„Cosmic Rays“

Teaching material in 3 blocks

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Baustein 3

„Cosmic Rays“

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Special Thanks to

Mr. David Waterman
Alfriston School ,Beaconsfield UK

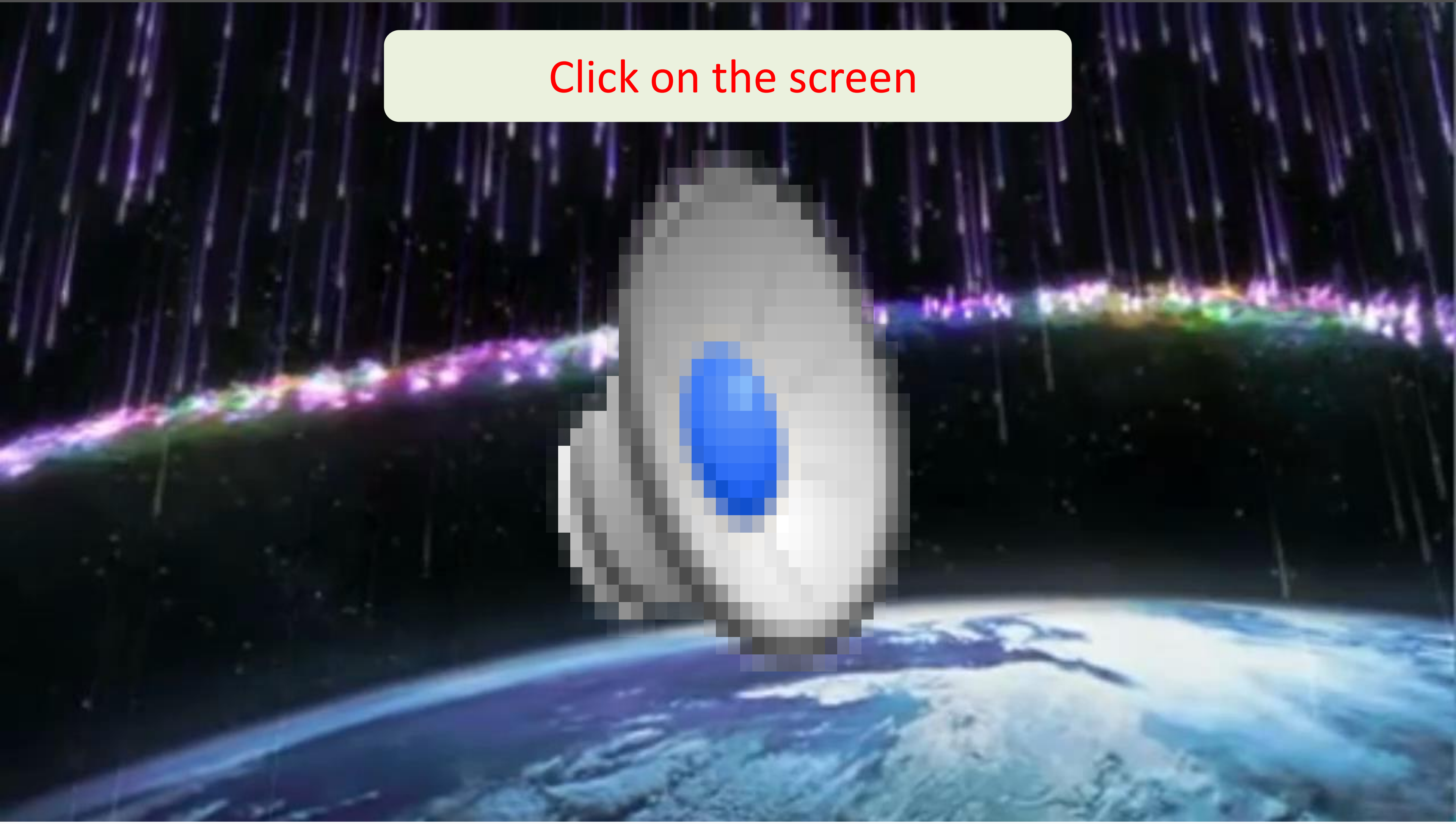
for the supporting in translation and for final reading as a result of ***Volos Summer School*** 2013

Cosmic Rays

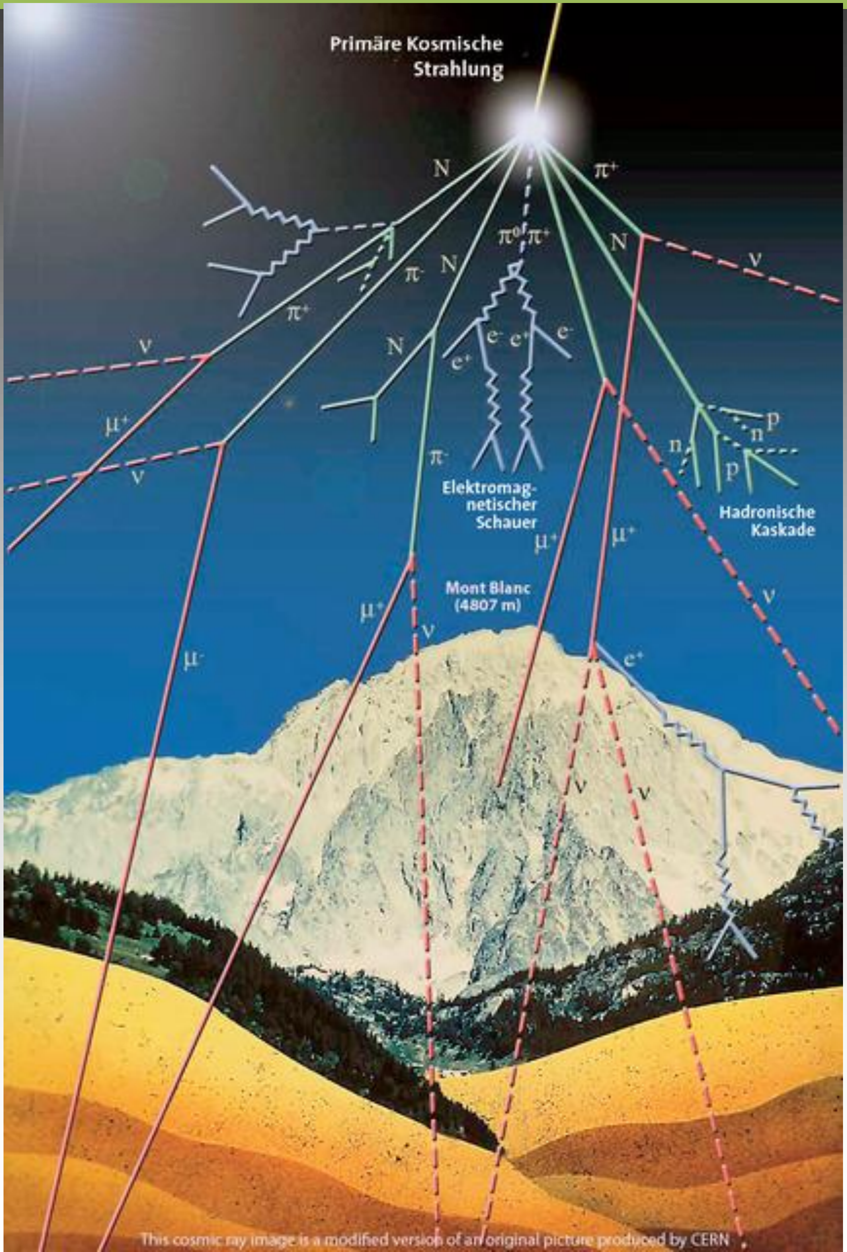
What comes to us from space?

Next

Click on the screen



What comes to us from space?



block 1

In every second reach us…

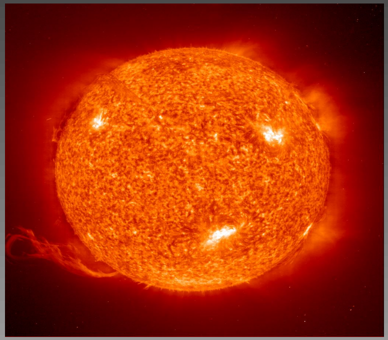
On every square meter

200 particles

- Where do these particles come from?
- What properties do they have?
- Which secrets do they hold?

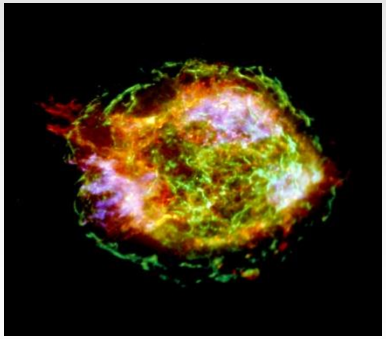
Where do these particles come from?

