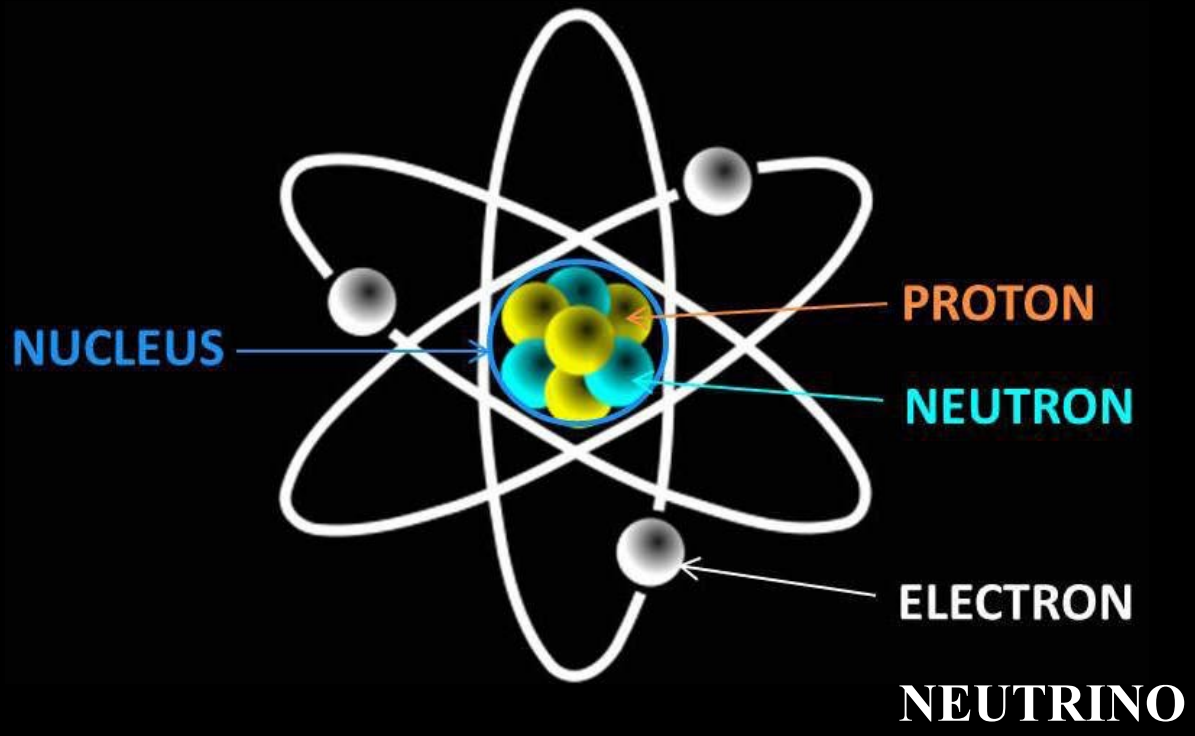
Cosmic rays; the first piece of the next puzzle

Freshman seminar

David Stuart, UC Santa Barbara

The last piece of the first puzzle was neutrinos



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If you take away the radioactive source (the clump of Uranium), there will still be a slow discharge

So there must be some background radiation.

From where? How would you figure it out?

Probing background radiation

Several people measured how the level of background radiation varied as you moved around.

Is it coming from the air?

Is it coming from the ground?

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Measure under ground:

Increases or decreases

Is it coming from the ground?

Probing background radiation

Several people measured how the level of background radiation varied as you moved around.

Is it coming from the air?

- Measure under ground:
  - Increases or decreases
- Measure under water:
  - Decreases.

Is it coming from the ground?

- Measure up in the air

Measure rate of background radiation away from the ground

Is it coming from the ground?

Theodor Wulf measured a decrease at the top of the Eiffel tower, by about half.

If the source is in the ground, how can it reach 300 m up?

Measure rate of background radiation as a function of altitude

Is it coming from the ground?

Victor Hess went higher in a hydrogen balloon.

Initially he saw no change between ground and 1100 m.

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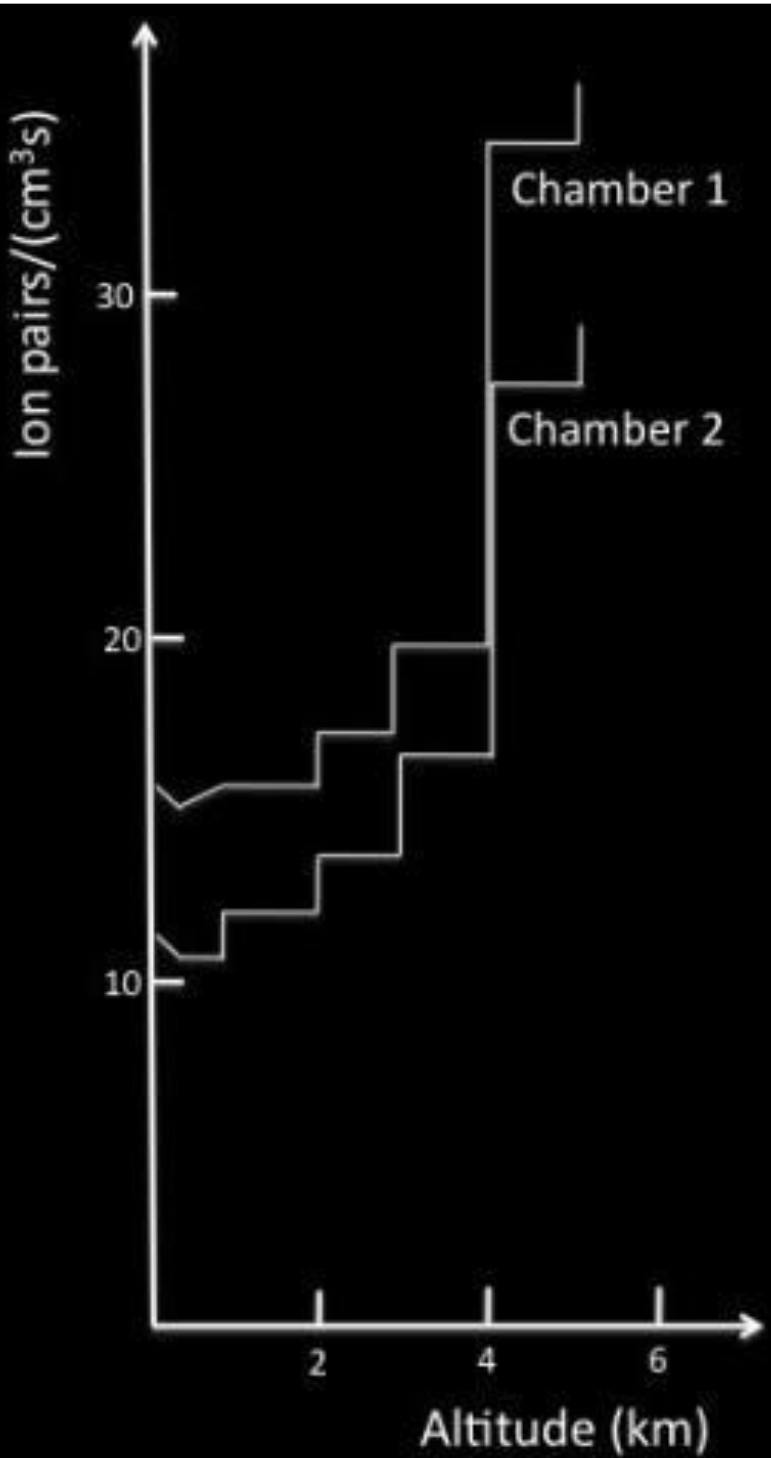
Measure vs altitude and see strong growth.



