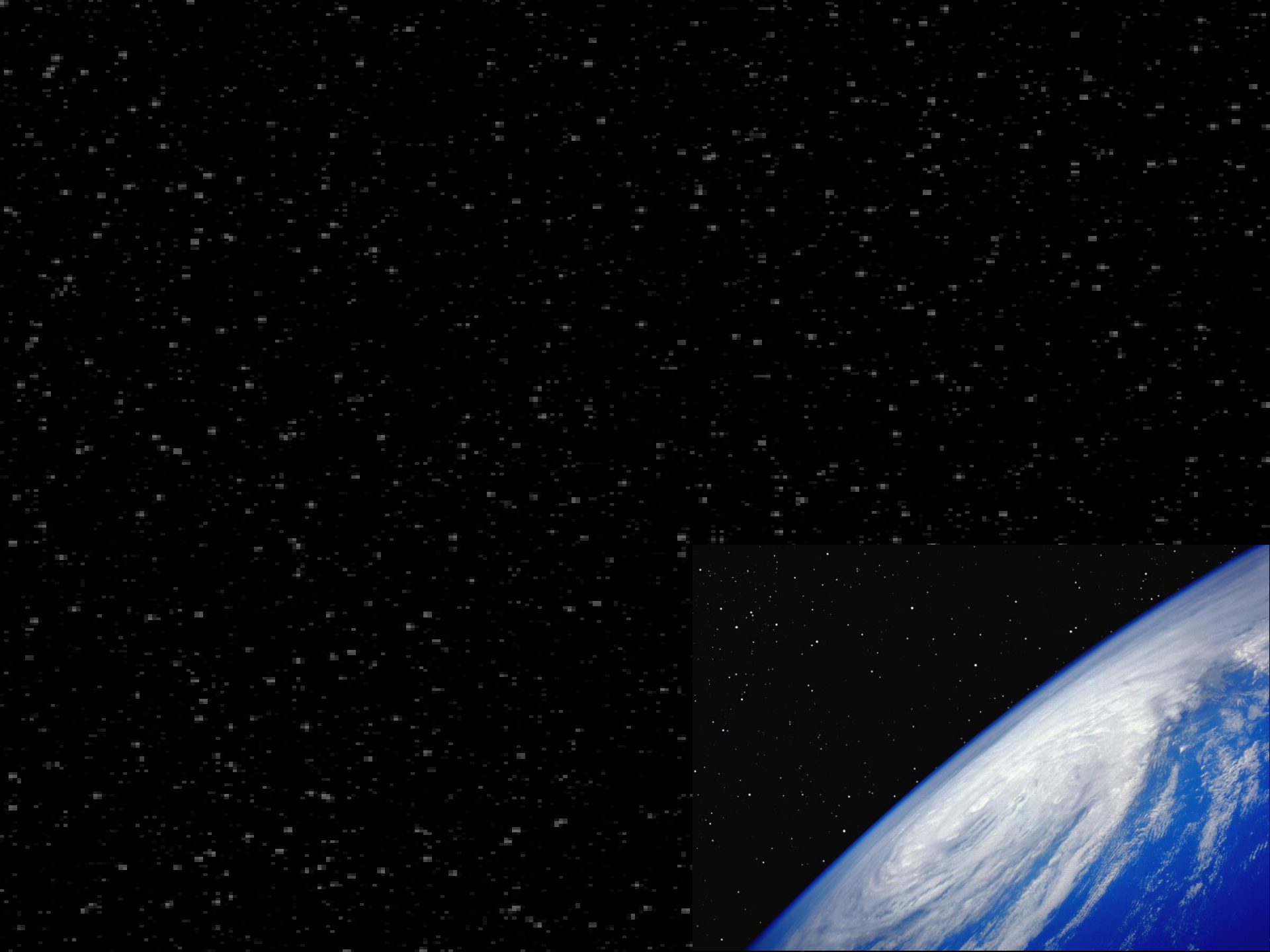


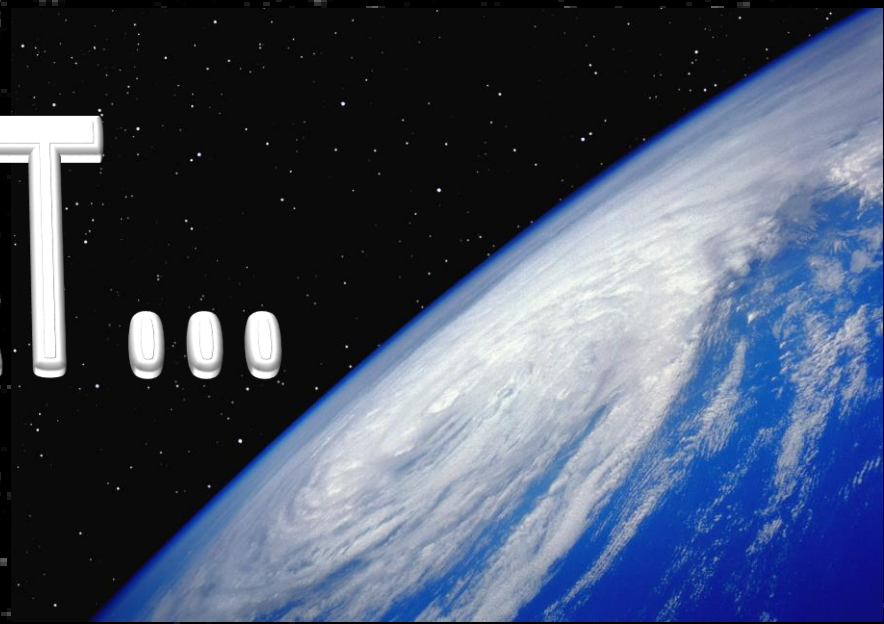
IN 1932, 4 YEARS AFTER

PAUL DIRAC

PREDICTED ITS EXISTENCE...

CARL ANDERSON DISCOVERED THE POSITRON...

THIS WAS THE FIRST INDICATION THAT...



ANTIMATTER

IS

REAL


IT
CAME FROM
OUTER SPACE

Cosmic Rays

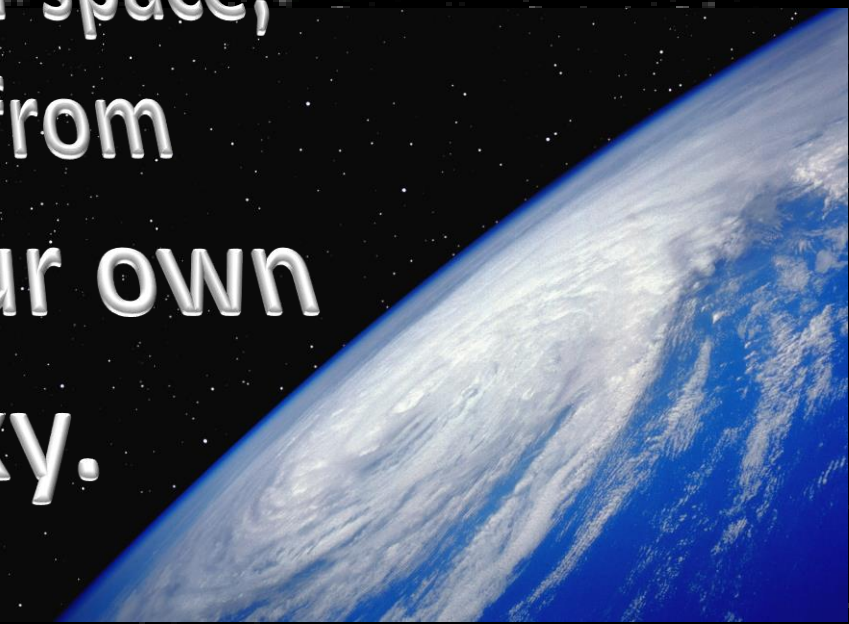
COMING

TO AN

ATMOSPHERE

NEAR YOU!

Cosmic "rays" are actually
high energy PARTICLES.
Most of them are protons.
Some of them come from our Sun,
but the most energetic come from
deep in outer space,
possibly from
outside our own
Galaxy.



When

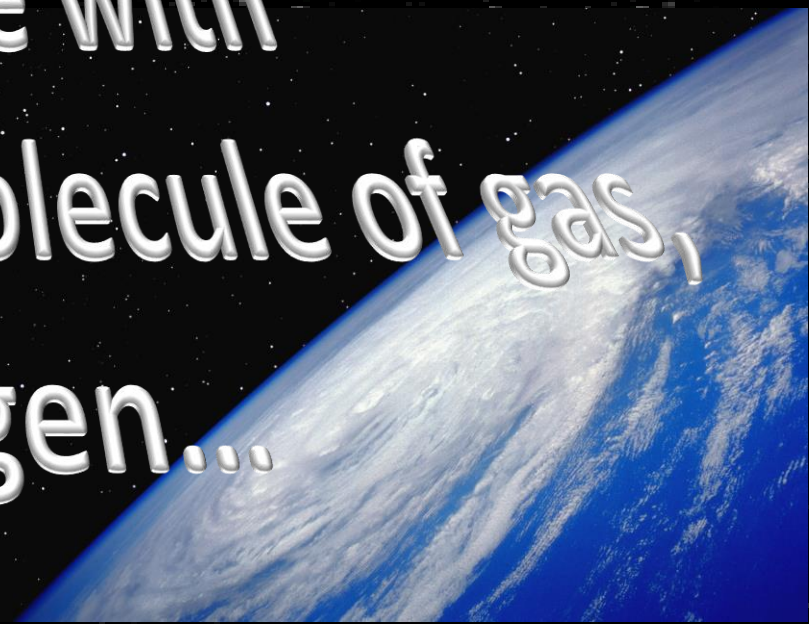
a high energy proton

enters the Earth's atmosphere,

it will collide with

the nucleus of a molecule of gas,

like nitrogen...

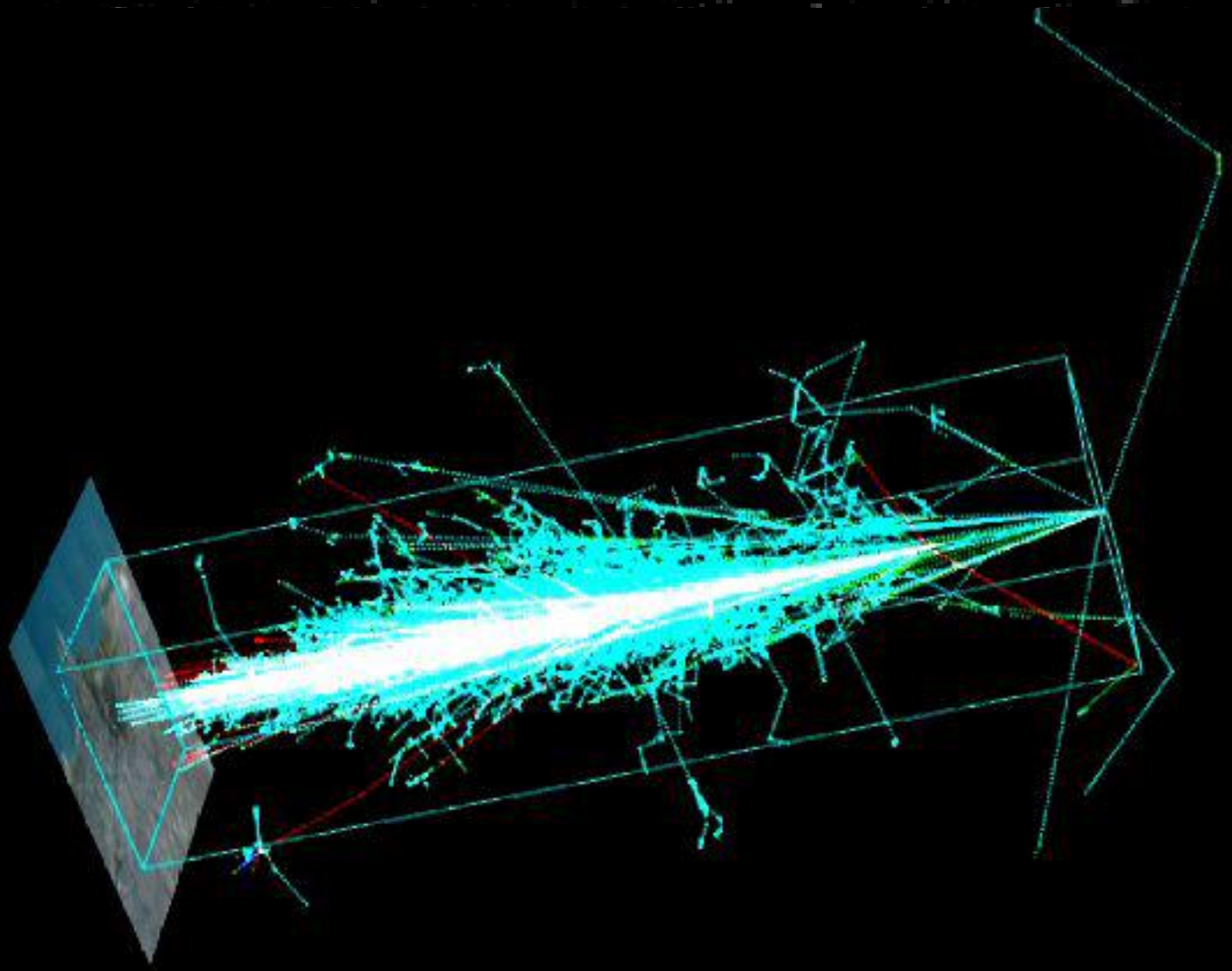


...and

that's when

the show

BEGINS....

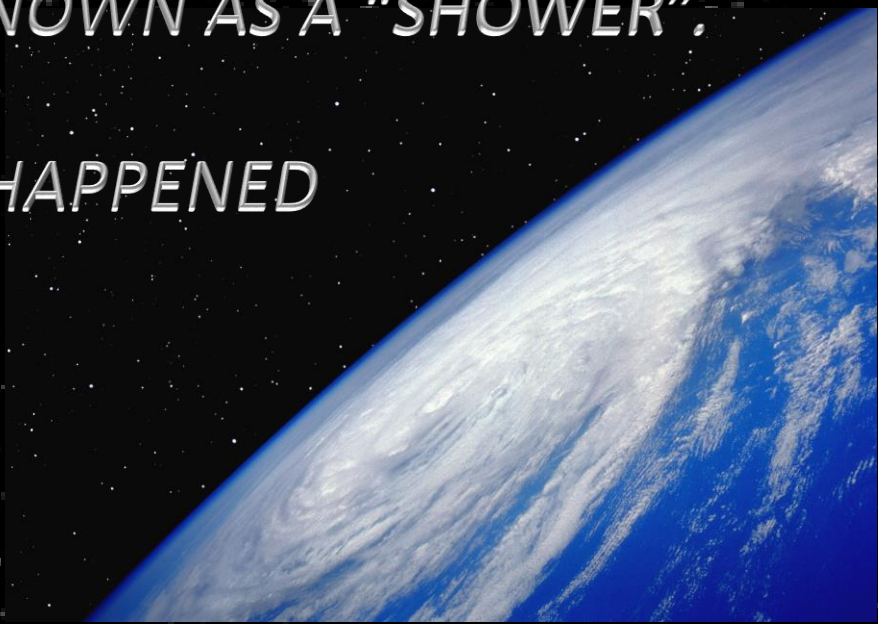


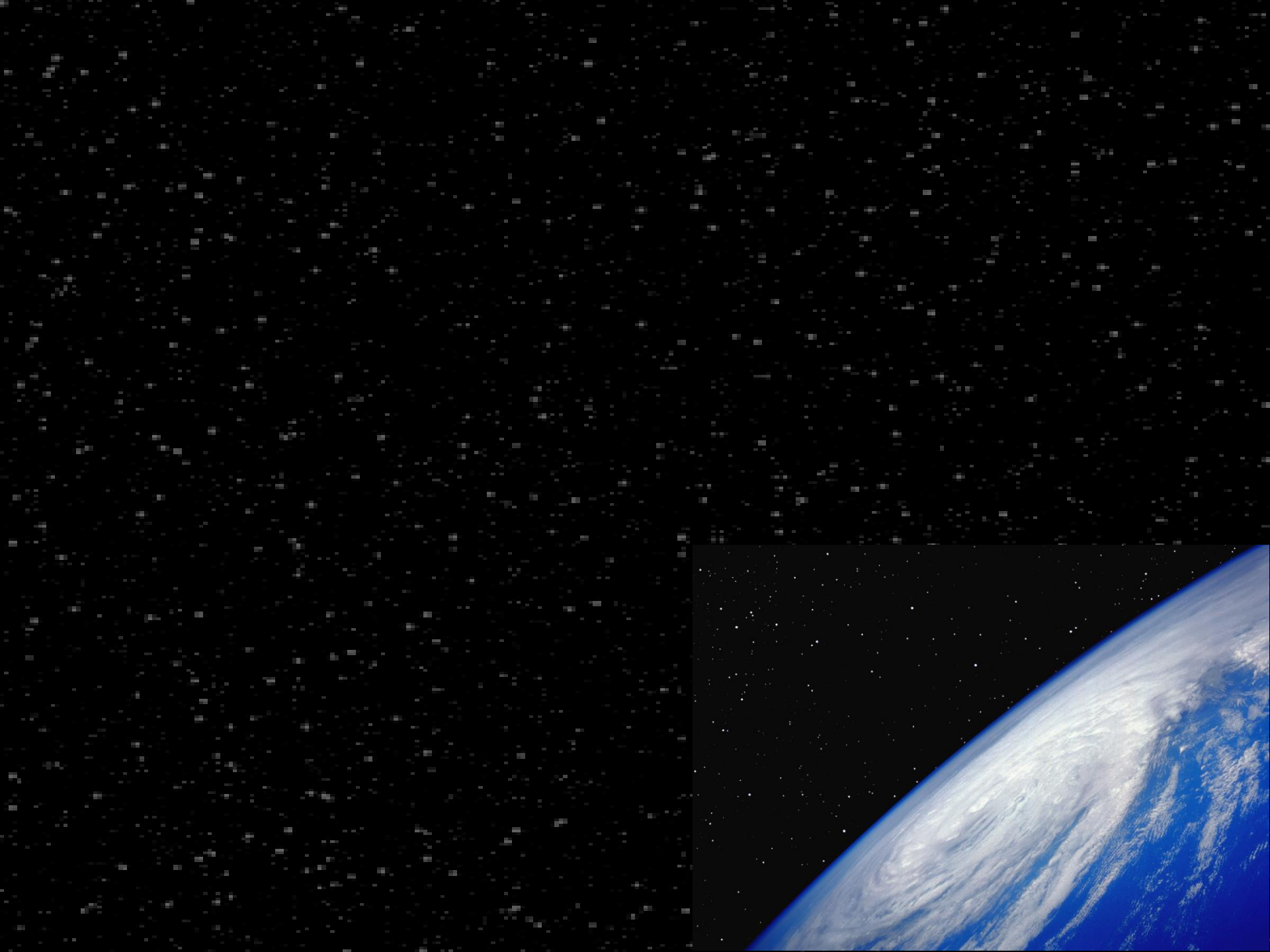
To see the animation, click on the picture

See this link for other cosmic ray animations: http://astro.uchicago.edu/cosmus/projects/aires/

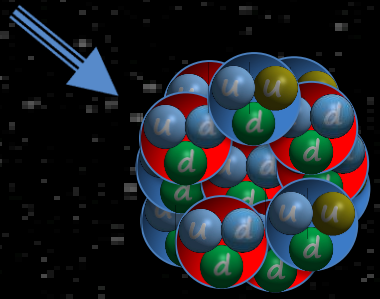
WHAT YOU HAVE JUST SEEN IS A COMPUTER SIMULATION OF A COSMIC RAY EVENT.
A HIGH ENERGY PROTON HAS COLLIDED WITH A MOLECULE OF NITROGEN GAS IN THE UPPER ATMOSPHERE. THIS HAS CAUSED A CASCADE OF SUBSEQUENT EVENTS KNOWN AS A "SHOWER".