- from our sun



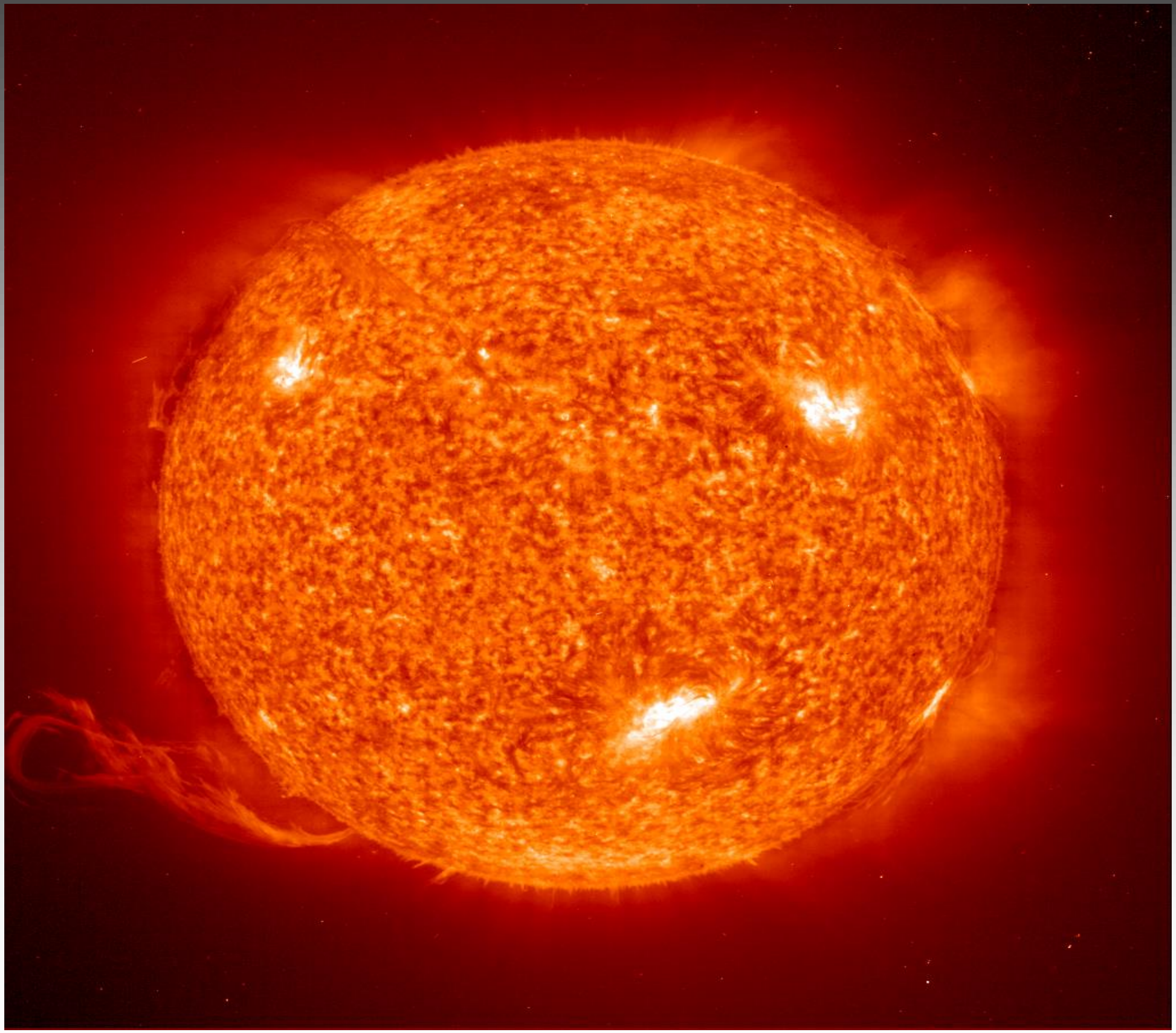
- from other galaxies

- from supernovae



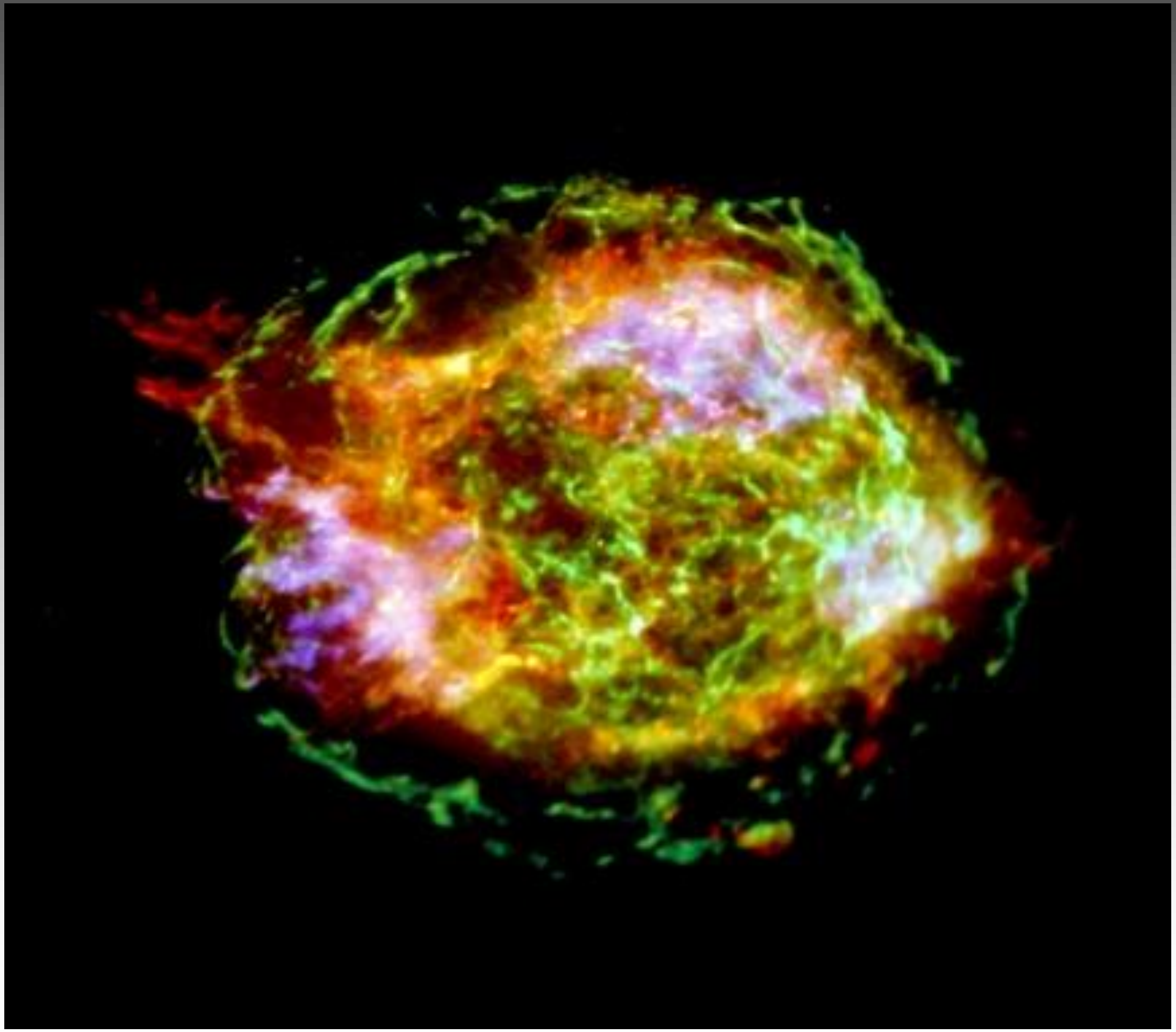
block 1

Sun…



block 1

Supernovae *(Starbust)*

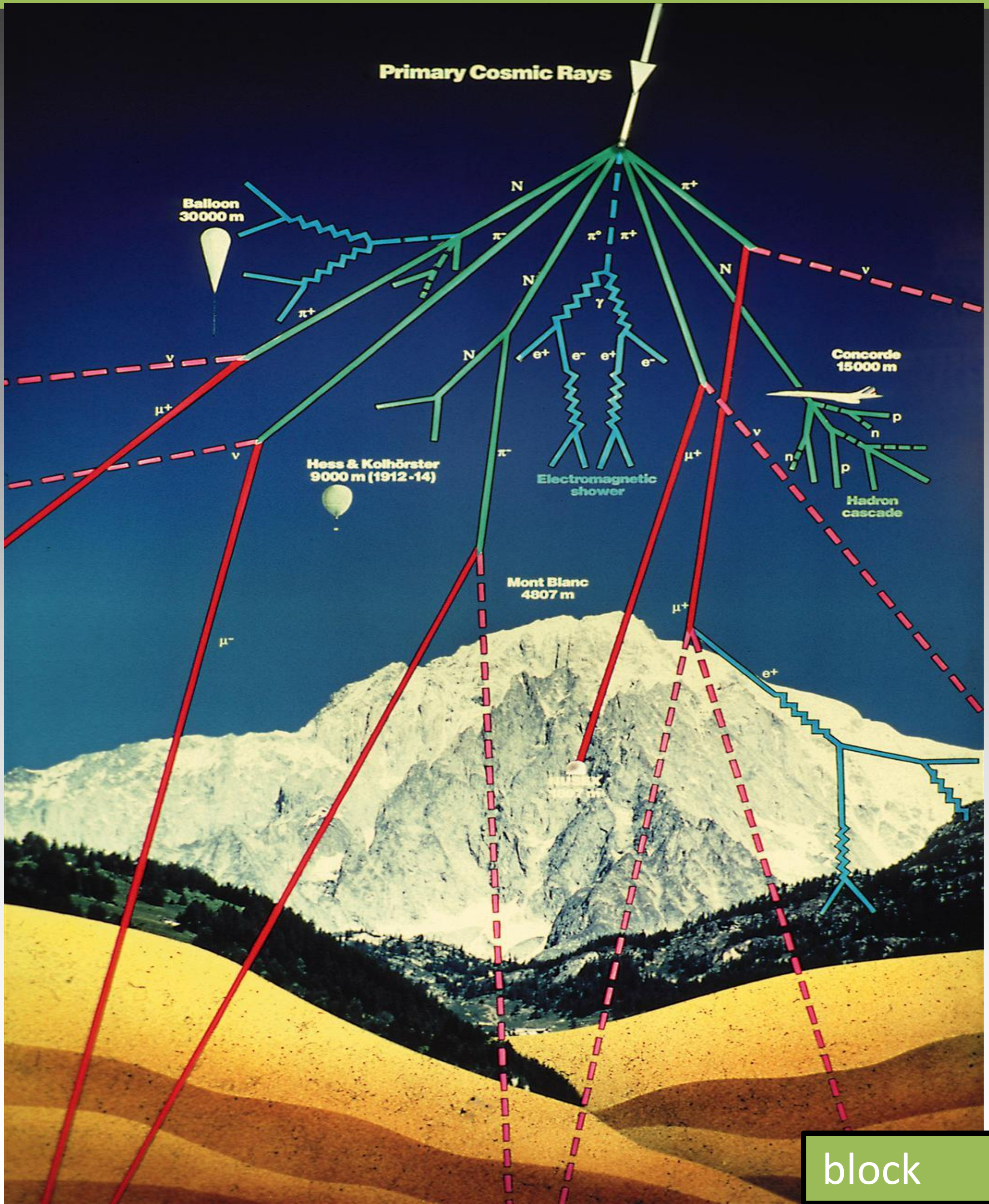


block 1

Other galaxies

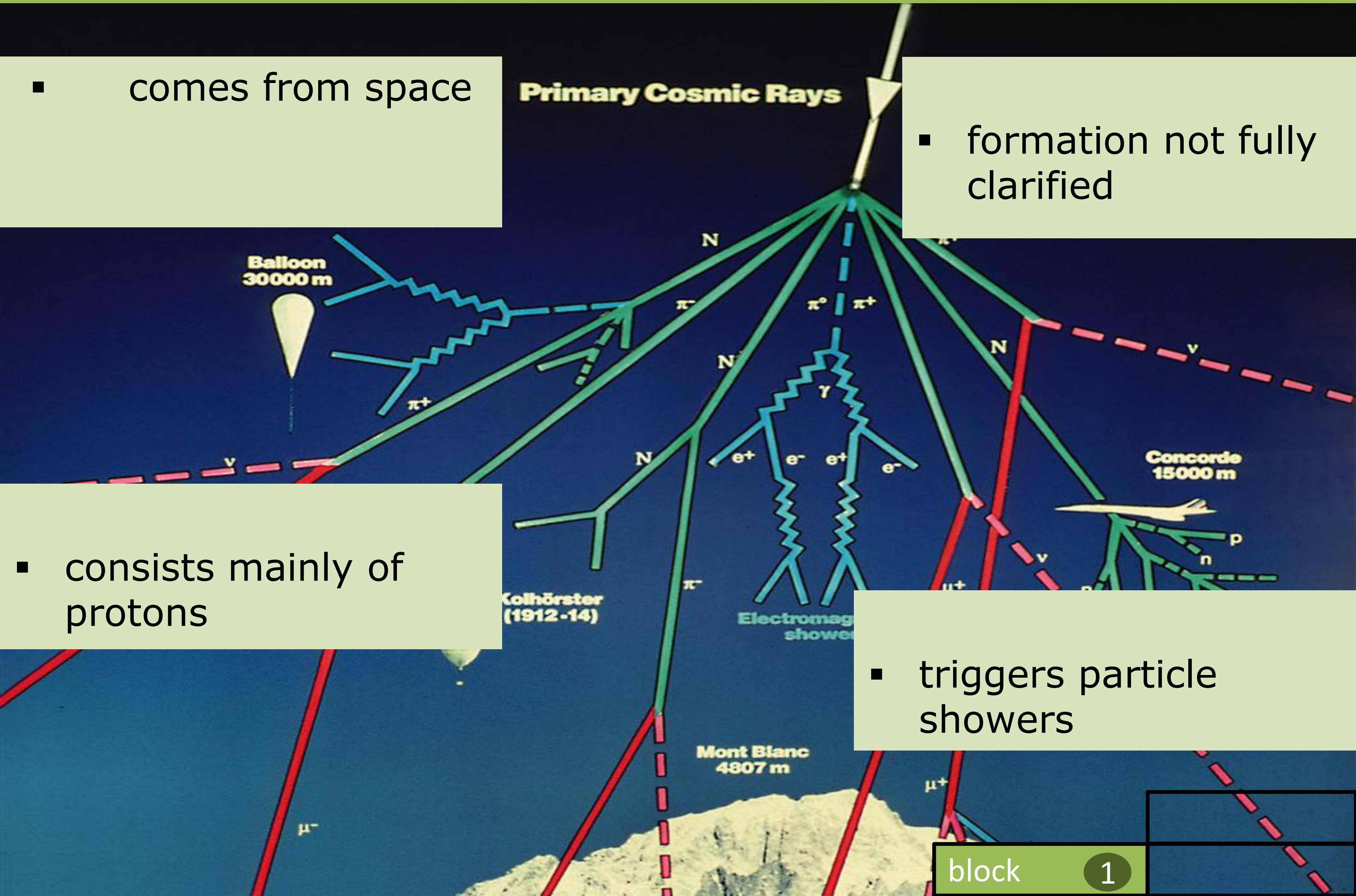
block 1

Formation of cosmic radiation



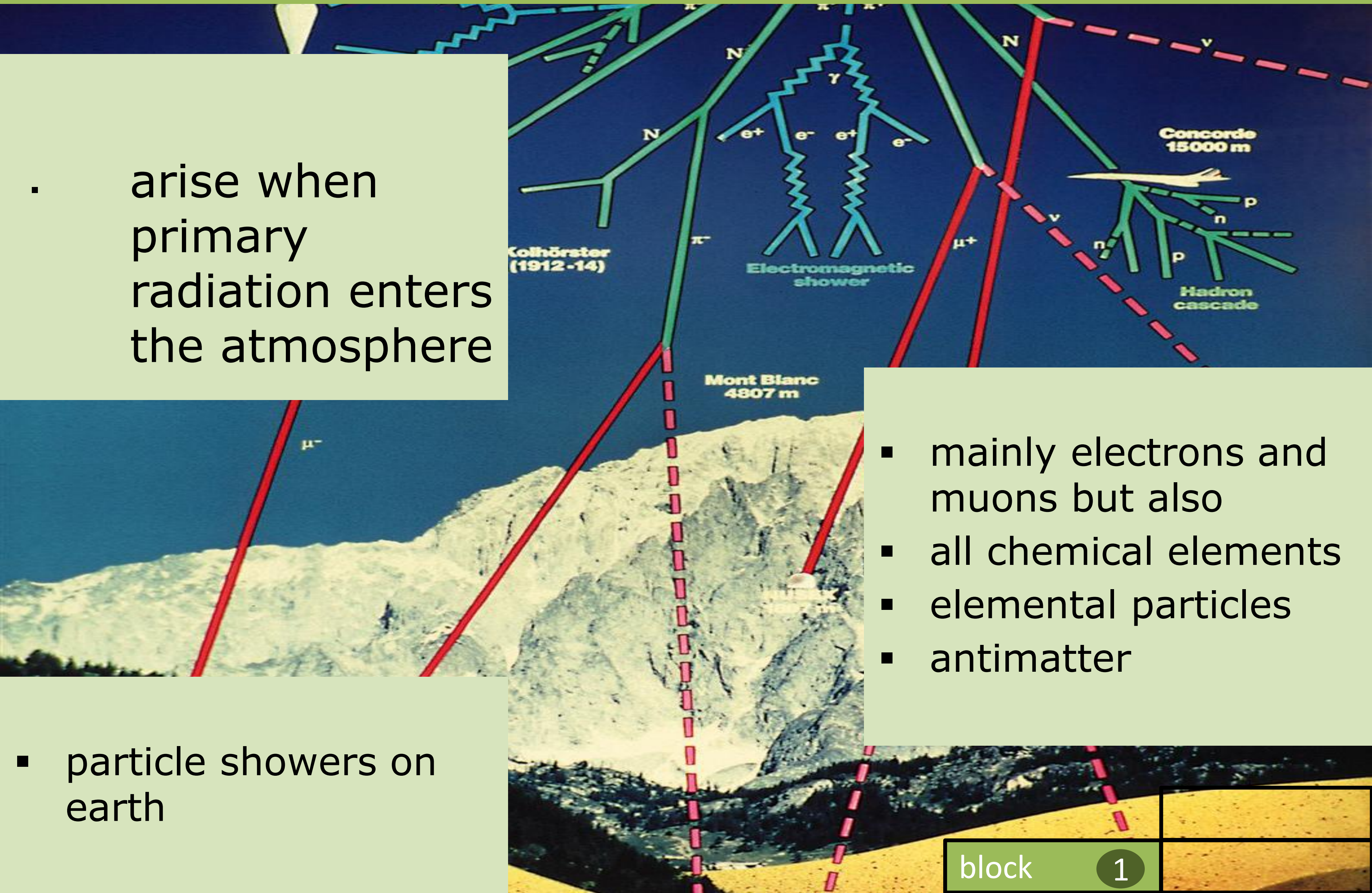
Primary radiation

- comes from space
- formation not fully clarified
- consists mainly of protons
- triggers particle showers



block 1

Secondary radiation



- arise when primary radiation enters the atmosphere

- mainly electrons and muons but also
- all chemical elements
- elemental particles
- antimatter

- particle showers on earth

Primary and secondary radiation

The primary radiation from space consists mainly of protons.