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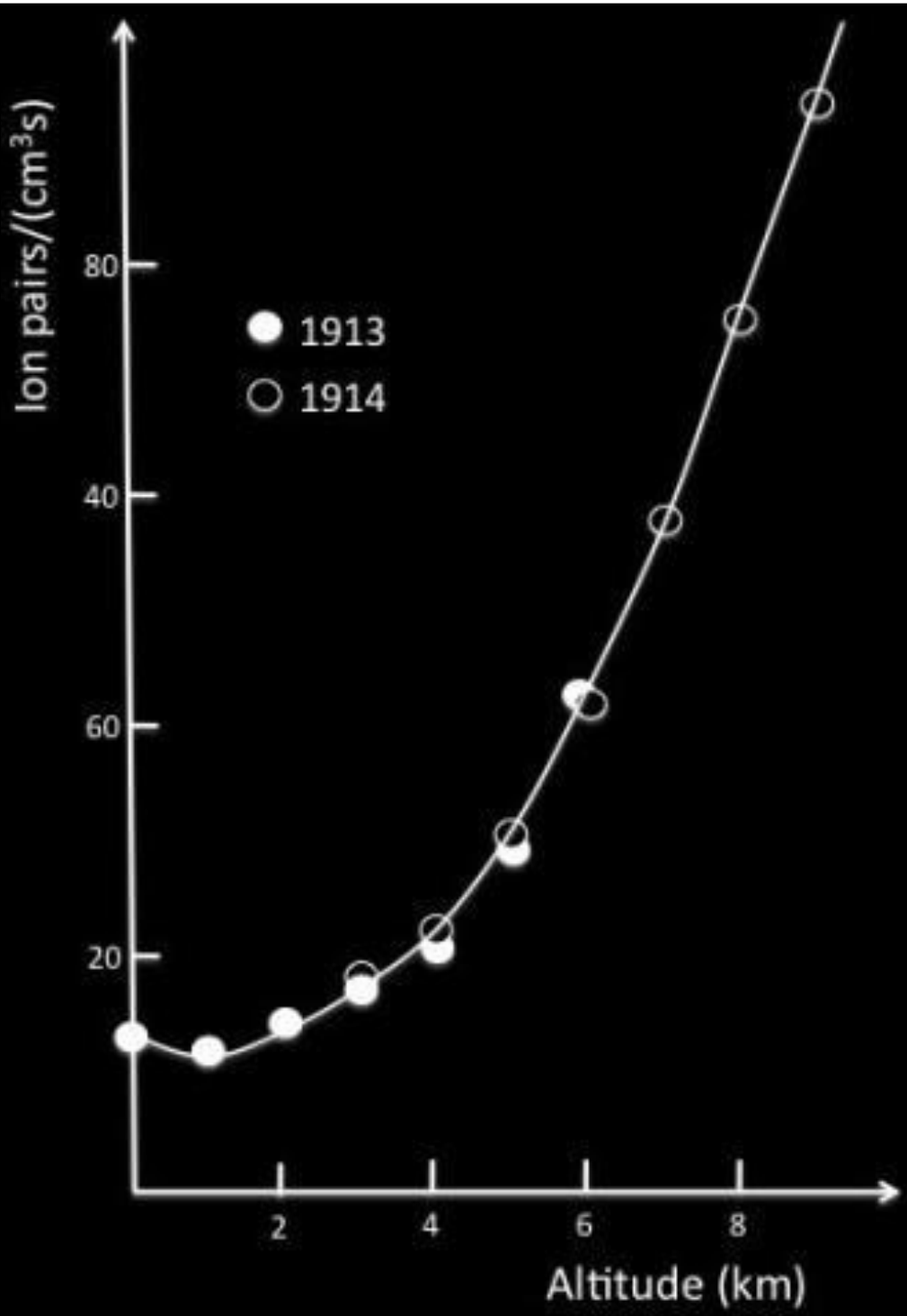
Kolhörster got up to 9.3 km on June 28, 1914, then WWI.



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The sun?

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The sun?

Victor Hess made a measurement during a solar eclipse and found no difference when the sun was blocked by the moon.

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The sun? There is **low energy** radiation from the sun → aurora.

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Increase with altitude due to absorption?

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So:

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Increase with altitude due to absorption?

Millikan measured rate vs depth in water in lakes at different altitudes. Found rate 2 m lower in water of upper lake matched rate in lake 2 km lower elevation.

So:

Absorption causes decrease toward the ground.

Coming from above.

Called them “Cosmic rays”

So what are they?

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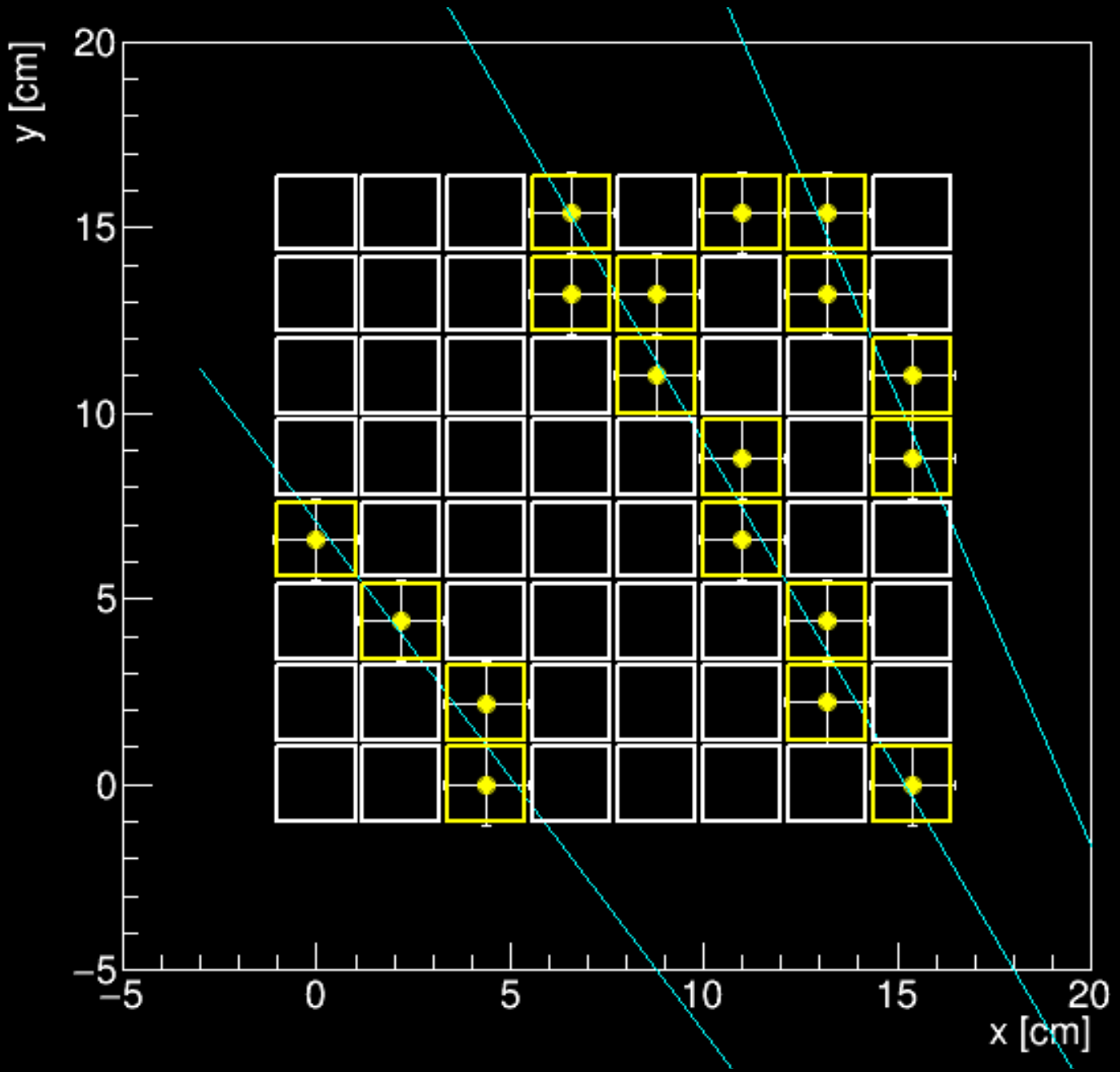

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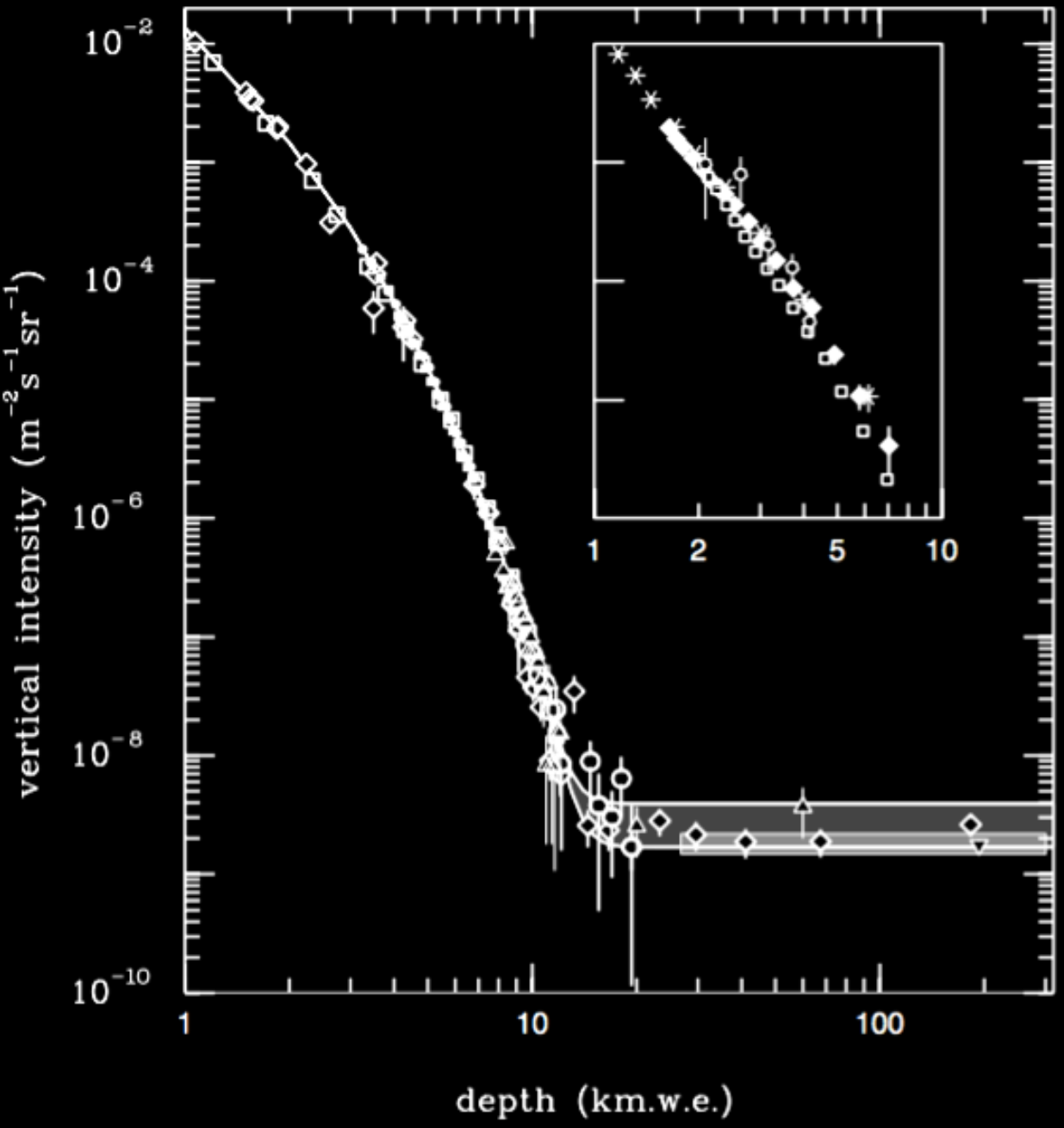