LET'S LOOK AT WHAT JUST HAPPENED IN MORE DETAIL...

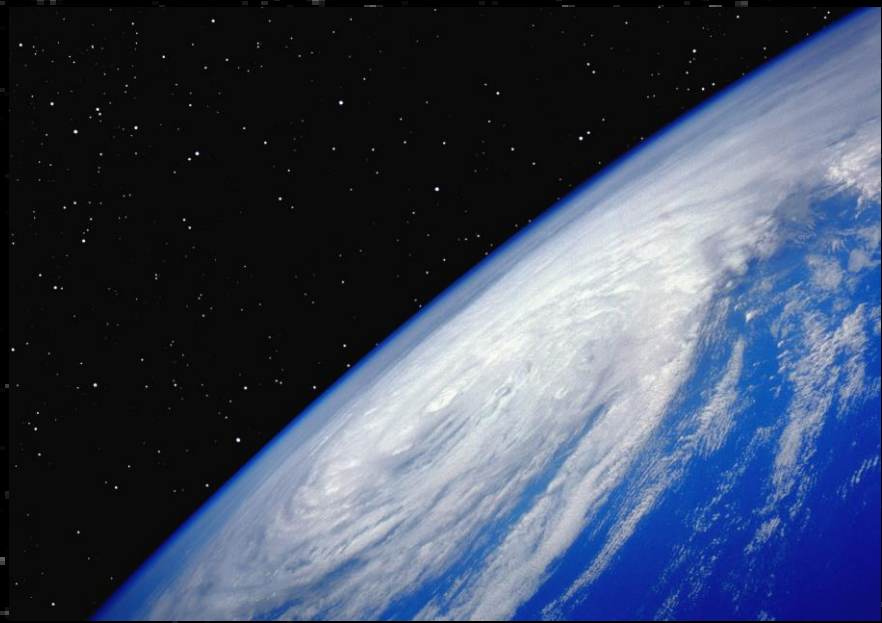


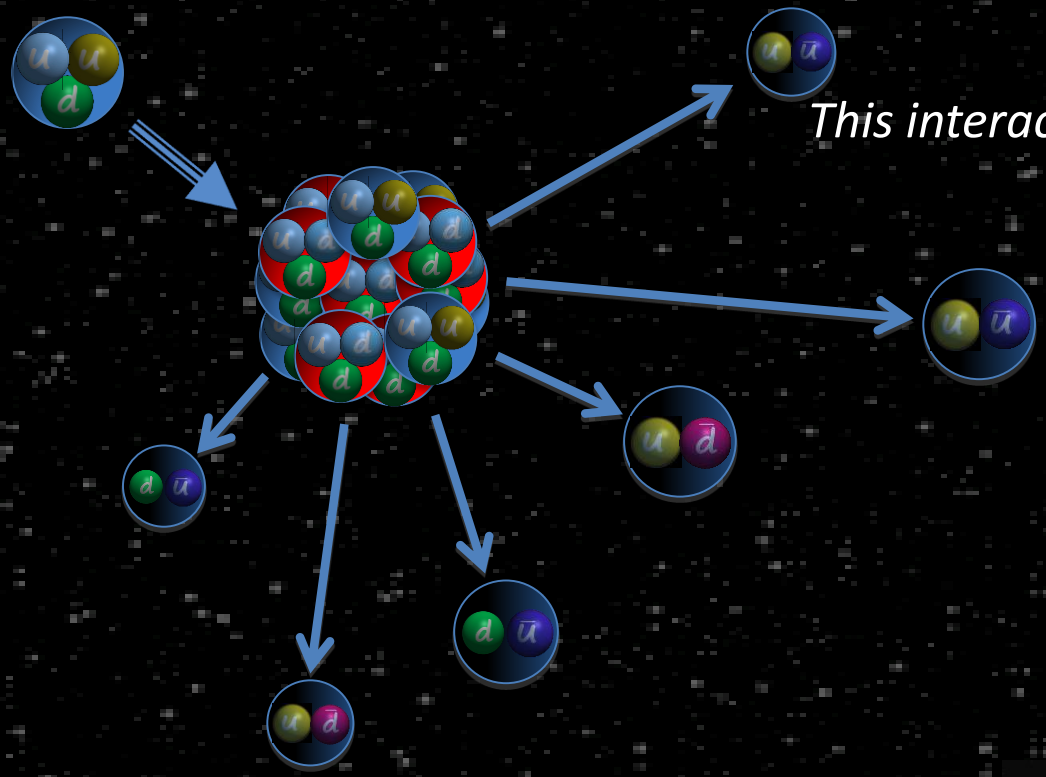


A high energy proton strikes a nitrogen nucleus.

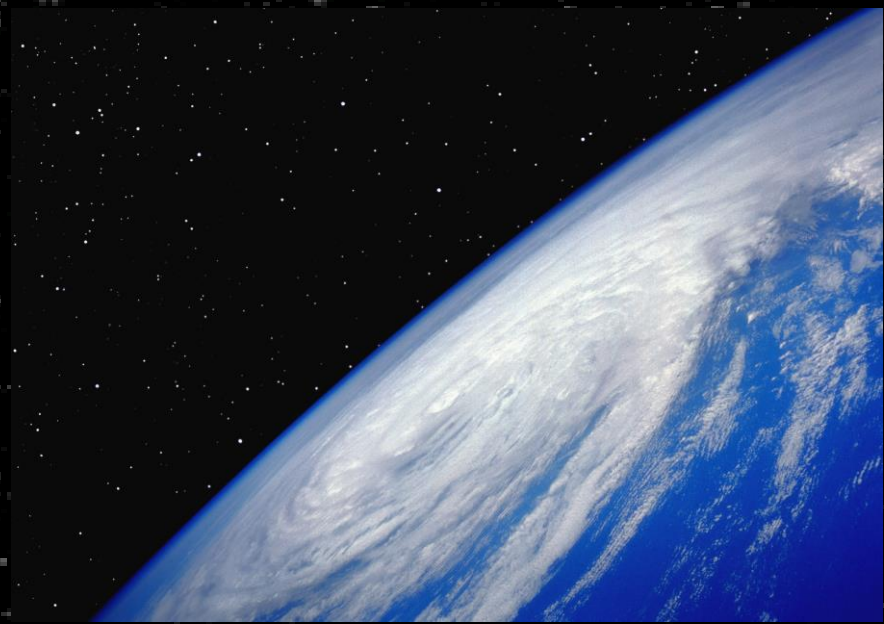


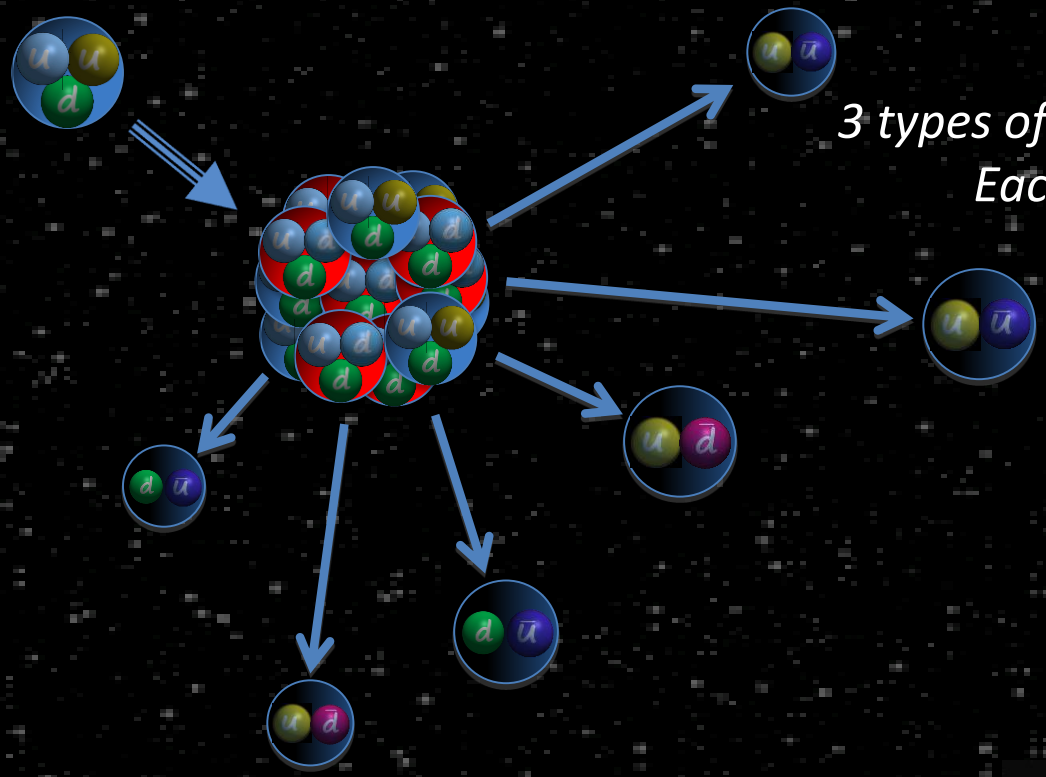
PLEASE NOTE:
PARTICLES ARE
NOT
DRAWN TO SCALE!



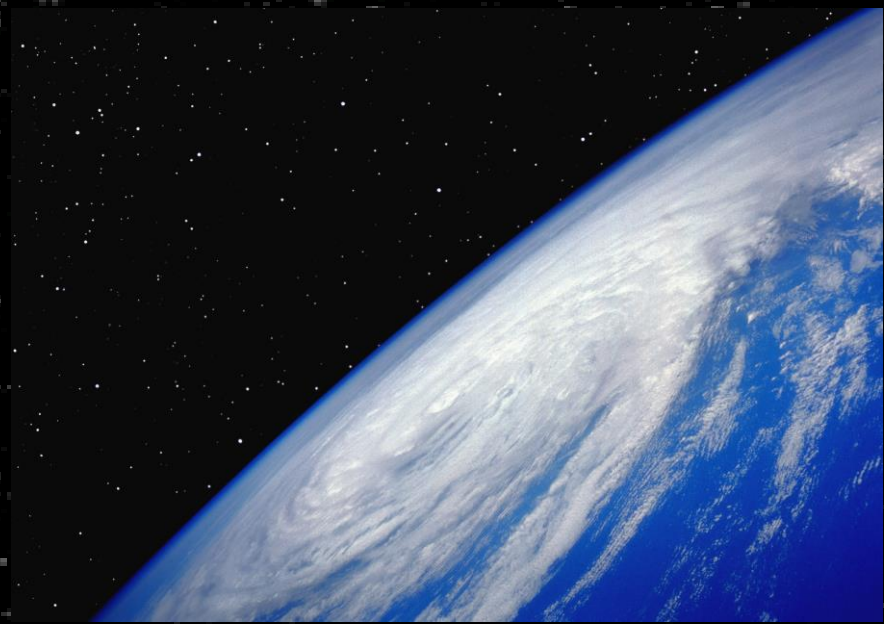


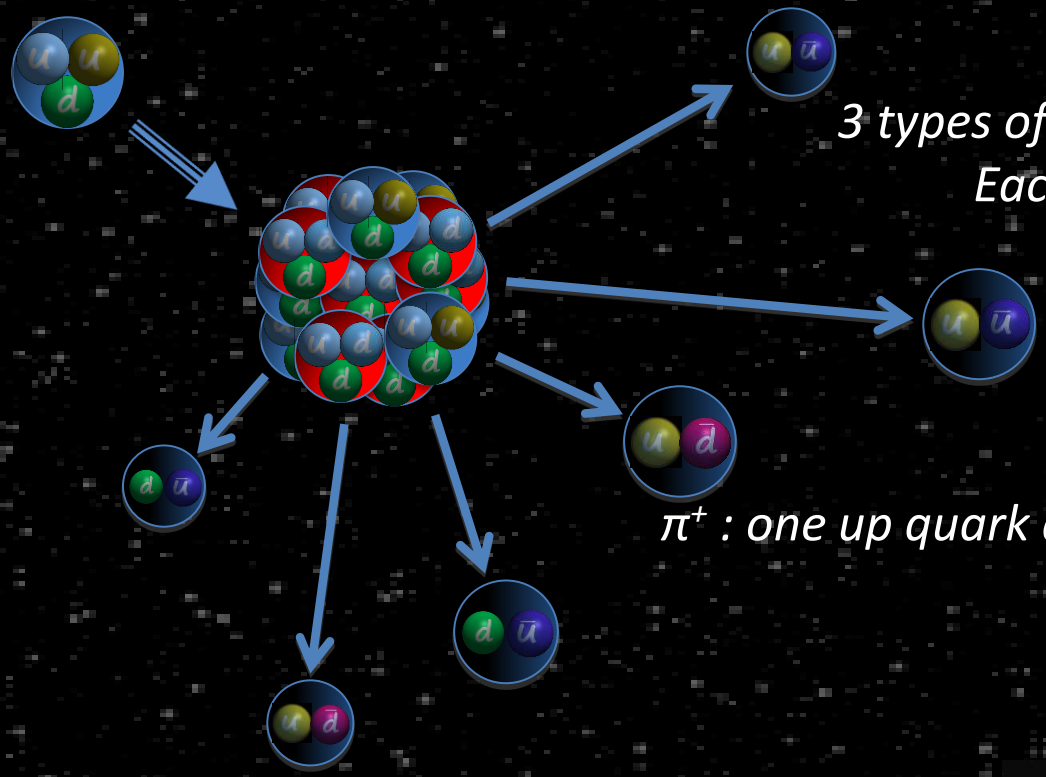
This interaction produces very unstable particles called pions.