We still don‘t know the exact causes of their formation.

When the primary radiation enters the atmosphere, then a particle shower arises (secondary radiation).

This particle shower can be detected on the Earth‘s surface.

Other particles reach us as the original started from space.

On the Earth we can detect mostly electrons and muons.

At high altitude, you can find nucleii of all chemical elements, pions, kaons and even antimatter particles.

Characteristics: proton

primary radiation

Proton

(nucleus of the hydrogen atom)

$$m_{proton} = 1.6 \cdot 10^{-27} kg = 1836 \bullet m_{electron}$$

positive electric charge

$$Q_{proton} = +e$$

stable

block 1

Characteristics: electron

secondary radiation

electron

$$m_{electron} = 9{,}11 \bullet 10^{-31} kg$$

$$Q_{electron} = -e$$

negative electric charge

stable

block 1

Characteristics: muon („Who ordered that?")

secondary radiation

muon (= a „heavy electron")

surprise (1937)!

mass $m_{muon} = 206 \bullet m_{electron}$

negative electric charge $Q_{muon} = -e$

unstable
average life $= 2{,}2 \bullet 10^{-6}\, s$

Main components of cosmic radiation

primary radiation

secondary radiation

proton

electron

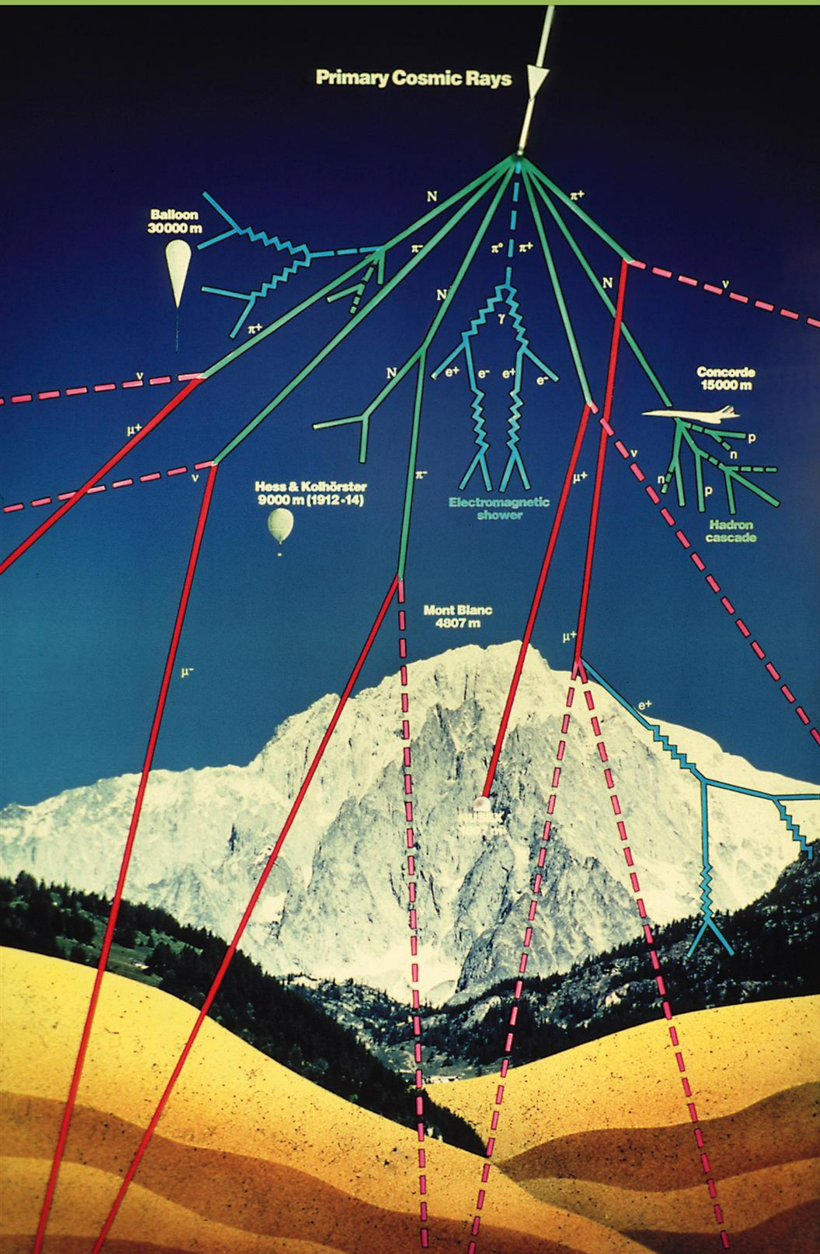
muon

stable

stable

unstable

How we can prove the radiation?



all detection methods use

charge and energy

of the particles

The spark chamber is an excellent detector

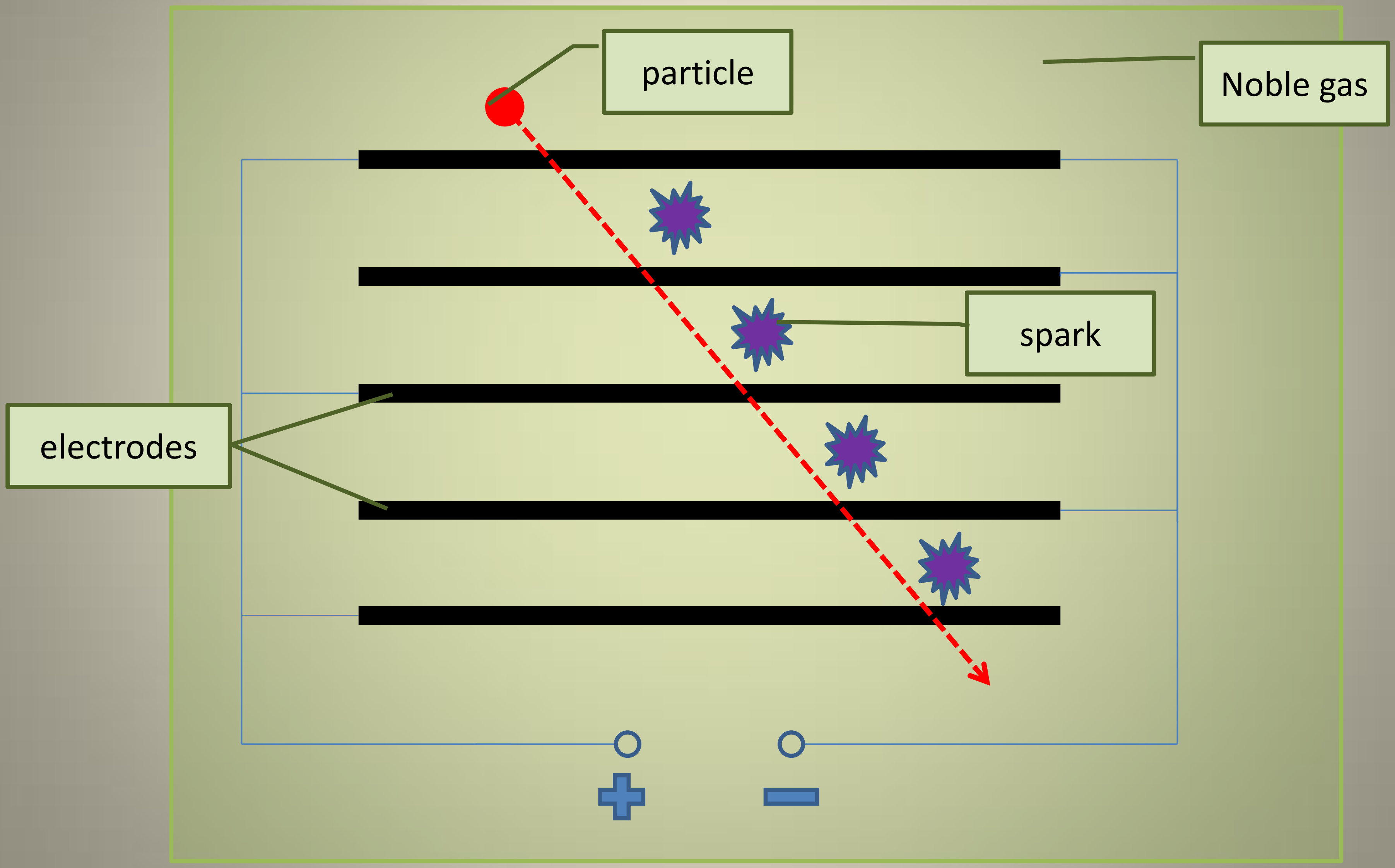
block 1

Spark chamber in action

Next

block 1

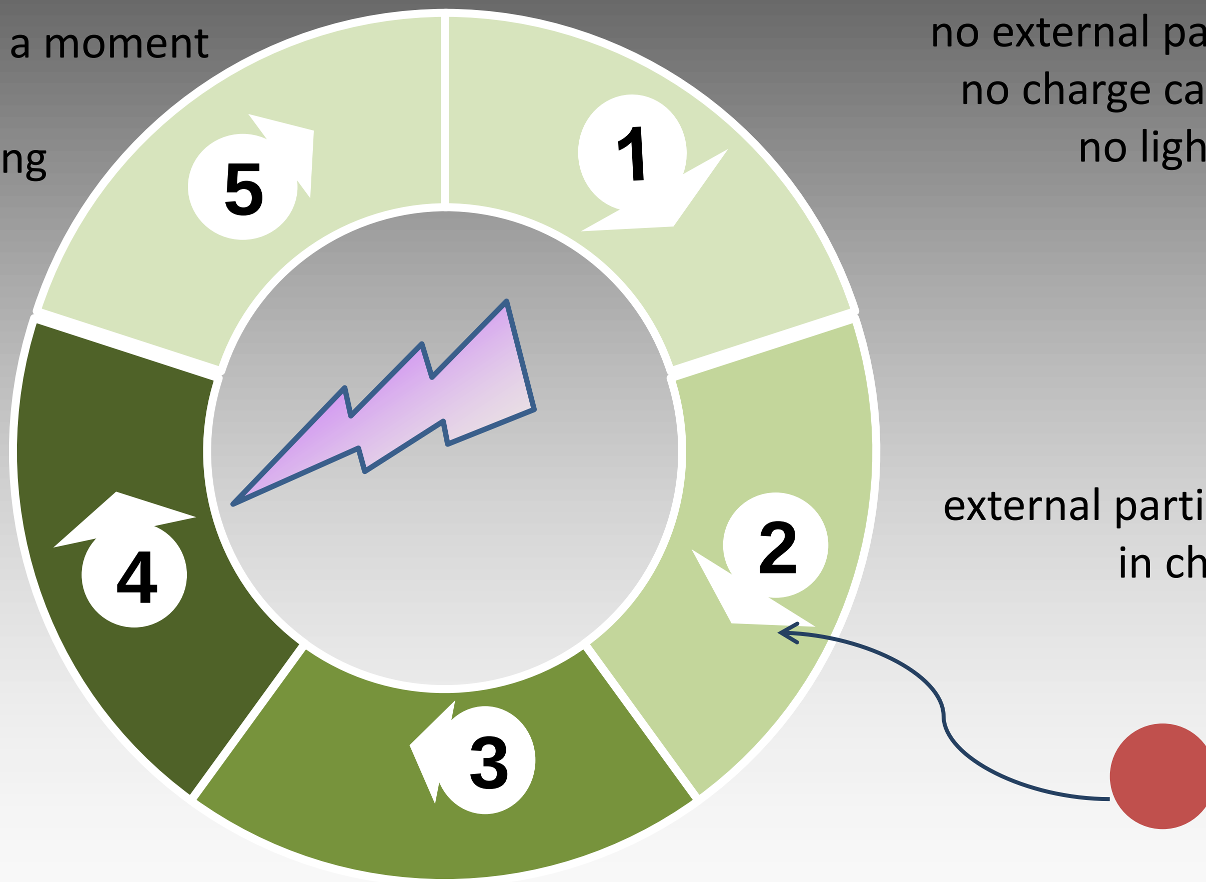
Construction of the Spark Chamber



Operation of the spark chamber

voltage is applied
no external particle
no charge carriers
no lightning

Turn off the voltage for a moment
no acceleration
spark breaks, no lightning
New measurement
possible