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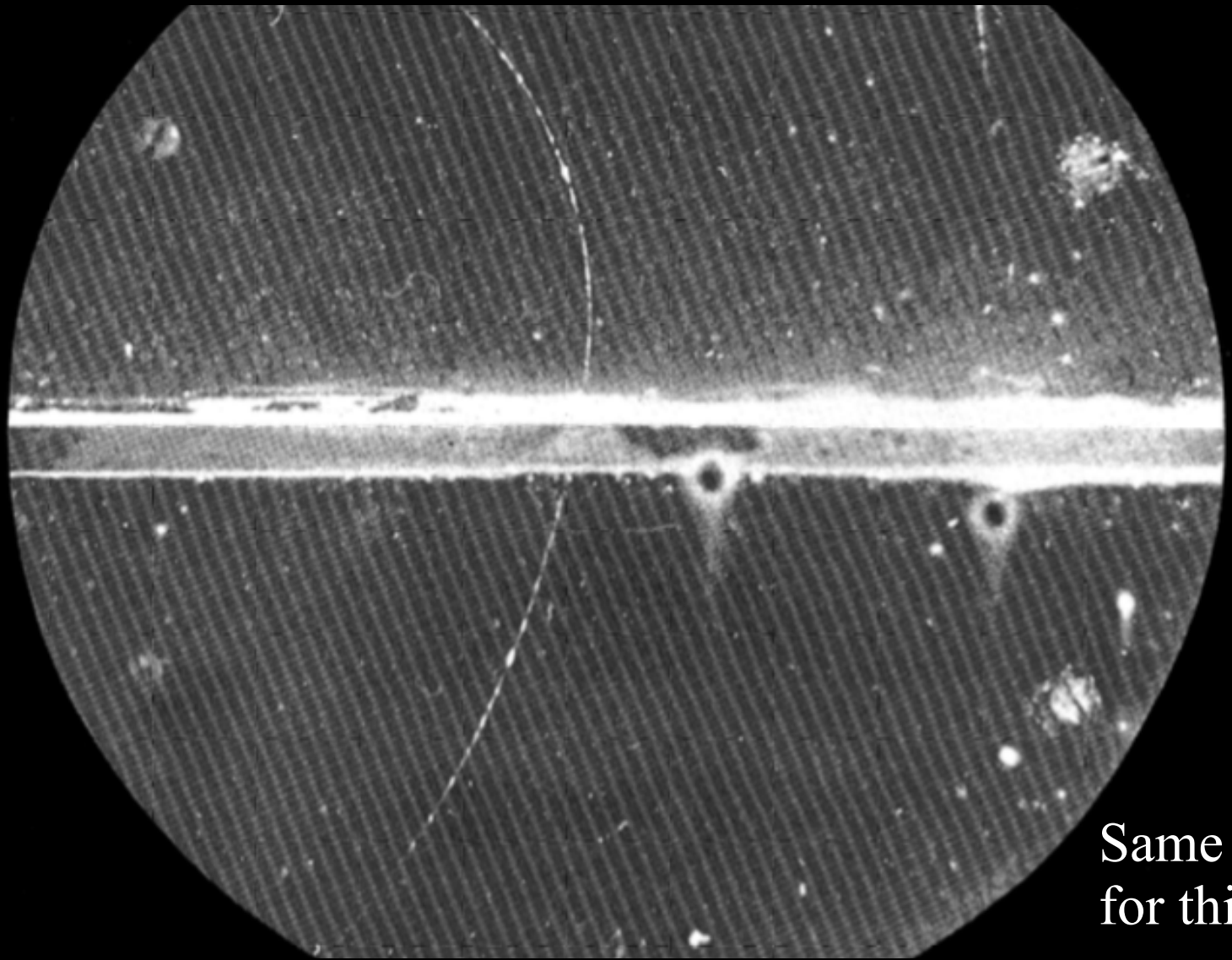
In 1937, Carl D. Anderson, who discovered the positron, and Seth Neddermeyer, used a cloud chamber in a magnetic field to measure cosmic ray momentum and mass, using energy loss.



Same method as used for this positron image.

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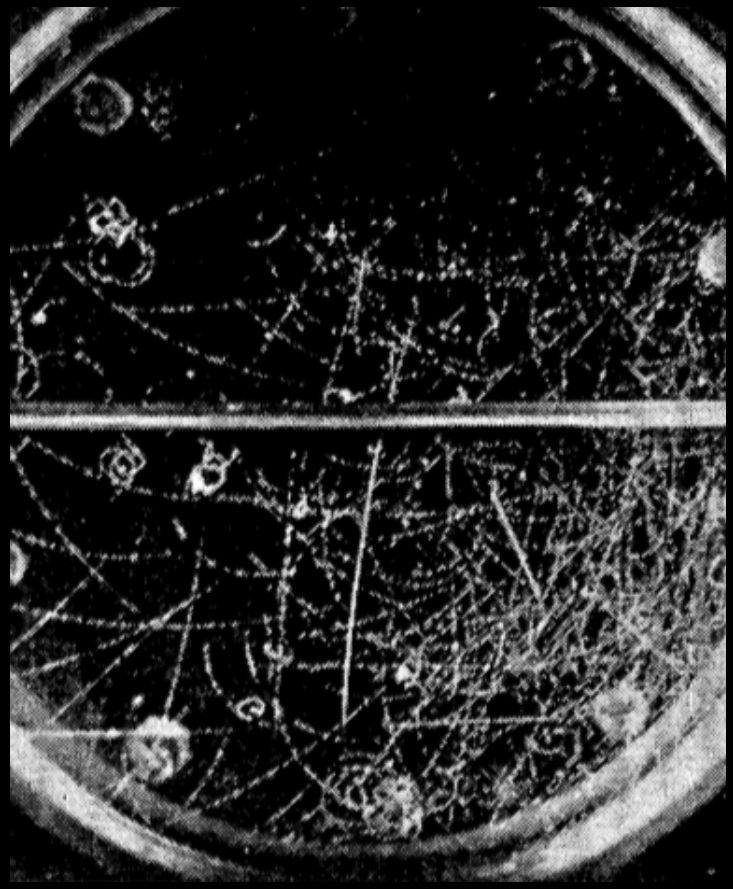


FIG. 13. Pasadena, 4500 gauss. A complex electron shower not clearly defined in direction, and three heavy particles with specific ionizations definitely greater than that of electrons. The sign of charge of two of these heavy particles represented by short tracks cannot be determined, but the assumption that they represent protons is consistent with the information supplied by the photograph. The third heavy track appears above the 0.35 cm lead plate where it has a specific ionization not noticeably different from that of an electron. It penetrates the lead plate and appears in the lower half of the chamber as a nearly vertical track near the middle. Below the plate it shows a greater ionization than an electron, and is deviated in the magnetic field to indicate a positively charged particle. Its $H\rho$ is apparently at most 1.4×10^5 gauss cm, which corresponds to a proton energy of 1 MEV and a range of only 2 cm in the chamber, whereas the observed range is greater than 5 cm. A difficulty of the same nature was discussed in the description of the previous photograph.

Found that the particles have a mass of about 200 times the electron mass. Both charges present in cosmic rays.

So what are they?