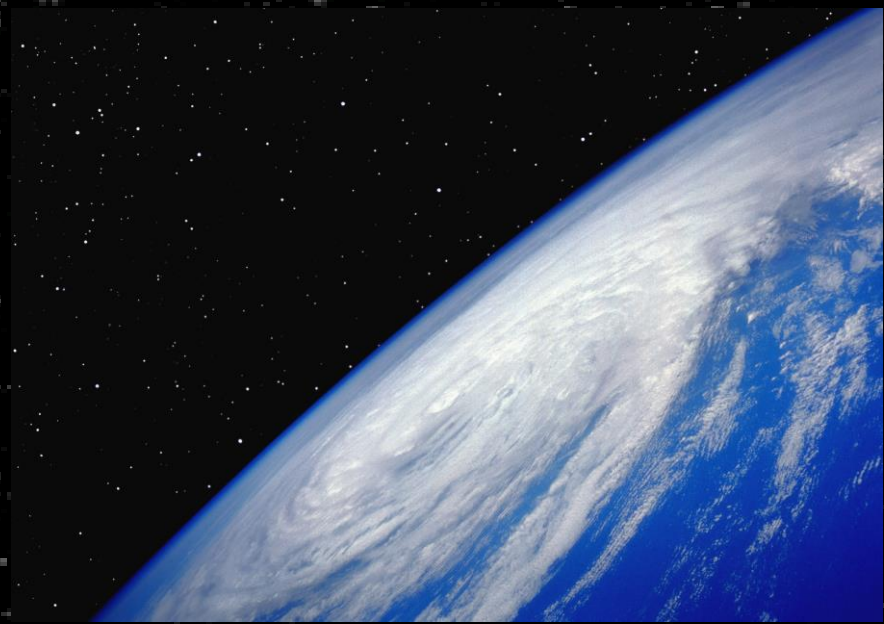
3 types of pions are produced: π^+, π^0, & π^-.
Each is composed of 2 quarks:

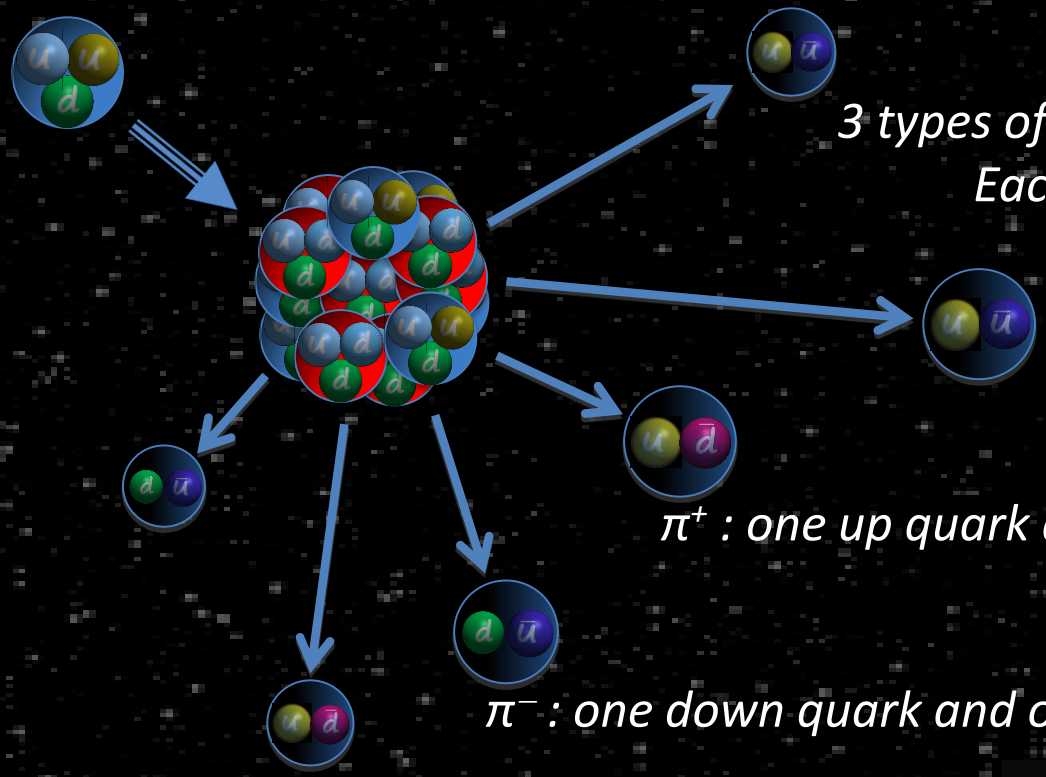




3 types of pions are produced: π^+, π^0, & π^-.
Each is composed of 2 quarks:

π^+ : one up quark and one anti-down quark

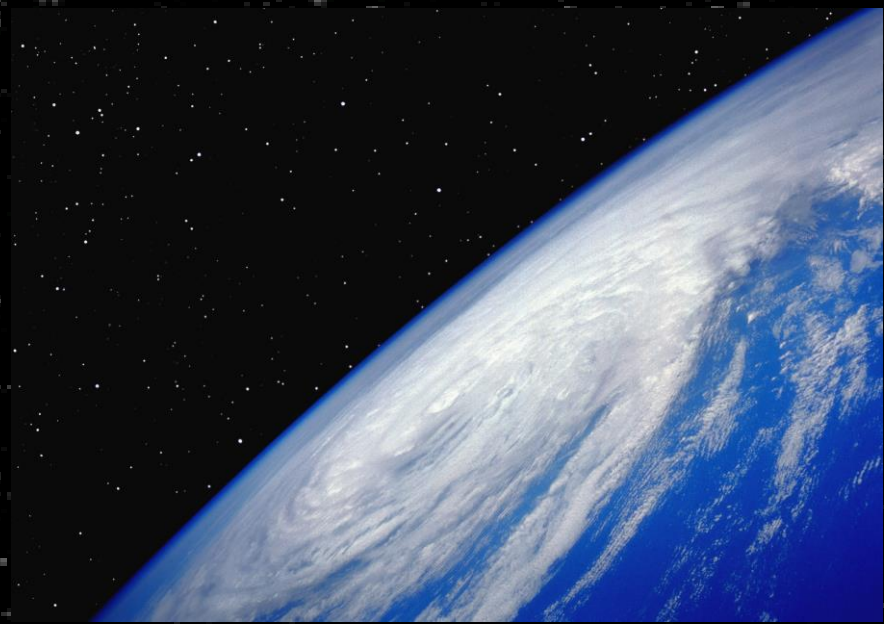


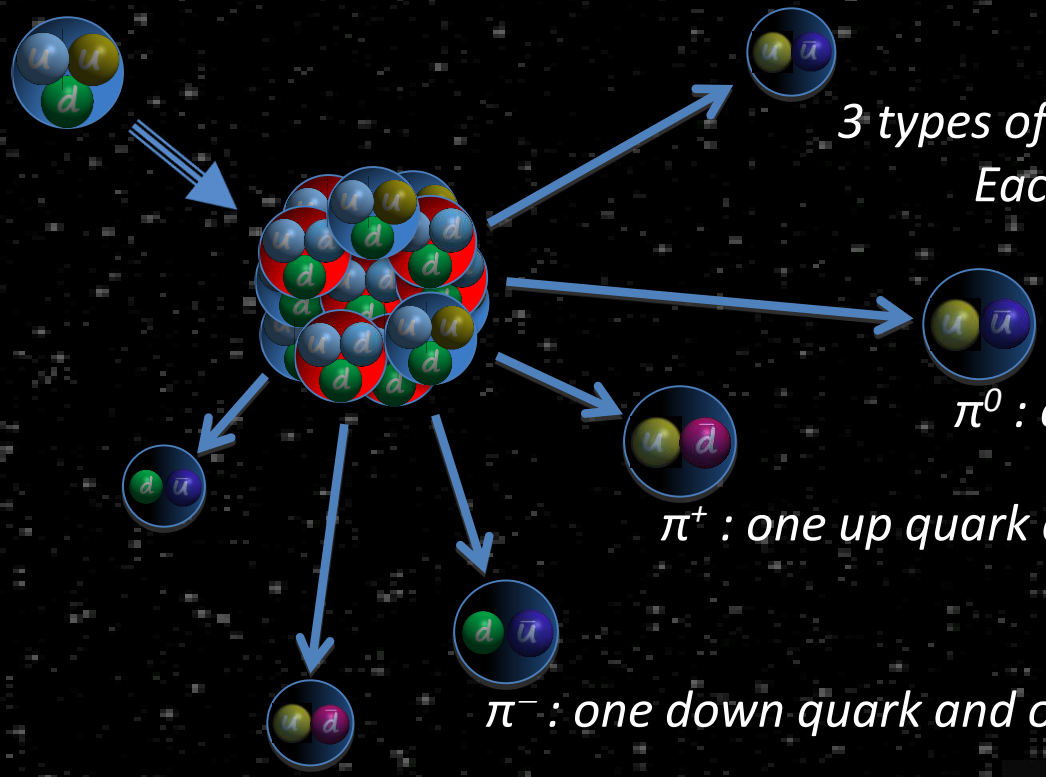


3 types of pions are produced: π^+, π^0, & π^-.
Each is composed of 2 quarks:

π^+ : one up quark and one anti-down quark

π^- : one down quark and one anti-up quark



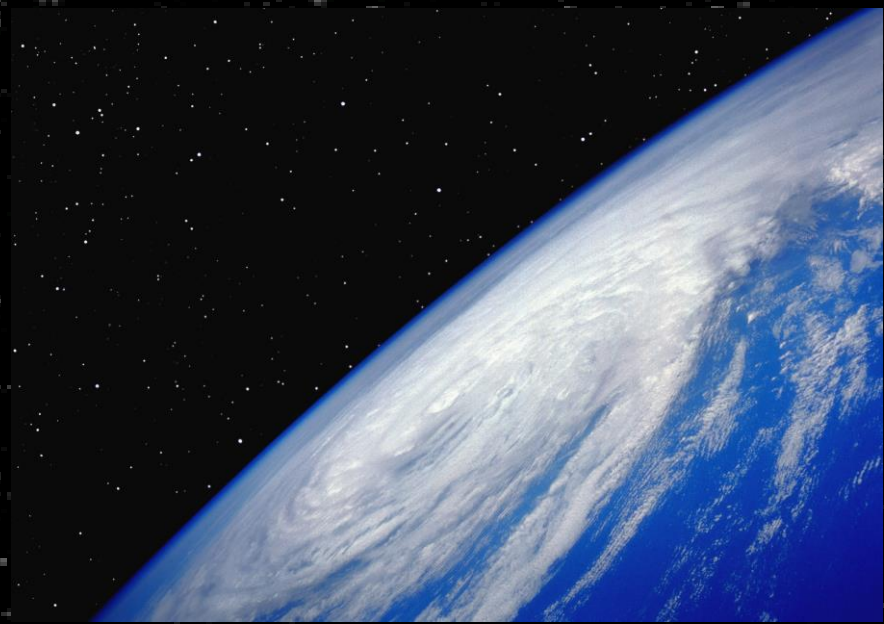


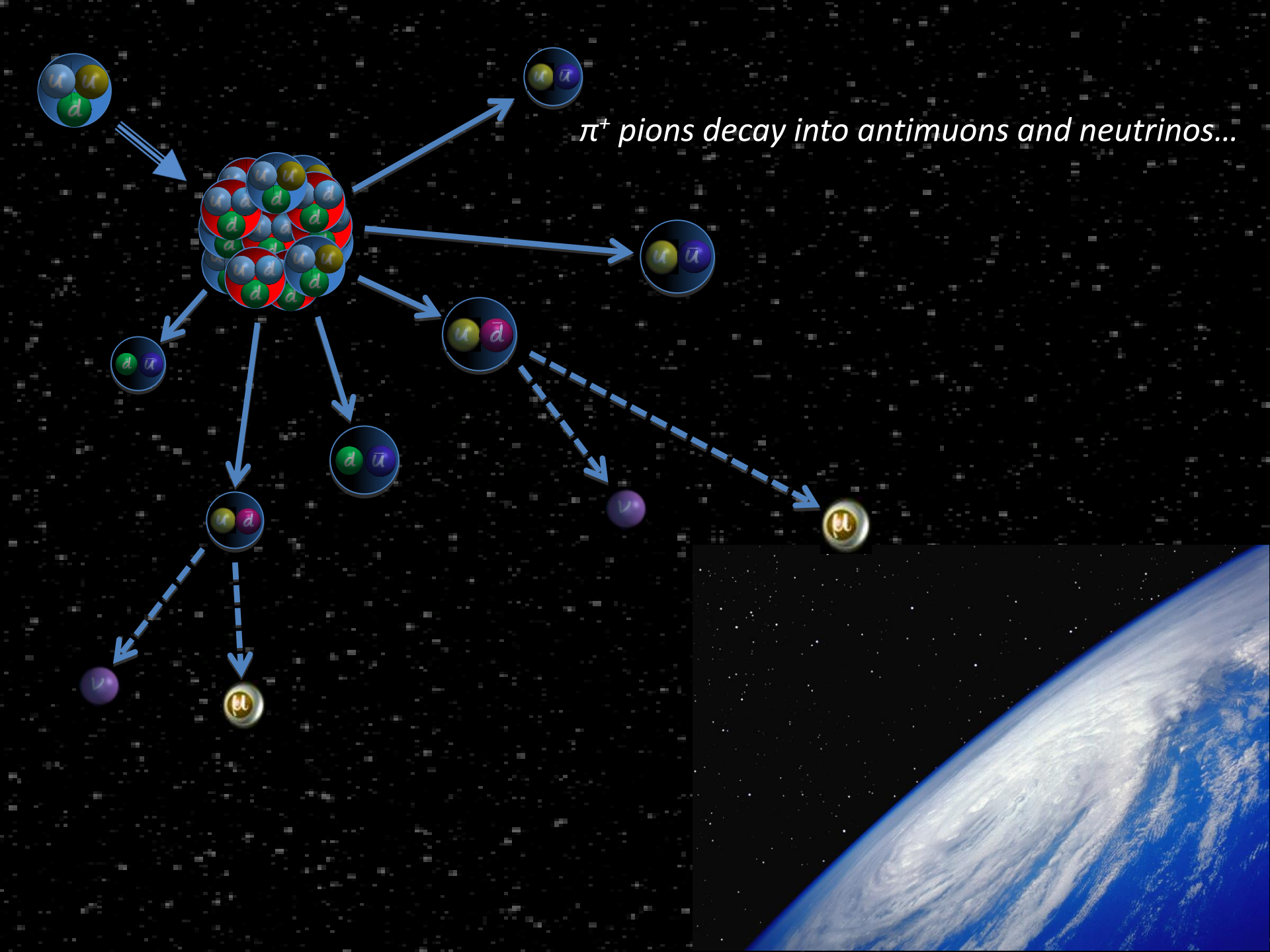
3 types of pions are produced: π^+, π^0, & π^-.
Each is composed of 2 quarks:

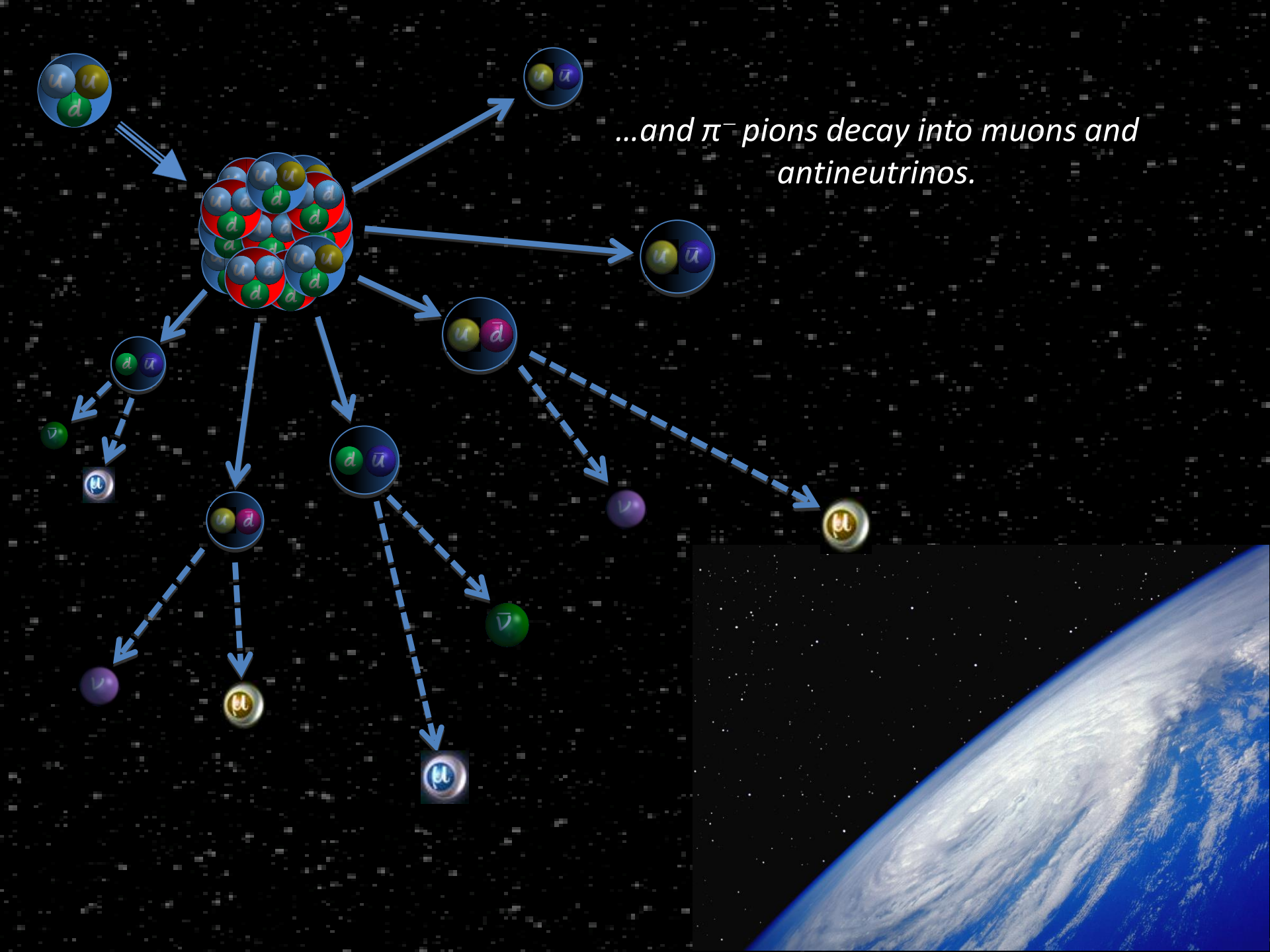
π^0 : one up quark and one anti-up quark