external particle flys
in chamber

large number of
charge carriers
acceleration
spark, lightning

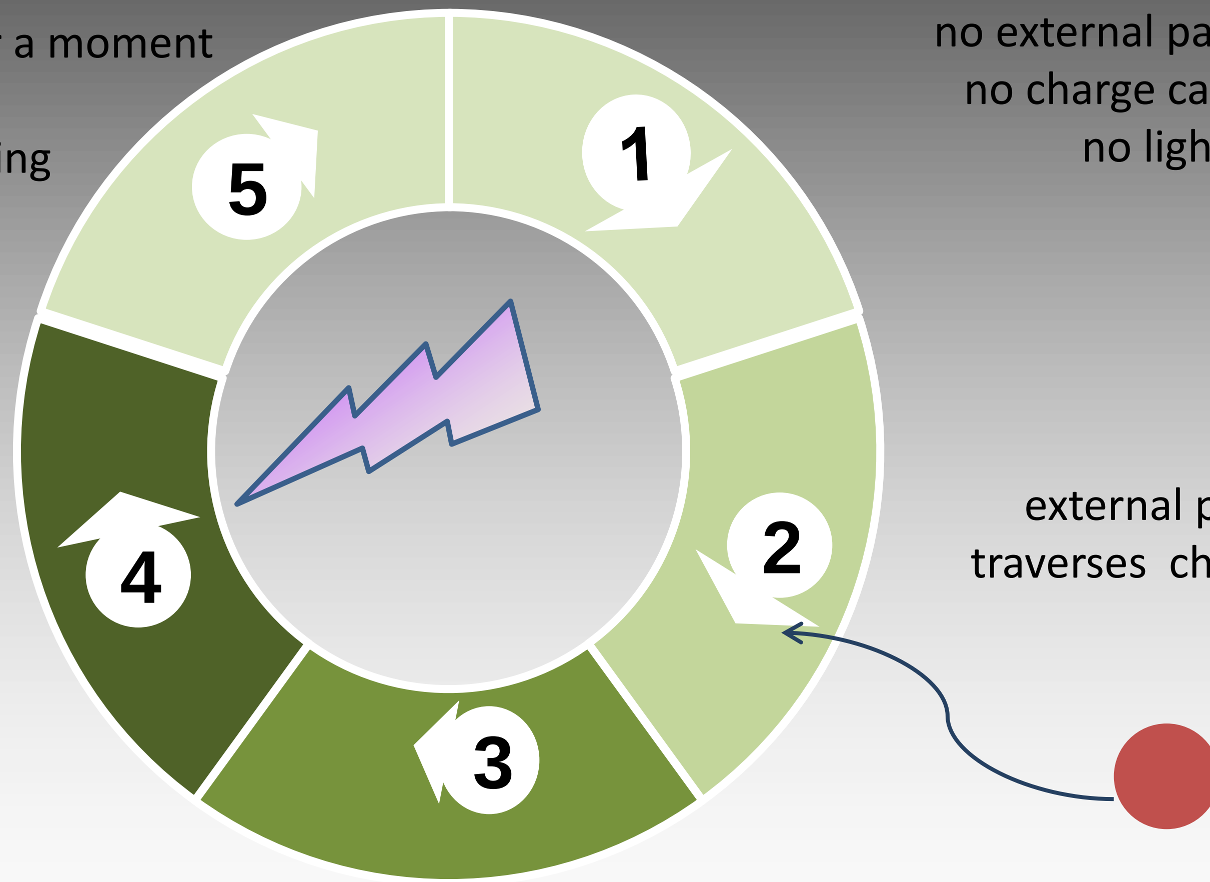
electrons are ripped from other gas atoms, impact
ionization

block 1

Operation of the spark chamber

voltage is applied
no external particle
no charge carriers
no lightning

Turn off the voltage for a moment
no acceleration
spark breaks, no lightning
New measurement
possible



external particle
traverses chamber

large number of
charge carriers
acceleration
spark, lightning

electrons are ripped from other gas atoms,
impact ionization

block 1

Other detection devices

cloud chamber

counter tube

electrometer

block 1

Other detection devices

electrometer

block 1

Other detection devices

Geiger-Muller-counter tube

Other detection devices

cloud chamber to build it yourself

Openday 16 October 2004

Cloud Chamber Workshop

BUILD YOUR OWN CLOUD CHAMBER AT HOME

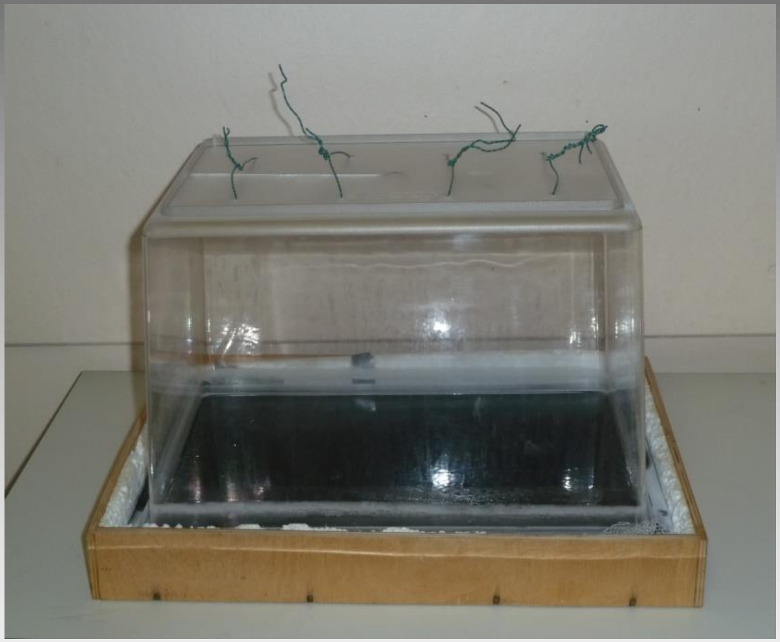
Particles coming from the universe (cosmic rays) are crossing the earth all the time – they are harmless but invisible to us, also called natural radiation. Cloud chambers are detectors to make the tracks of the particles visible. Some decades ago – these detectors were used at CERN in the first experiments to detect particles. Wouldn't it be nice to build such a detector at home in your kitchen? We show you how to build a small one at home in your kitchen for your own research ....

Shopping list

- A clear, see-through box-like plastic container, with flat sides and an open top, roughly 20 x 30cm (open side) x 15cm (height)
- A metal plate (at least 5mm thick) to cover the open size of the container completely (plate must be a little bit larger than the box). The plate should be preferably black and should have a little grooves matching the side walls of the plastic box. As this is probably hard to find, you can also use a flat metal plate and use black electrical tape to make the metal plate surface black.
- A thick felt (few mm), a bit smaller than the bottom of the box.
- 4 clips (self-adhesive cable-tie holders + cable ties) to attach the felt to the inside of the bottom of the box
- A small wooden box that is just a little bit larger in area than the metal plate and approx. 5cm in height. The box later on has to take the ice plates and the metal plate but the sides should not be much higher so that it doesn't cover the plastic box.
- A very intense, bundled light source, e.g. a slide projector, strong flashlight ...
- Pure (not 70%) isopropyl alcohol – make sure you get the right one – it will only work well with this one it and keep it out of reach of children).
- Dry Ice (Careful with your hands – always use thick gloves and never touch the ice directly! The ice is at -78°C; touching it directly will give you a burn.)
- Security goggles to handle the ice
- Gloves to handle the ice and the alcohol

A word of warning:

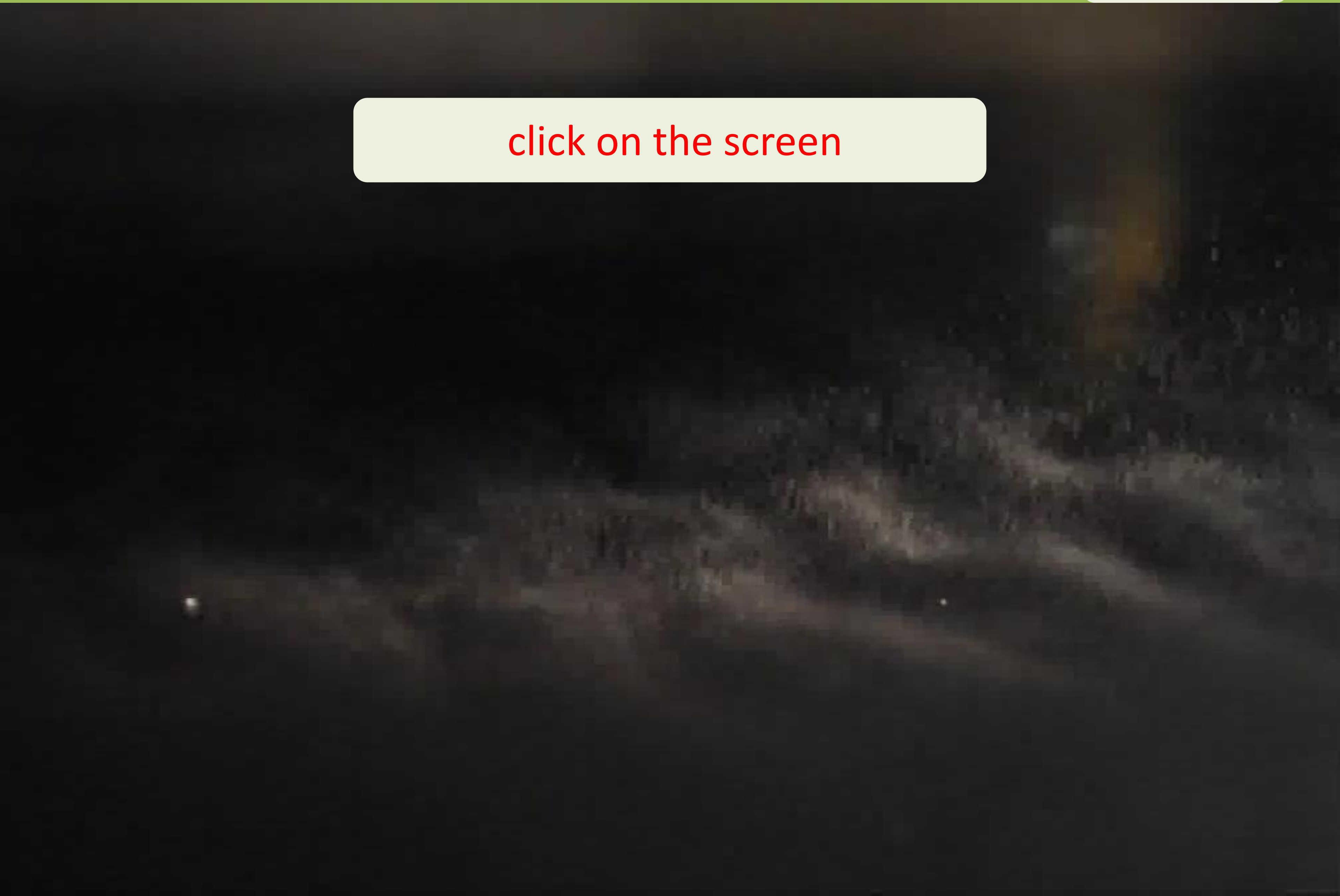
Isopropyl alcohol is not intended for drinking and harms your health if you drink it. So never ever drink it and keep it out of range of children. Handle it only with plastic gloves. Dry ice is at -78°C so never touch it directly – it will burn your skin – always use thick gloves and security goggles to handle it and watch children carefully. Also dry ice (CO_2) evaporates as it heats up which can harm your health in large quantities. So make sure you ventilate your room very well while doing the experiment.