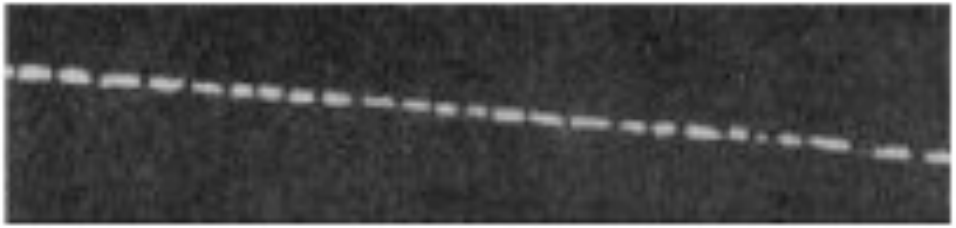
Cosmic rays contain these with both + and - charge

So what are they?

Finally understood to be a heavier version of an electron.
Called a muon.

Alpha-Teilchen
(Helium-Kern)

Beta-Teilchen
(Elektron)

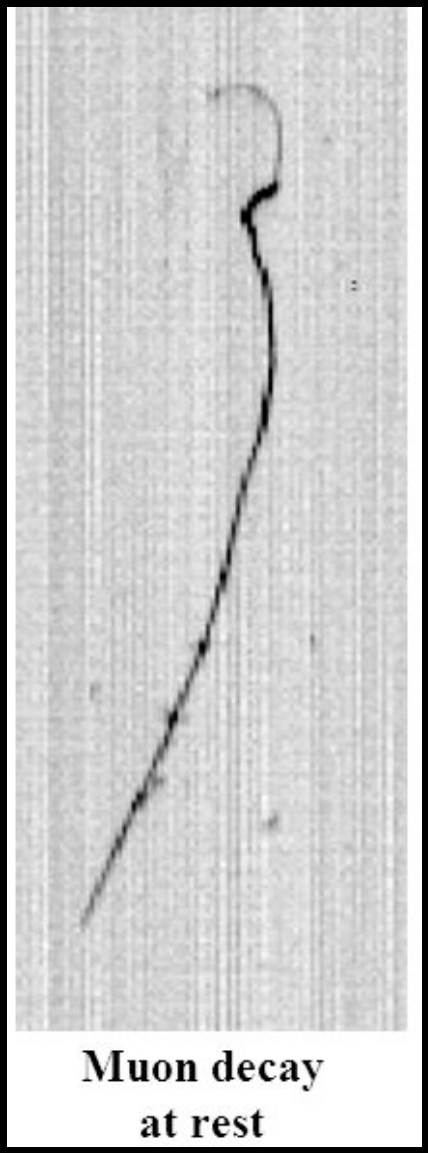


Myon
(schweres Elektron)

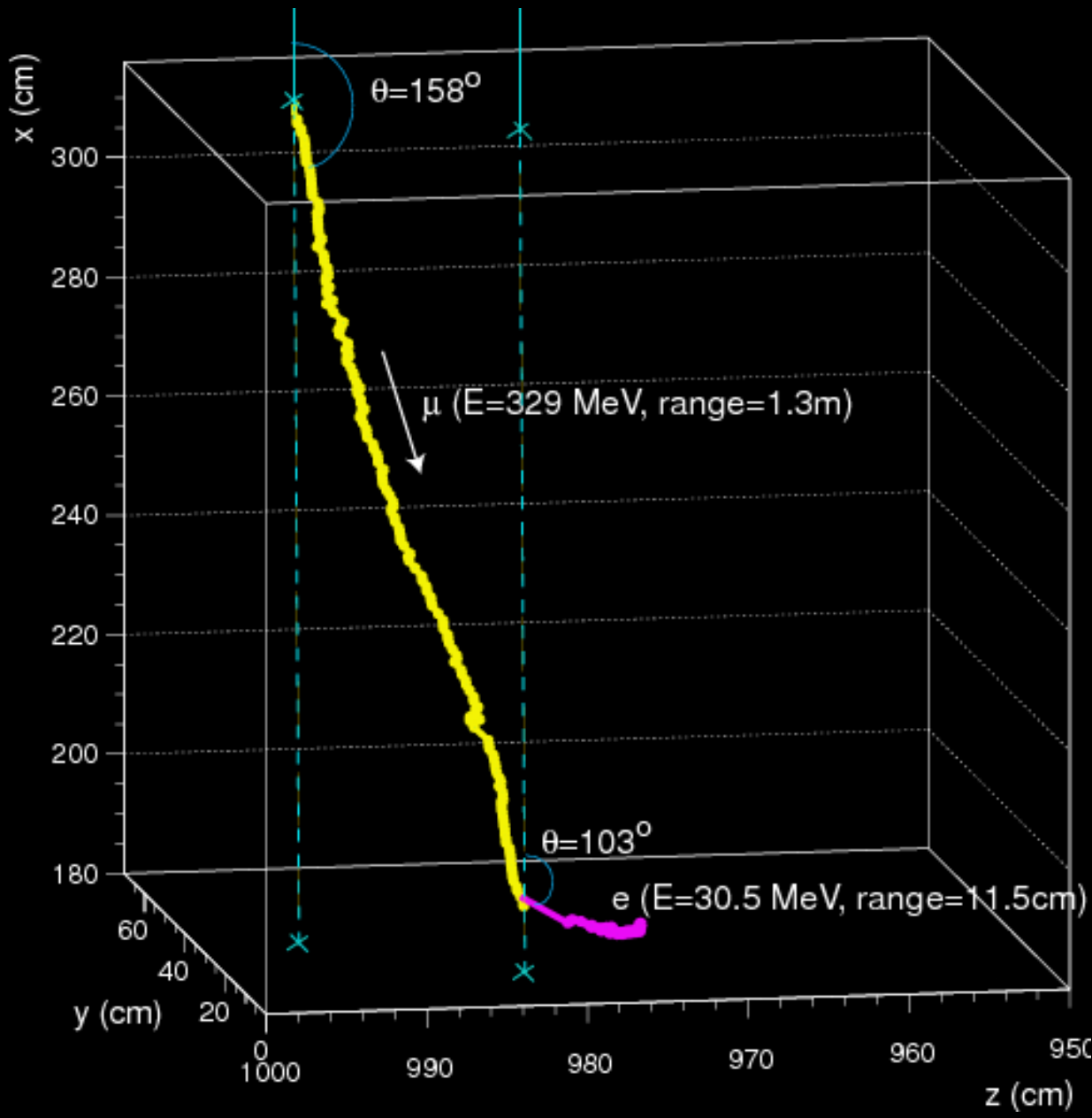
Proton

What are these muons?

Muons decay to electrons with ~2 microsecond lifetime.
The decay involves two neutrinos: $\mu \rightarrow e\,\nu\,\nu$



Muon decay at rest



Icarus, Eur. Phys. J. C33 (2004) 233-241

A new puzzle

If antimatter exists, and a heavier version of the electron exists, then the fundamental “stuff” of the universe is more than just the “stuff” of atoms.

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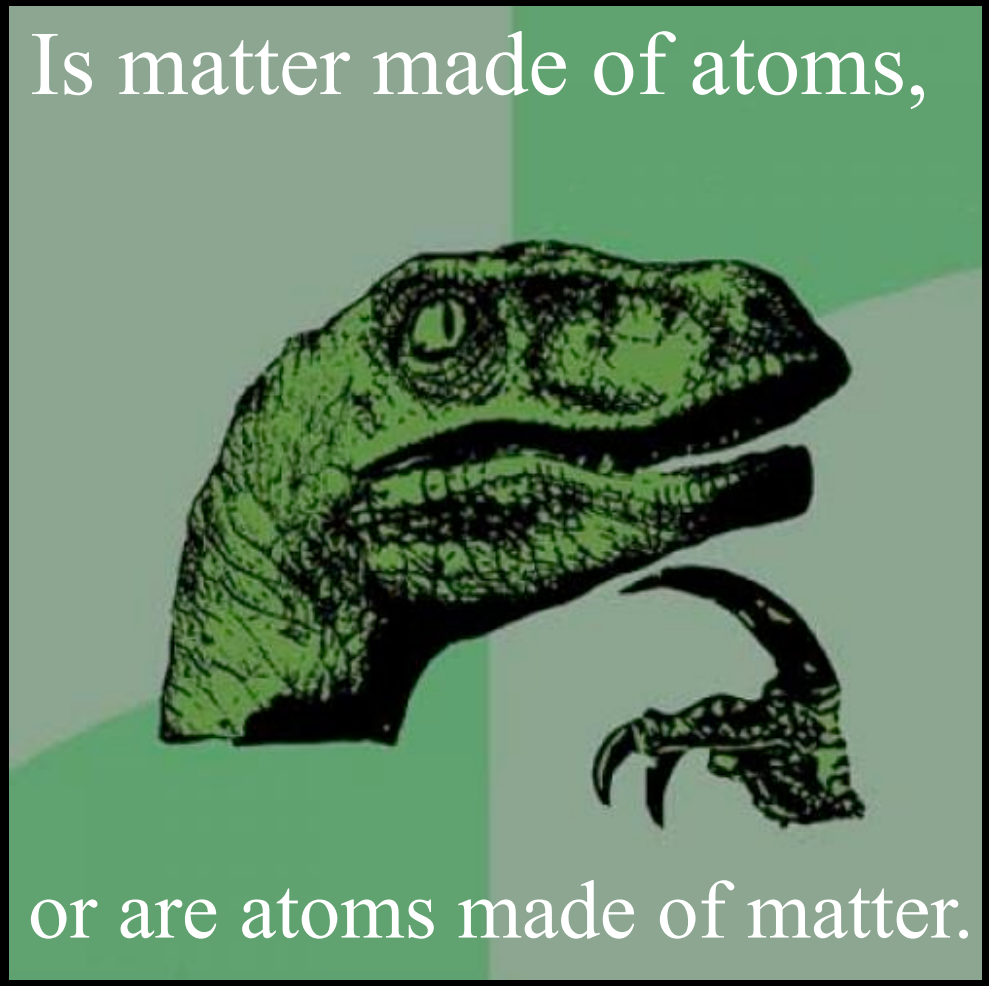