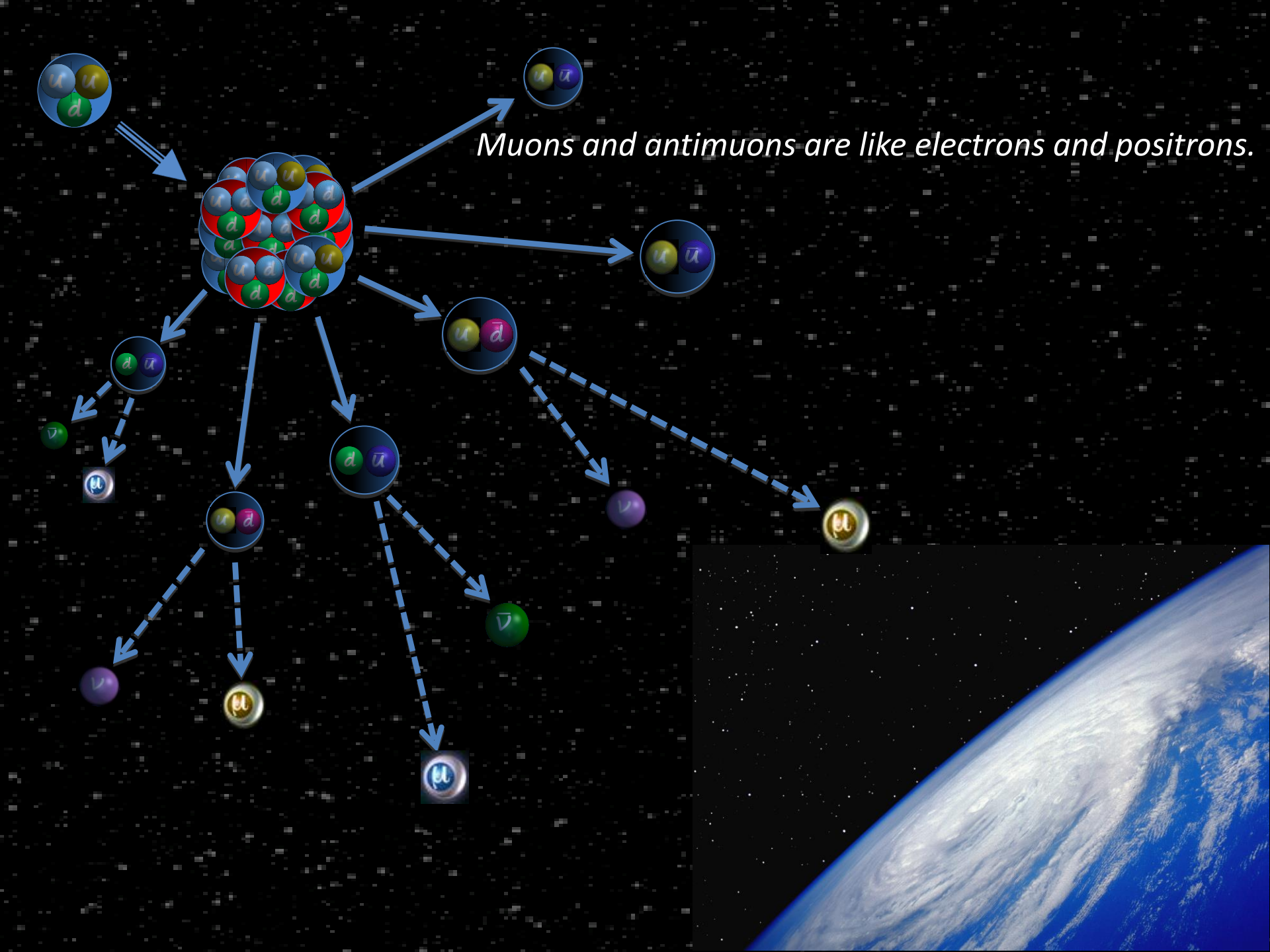
π^+ : one up quark and one anti-down quark

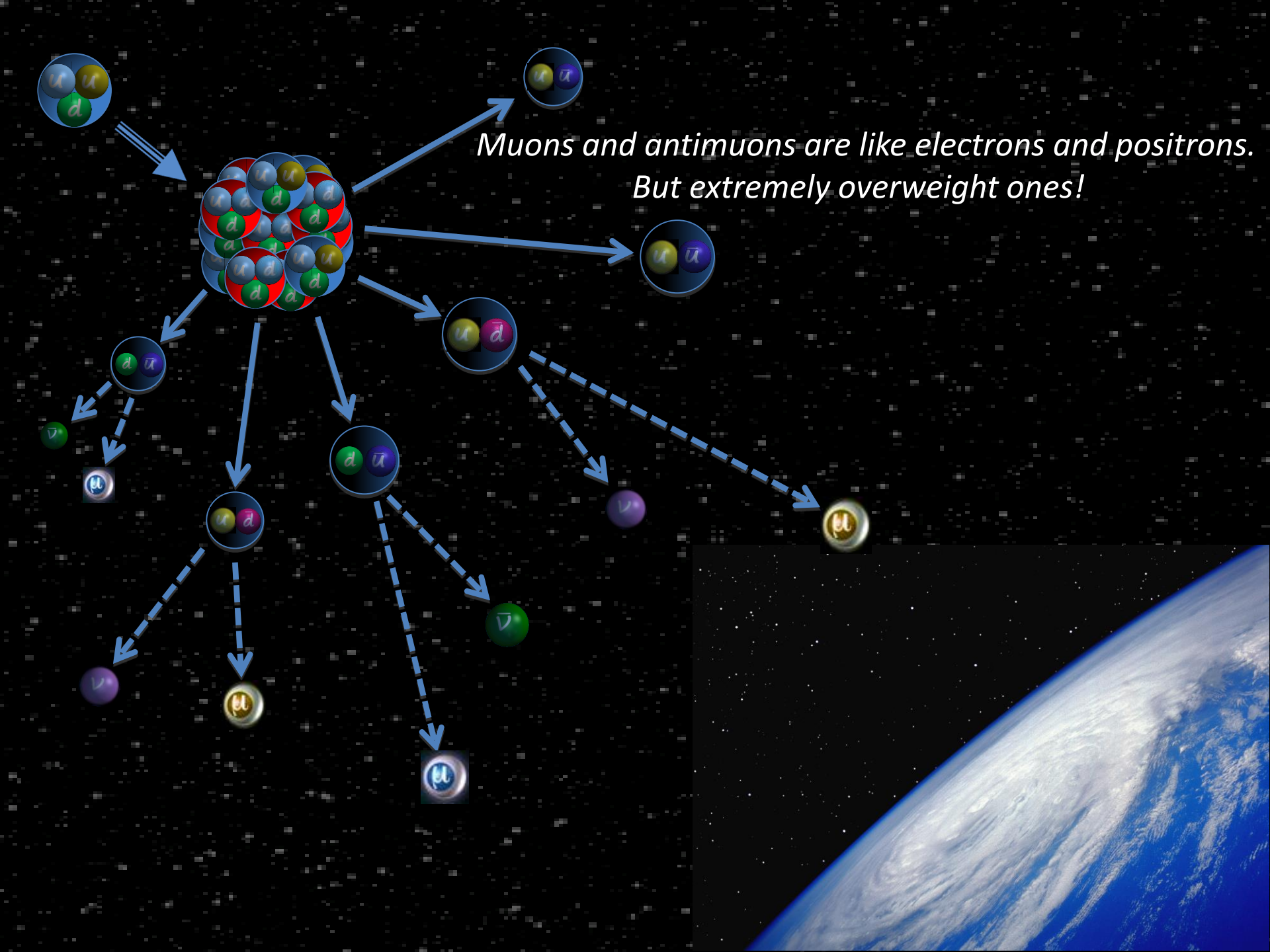
π^- : one down quark and one anti-up quark

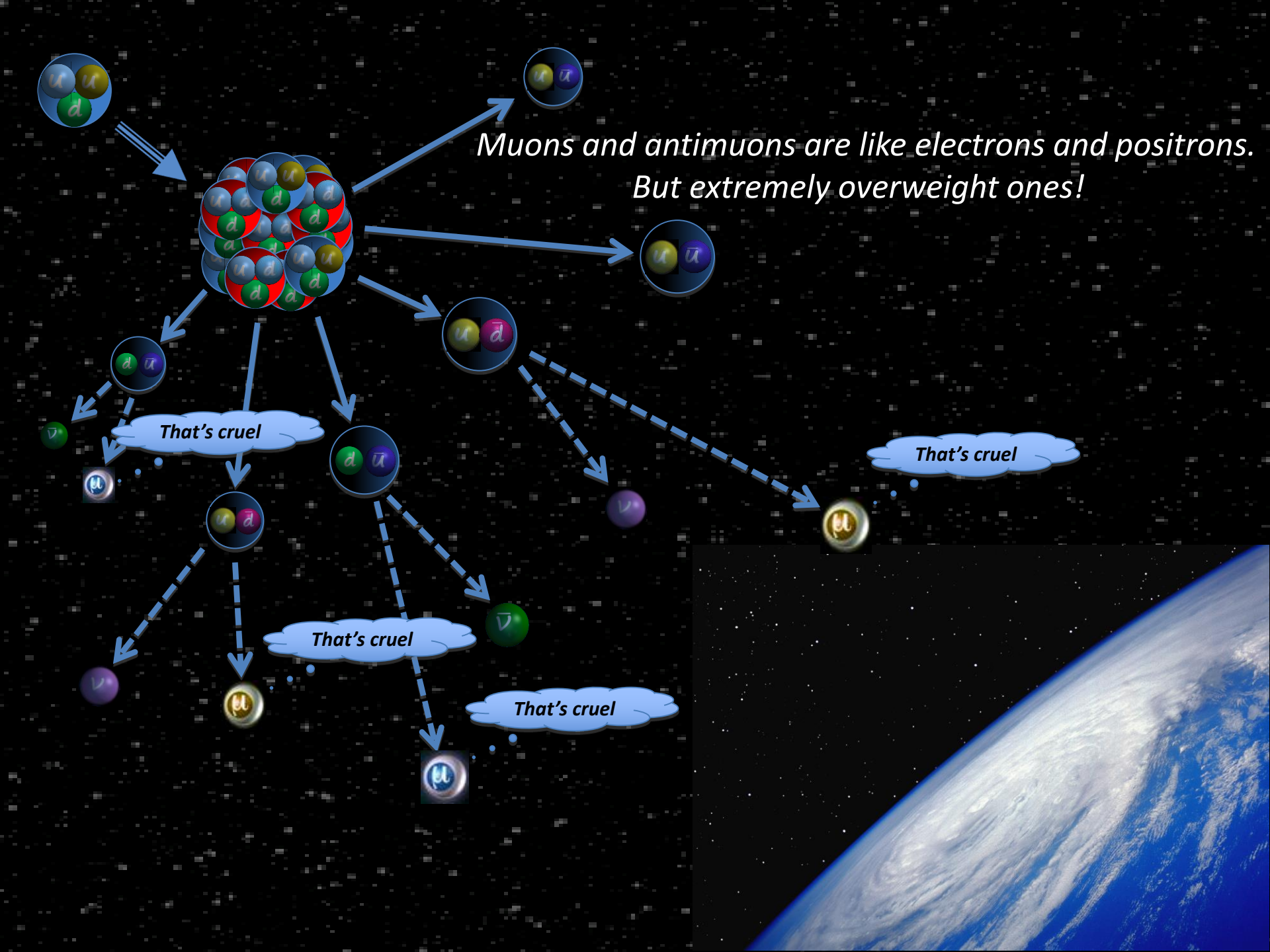


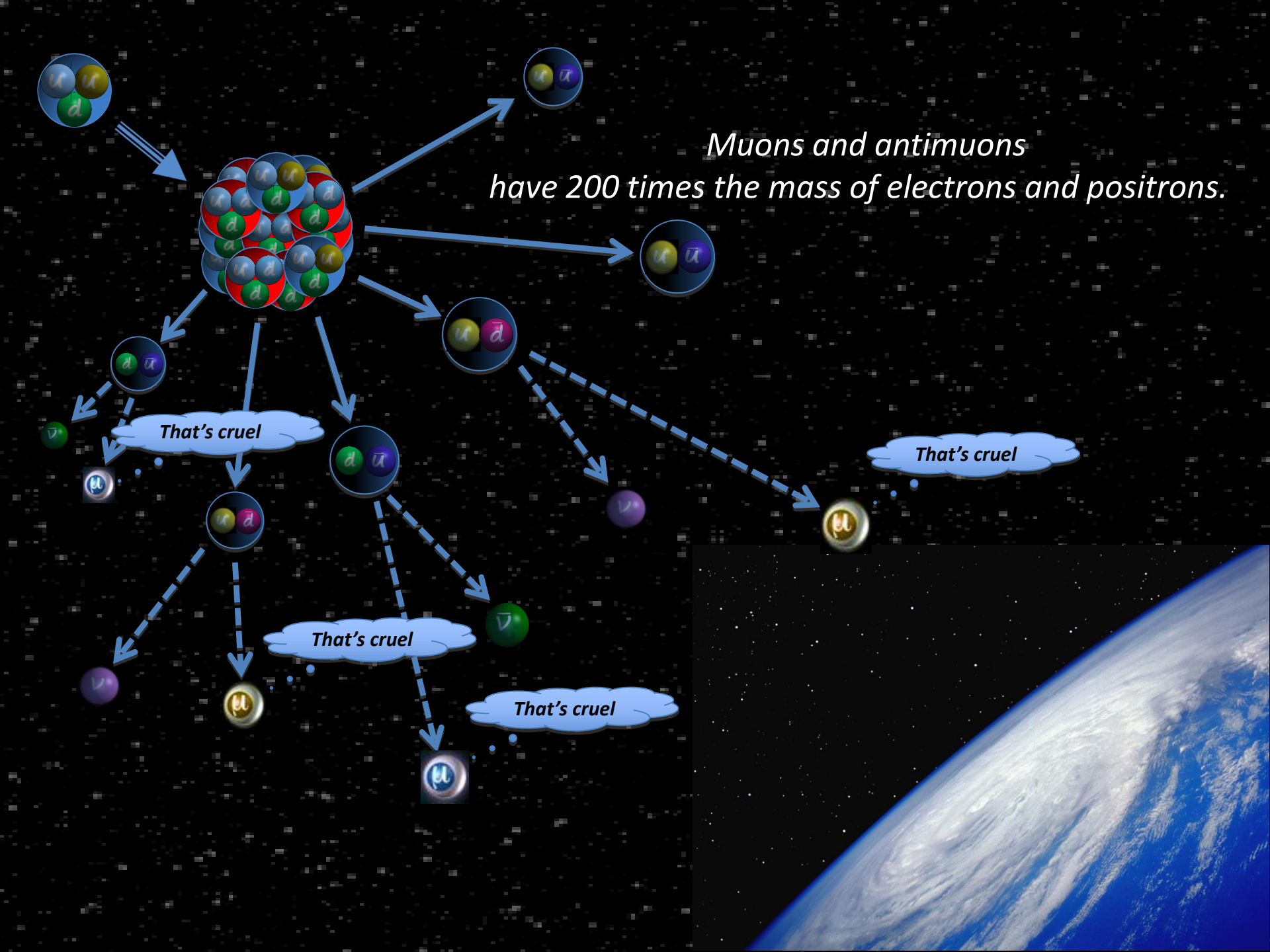

π^+ pions decay into antimuons and neutrinos…

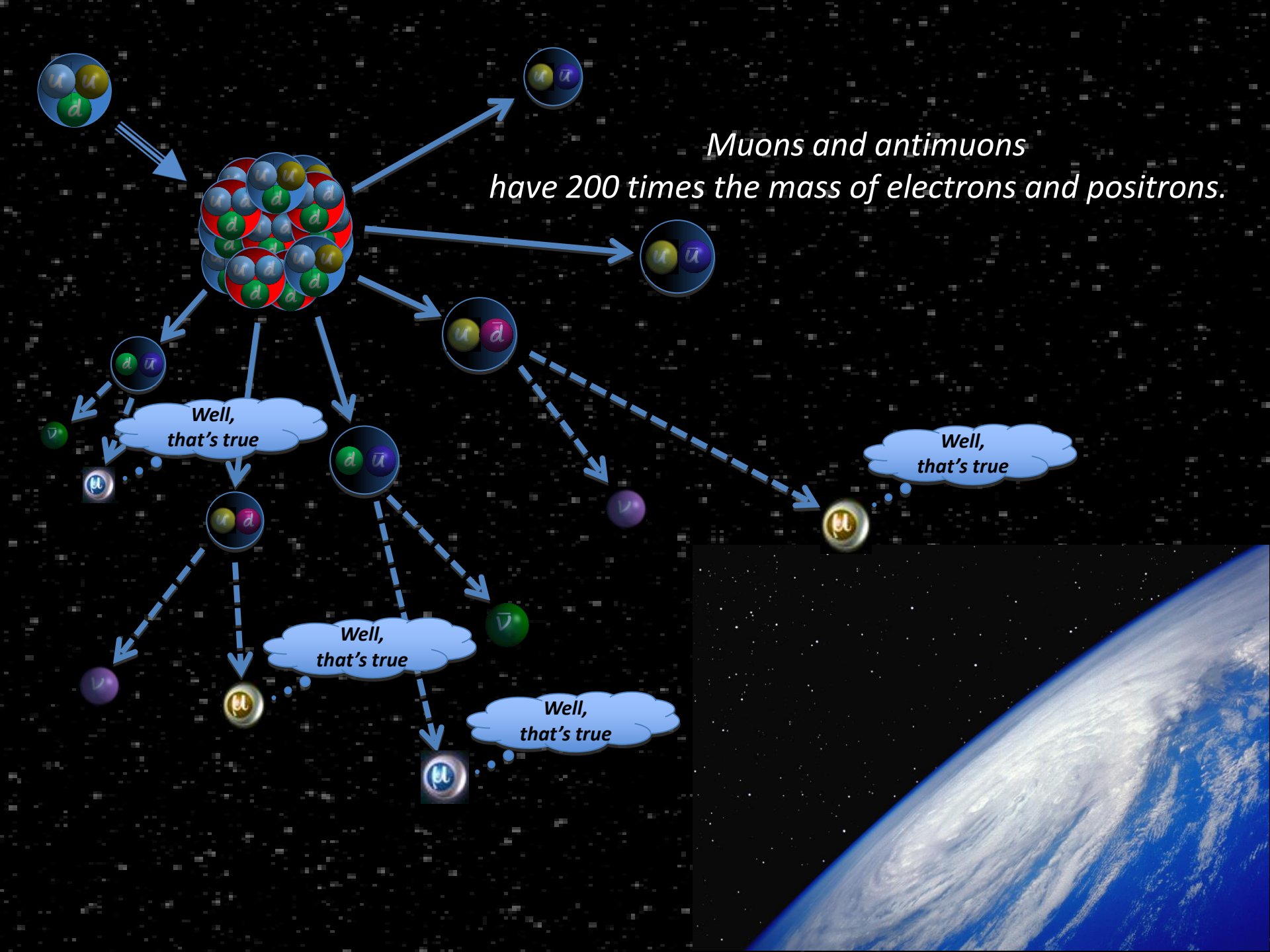

...and π⁻ pions decay into muons and antineutrinos.

