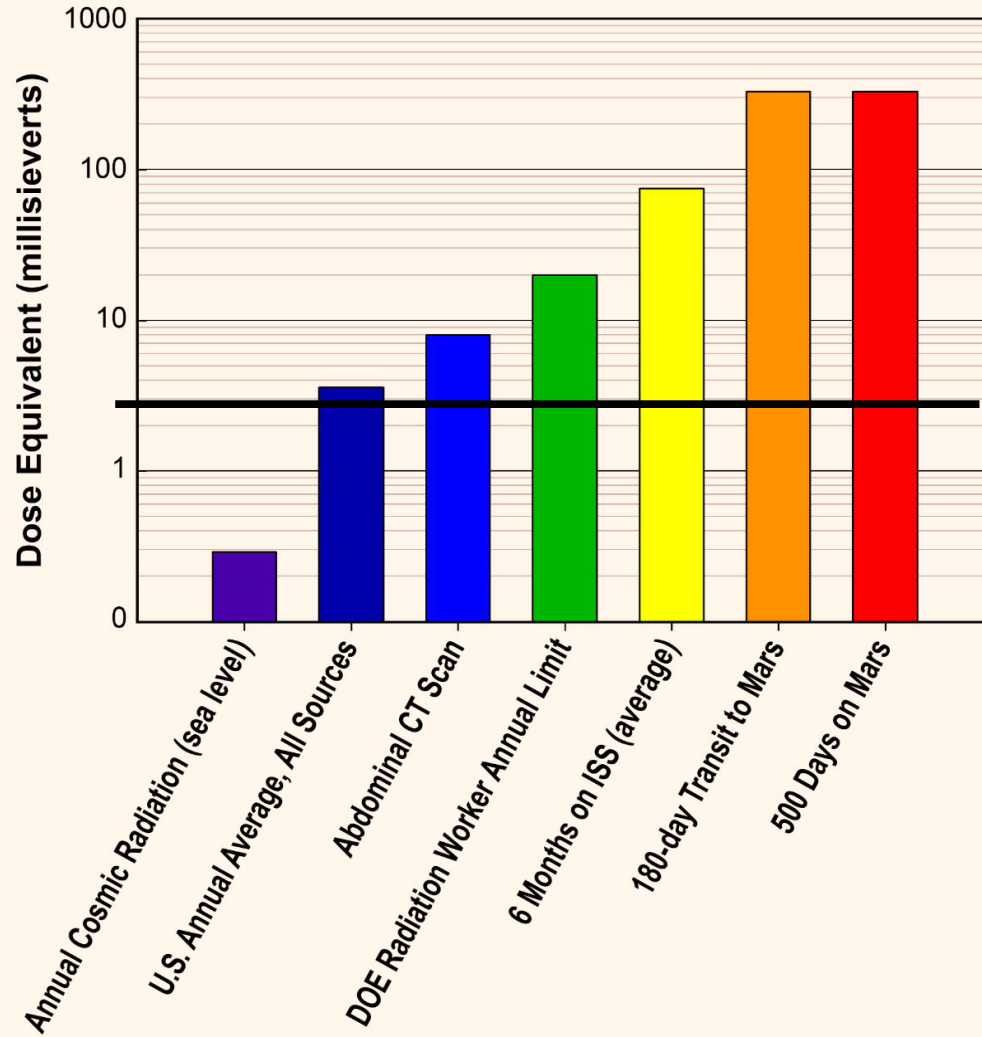
BEN!

10

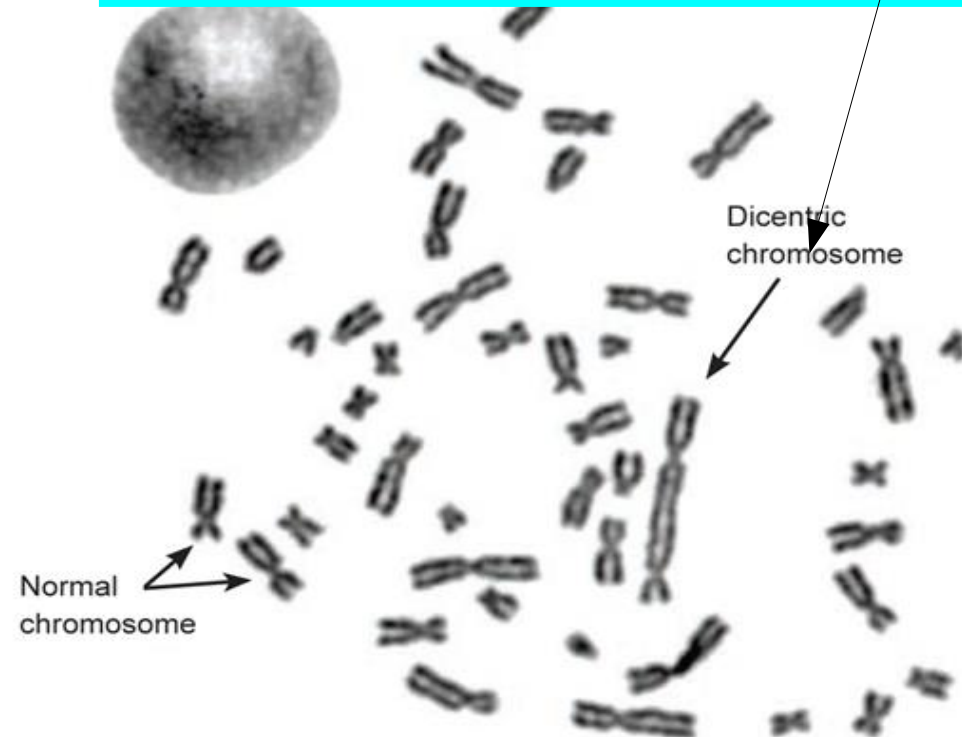


Practical consequences: Cancer rates in airline pilots x2 general population

Bush proposal to send man to Mars (2004)