A new puzzle

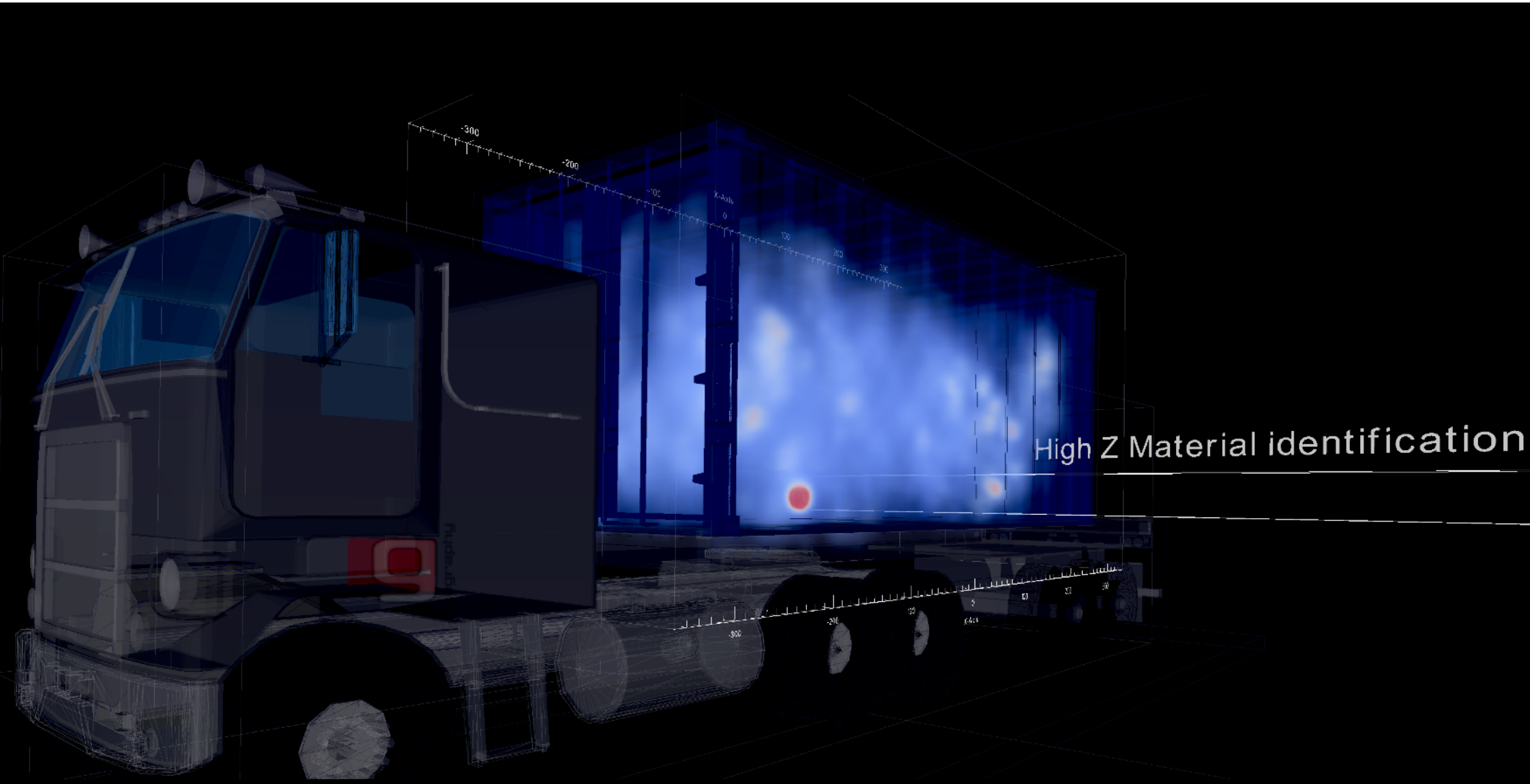
If antimatter exists, and a heavier version of the electron exists, then the fundamental "stuff" of the universe is more than just the "stuff" of atoms.

Rather than "matter is made of atoms", the improved statement is:

- Your stuff is made of atoms.
- Atoms are made of matter.
- There can be other stuff, like:
  - Anti-atoms made of anti-matter.
  - And other bound states made of other stuff.

Is there a heavier proton and neutron?
We will see the answer to that soon.

Muon tomography



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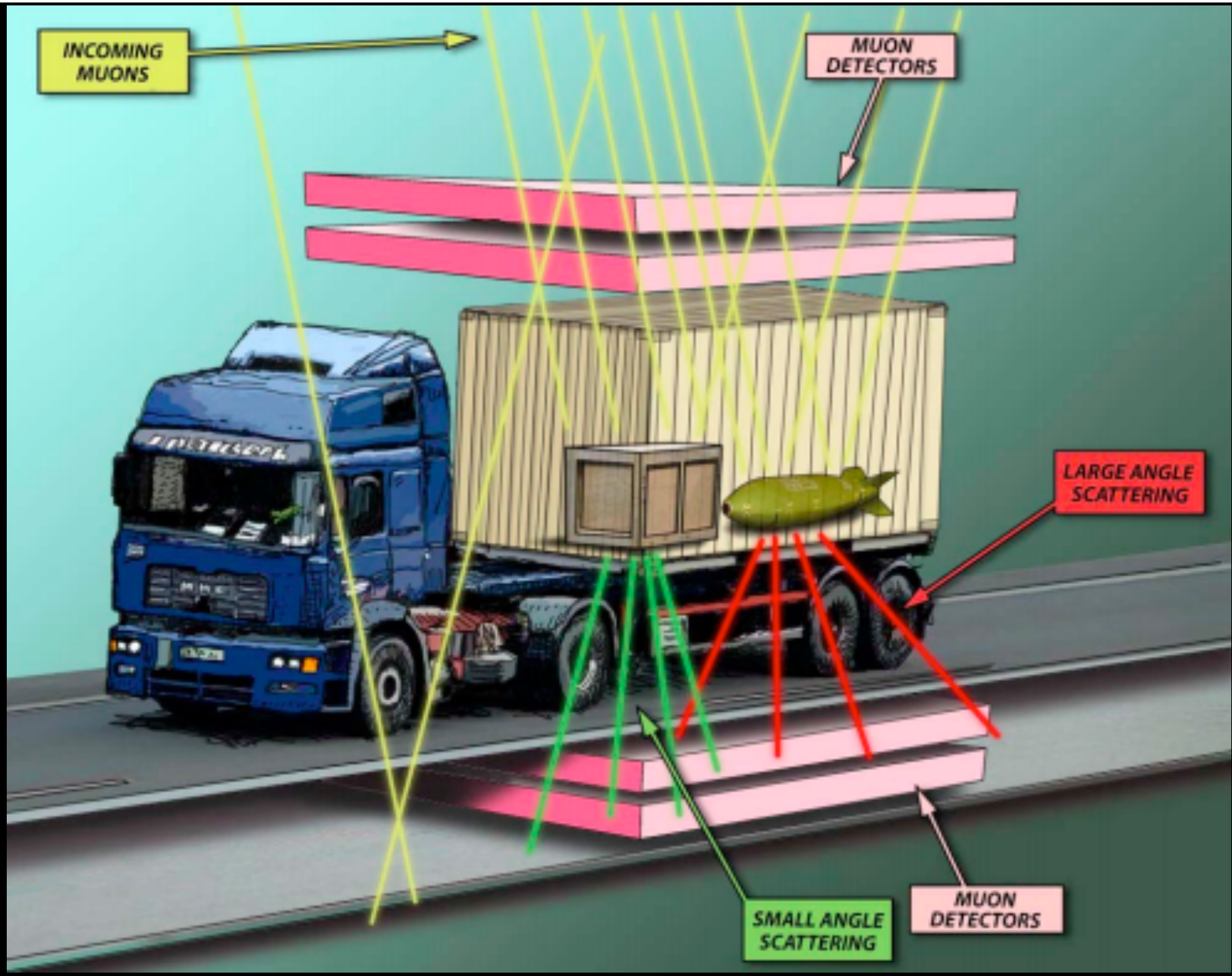