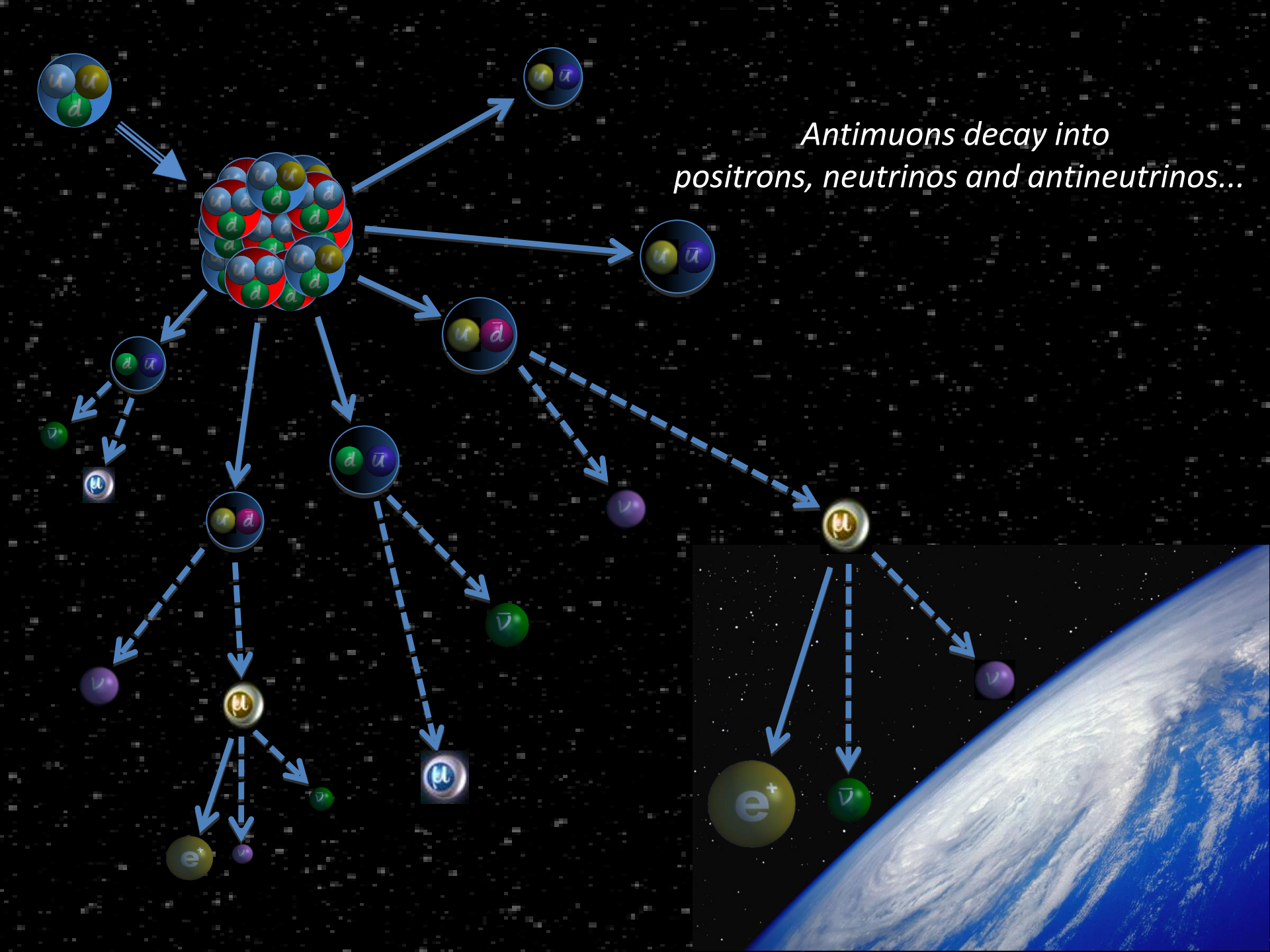

Muons and antimuons are like electrons and positrons.

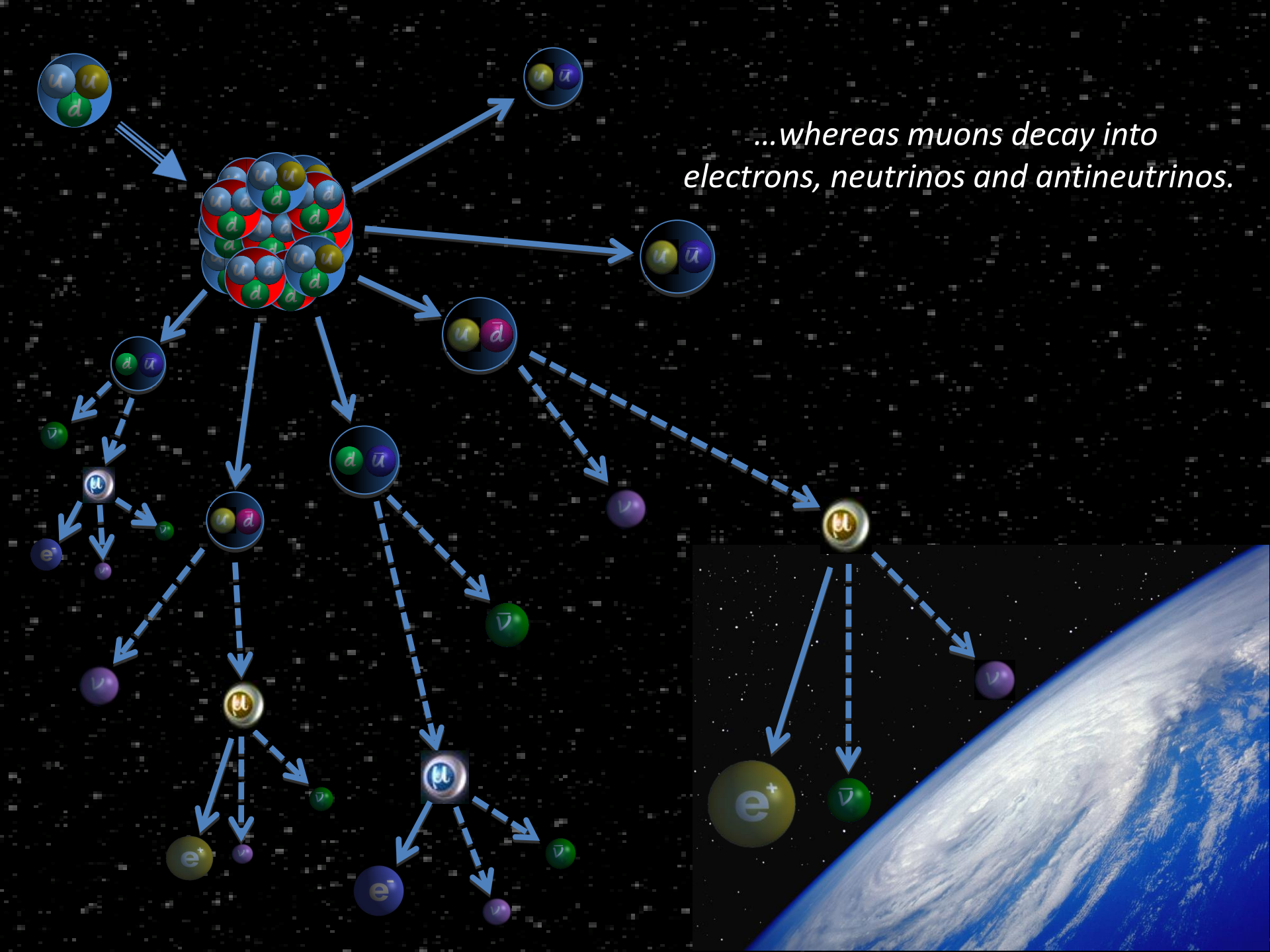

Muons and antimuons are like electrons and positrons.
But extremely overweight ones!

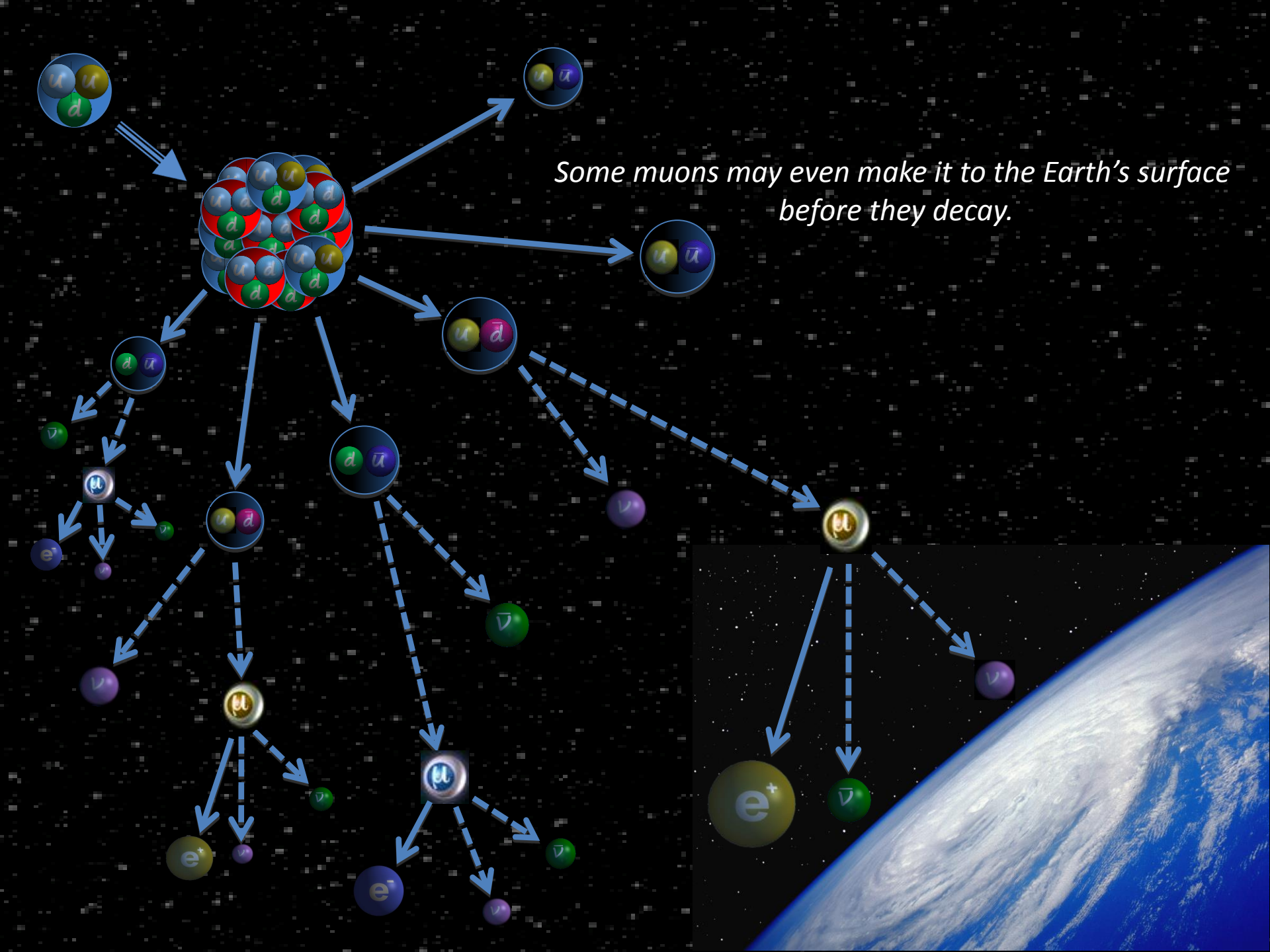

Muons and antimuons are like electrons and positrons.
But extremely overweight ones!
That's cruel
That's cruel
That's cruel
That's cruel

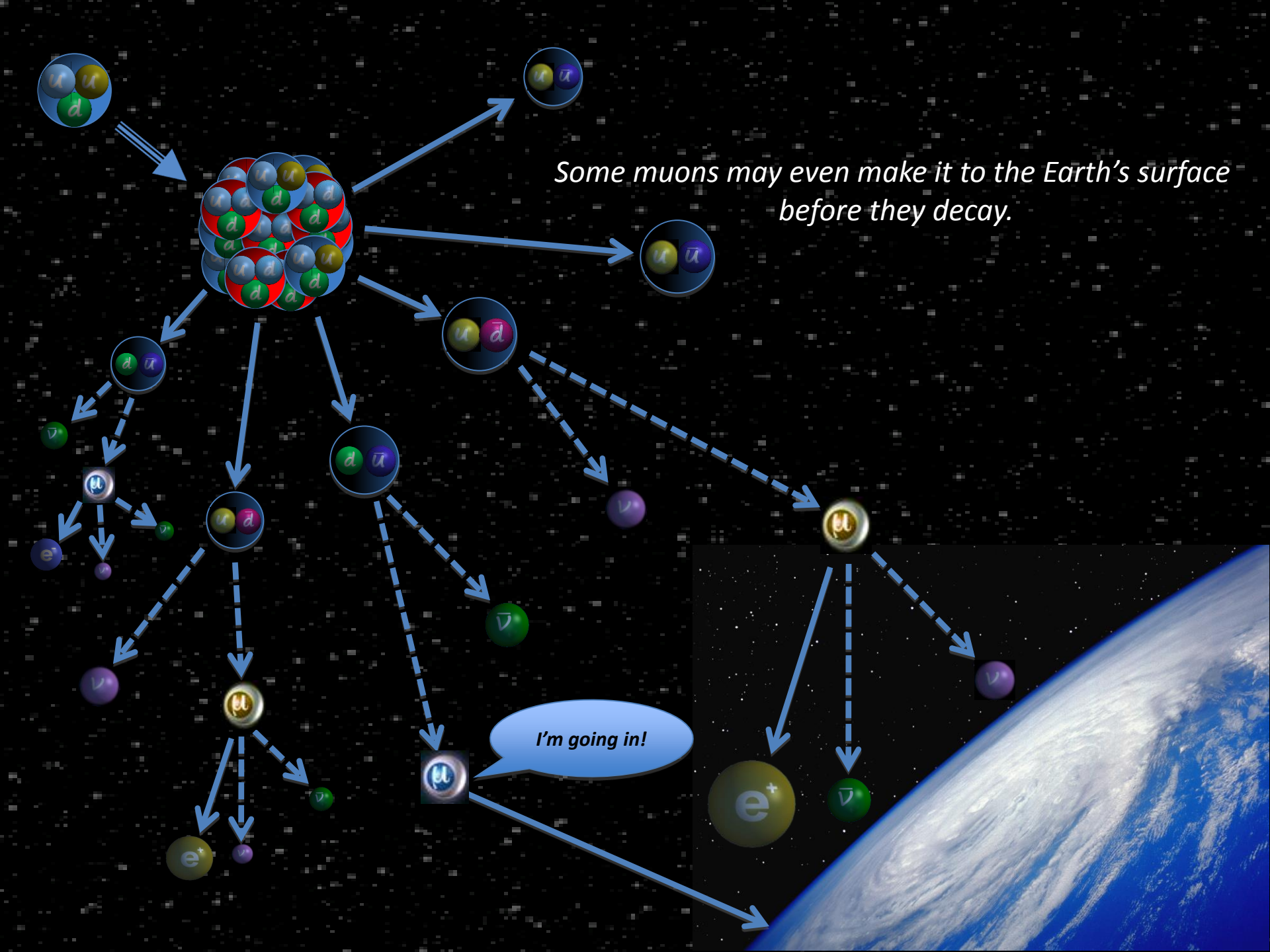

Muons and antimuons
have 200 times the mass of electrons and positrons.
That's cruel
That's cruel
That's cruel
That's cruel

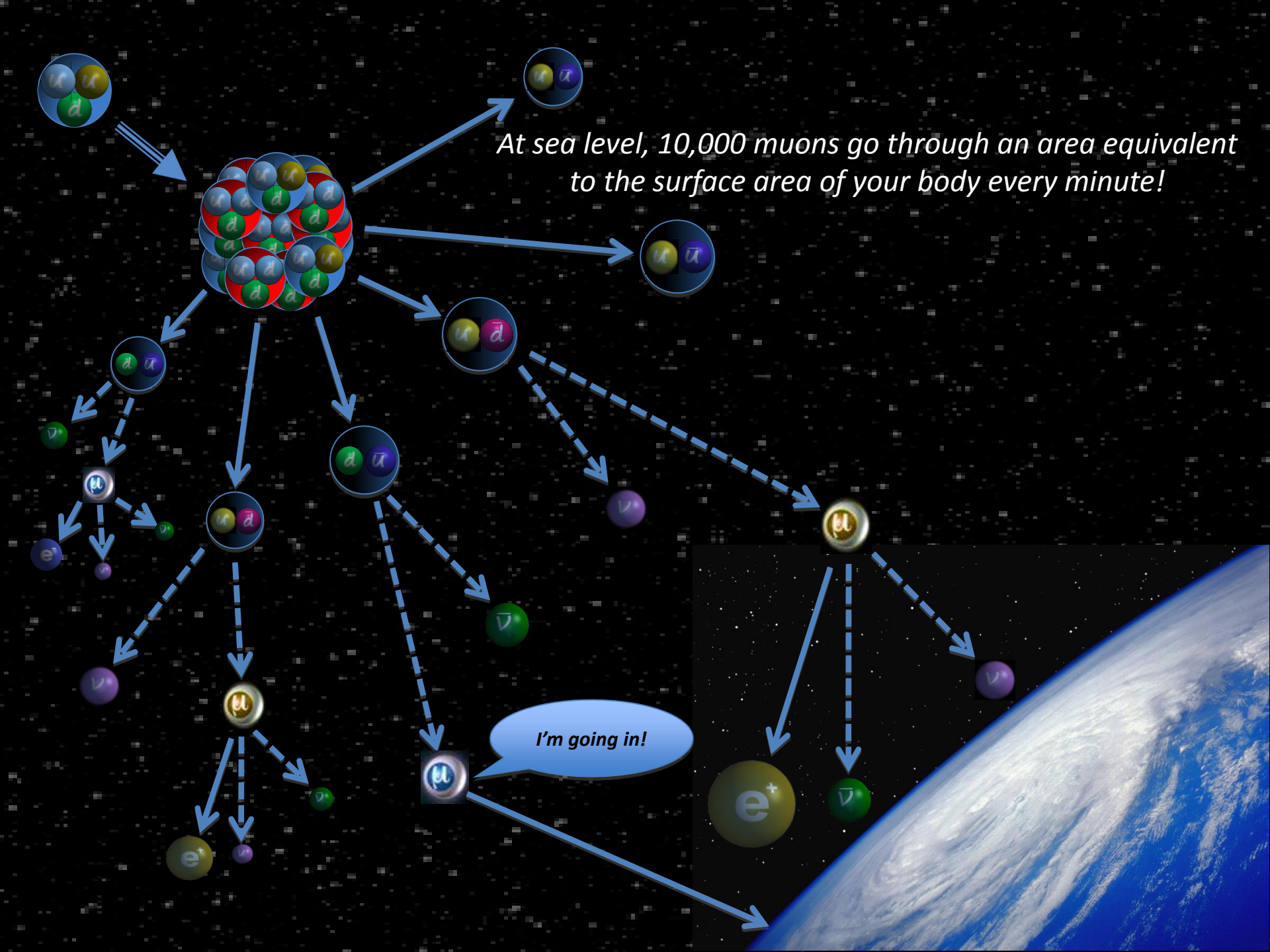

Muons and antimuons
have 200 times the mass of electrons and positrons.
Well, that's true
Well, that's true
Well, that's true
Well, that's true