Self – built cloud chamber in action

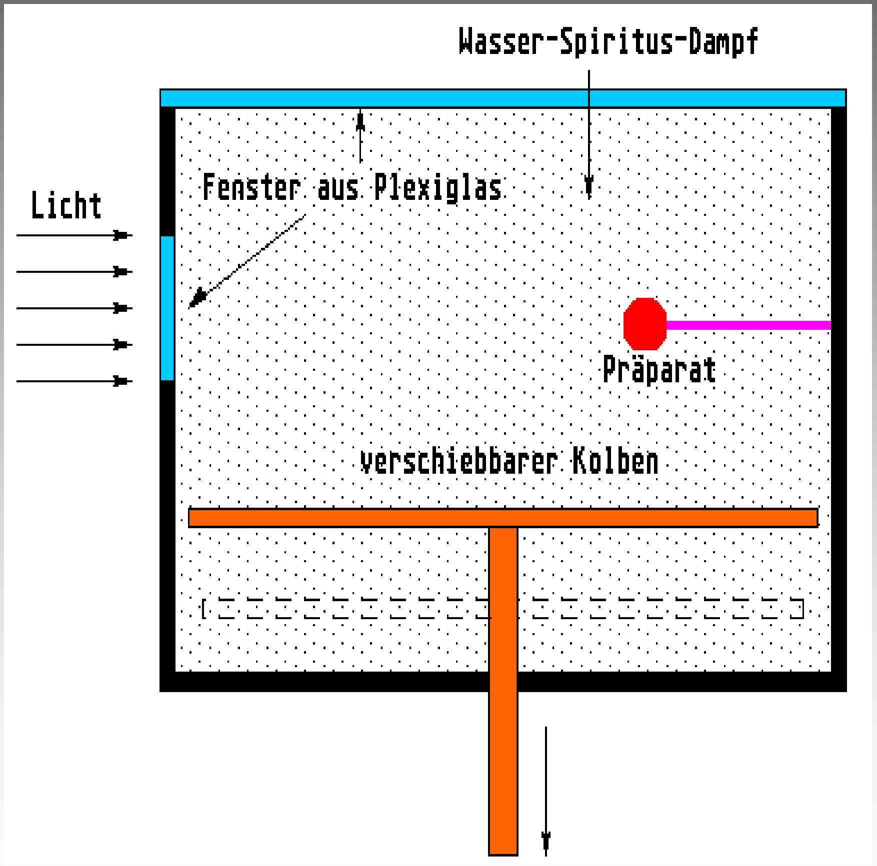
Next

click on the screen



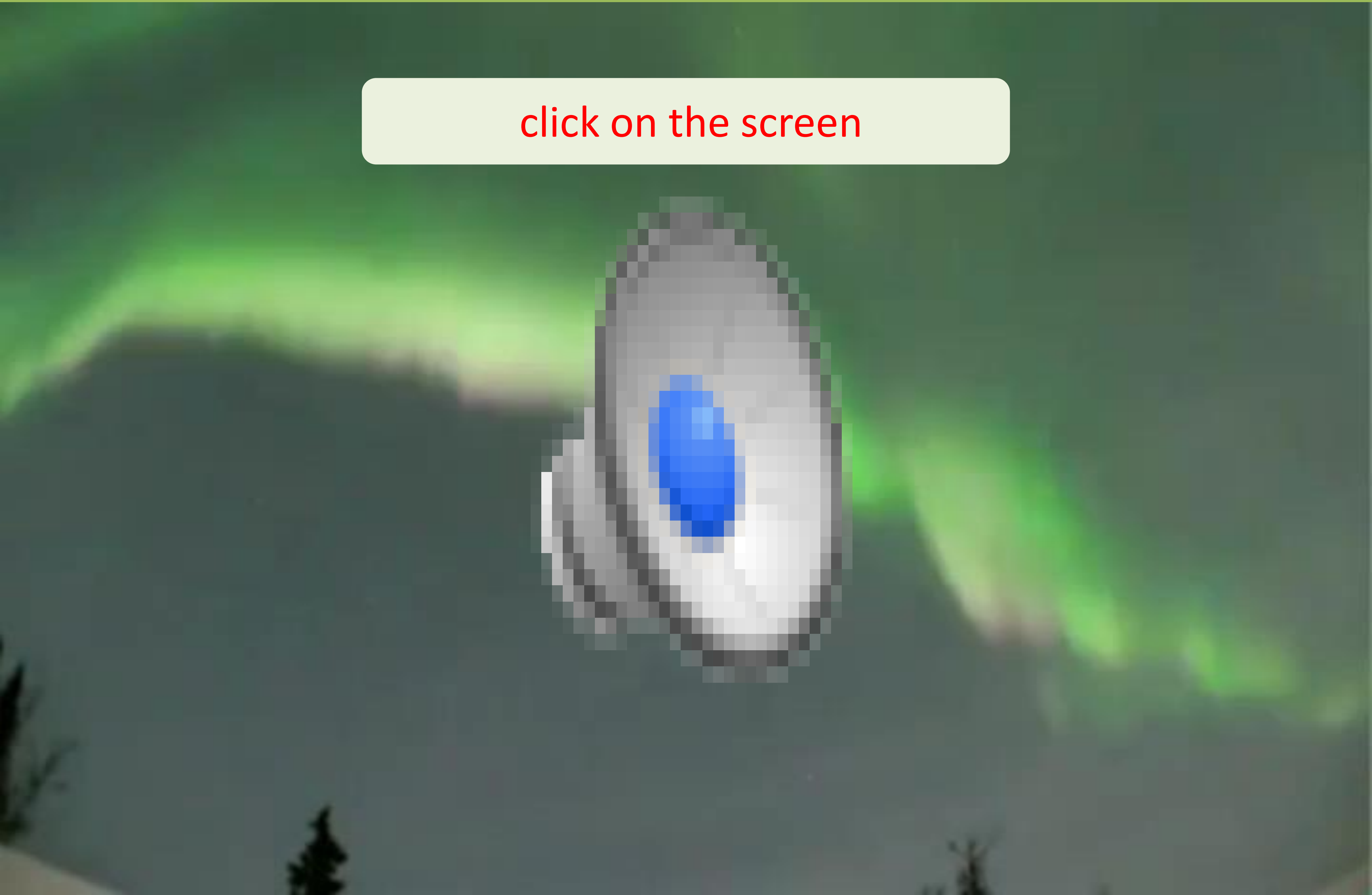
Other detection devices

cloud chamber



Video: auroras

Next



click on the screen

?

How are such impressive phenomena created?

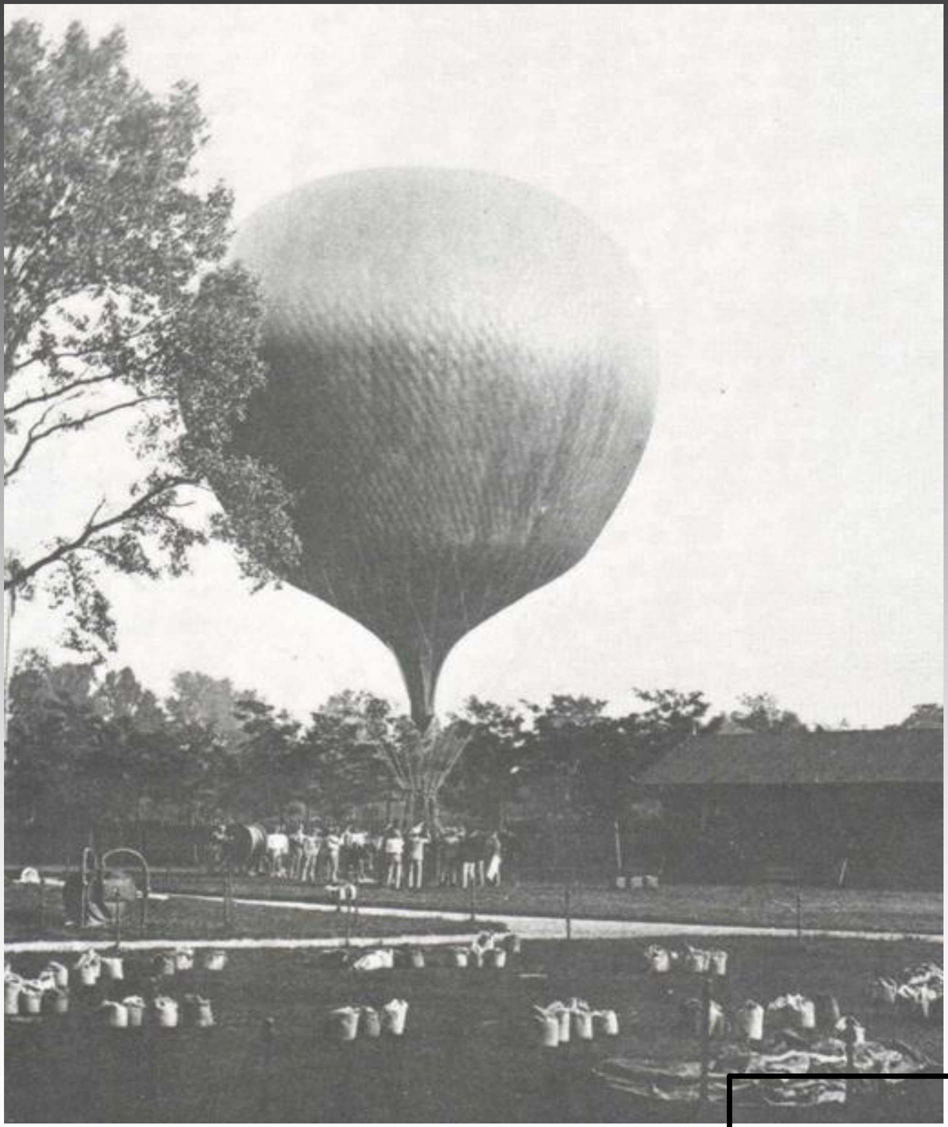
How are aurora created?

- Cosmic rays from the Sun reach the atmosphere
- energy is transferred to air atoms
- Excitation of atoms in the air
- Energy output of the air atoms in the form of light
- nitrogen – blue light
- oxygen – green and red light

How were these cosmic rays first detected?

- Viktor Hess (1912)
- ballooning up to a altitude of 5 km
- conductivity of the air rises
- What is responsible? - a new type of radiation!

Cosmic radiation!



How did they come to the particles on the track?

Victor Hess (Austria) wanted to clarify, where the ionizing radiation at the Earth�to surface came from – from below or from above?

He observed this radiation using the discharge of an electrometer.

His measurements led him to make a balloon flight to a height of 5000m.

To his surprise, he discovered that the discharge was faster as the altitude increaed.

He concluded that the ionizing radiation must come from space.

In 1936, Hess received the Nobel prize in physics.

block 1

Who discovered the radiation?

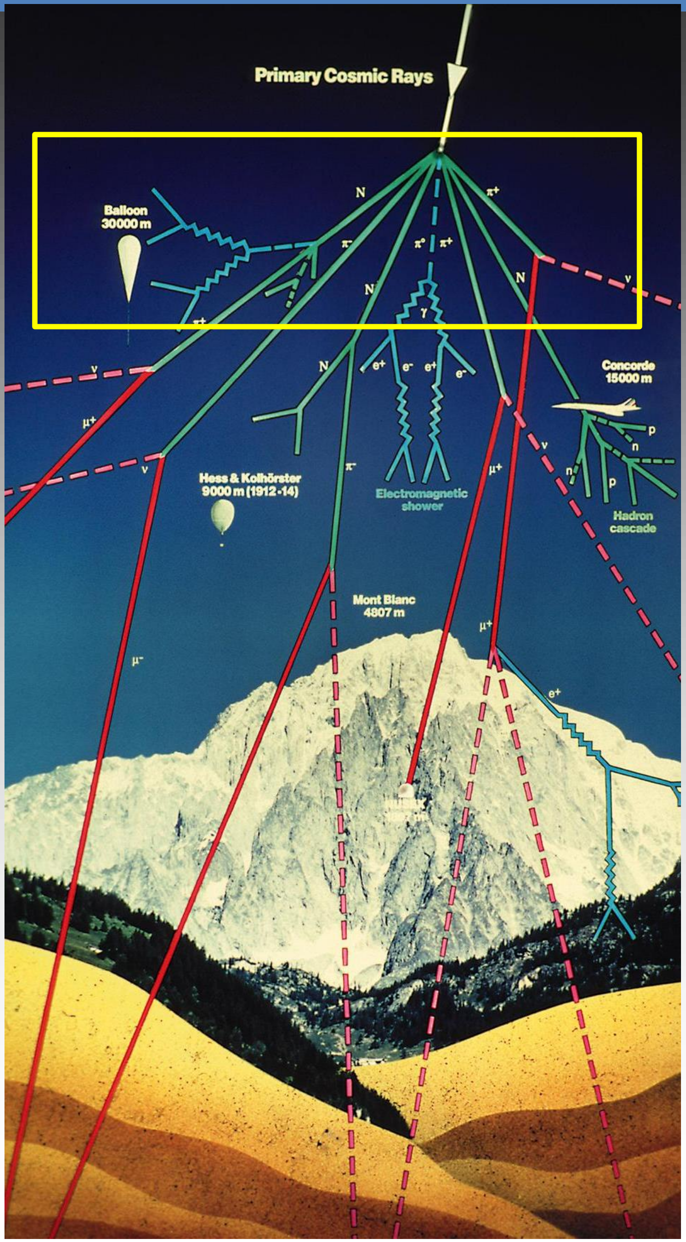
- Victor Hess

  with a self developed electroscope

- discovery of the cosmic radiation (1912)

- Nobel prize in physics(1936)

About the particle showers



block 2

How is a particle shower created?

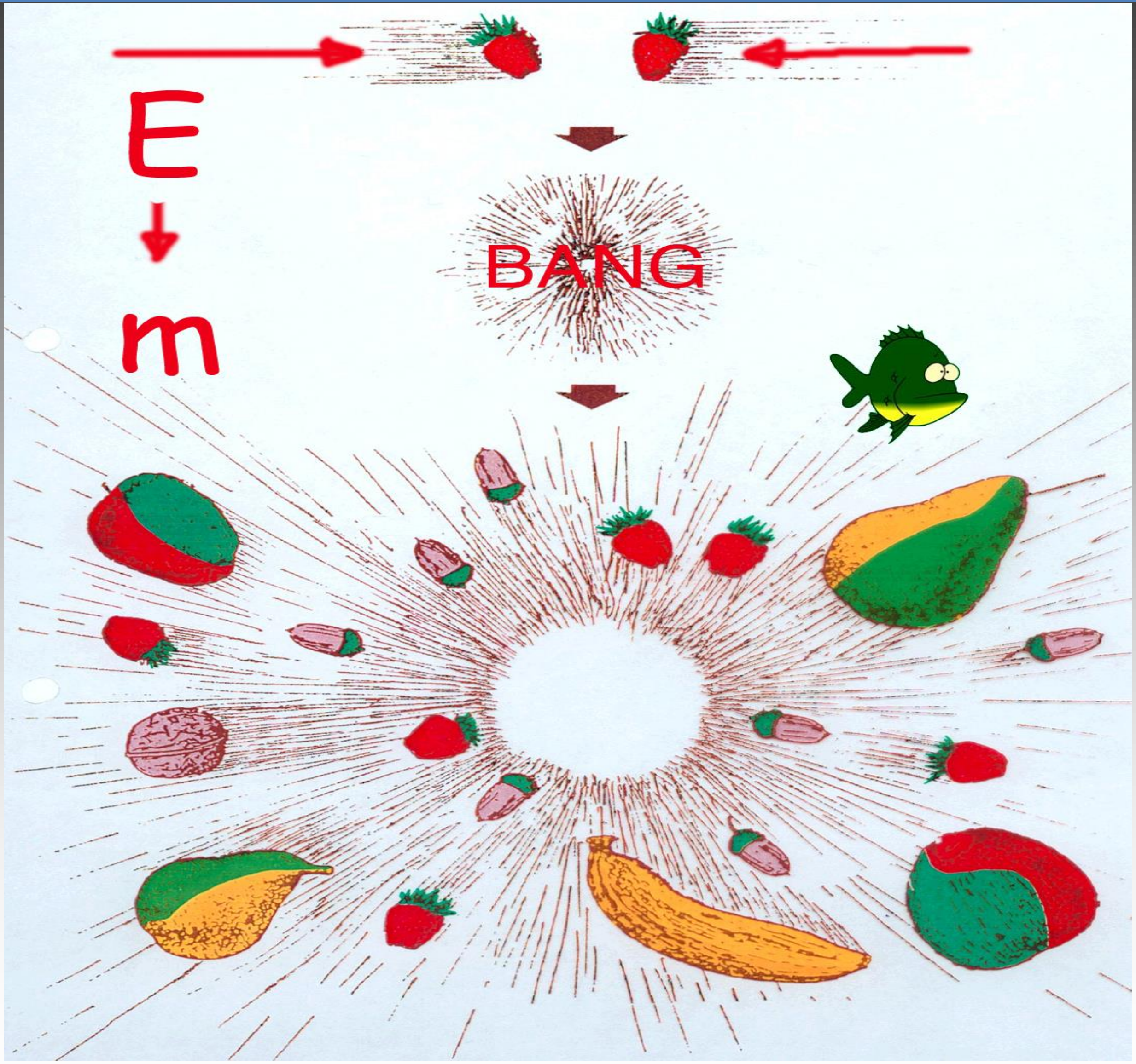
containing 1,000,000 particles

within a circle of d=5 km

on the surface of the Earth?