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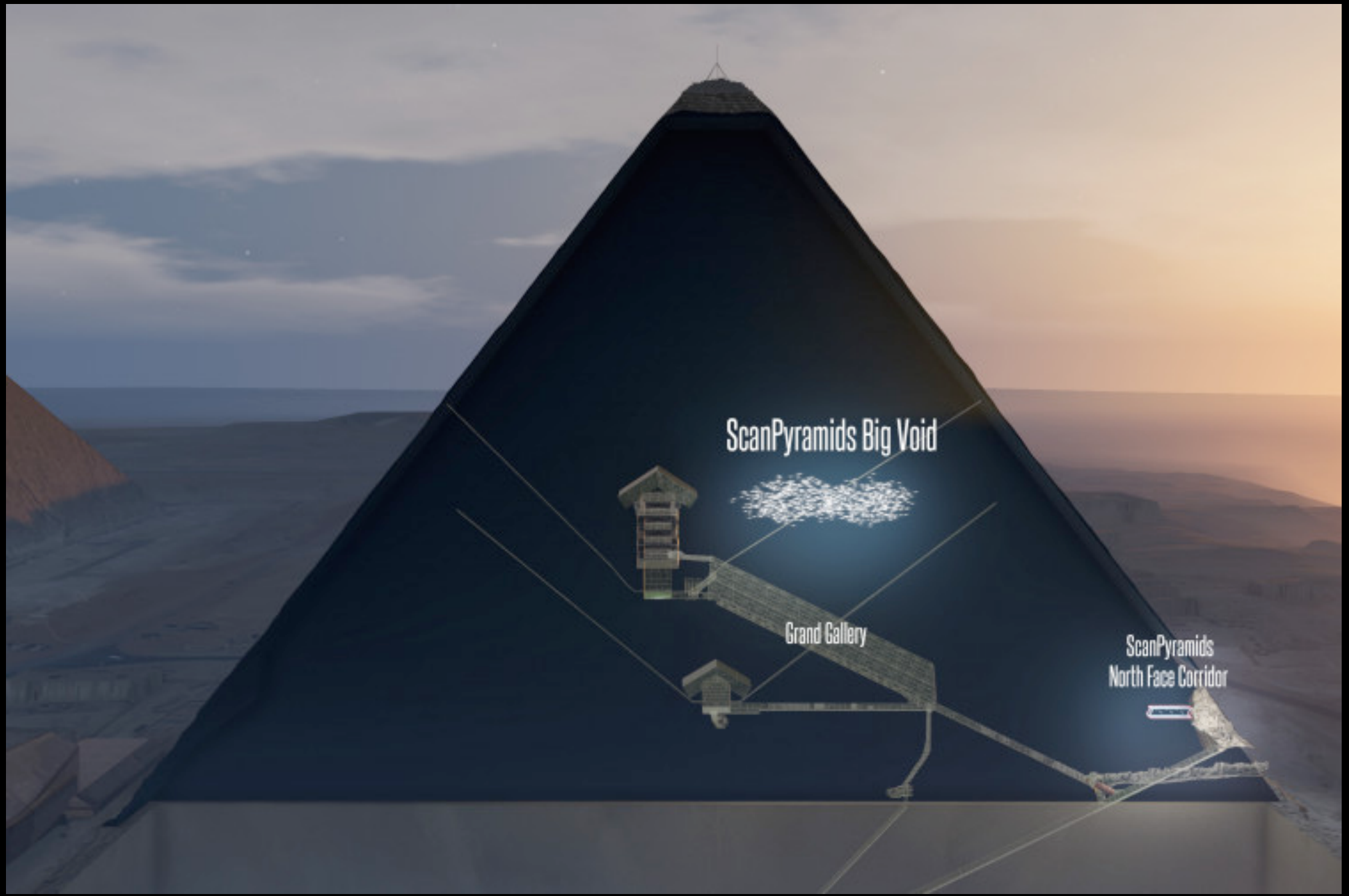

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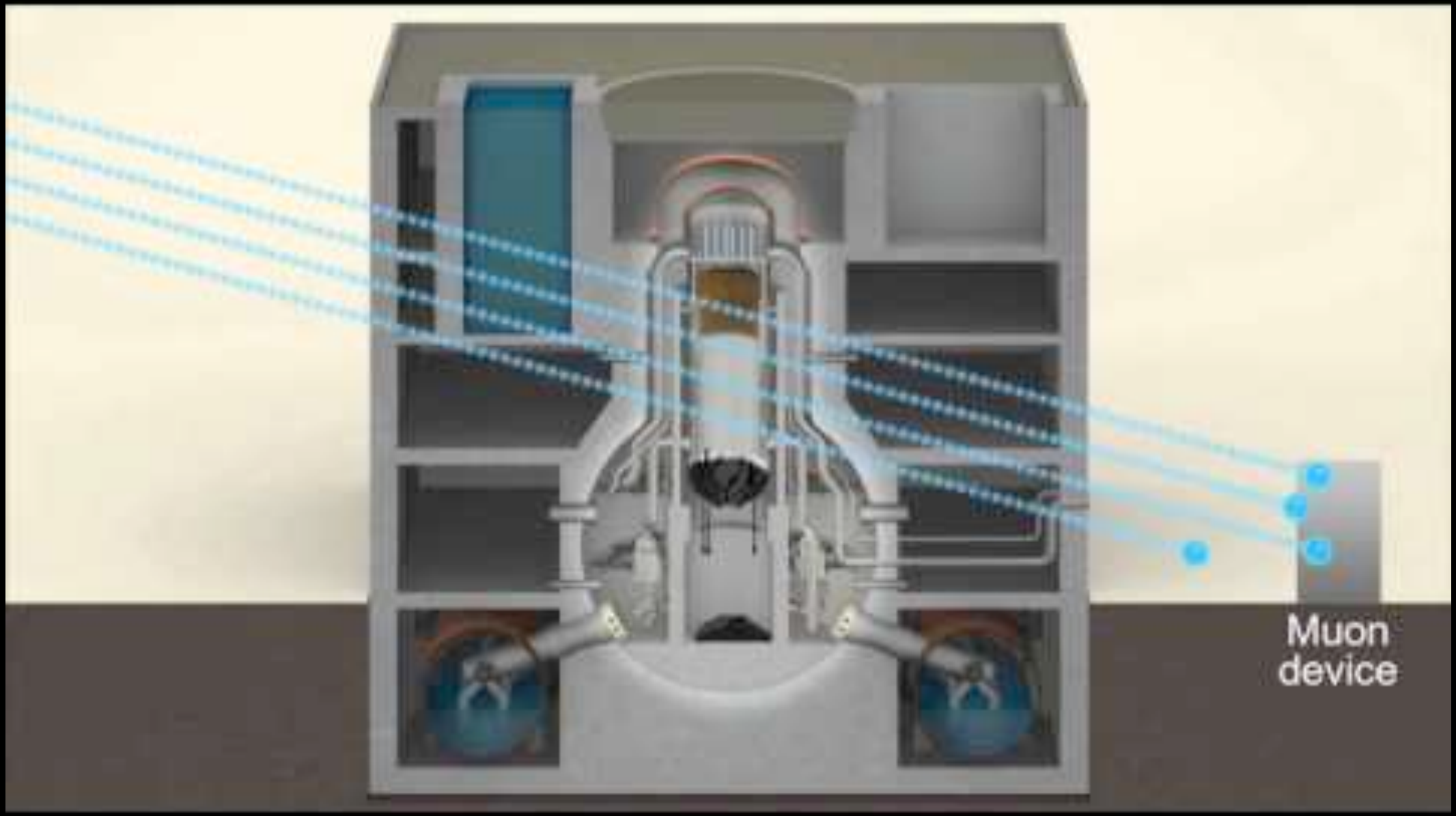