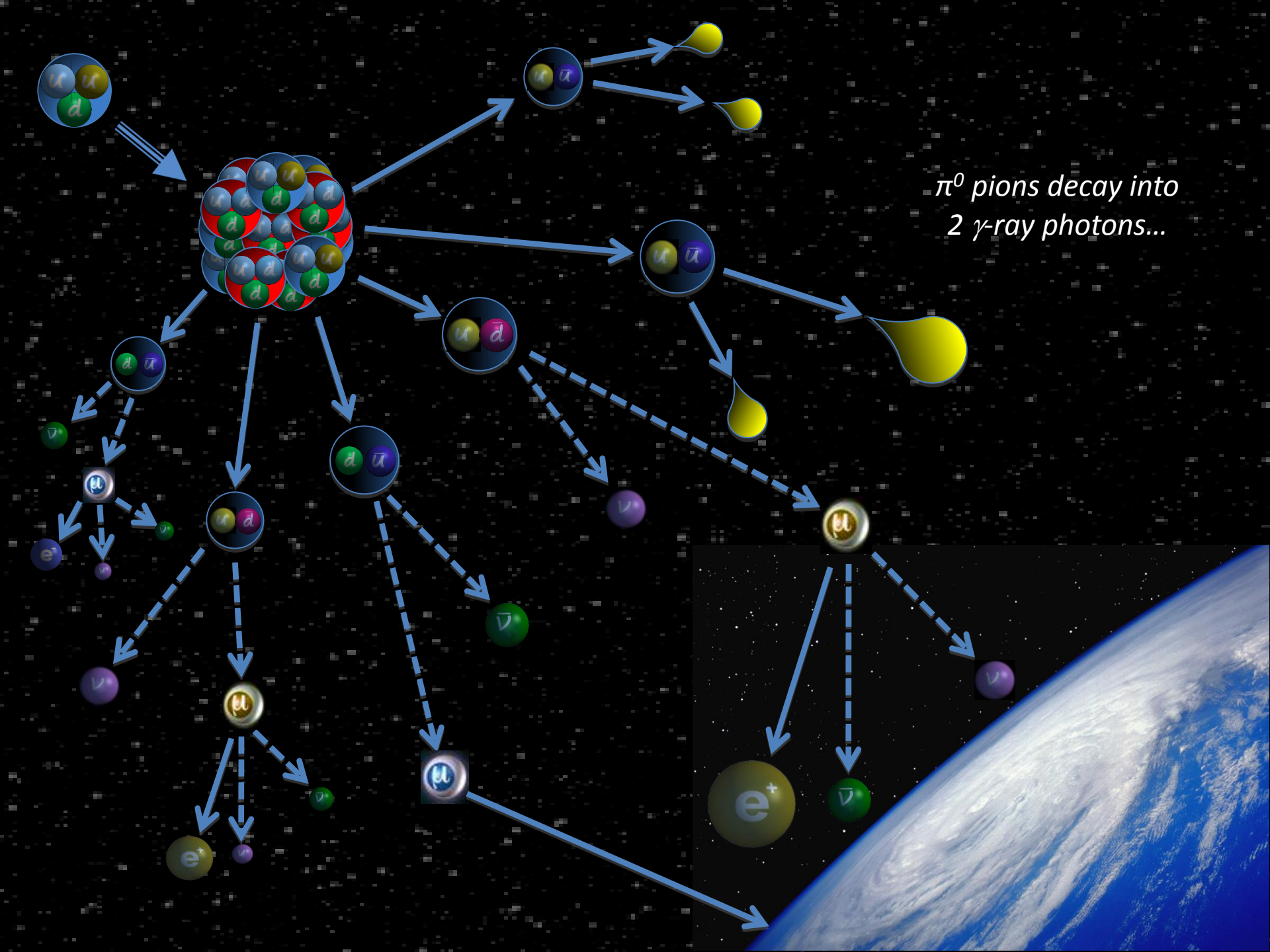

Antimuons decay into
positrons, neutrinos and antineutrinos...

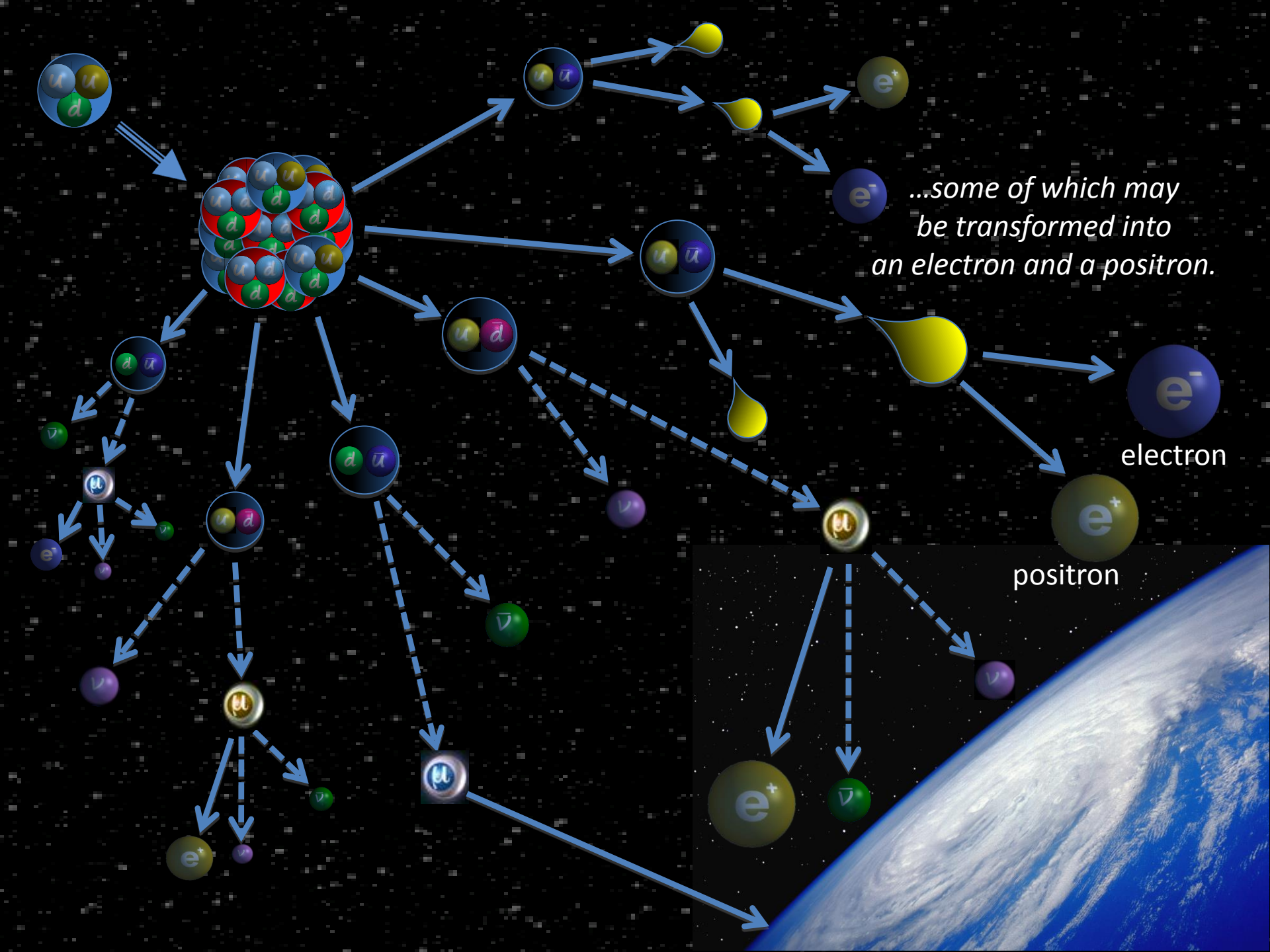

…whereas muons decay into
electrons, neutrinos and antineutrinos.


Some muons may even make it to the Earth's surface before they decay.

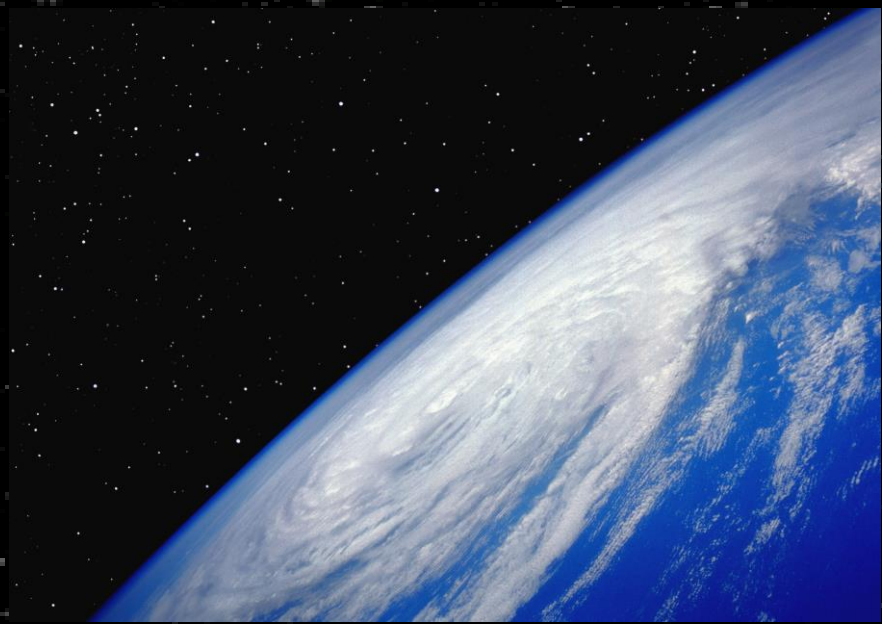

Some muons may even make it to the Earth's surface before they decay.
I'm going in!

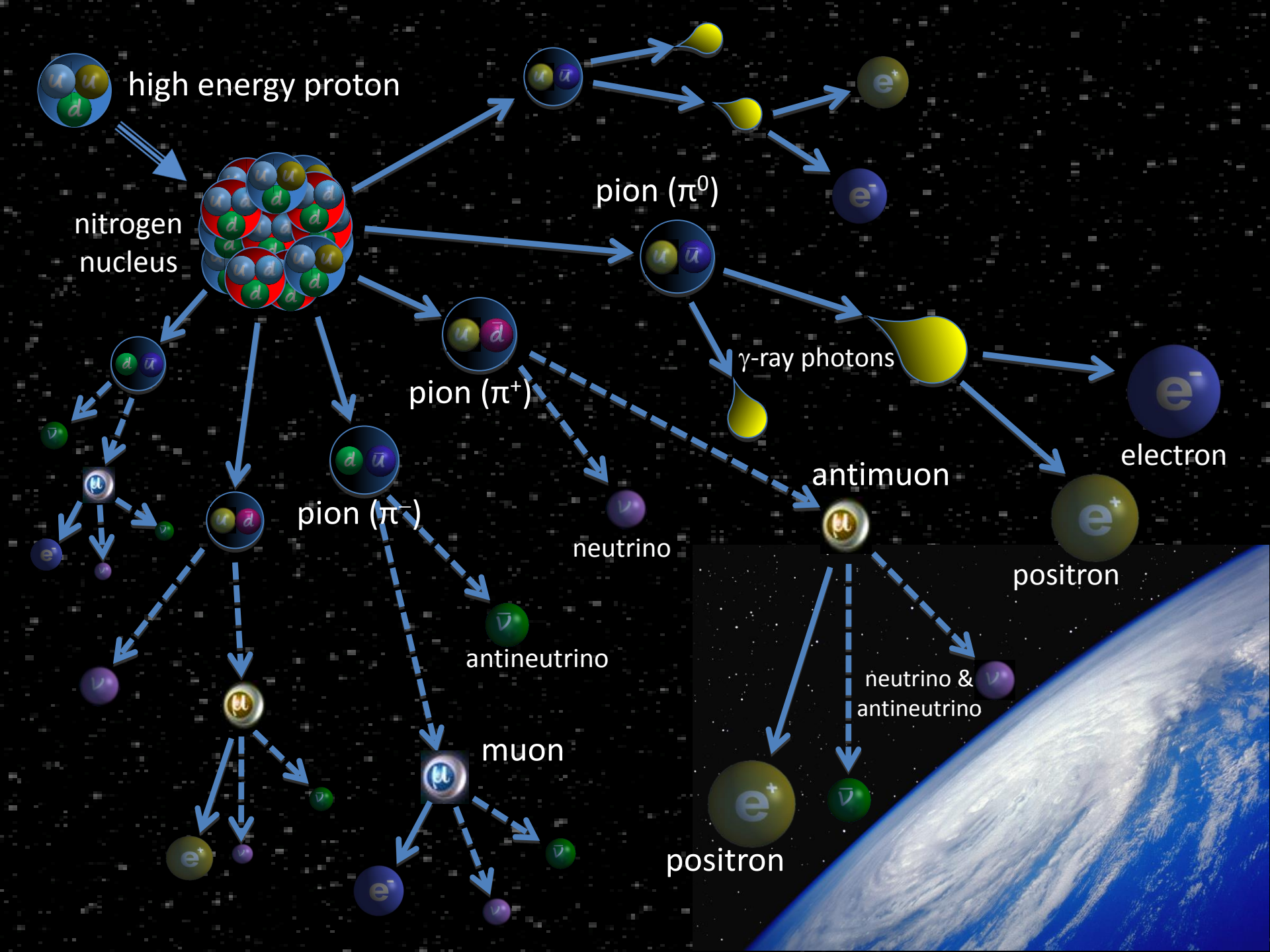

At sea level, 10,000 muons go through an area equivalent to the surface area of your body every minute!
I'm going in!


π^0 pions decay into
2 γ-ray photons…

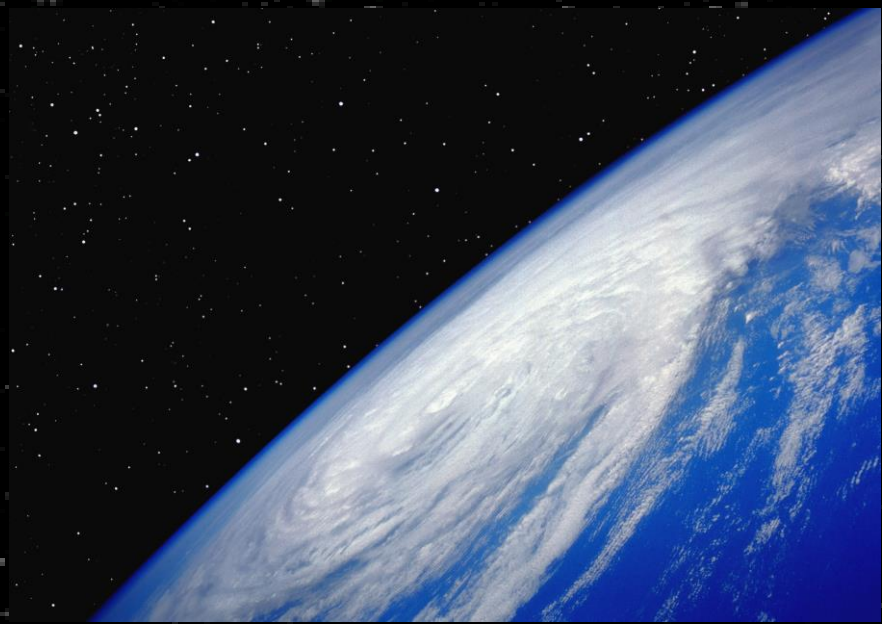

...some of which may
be transformed into
an electron and a positron.
electron
positron

AND NOW, A SUMMARY…



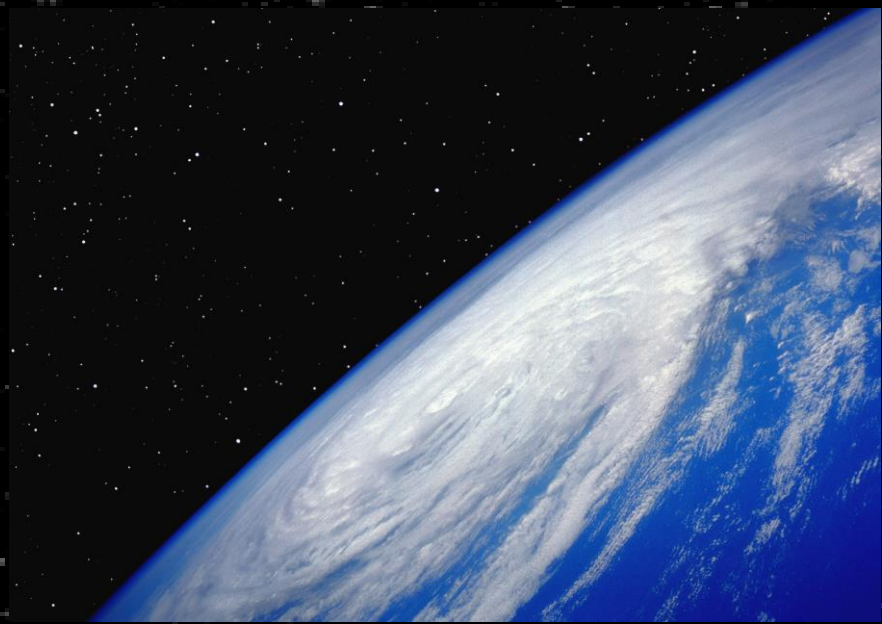

high energy proton
nitrogen nucleus
pion (π^0)
pion (π^+)
pion (π^-)
γ-ray photons
electron
antimuon
positron
neutrino
antineutrino
muon
neutrino & antineutrino
positron

SOME PARTICLES PRODUCED IN COSMIC RAYS REPRESENT “NATURALLY-OCCURRING” ANTIMATTER.