ISS astronaut blood cells



A. Niger thrives in radiation environments! Why? KUBEsat project (launch 2020): astrobiology

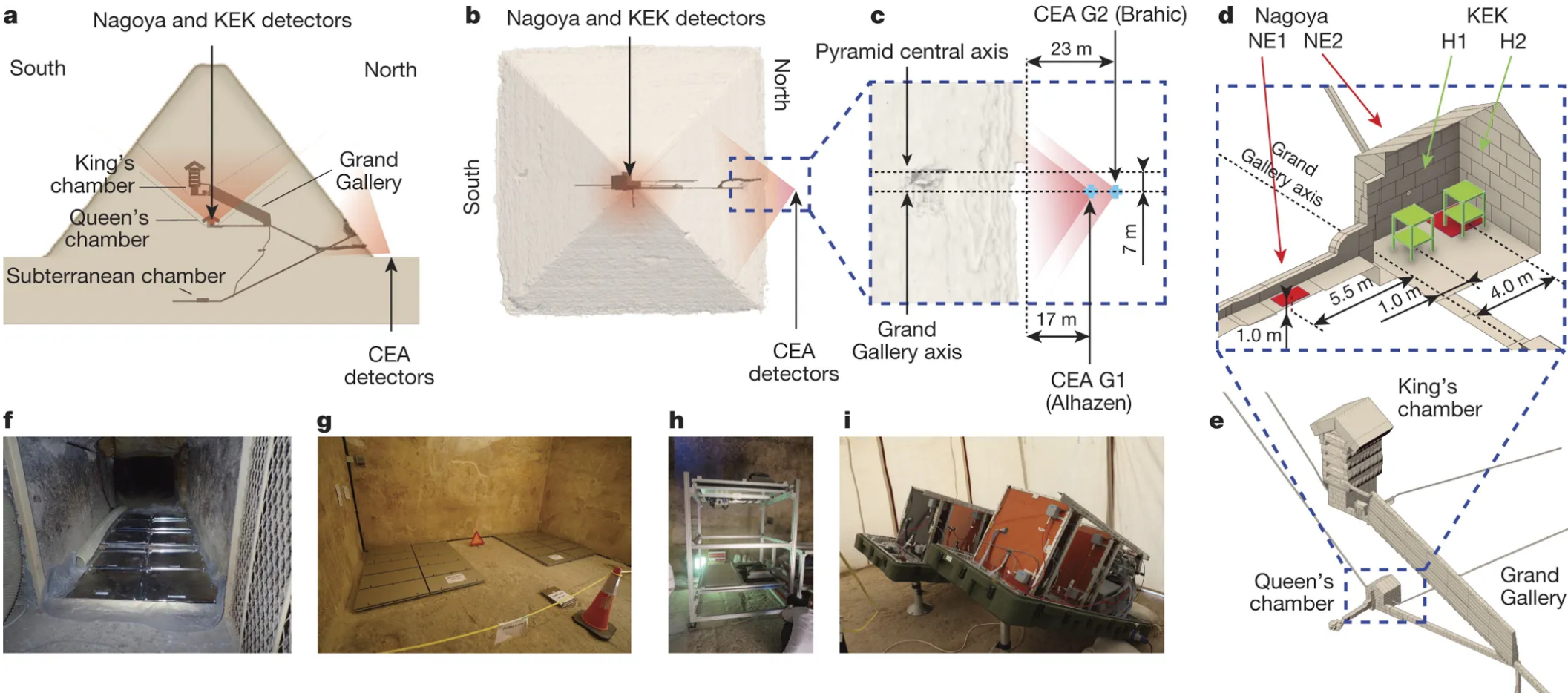


Space station mold survives 200 times the radiation dose that would kill a human

By [Richard A. Lovett](#) | Jun. 28, 2019, 8:05 PM

Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons

Kunihiro Morishima , Mitsuaki Kuno, [...] Mehdi Tayoubi 



Cosmic Rays in Everyday life

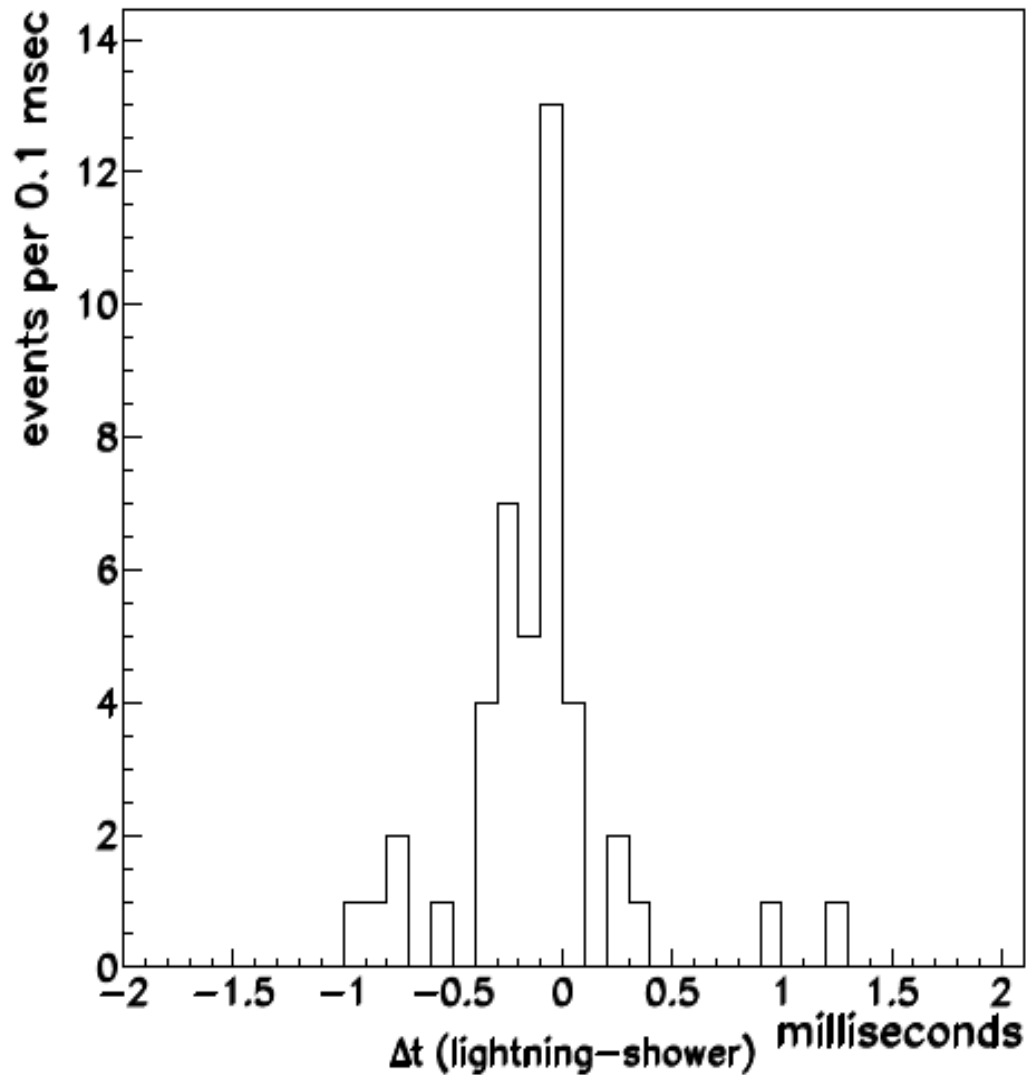
Runaway Breakdown and the Mysteries of Lightning

The observed electric fields in thunderclouds are generally too weak to initiate the atmosphere's electrical breakdown. But cosmic rays can play a surprising role in the drama of lightning.

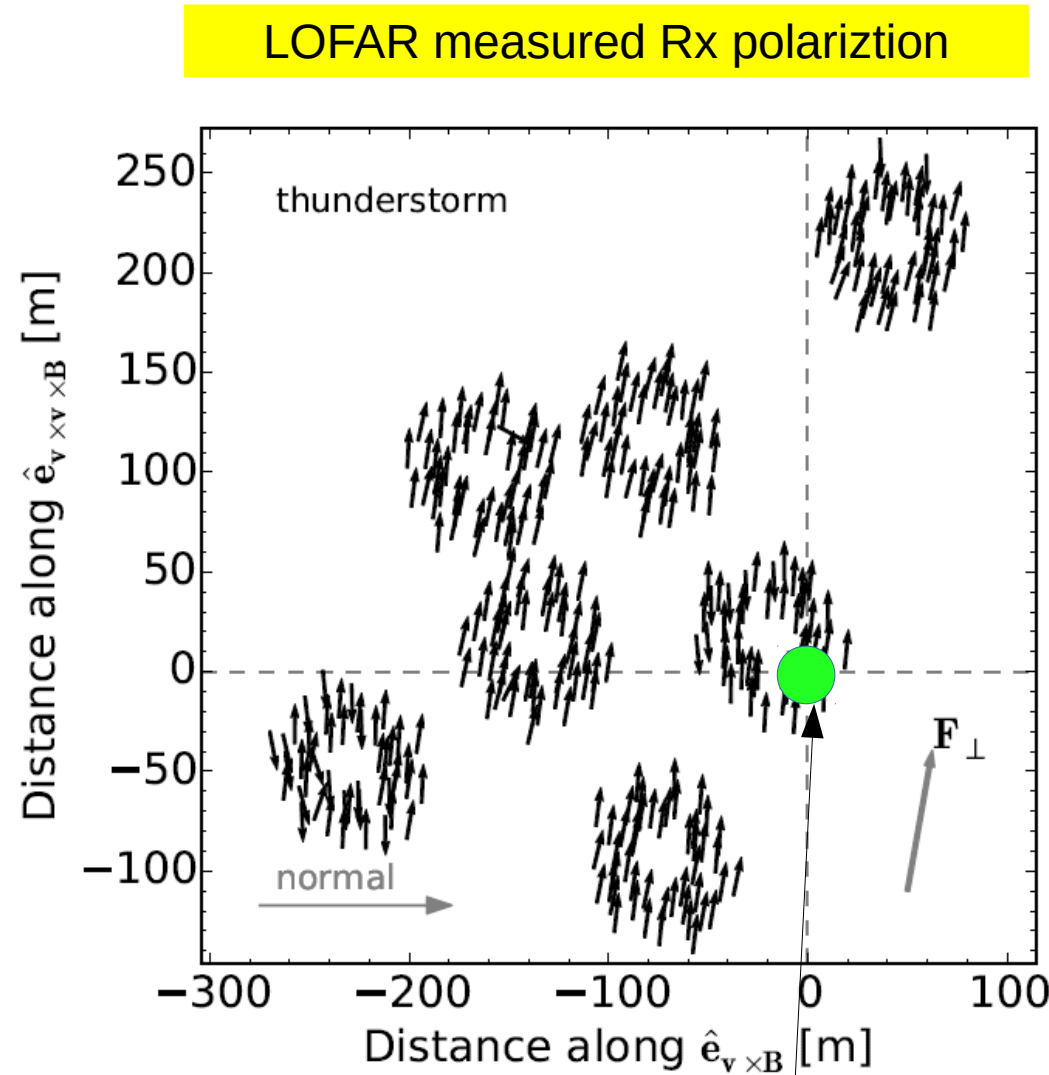
Alexander V. Gurevich and Kirill P. Zybin



Lightning Detection at the Telescope Array Cosmic Ray Observatory



Time Difference (in milliseconds)
between registration of cosmic
ray and lightning strike