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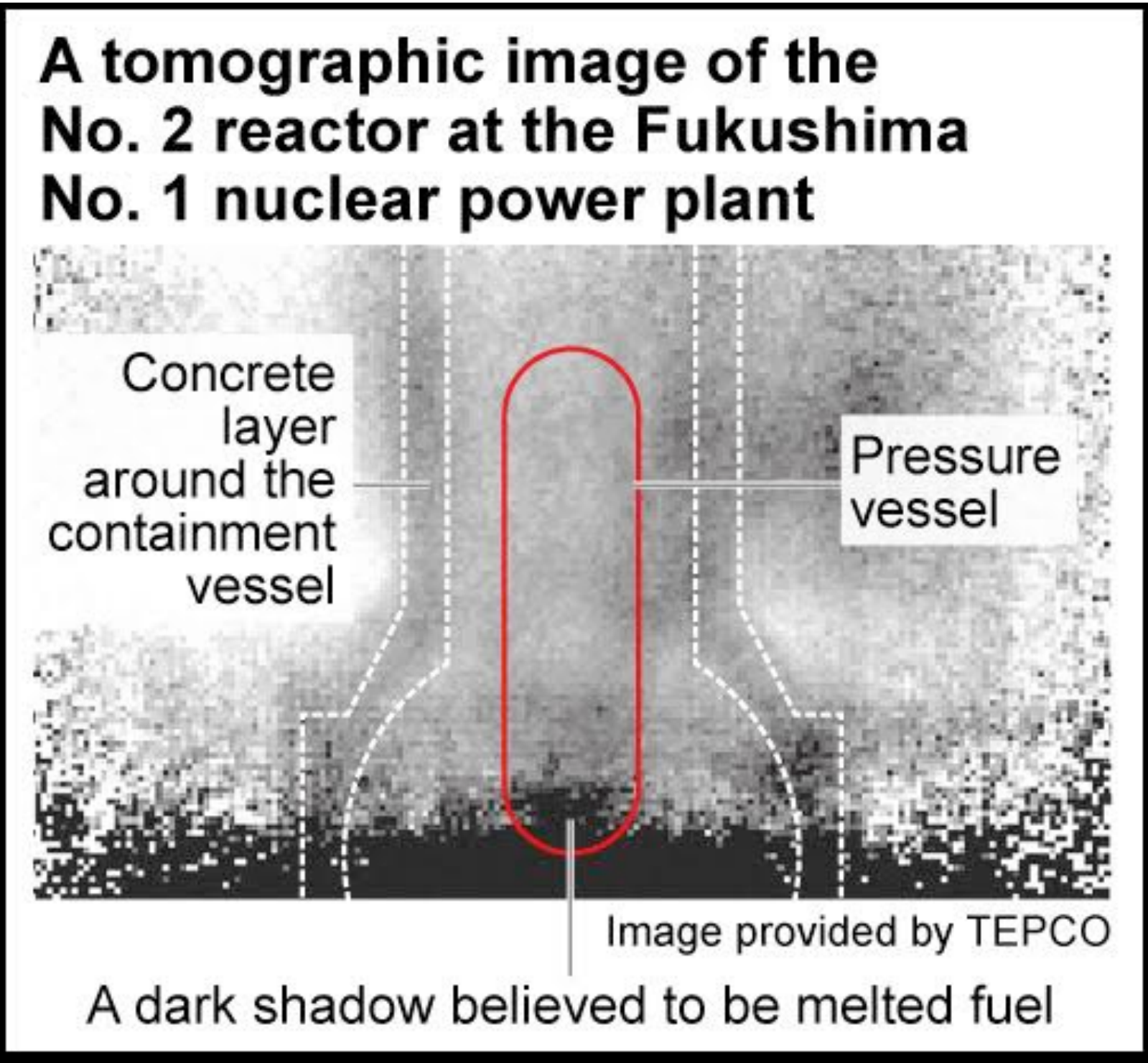

Finally, a bit more about cosmic rays

Many measurements of cosmic rays have been made, they are mostly very high energy protons hitting the upper atmosphere producing a large shower of secondary particles. Muons live the longest, to reach ground.

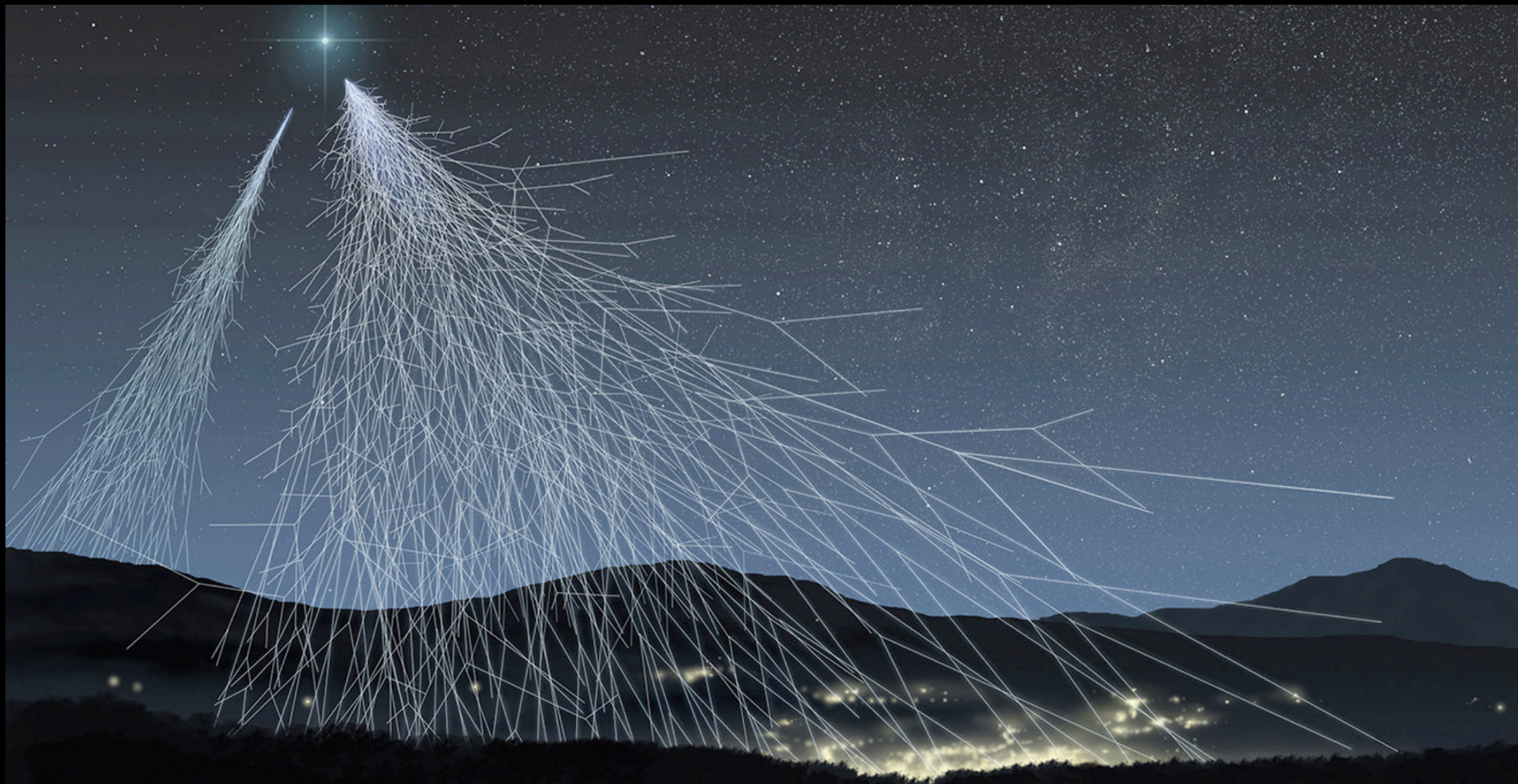

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Photo from Pierre Auger observatory

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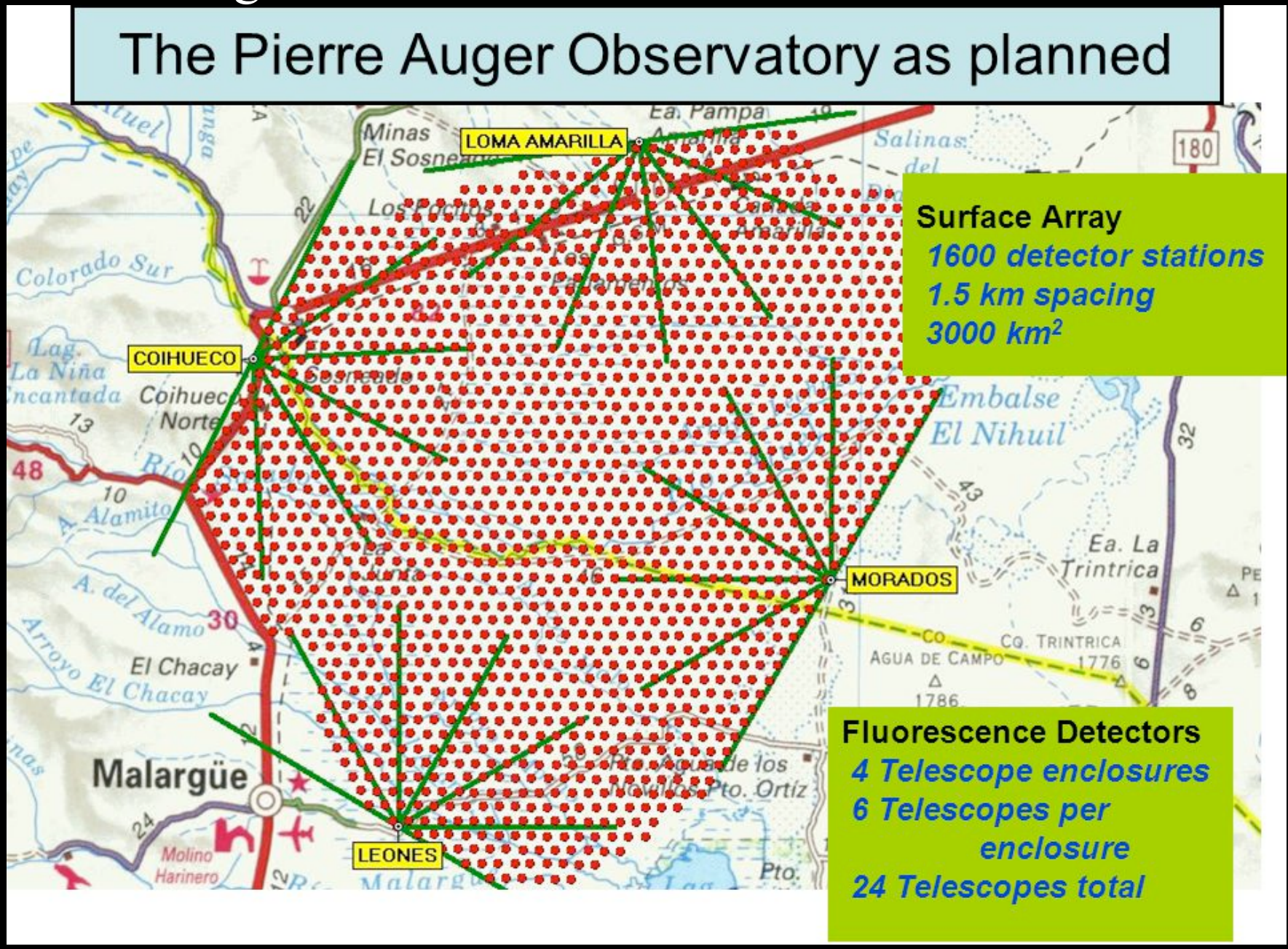