SOME PARTICLES PRODUCED IN COSMIC RAYS REPRESENT “NATURALLY-OCCURRING” ANTIMATTER.

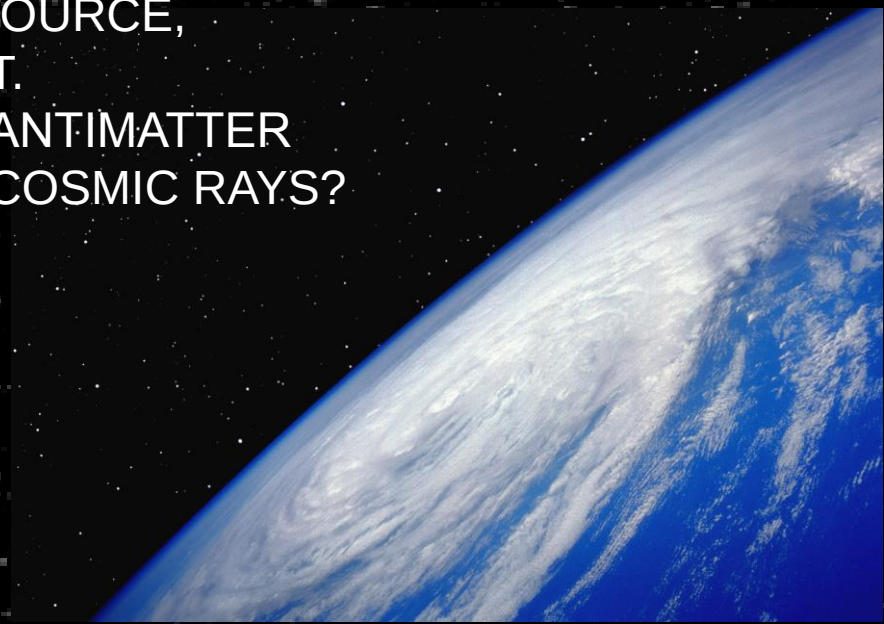
AS AN EXERCISE, LIST ALL OF THE ANTIMATTER PARTICLES THAT WERE CREATED AFTER THE PROTON COLLIDED WITH THE NITROGEN NUCLEUS.

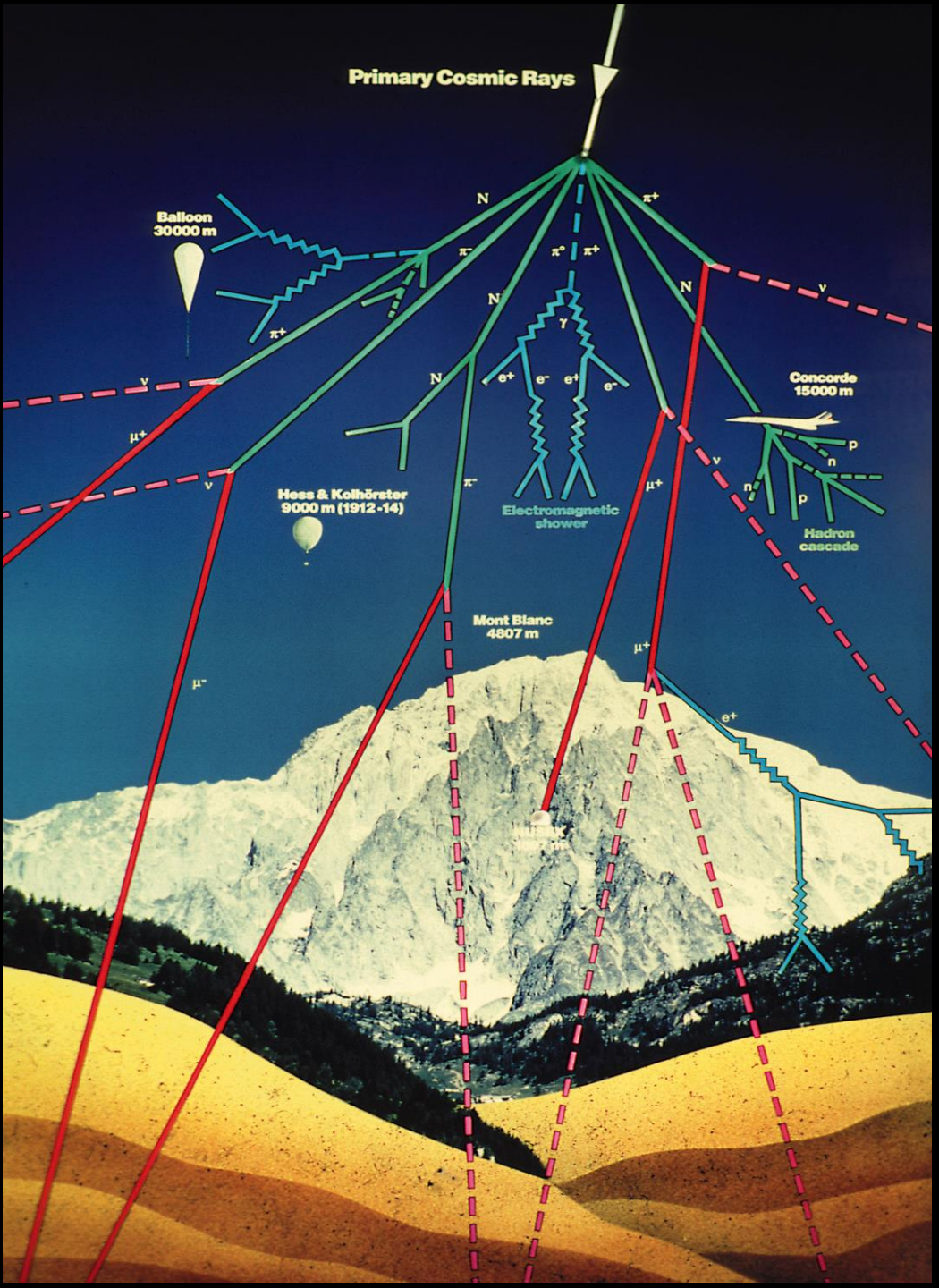


SOME PARTICLES PRODUCED IN COSMIC RAYS REPRESENT “NATURALLY-OCCURRING” ANTIMATTER.

AS AN EXERCISE, LIST ALL OF THE ANTIMATTER PARTICLES THAT WERE CREATED AFTER THE PROTON COLLIDED WITH THE NITROGEN NUCLEUS.

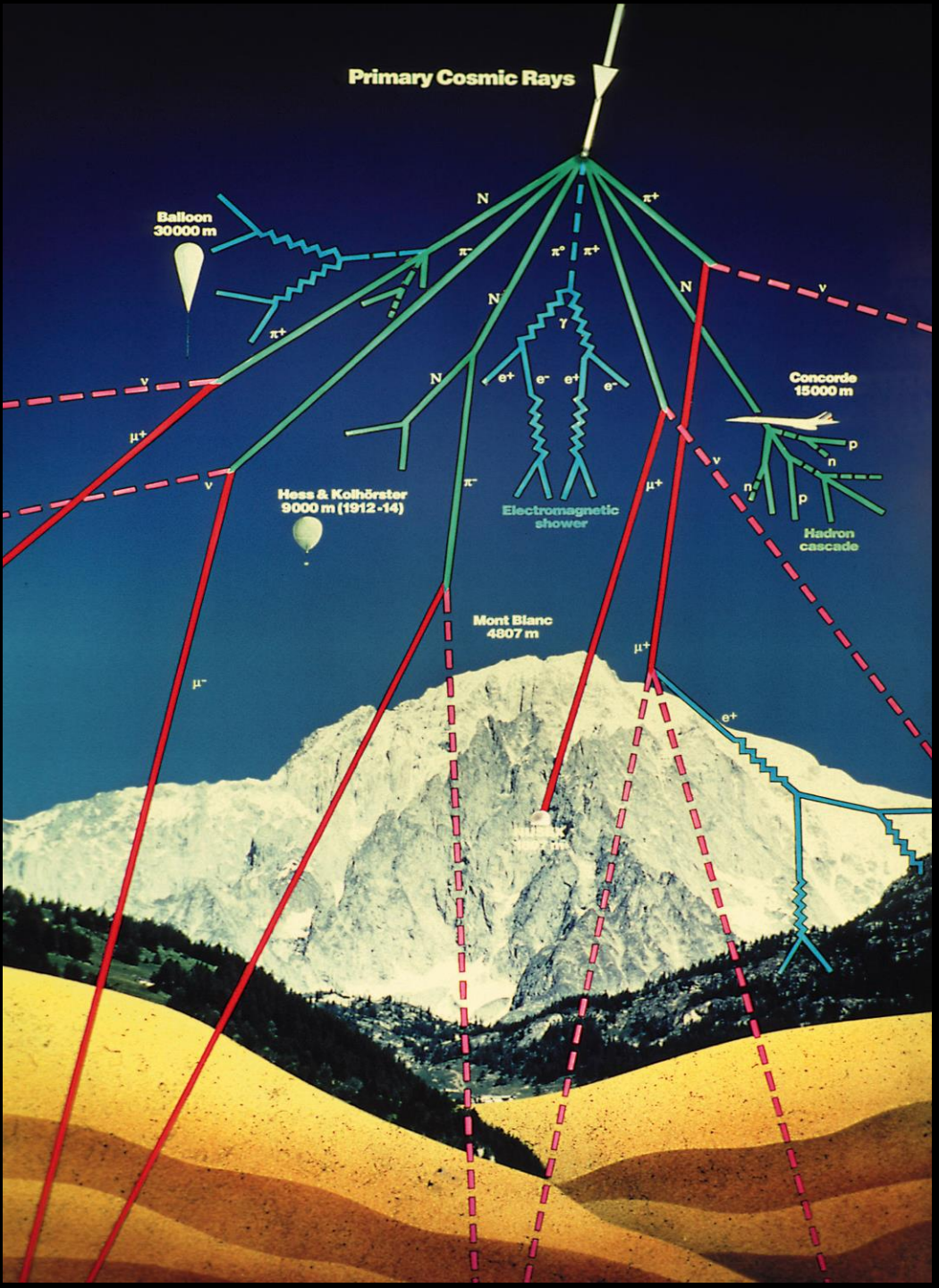
YOU LEARNED PREVIOUSLY THAT IN ORDER TO USE ANTIMATTER AS SAY, AN ENERGY SOURCE,
WE WOULD HAVE TO FIRST MAKE IT.
WHY CAN’T WE MAKE USE OF THE ANTIMATTER PARTICLES THAT ARE FORMED BY COSMIC RAYS?





ANY ANTIMATTER PARTICLES THAT ARE CREATED IN COSMIC RAYS INSTANTLY ANNIHILATE WHEN THEY COME INTO CONTACT WITH MATTER, AND THIS HAPPENS HIGH UP IN THE ATMOSPHERE.

MOST OF THE COSMIC RAYS THAT CAN BE DETECTED ON EARTH ARE MUONS.



SO HOW DID CARL ANDERSON MANAGE TO DISCOVER THE POSITRON, RIGHT HERE ON EARTH?

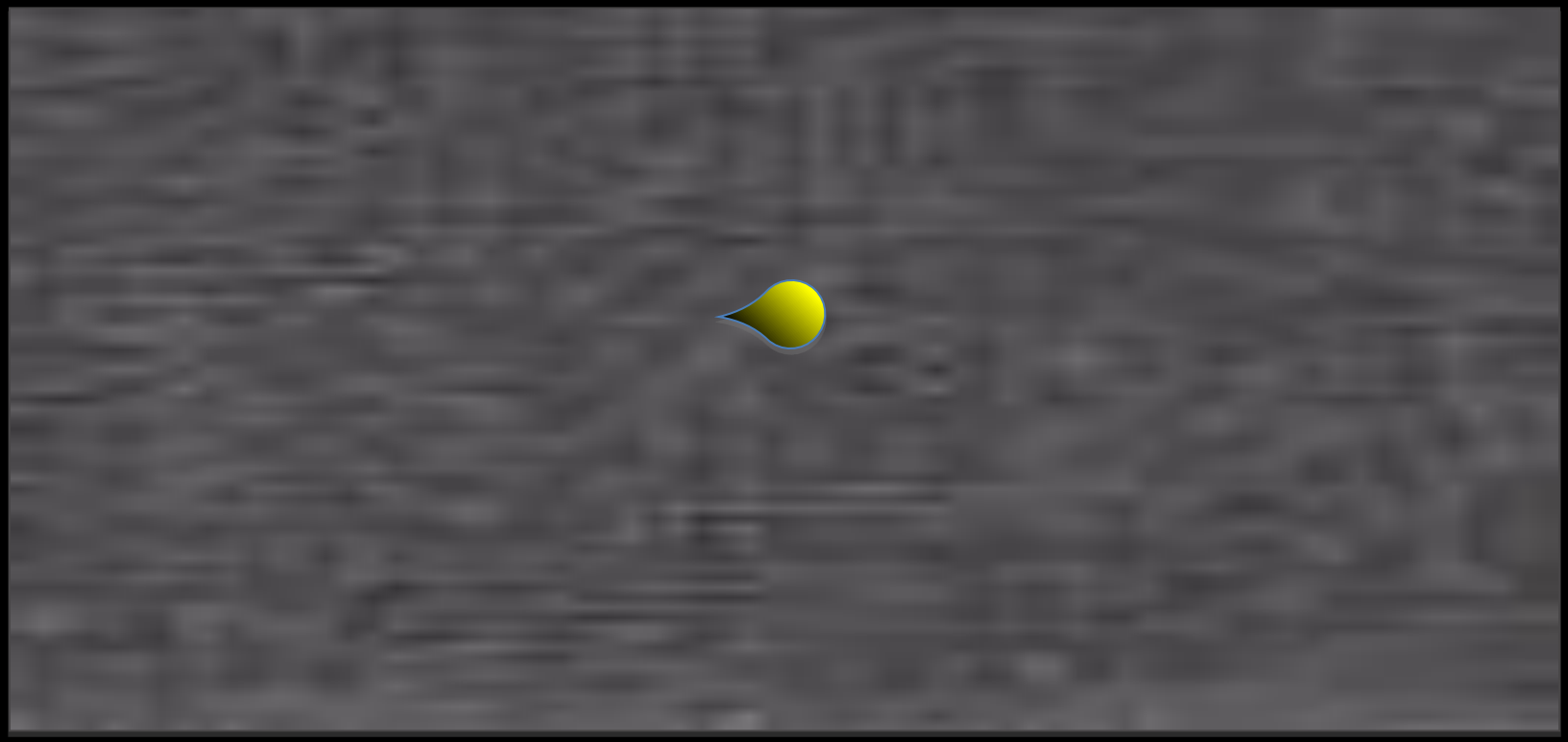
IN THE LESSON “ENERGY’S SPAWN”, YOU LEARNED THAT
ENERGY (PHOTONS) CAN TRANSFORM INTO MASS,
AND THAT WHEN IT DOES,
MATTER AND ANTIMATTER ARE ALWAYS FORMED IN EQUAL PARTS.

IT WAS BY THIS PROCESS THAT THE POSITRON WAS DISCOVERED.

A HIGH ENERGY PHOTON IN COSMIC RAYS MADE IT TO EARTH (AS MANY DO).

A HIGH ENERGY PHOTON IN COSMIC RAYS MADE IT TO EARTH (AS MANY DO).

A HIGH ENERGY PHOTON IN COSMIC RAYS MADE IT TO EARTH (AS MANY DO).



A HIGH ENERGY PHOTON IN COSMIC RAYS MADE IT TO EARTH (AS MANY DO).

THIS PHOTON TRANSFORMED INTO AN ELECTRON AND A POSITRON IN ANDERSON'S DETECTOR (CALLED A CLOUD CHAMBER).

A HIGH ENERGY PHOTON IN COSMIC RAYS MADE IT TO EARTH (AS MANY DO).

THIS PHOTON TRANSFORMED INTO AN ELECTRON AND A POSITRON IN ANDERSON'S DETECTOR (CALLED A CLOUD CHAMBER).