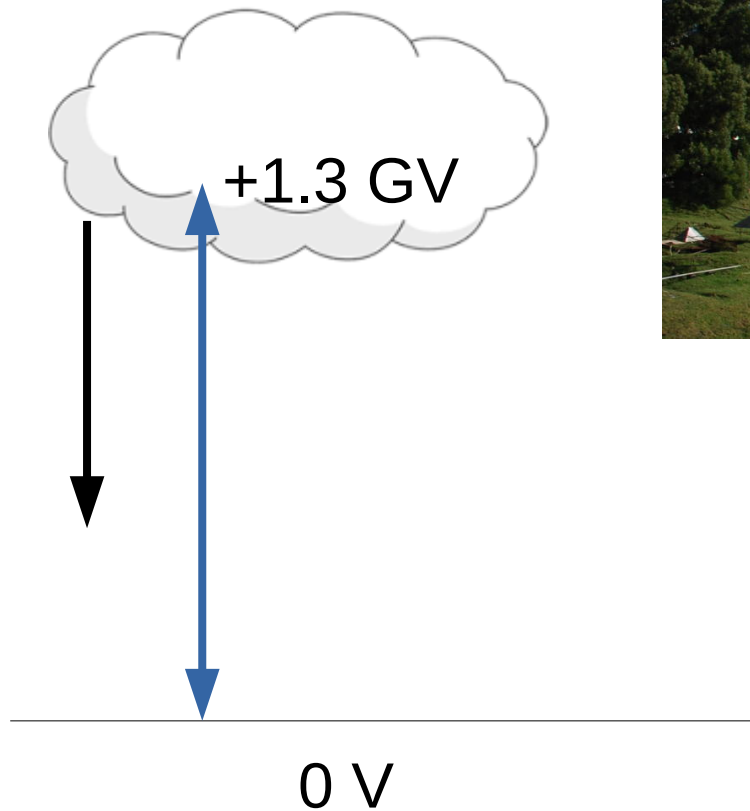


LOFAR measured Rx polariztion

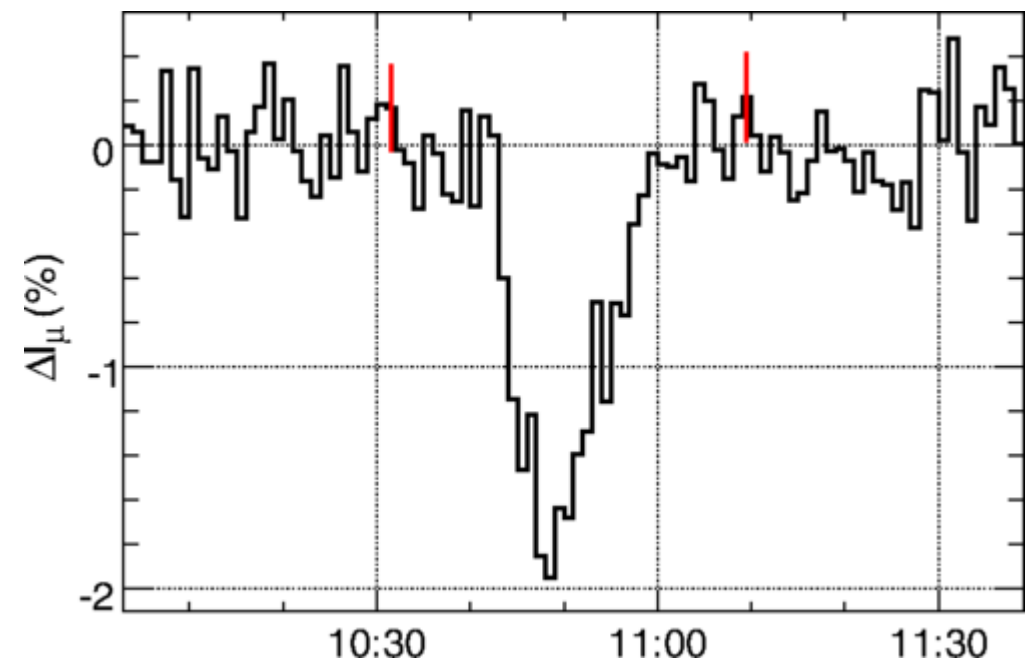
Location of shower core

GRAPES-3 measured $V_{\text{thundercloud}}$!

2014-12-01: GRAPES-3 (Gamma Ray Astronomy PeV EnergieS phase-3; Ooty) measures 1.3 gigaVolt thundercloud potential!



Negative muons with $\text{KE} < 1.3 \text{ GeV}$ don't reach ground!



Your smartphone camera is a CR detector

- <http://wipac.wisc.edu/deco> - (2-3/24 hrs)

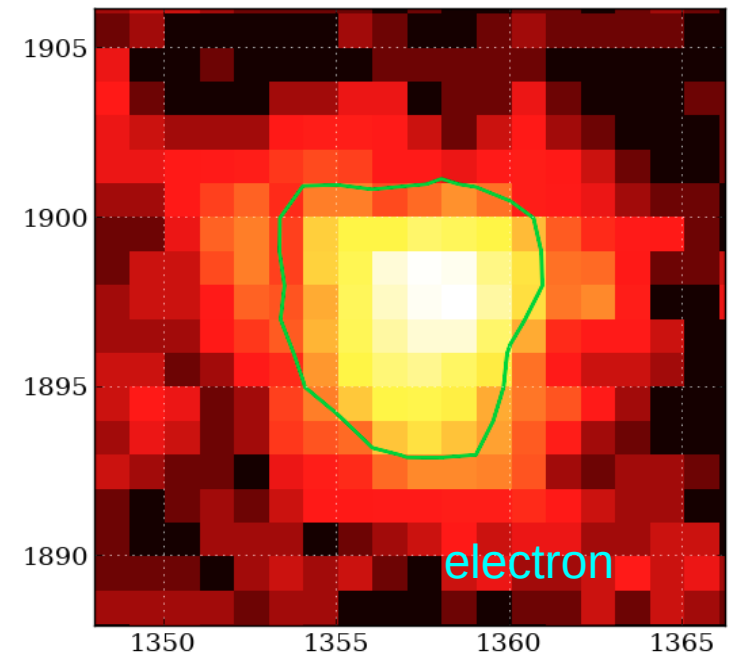
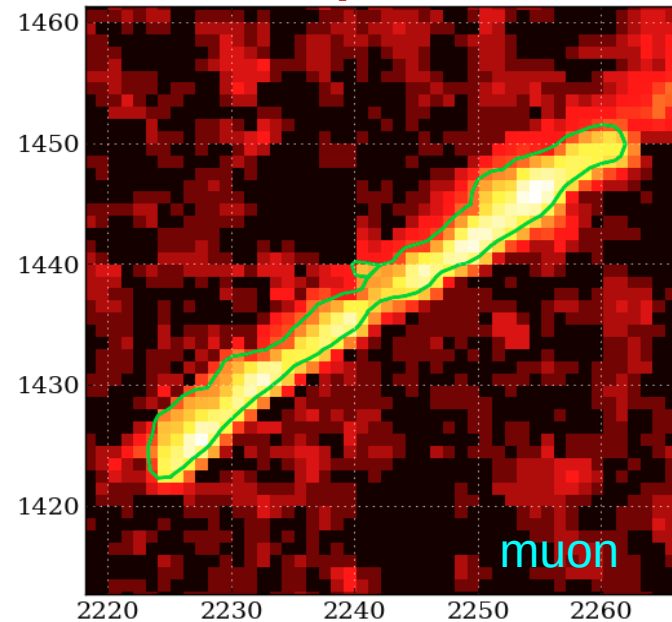
Device status and location information:

43.07515° Latitude -89.40767° Longitude
238.00m Altitude 293° Bearing

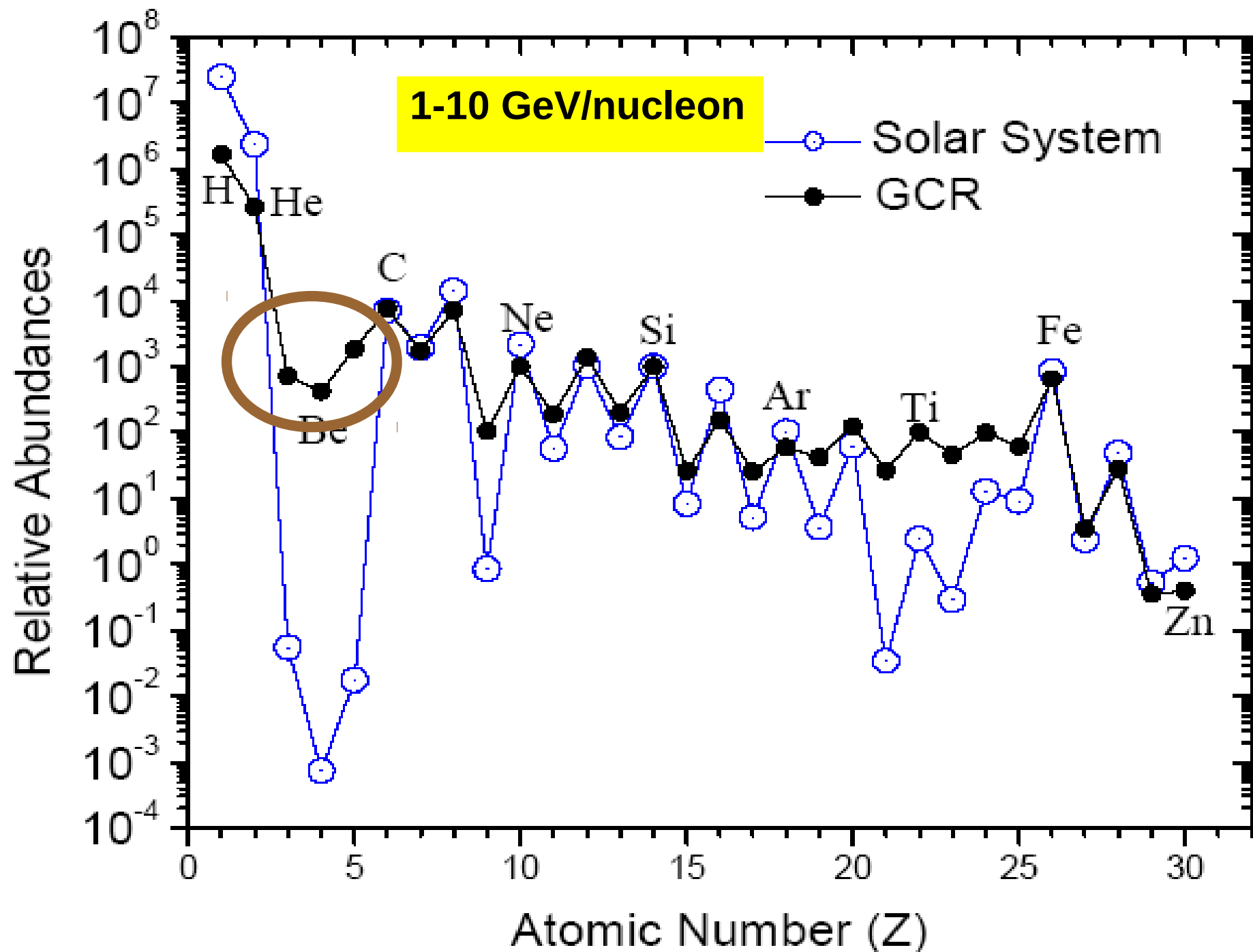
Device Id: 00000000-7f71-62fb-f647-baf70033c587
Status: Scanning
Battery: 90% (32.0°C / 89.6°F) discharging
RGB Noise: (99,99,99)