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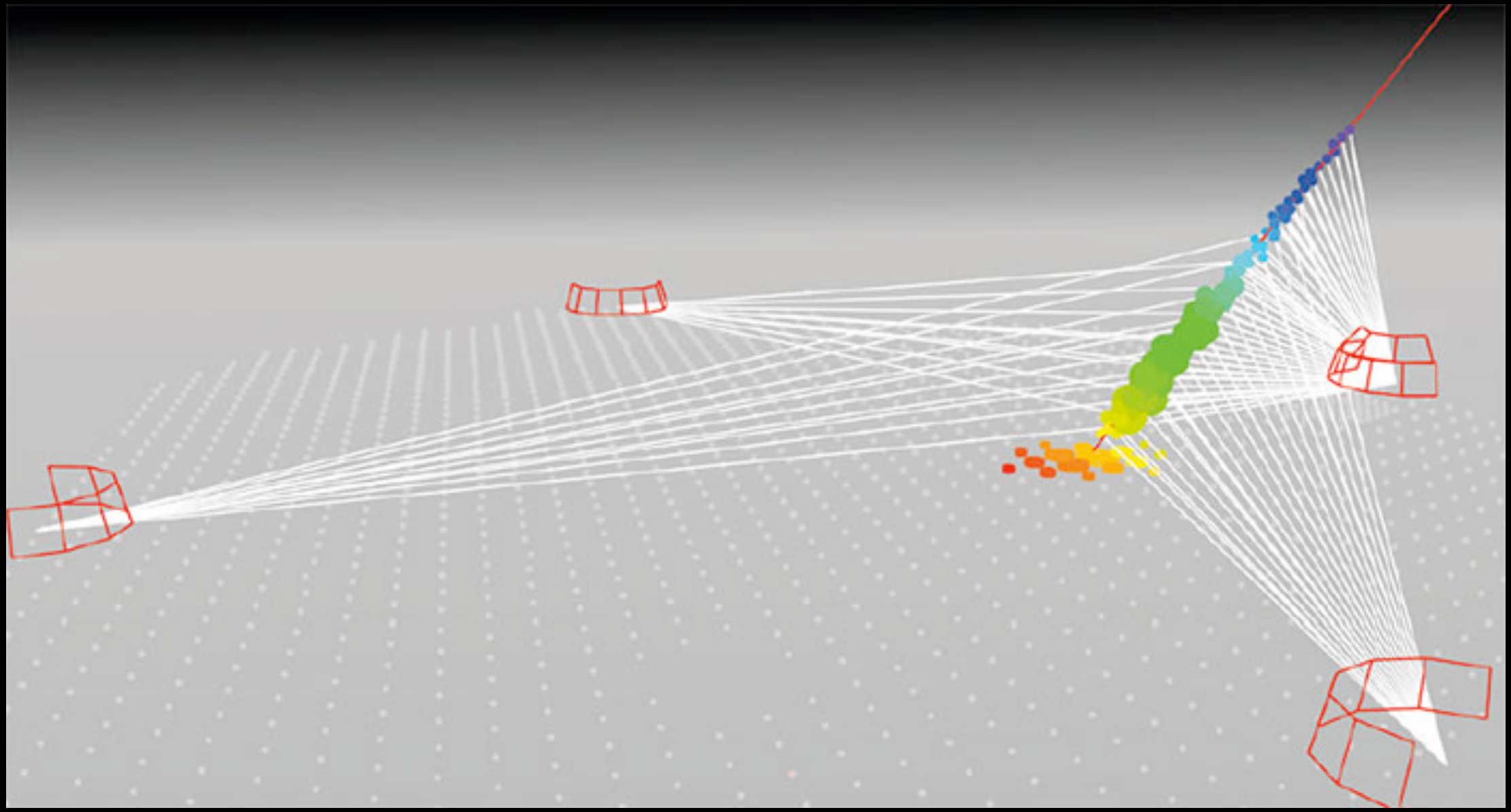

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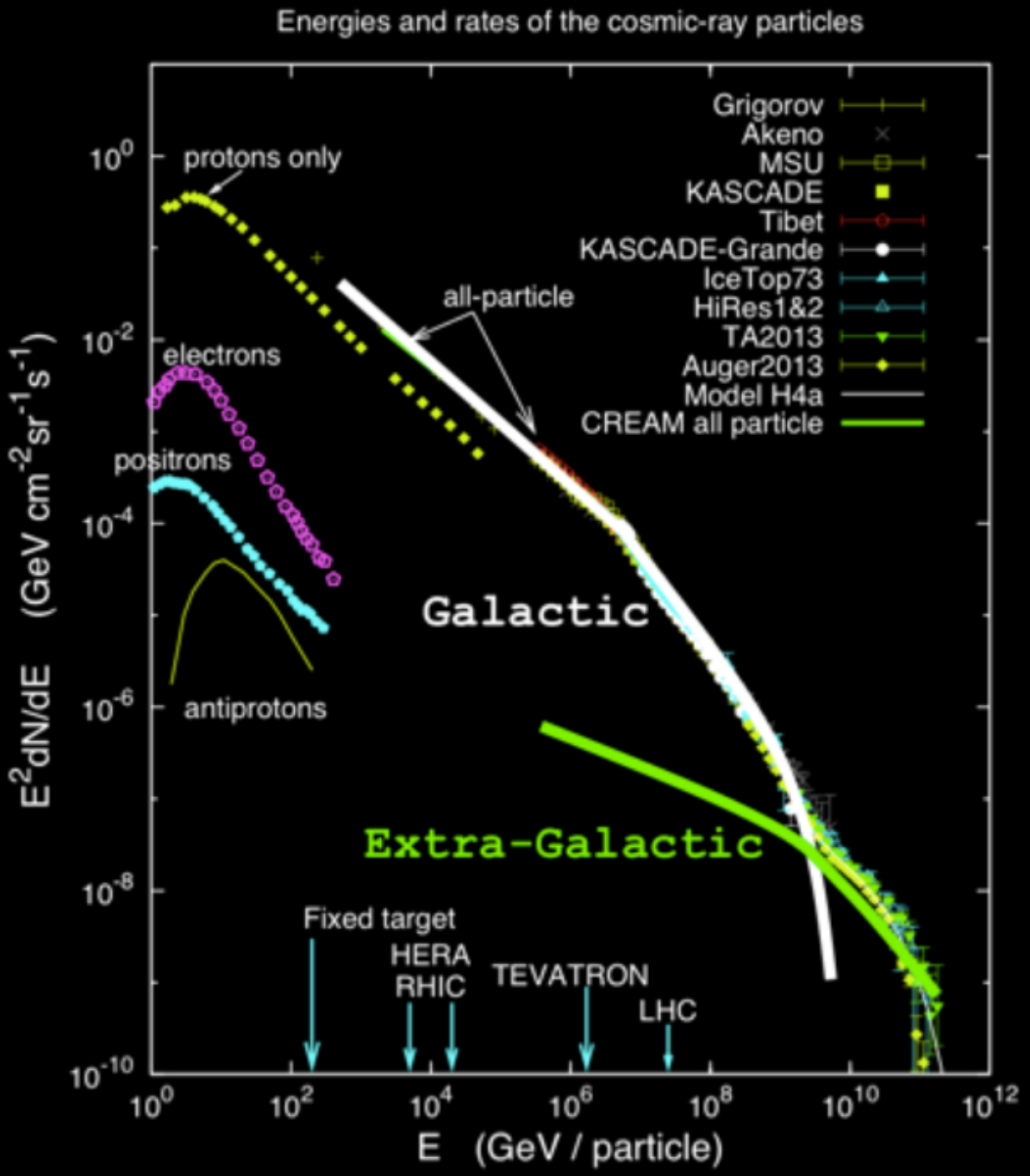
They are a rich mix in terms of particle type and source.

Extra-galactic & GZK

Stellar detritus

Antiprotons and positrons



Alpha magnetic spectrometer: Measuring cosmic rays on space station