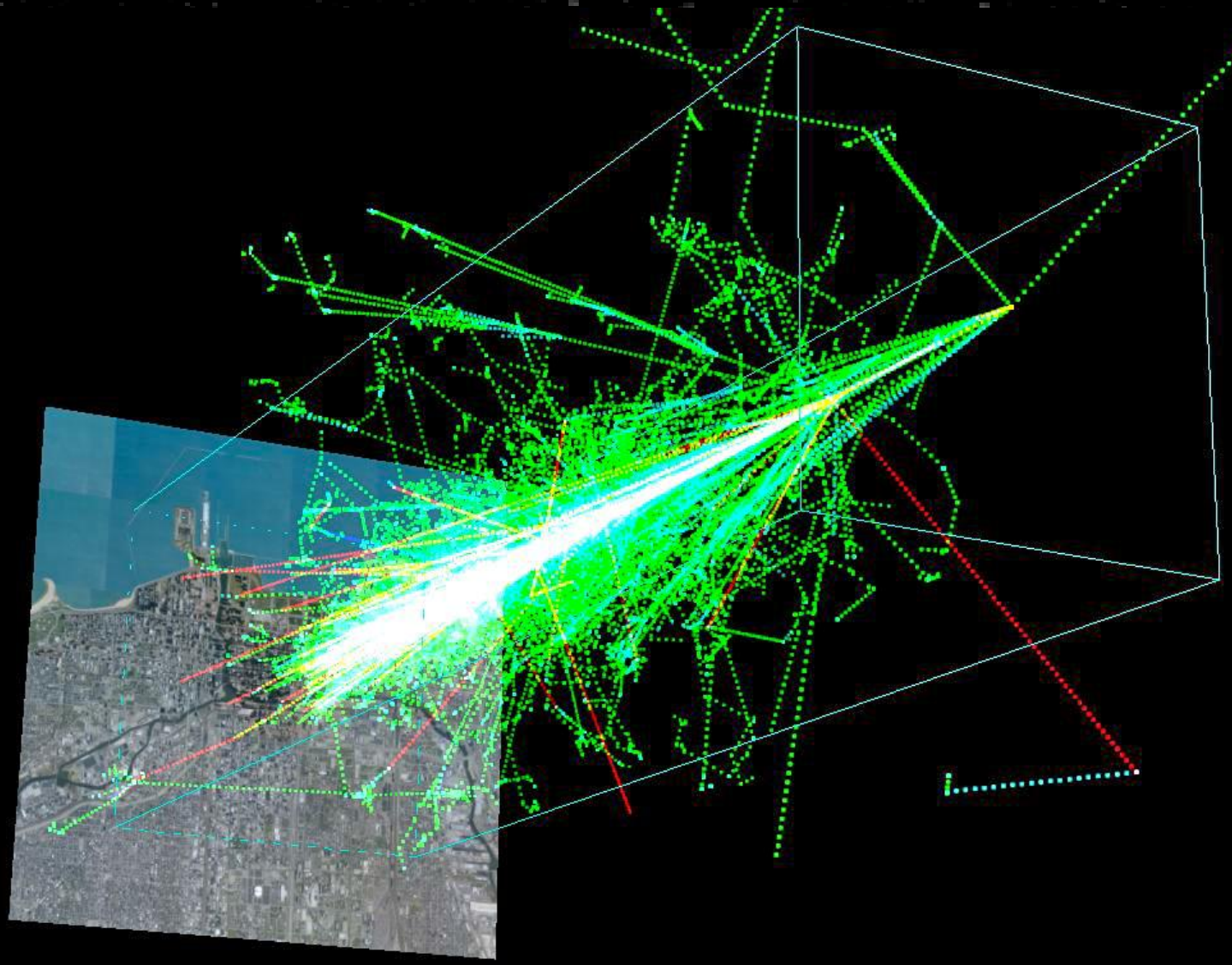
A HIGH ENERGY PHOTON IN COSMIC RAYS MADE IT TO EARTH (AS MANY DO).

THIS PHOTON TRANSFORMED INTO AN ELECTRON AND A POSITRON IN ANDERSON'S DETECTOR (CALLED A CLOUD CHAMBER).

IN THE PRESENCE OF A MAGNETIC FIELD,
THE POSITRON HAS BEEN DEFLECTED ONE WAY
AND THE ELECTRON HAS BEEN DEFLECTED IN THE OPPOSITE DIRECTION.

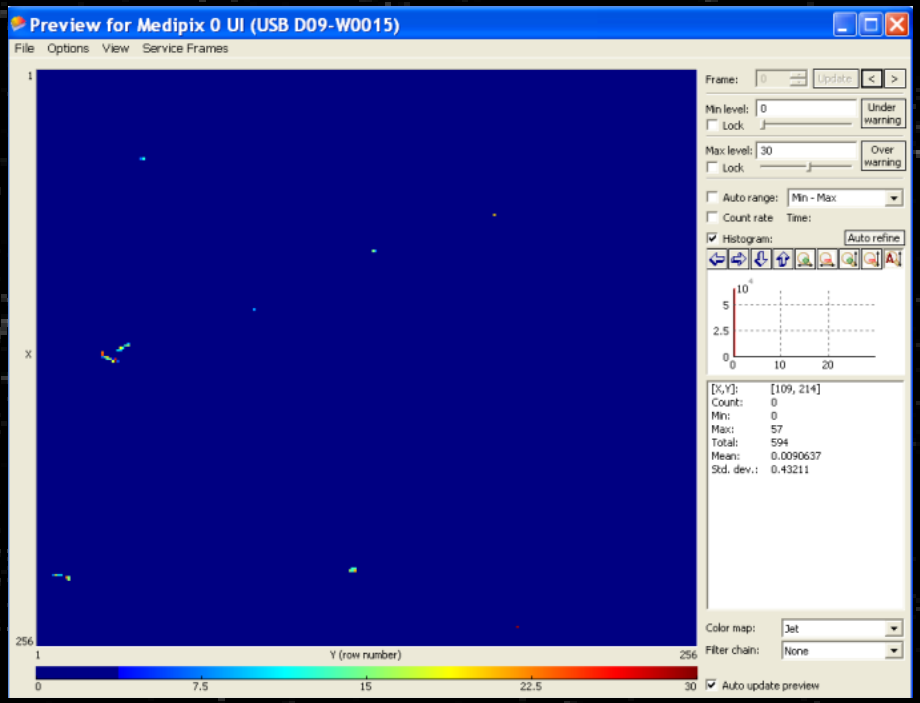
IN THE PRESENCE OF A MAGNETIC FIELD,
THE POSITRON HAS BEEN DEFLECTED ONE WAY
AND THE ELECTRON HAS BEEN DEFLECTED IN THE OPPOSITE DIRECTION.
WHAT ADDITIONAL INFORMATION DO YOU NEED IN ORDER TO DETERMINE WHICH PARTICLE IS WHICH?

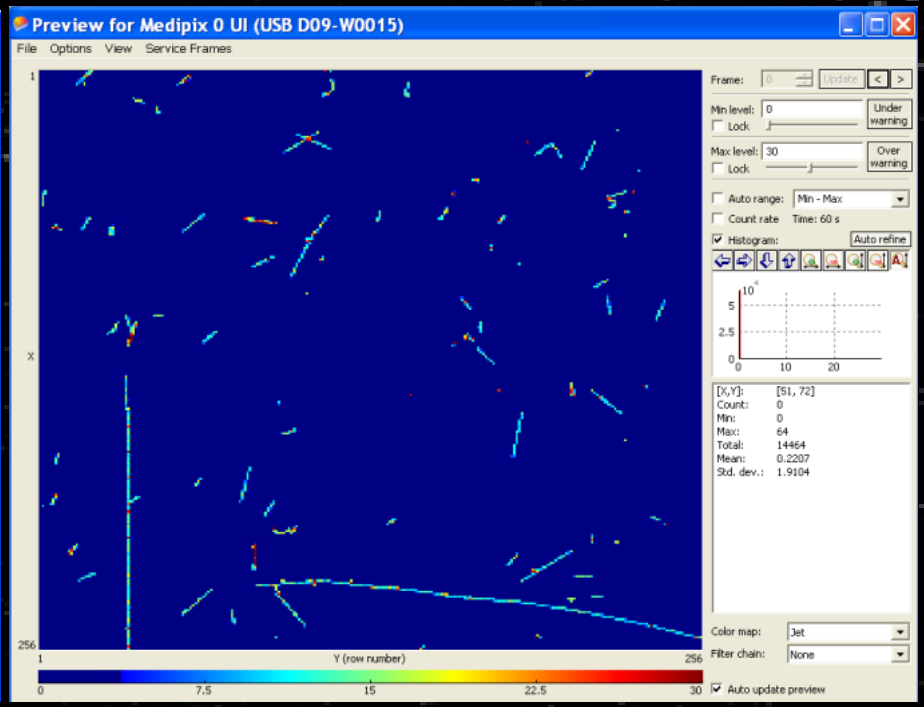
ON THE FOLLOWING SLIDES, YOU WILL FIND SOME MORE IMAGES, EXERCISES, AND LINKS ON COSMIC RAYS…



This is a simulation of a high energy proton hitting the atmosphere about 20km above the ground. The "shower" takes place in a 20km x 5km x 5km "box" above the Earth's surface. Electrons and positrons are coloured green, muons are red, and gamma rays are cyan.

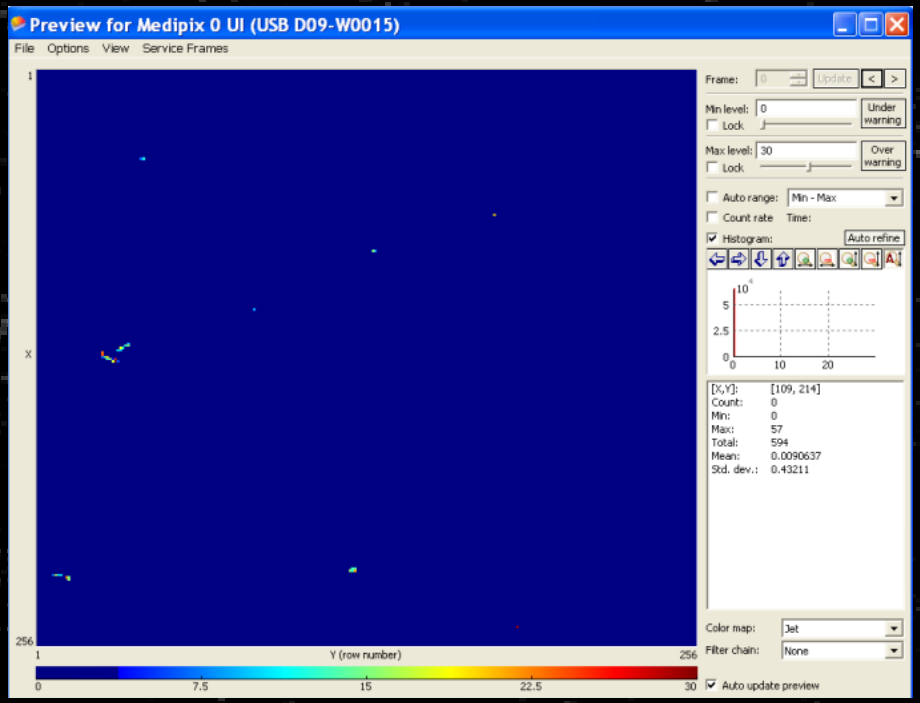
http://astro.uchicago.edu/cosmus/projects/aires/

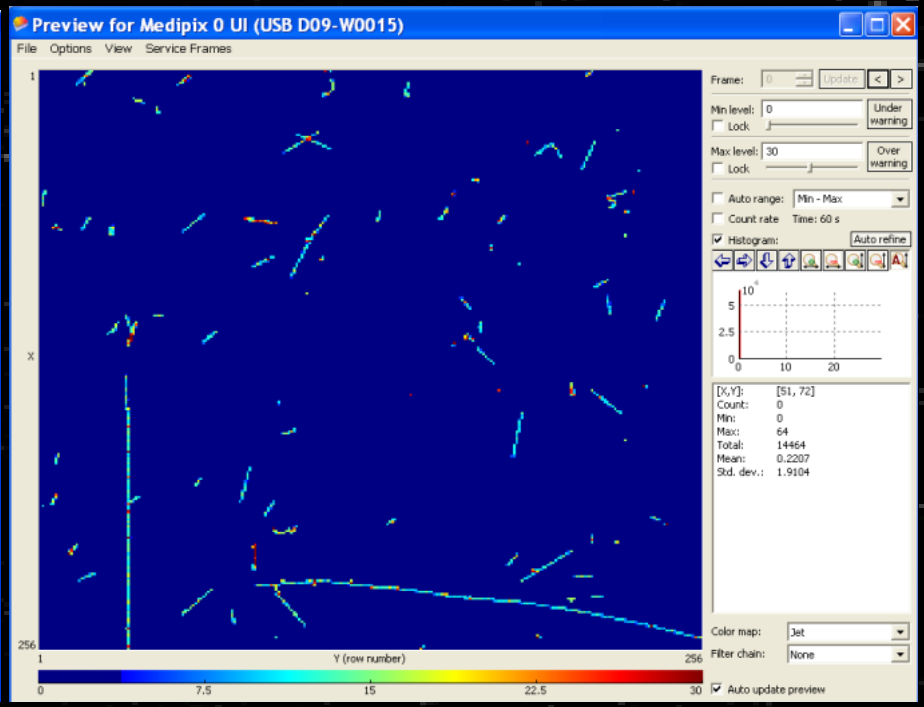




Images courtesy of Michael Campbell, CERN

These images were made with a small particle detector (developed at CERN) called a Medipix chip. When a particle strikes the chip, a coloured mark appears. The different colours indicate different energies.

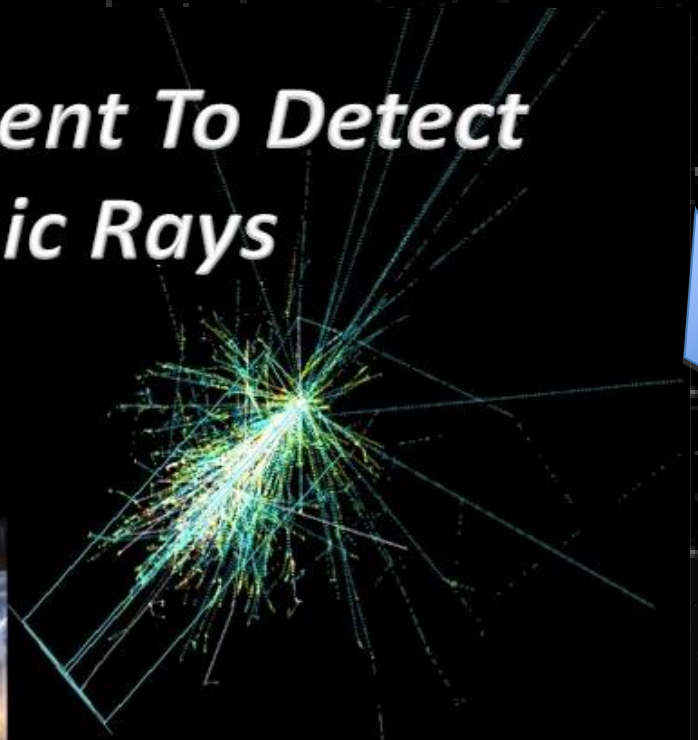




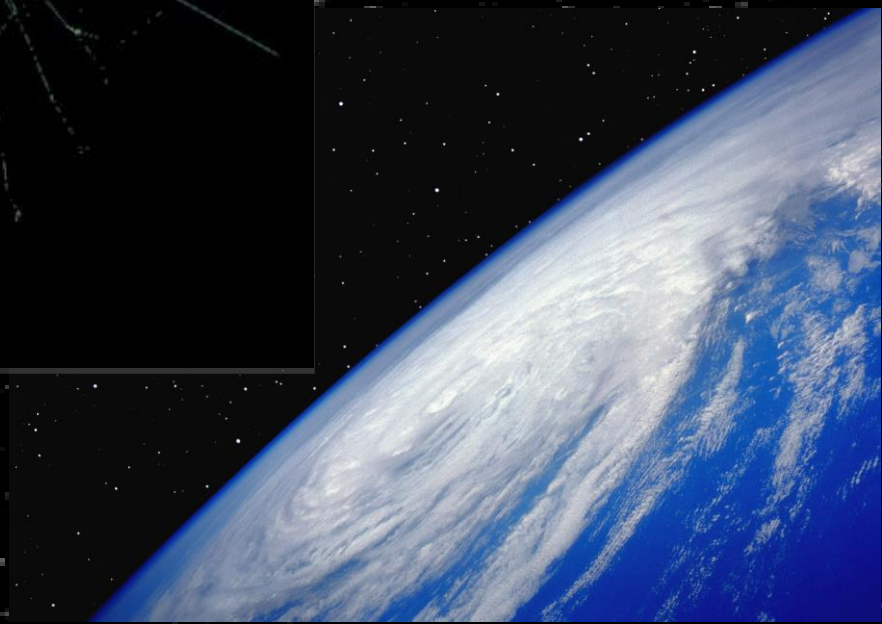
Images courtesy of Michael Campbell, CERN

One of the images was taken at ground level and the other was taken during a commercial airline flight. Can you determine which is which? Explain how you made your choice.

An Experiment To Detect Cosmic Rays



CLICK ON THE IMAGE TO DOWNLOAD THE PROCEDURE



AND THE NOBEL PRIZE GOES TO...

CLICK HERE FOR MORE INFO

The 1936 Nobel Prize In Physics

If you would like to learn more about cosmic rays, have a look at some of these websites:

http://www2.slac.stanford.edu/vvc/cosmicrays/cratmos.html
http://www.esa.int/SPECIALS/Lessons_online/SEM8V1V7D7F_0.html
http://astro.uchicago.edu/cosmus/projects/aires/
http://public.web.cern.ch/public/en/LHC/LHCf-en.html
http://public.web.cern.ch/public/en/Research/CLOUD-en.html