block 2

A particle shower is created………as a fruit cocktail



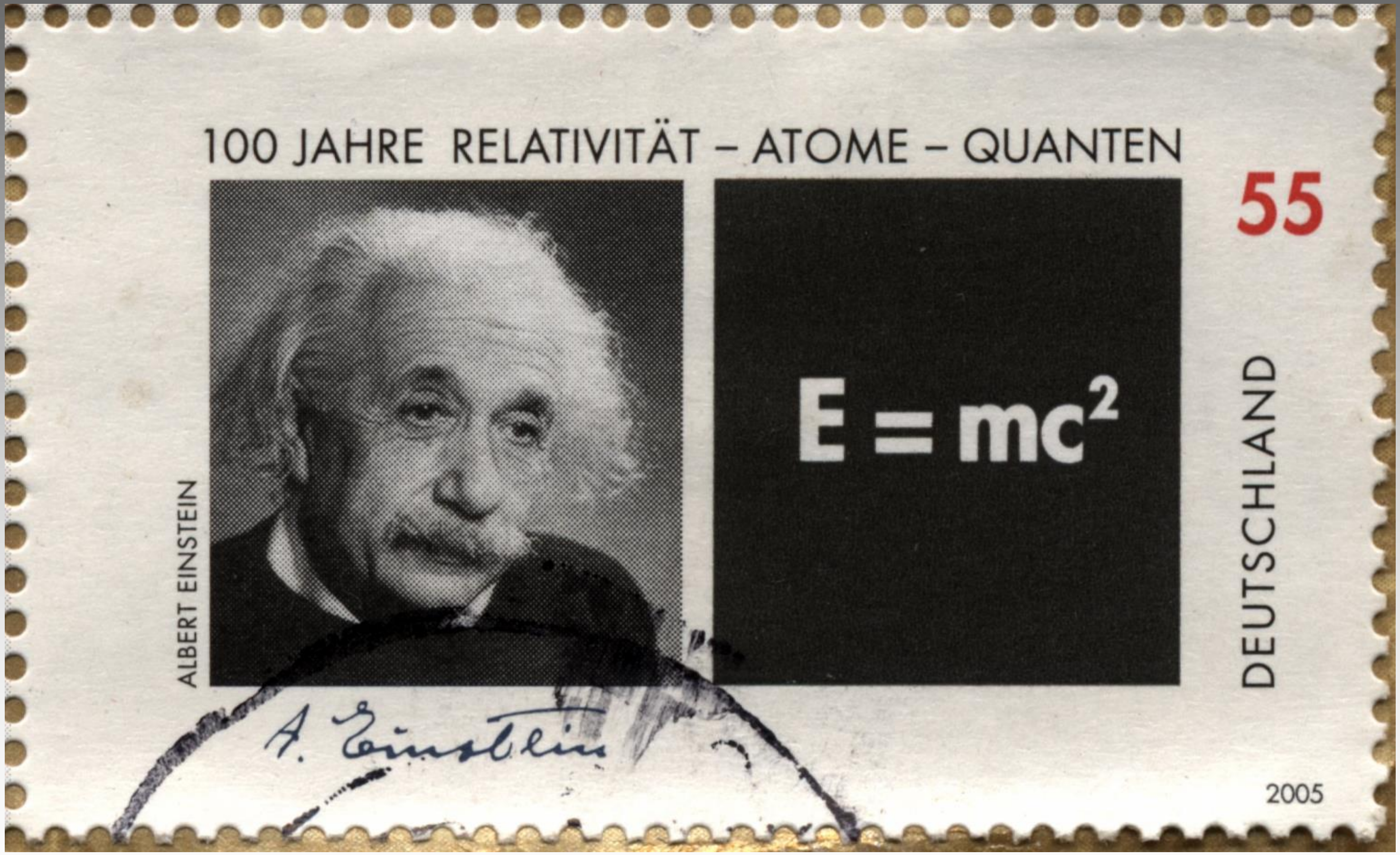
block 2

Exactly

A fast proton from space hits a proton (or neutron) in an atomic nucleus in the air (oxygen or nitrogen).

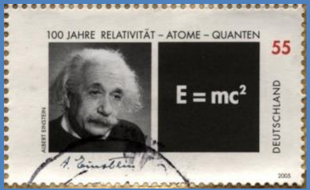
A part of the proton energy transforms to generate the new (secondary) particles with their respective mass and energy.

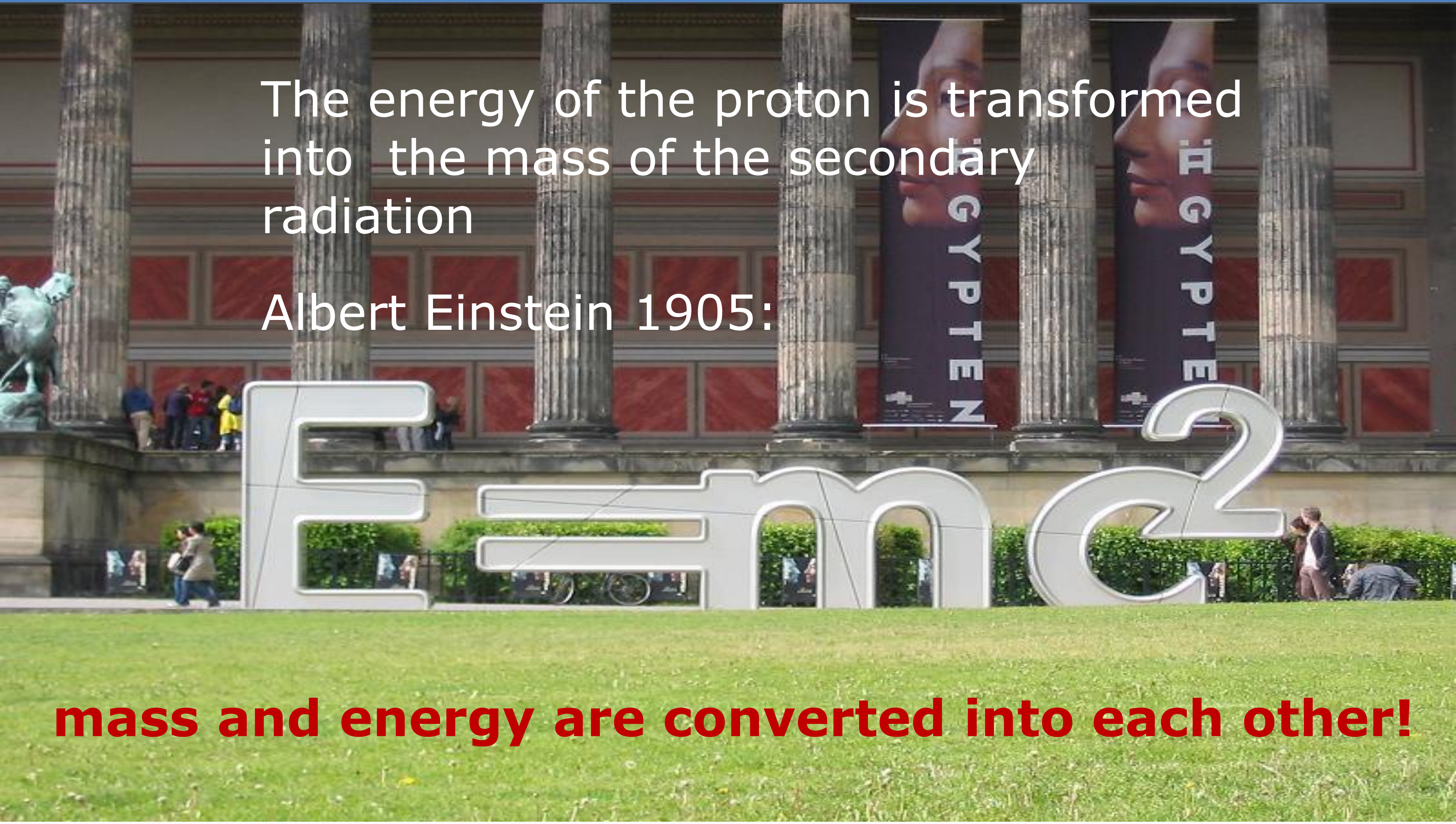
Mass results from energy?



block 2

Mass results from energy?





The energy of the proton is transformed into the mass of the secondary radiation

Albert Einstein 1905:

mass and energy are converted into each other!

Mass results from energy?

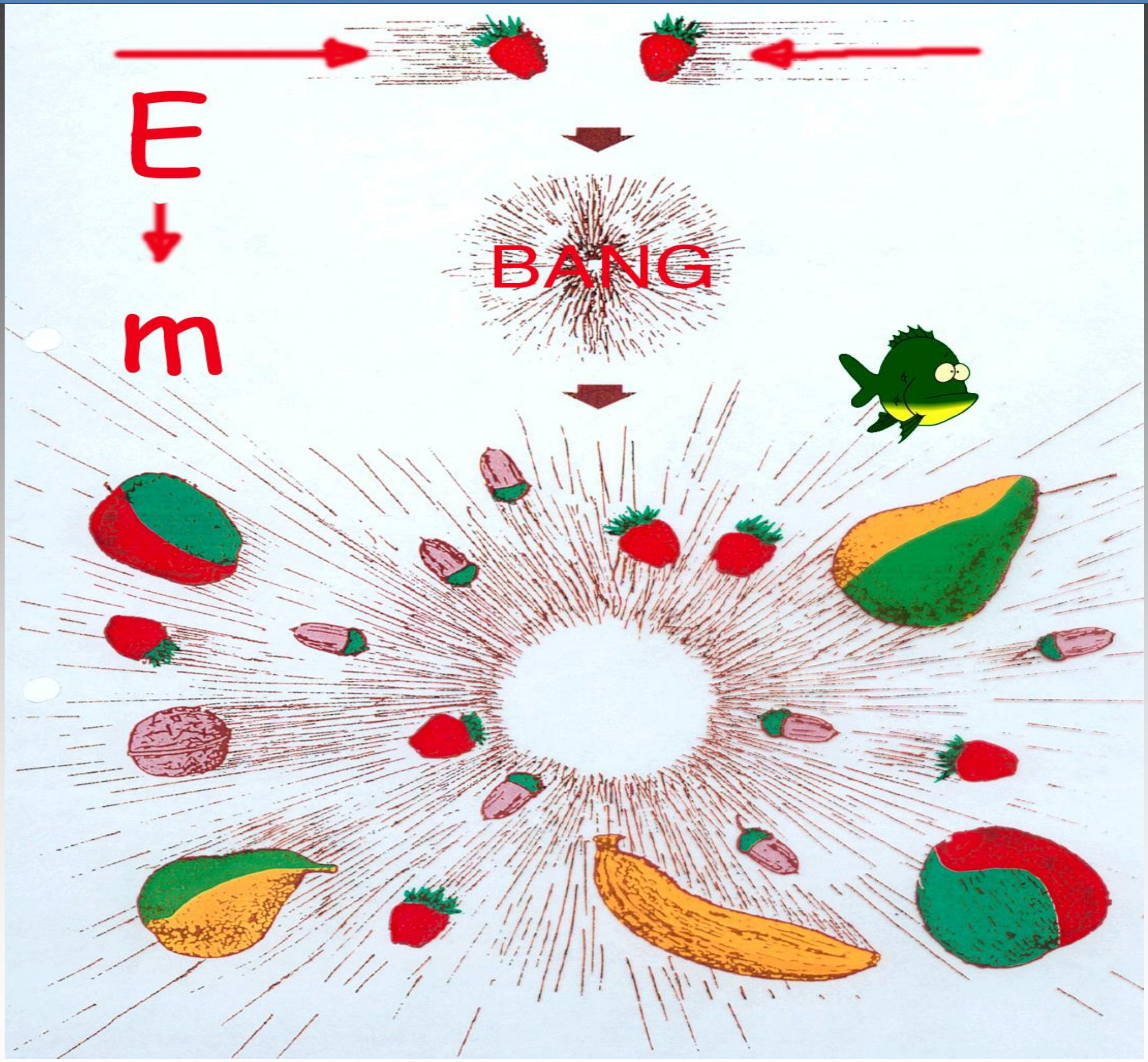
Part of the energy from the fast proton creates the mass of the secondary particles.

Einstein explains this amazing process with his famous equation

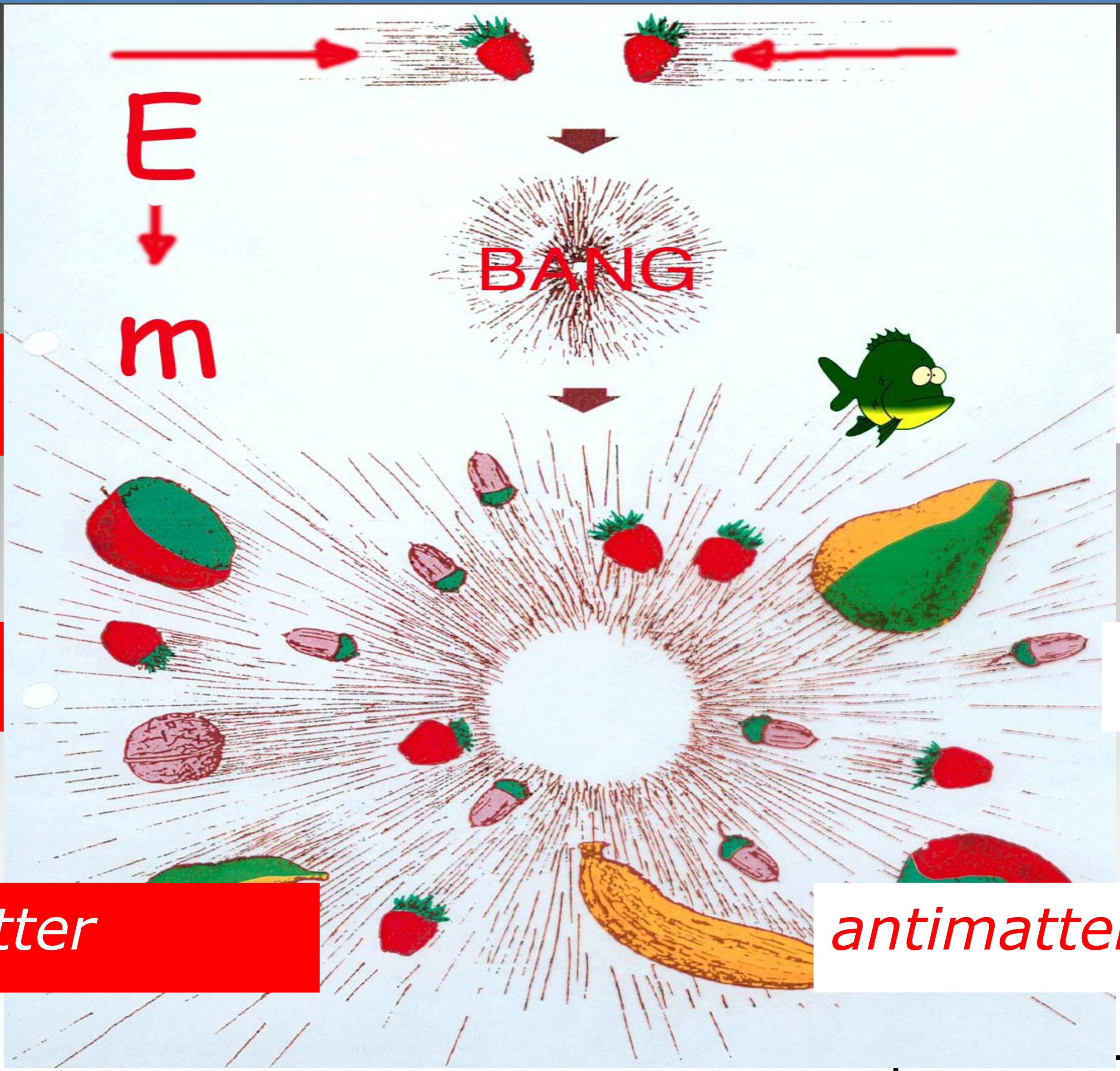
$$E = m \bullet c^2$$

It says, that mass and energy are interconvertible.