Samples	Candidates	Events
2292781	310	142
Count	Count	Count
1.6 sec	---	---
Rate	Rate	Rate

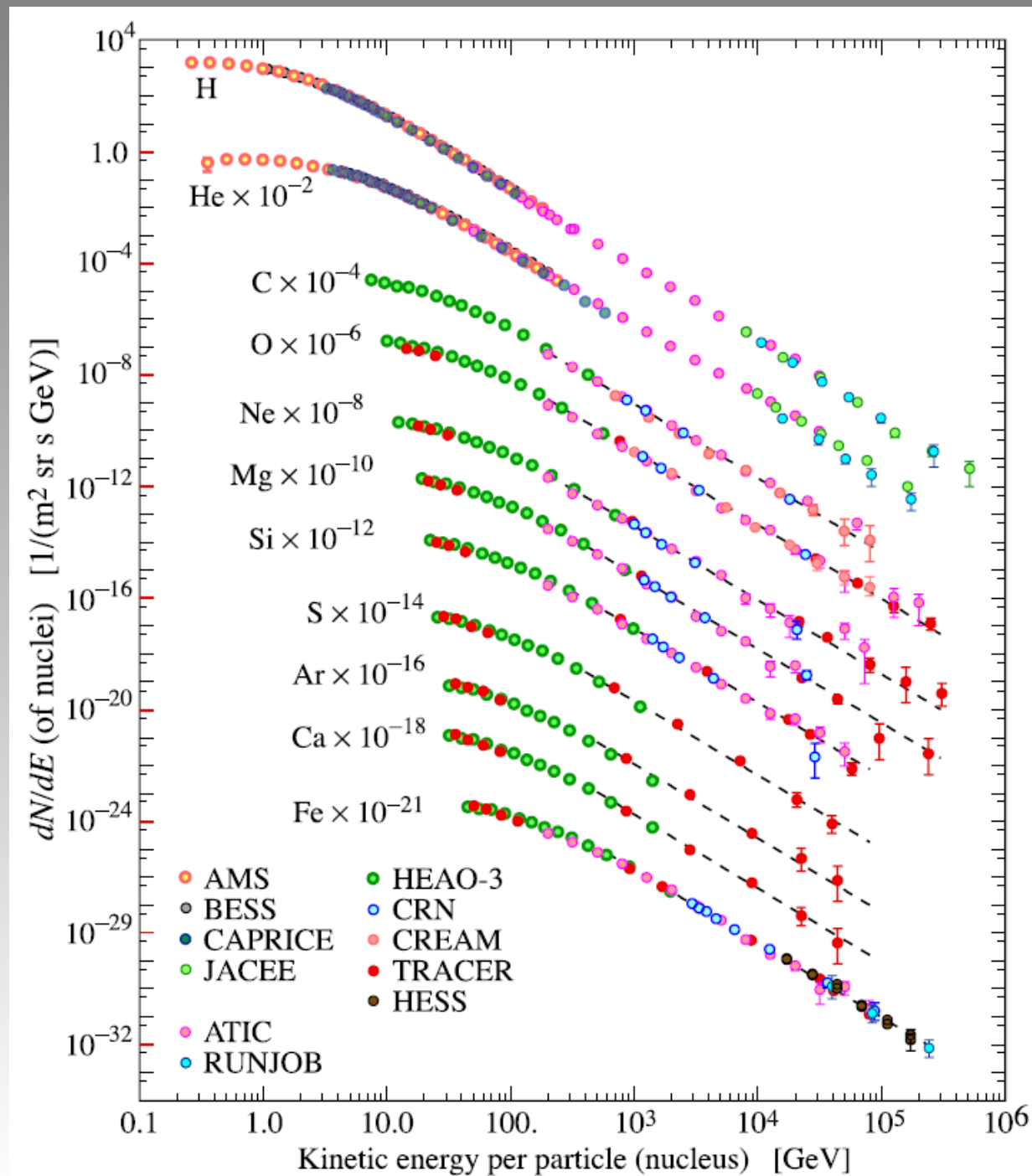
Orientation: -3° / -5° / 293°
Magnetic Field (μT): 29 / 7 / -51

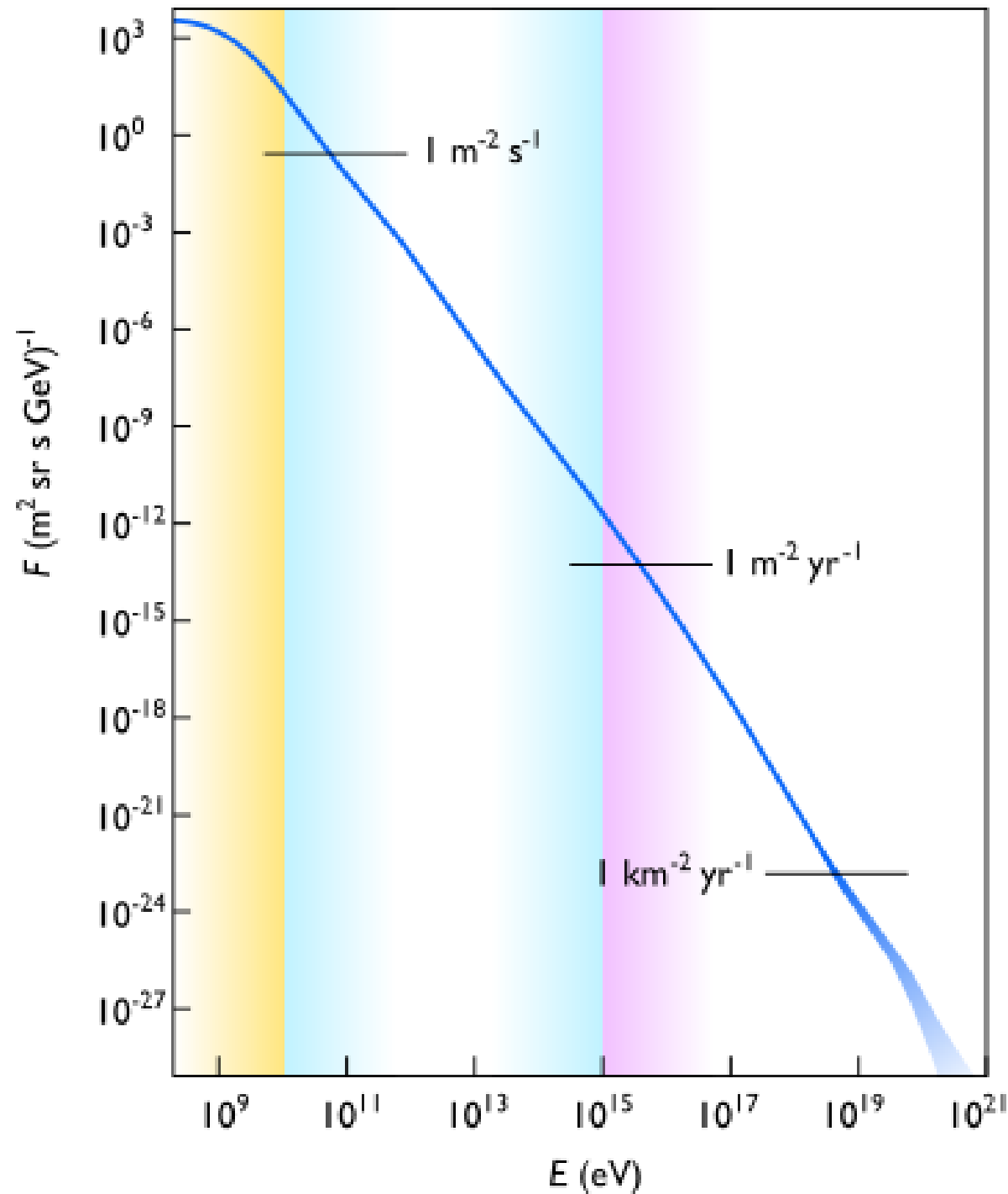


What is the cosmic ray abundance on planet Zolar?



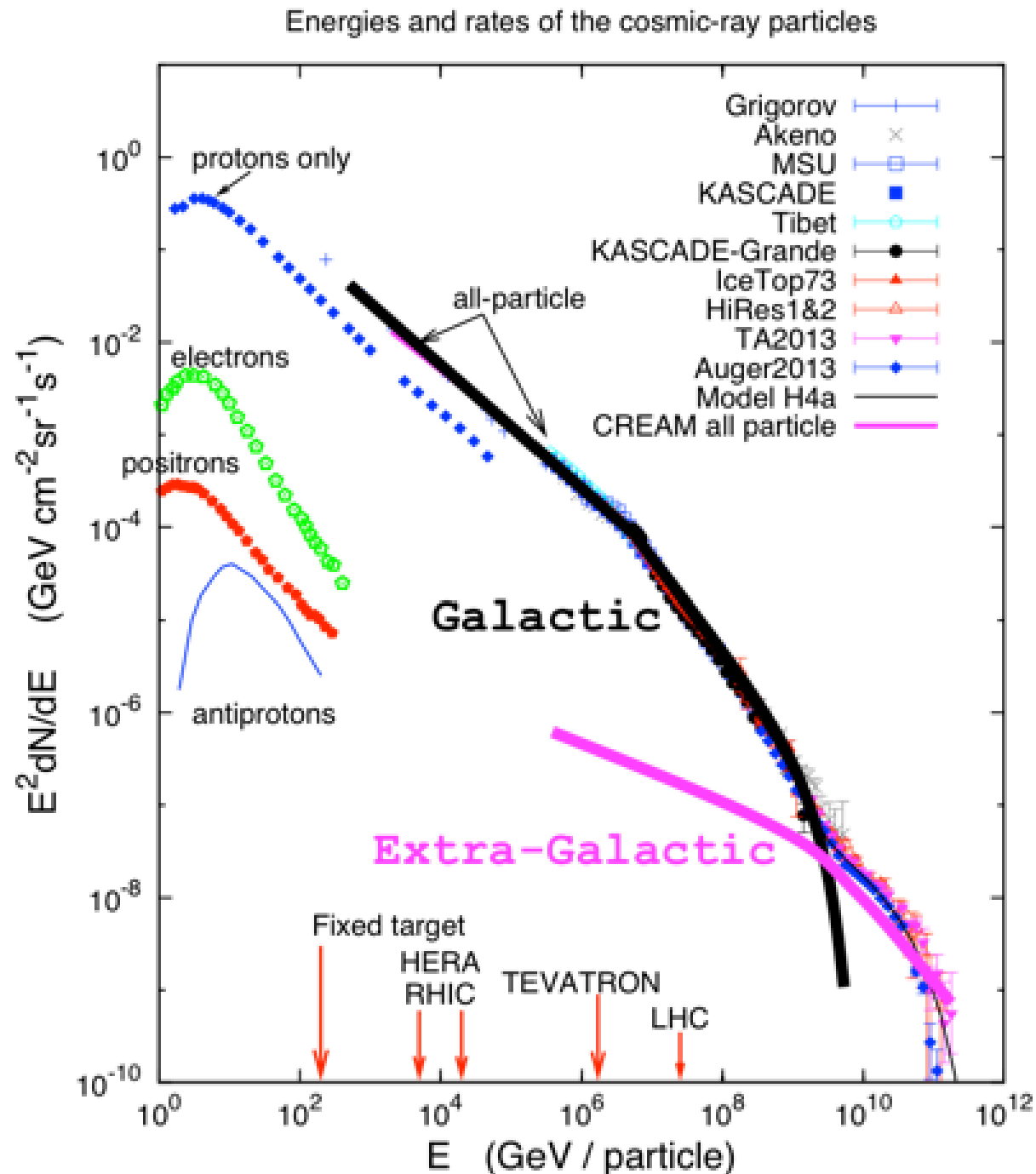
Energy spectrum of various CR nuclei



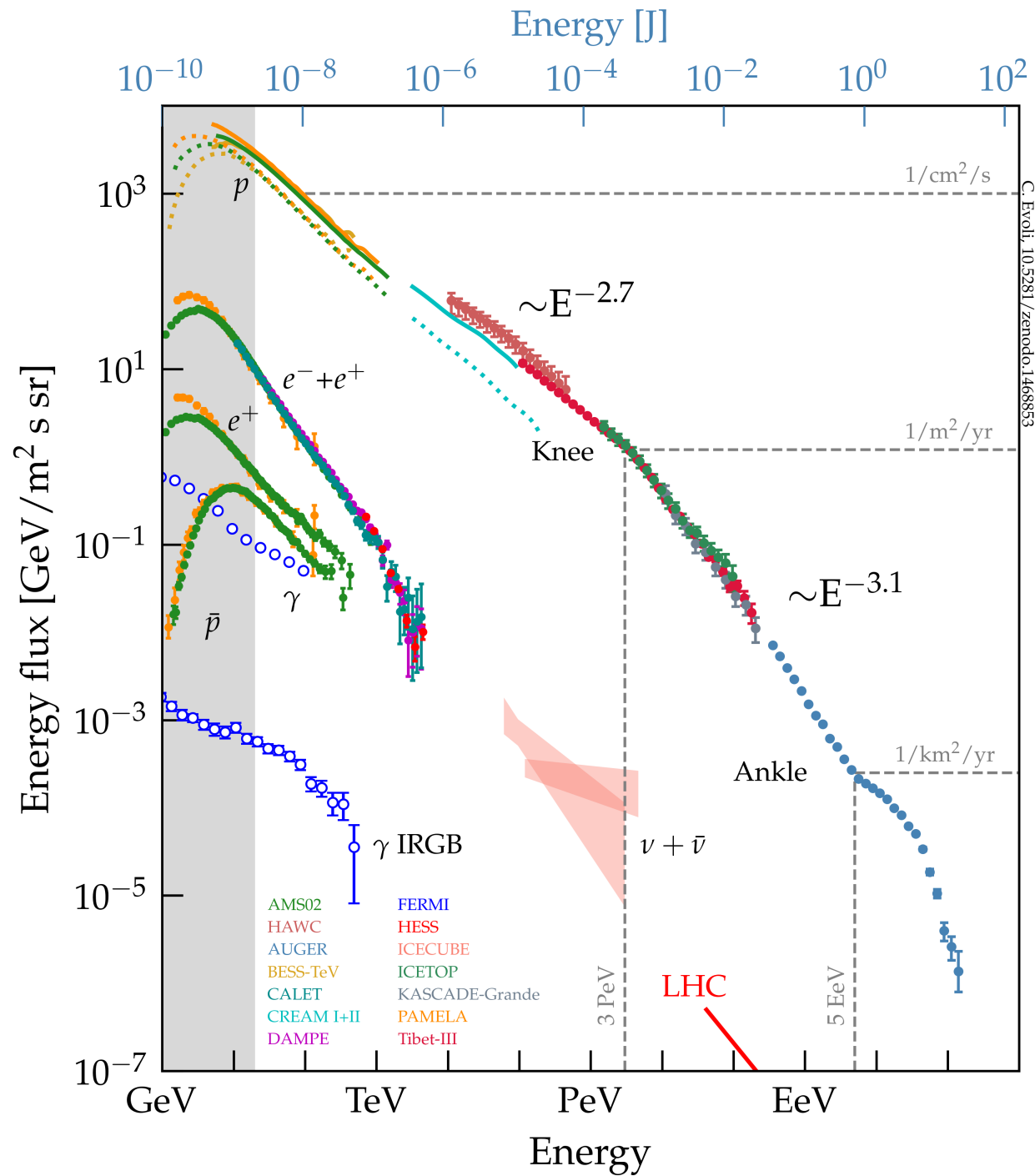


The
charged
cosmic
ray
energy
spectrum
at Earth

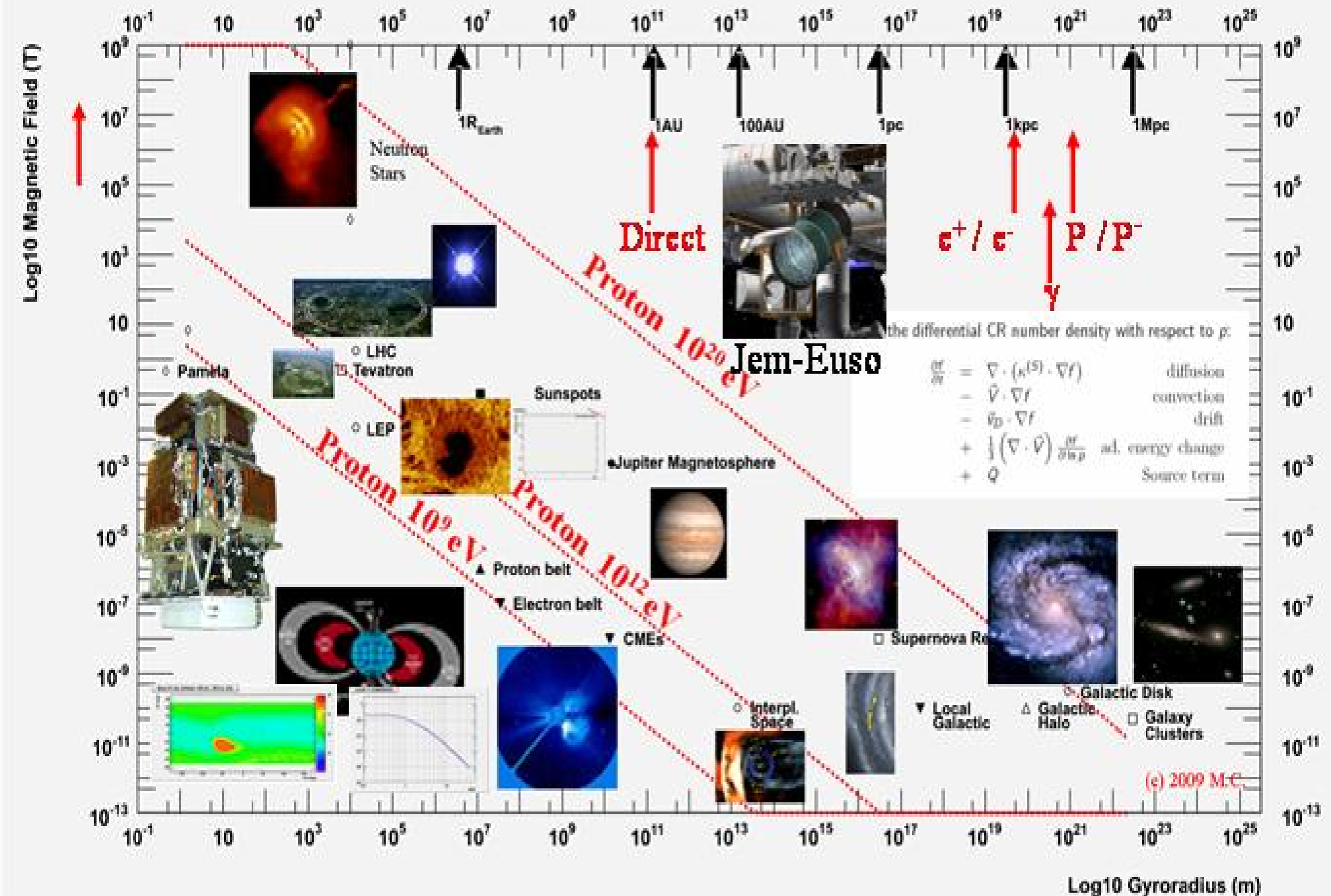
By particle type, and sources



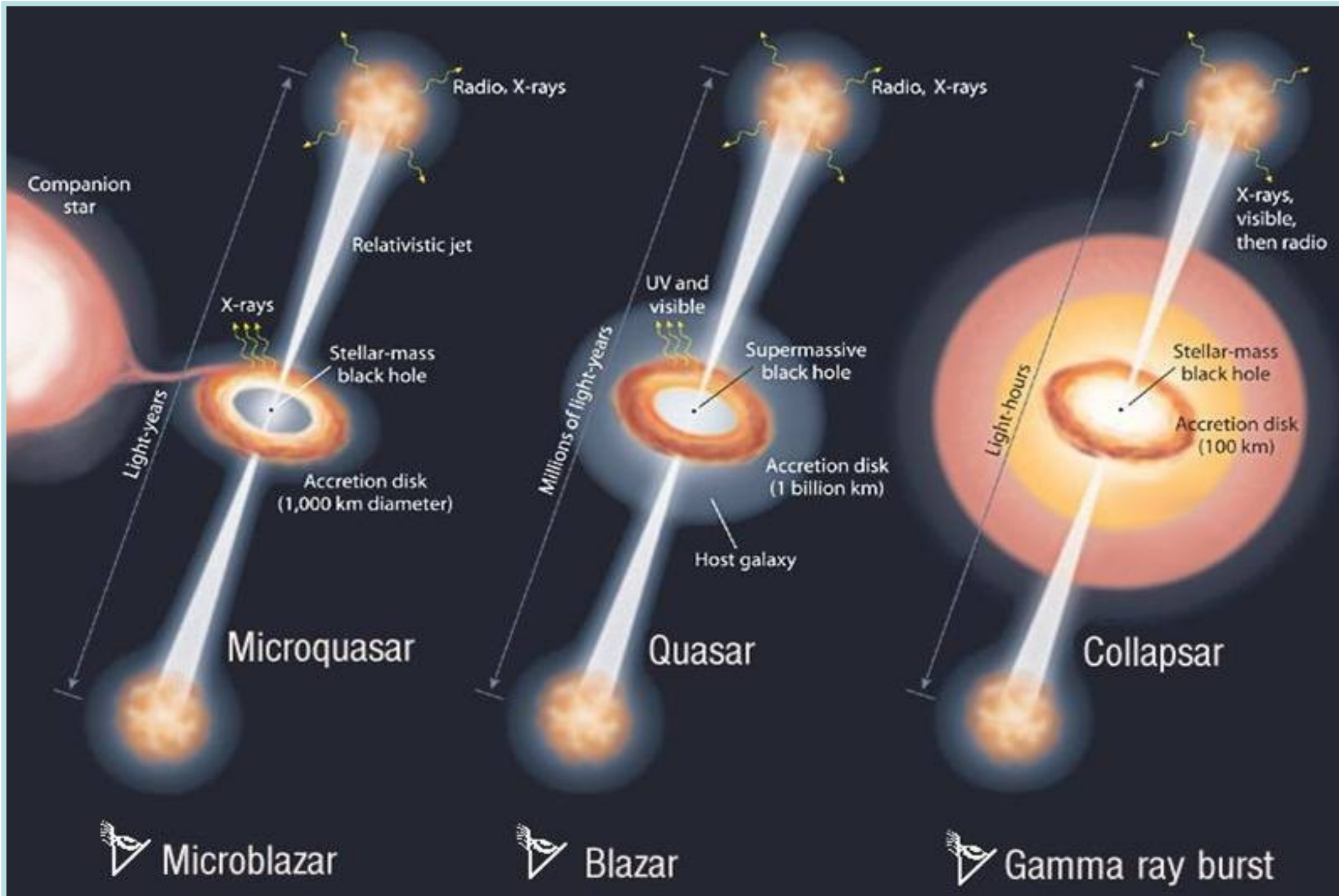
And overlaid with gamma-ray fluxes



Need large product of B-field x gyroradius



Sources of UHE Charged Cosmic Rays



источник космических лучей - отдаленные AGN