Which fruits are in the cocktail?



What is in the cocktail?



electron

positron

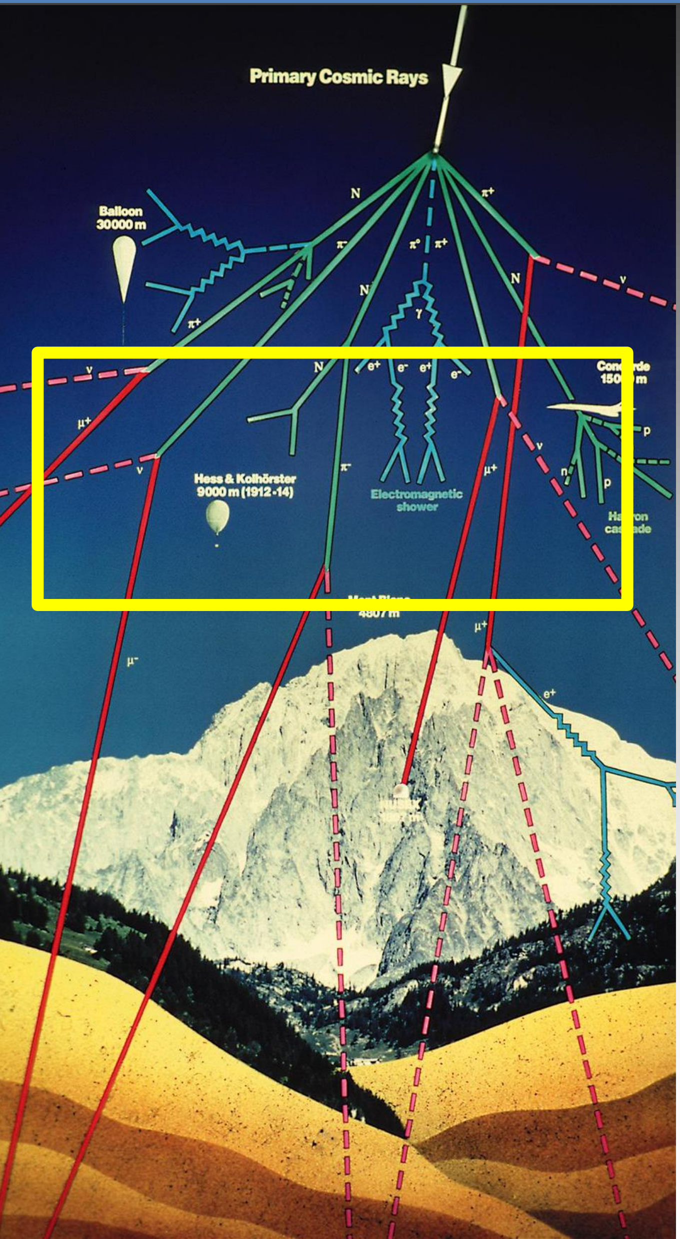
muon

antimuon

matter

antimatter

What is in the shower?



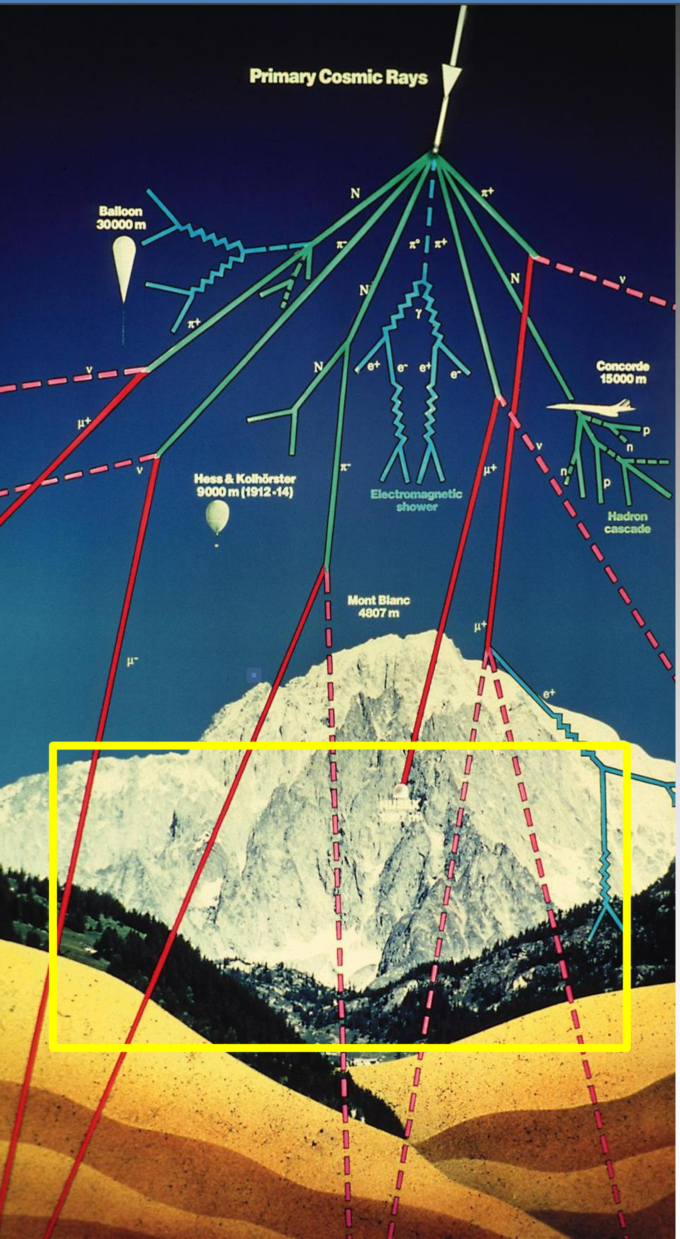
basic building blocks of all atoms

proton	*electron*	*muon*
	+	
antiproton	*positron*	*antimuon*

matter and antimatter

basic building blocks of our world

What comes to us?



proton, electron + antiproton, positron,

muon antimuon

more nuclear transformations

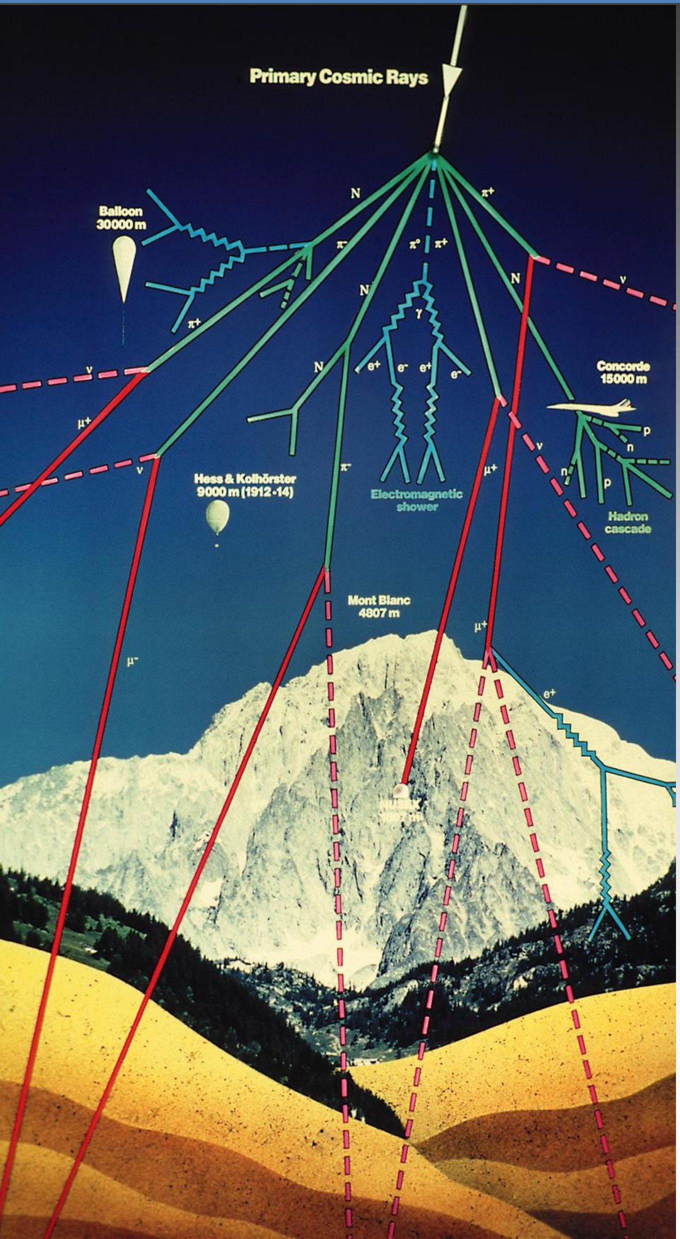
also radioactive nuclei! (C-14)

proof on earth

decay in atmosphere

block 2

What comes to us?



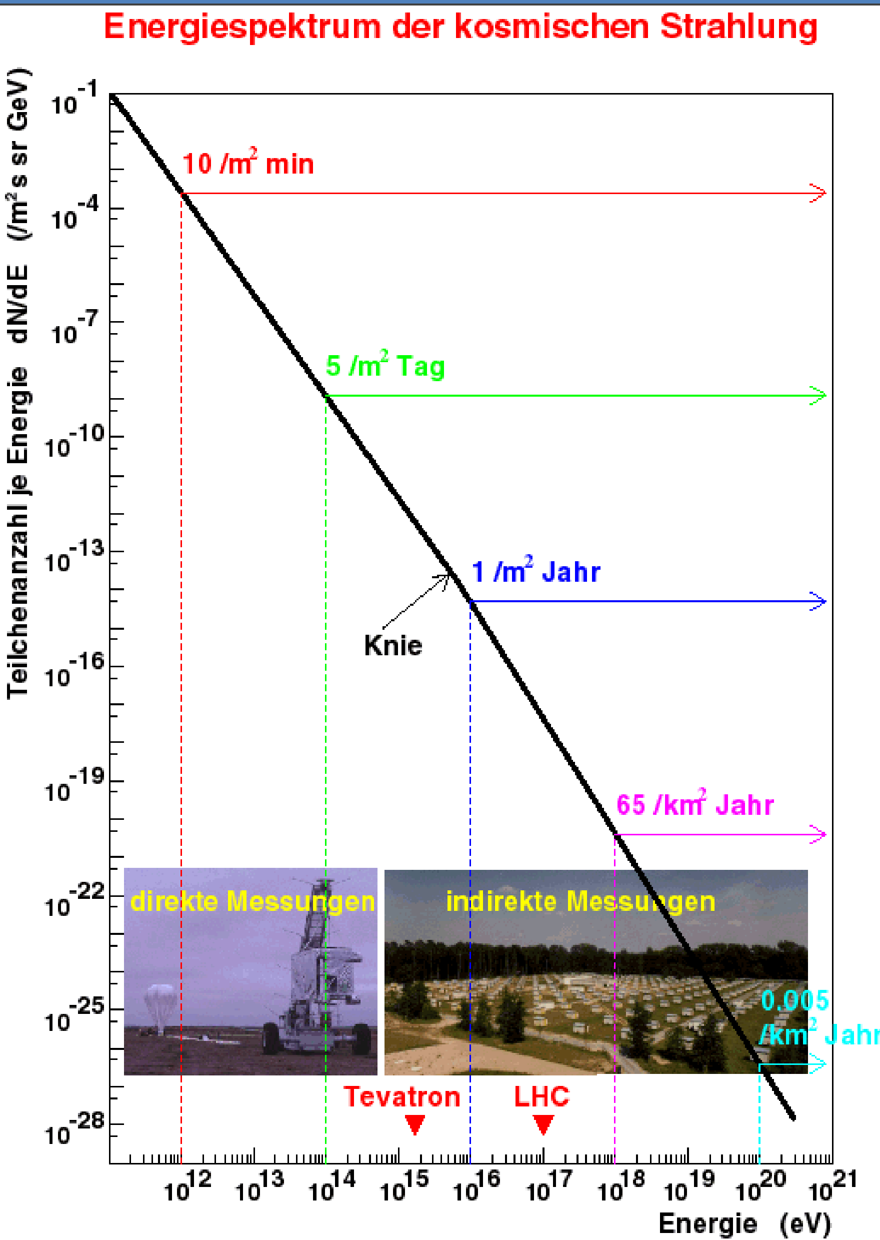
The secondary radiation essentially consists of protons, electrons and muons, the basic building blocks of our Earth and the associated antiparticles.