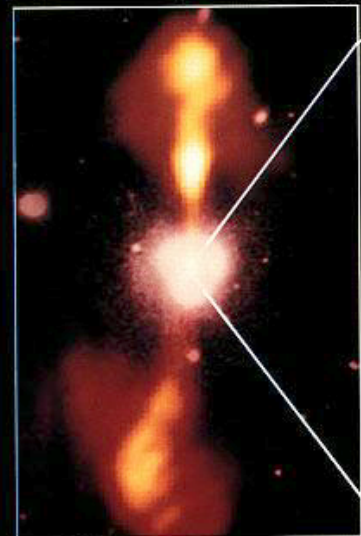
Active galaxies

Galaxy 3C296

Core of Galaxy NGC4261

Hubble Space Telescope
Wide Field/Planetary Camera

Ground-Based Optical/Radio Image



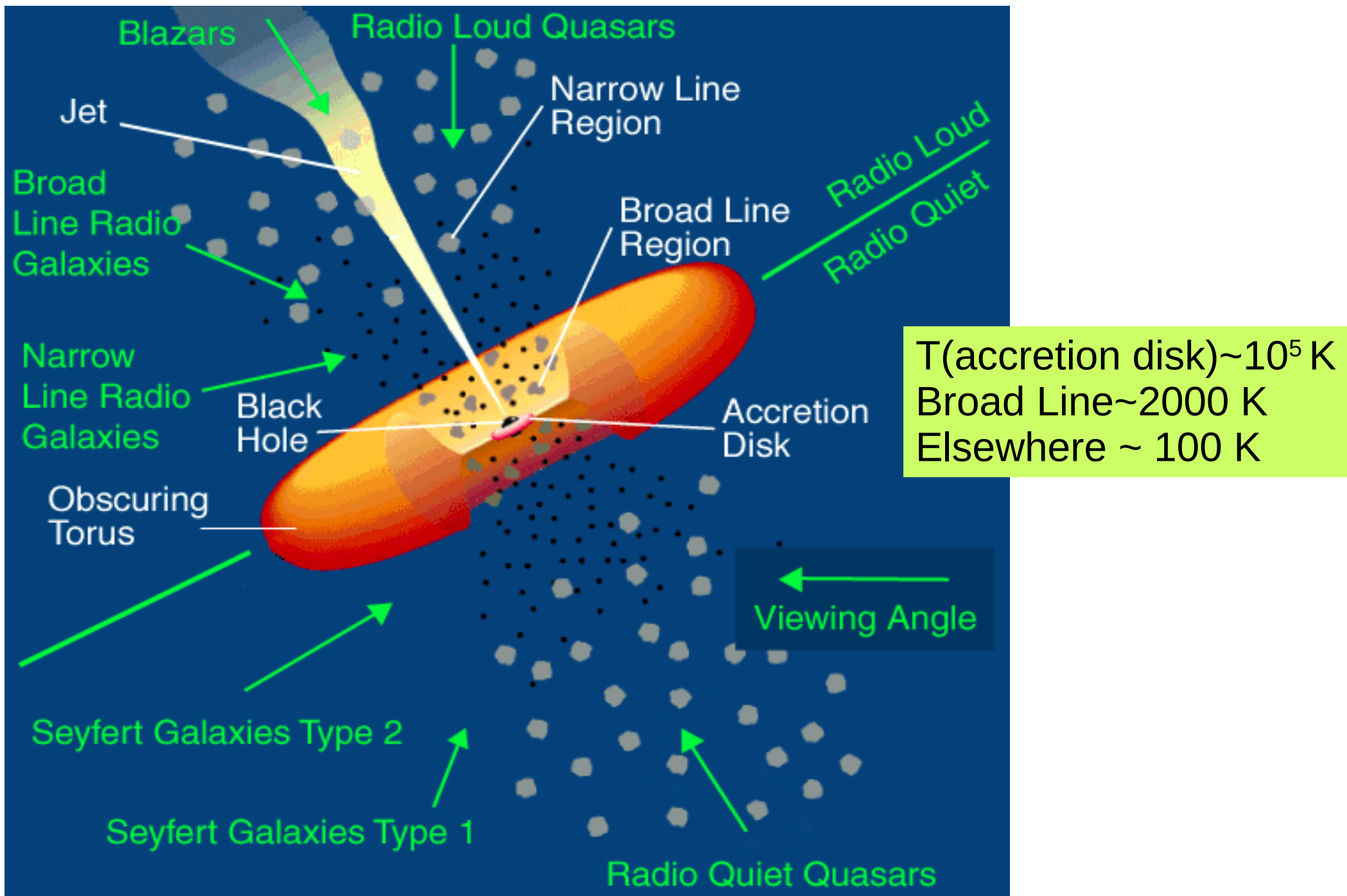
380 Arc Seconds
88,000 LIGHT-YEARS

HST Image of a Gas and Dust Disk

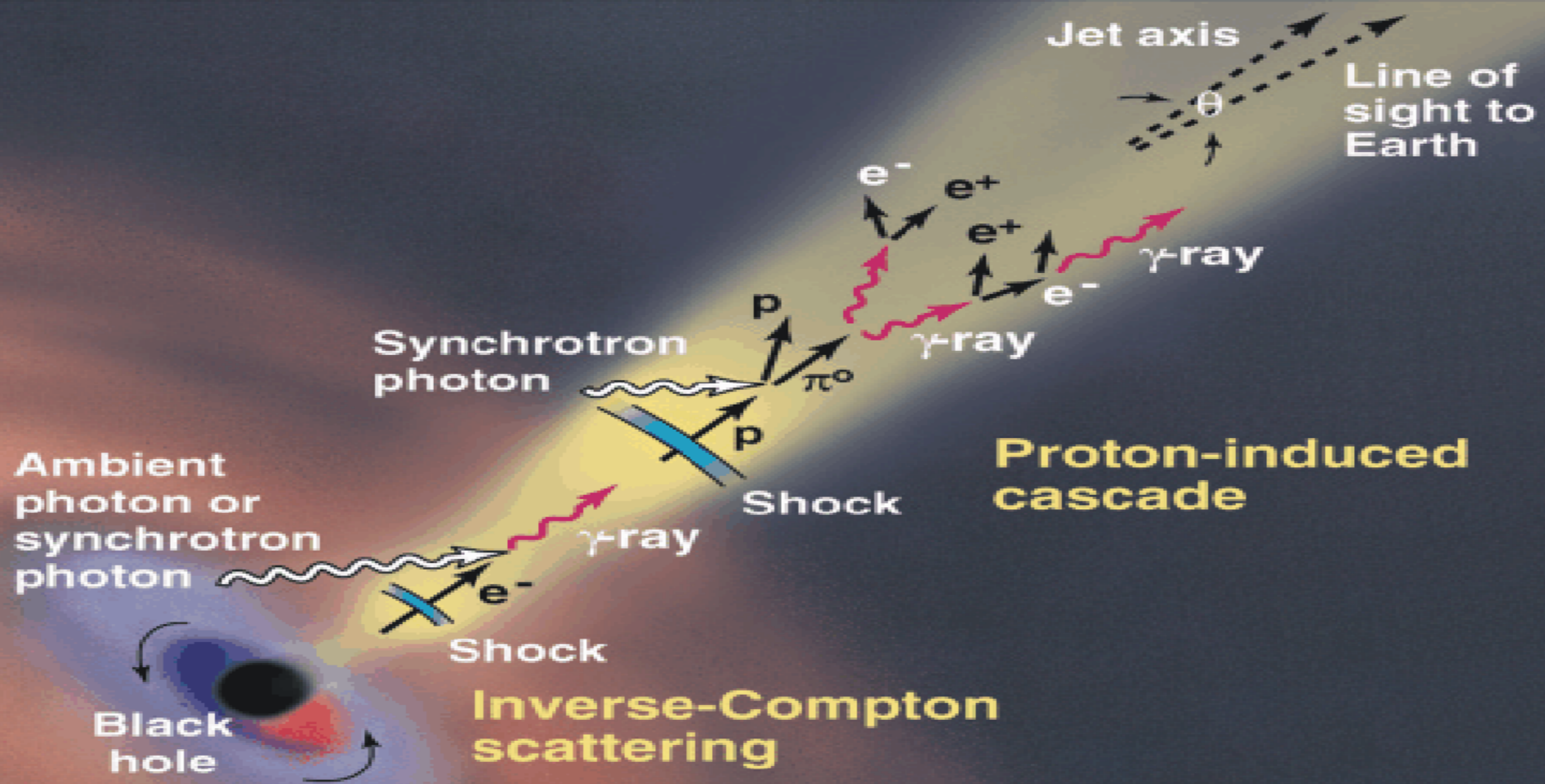


17 Arc Seconds
400 LIGHT-YEARS

AGN-many names



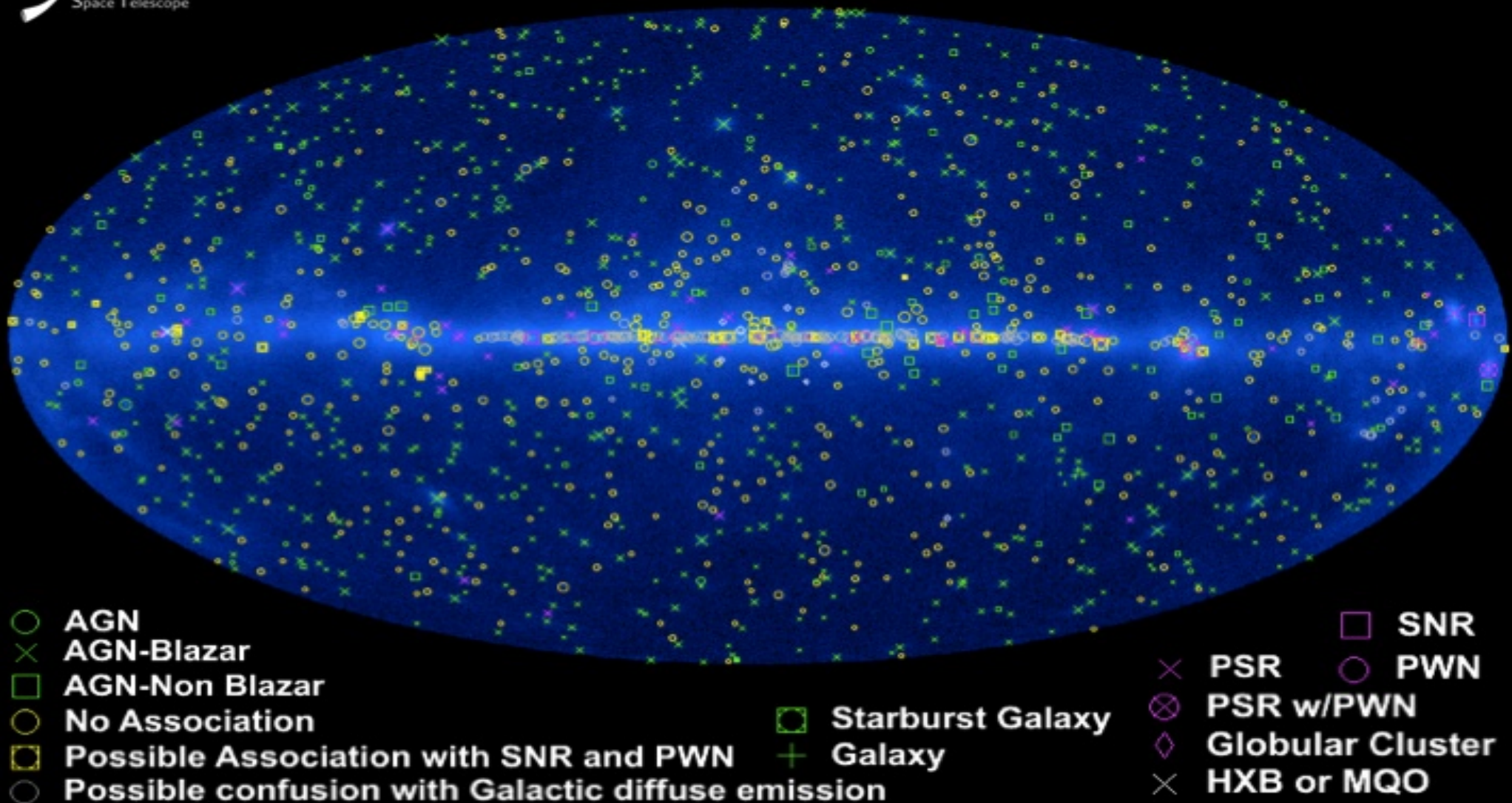
Shock Acceleration around AGN



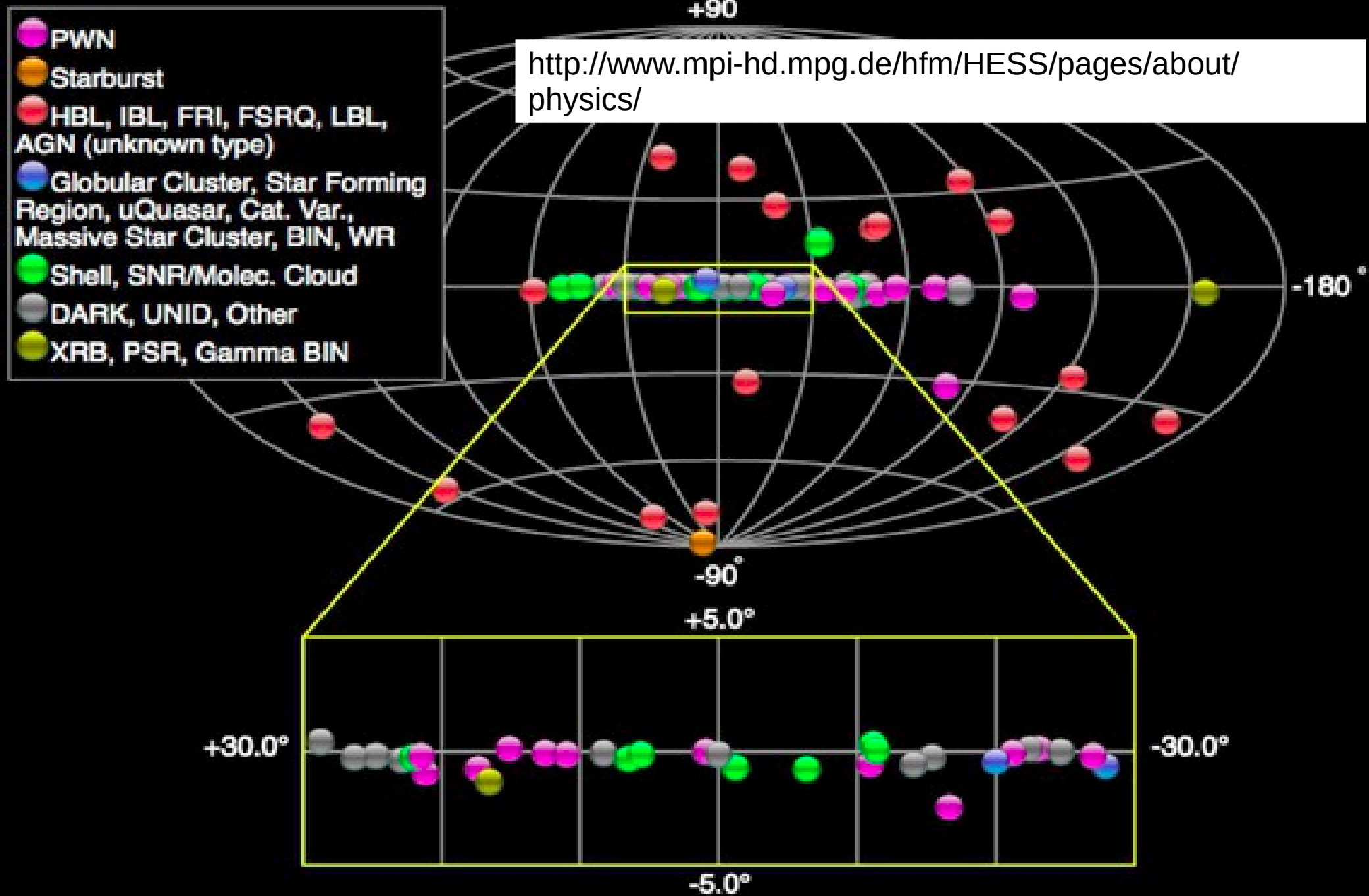
γ -ray observations



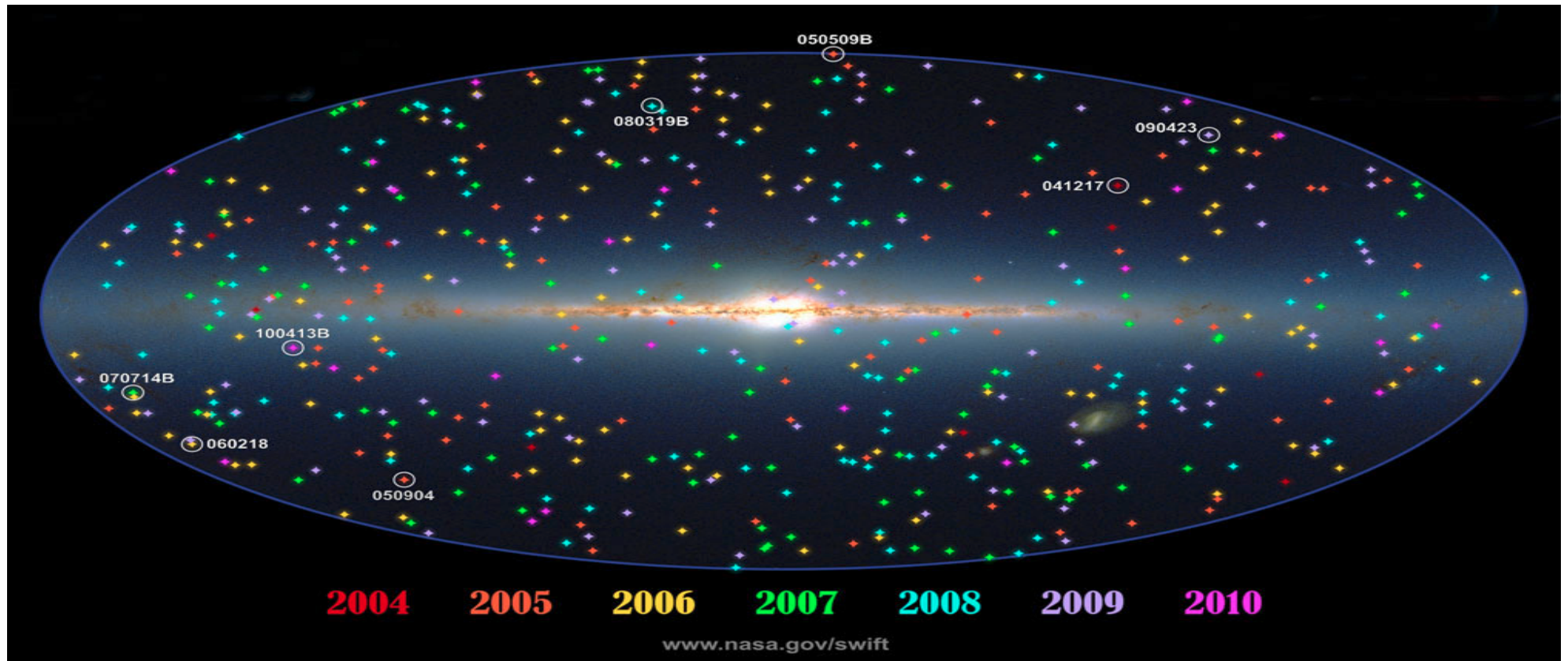
The Fermi LAT 1FGL Source Catalog



HESS VHE γ sources



Gamma-Ray Bursts



Taglines

- UHECR are out there
 - Lots of uses, aside from just astrophysics
- Local environment is typical
- Protons, gamma-rays, neutrinos
 - Primary vs. Secondary CR's?
 - We really want the primary CR's!

Next: CR's are out there; how do we detect them?

Two Basic Approaches:

A) Stuck on Earth:

- 1) Identify the CR primary particle you're most interested in
- 2) Identify the energy range that you're most interested in for that CR
- 3) Look up the interaction cross-section of that CR, at that E, with matter (air, e.g.)
- 4) Figure out decay products (aka, `secondaries')
- 5) Determine layout of an experiment designed to detect the maximum number of secondaries

B) Out in space:

- 1) No atmospheric target => detect primary directly!