They can also trigger more nuclear transformations, which can create more radioactive nuclei.

The carbon isotope C-14, that is important for the age determination of fossils, arise only in this way.

Many of the particles are unstable, therefore only a few of them reach the Earth.

What is coming to us? (*energy spectrum*)



Anzahl der Teilchen	Energie des Teilchens
10/m² je min	$10^{12}eV$
5/m² je Tag	$10^{14}eV$
1/m² je Tag	$10^{16}eV$
65/km je Jahr	$10^{18}eV$
0,005/km² je Jahr	$10^{20}eV$

Energy spectrum

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0,005/km² je Jahr	$10^{20} eV$

The particles have very different energies

Despite their low mass the highest-energy particles have the energy of a well hit tennis ball.

The unit of energy used is the Electronvolt (eV)

$$1\ Joule = 1\ Nm = 6{,}24 \cdot 10^{18} eV$$

Energy spectrum

Anzahl der Teilchen	Energie des Teilchens
10/m² je min	$10^{12} eV$
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1/m² je Tag	$10^{16} eV$
65/km je Jahr	$10^{18} eV$
0,005/km² je Jahr	$10^{20} eV$

The highest-energy particles are very rare!

Example: $10^{20} eV$

particles of energy on an area

of 1km²

1 event in 200 years

As a result the search for them is complex and difficult!

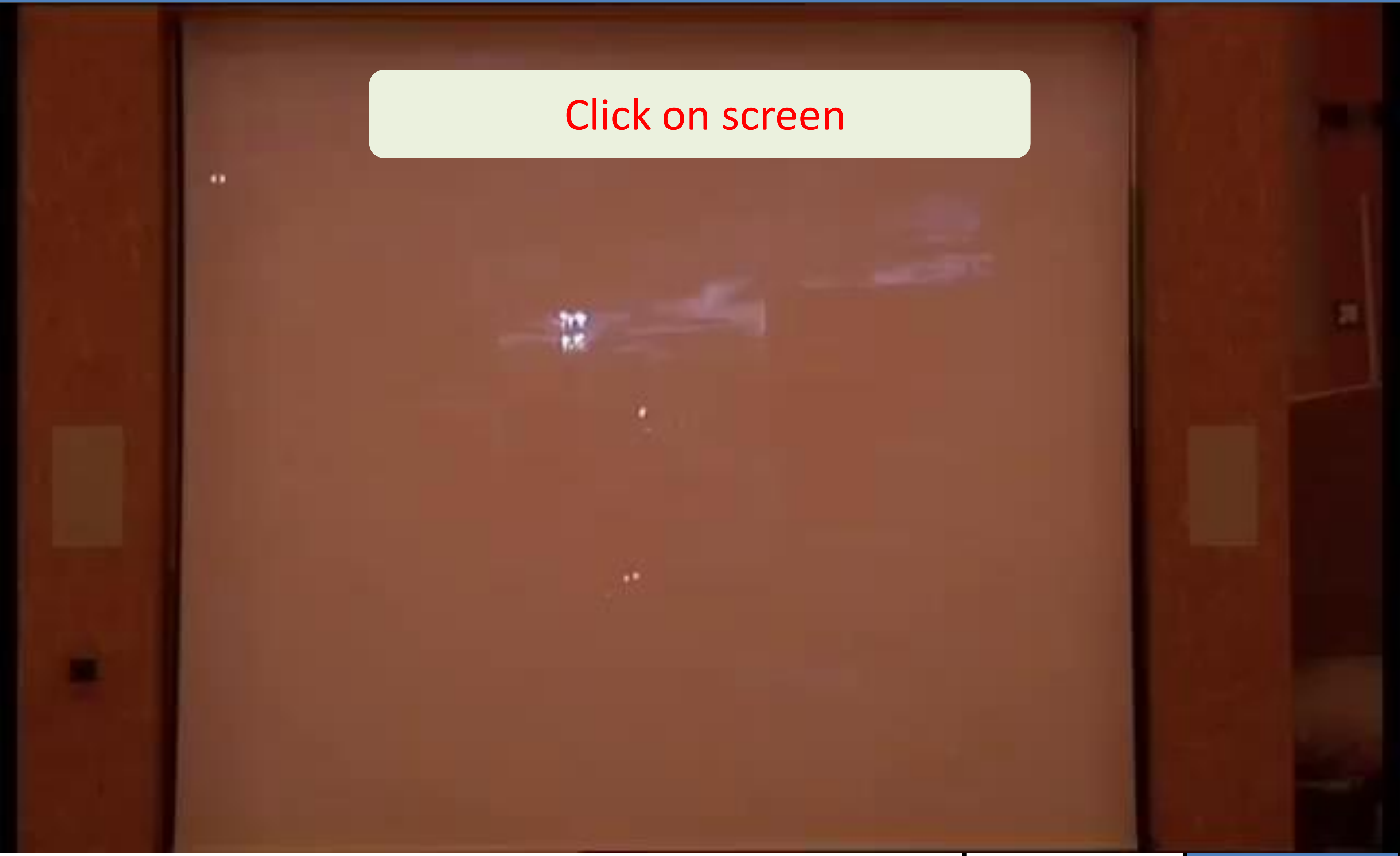
Search for the highest-energy particles

Kascade experiment (Karlsruhe)

- area 700 m • 700 m
- Detection of primary particles up to $10^{18}\,eV$
- so far about 40 000 000 air showers were measured

Video Kascade experiment Karlsruhe

Next



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block 2

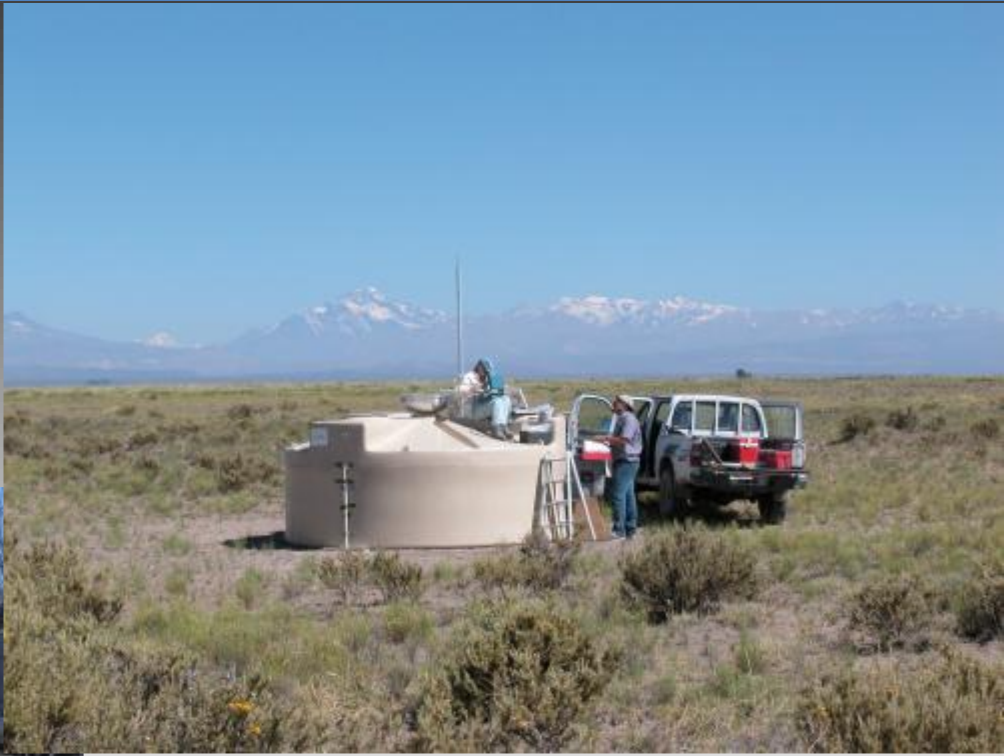
Auger Observatory in Mendoza

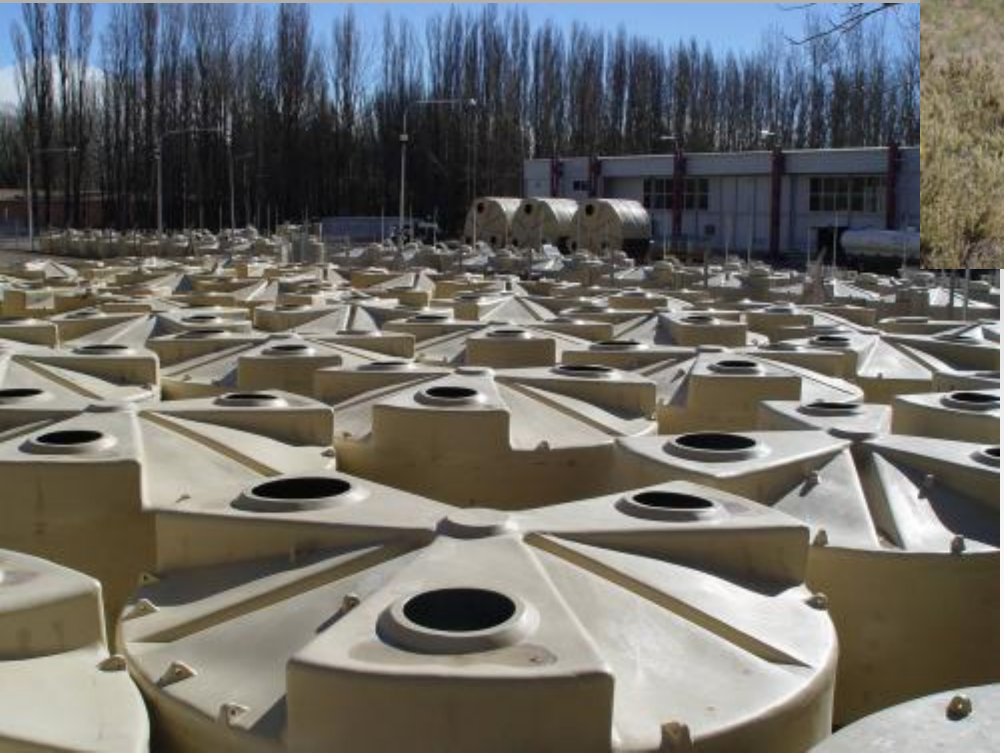
largest system in the world!

Proof of showers up to 10^{20} eV

Detectors at the Auger Observatory

total area: 3000 km²





1600 detectors

block 2

Particle accelerator *made by man*

Maximum energy of the protons in the largest particle accelerator of the world

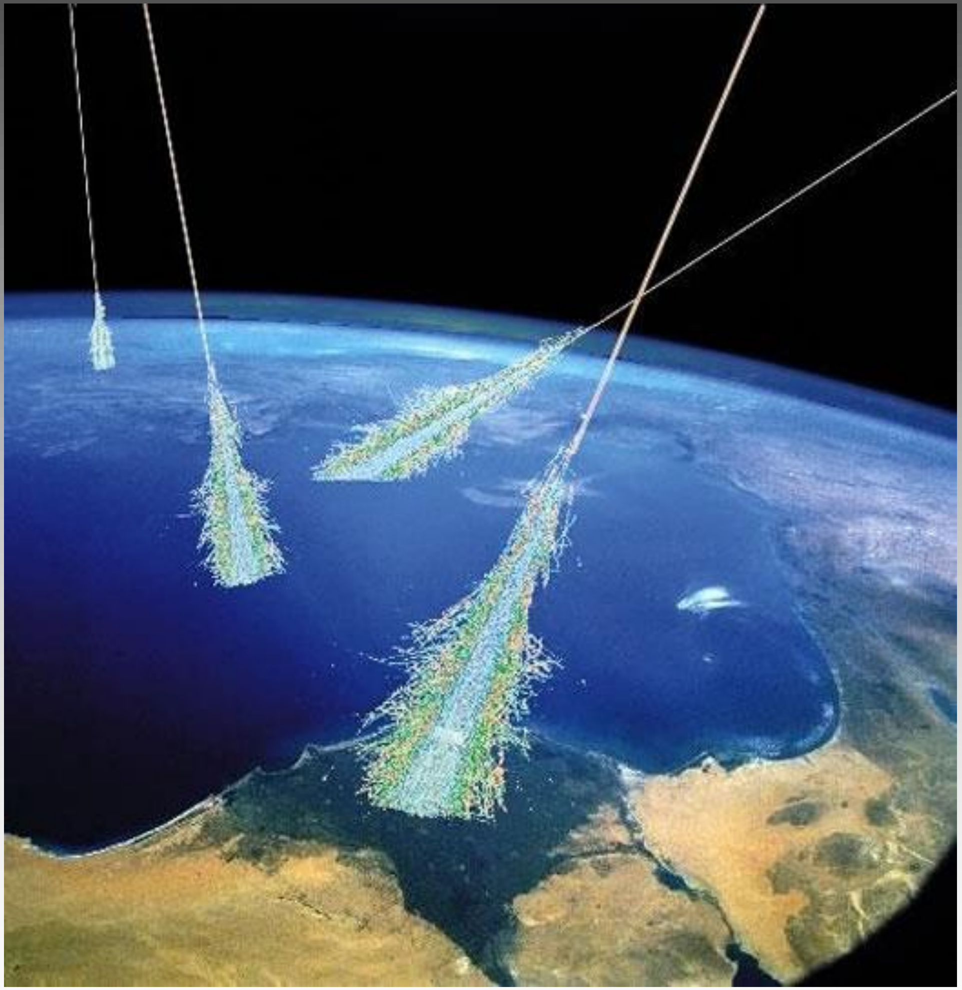
(LHC at CERN)

$$7 \cdot 10^{12}\, eV$$

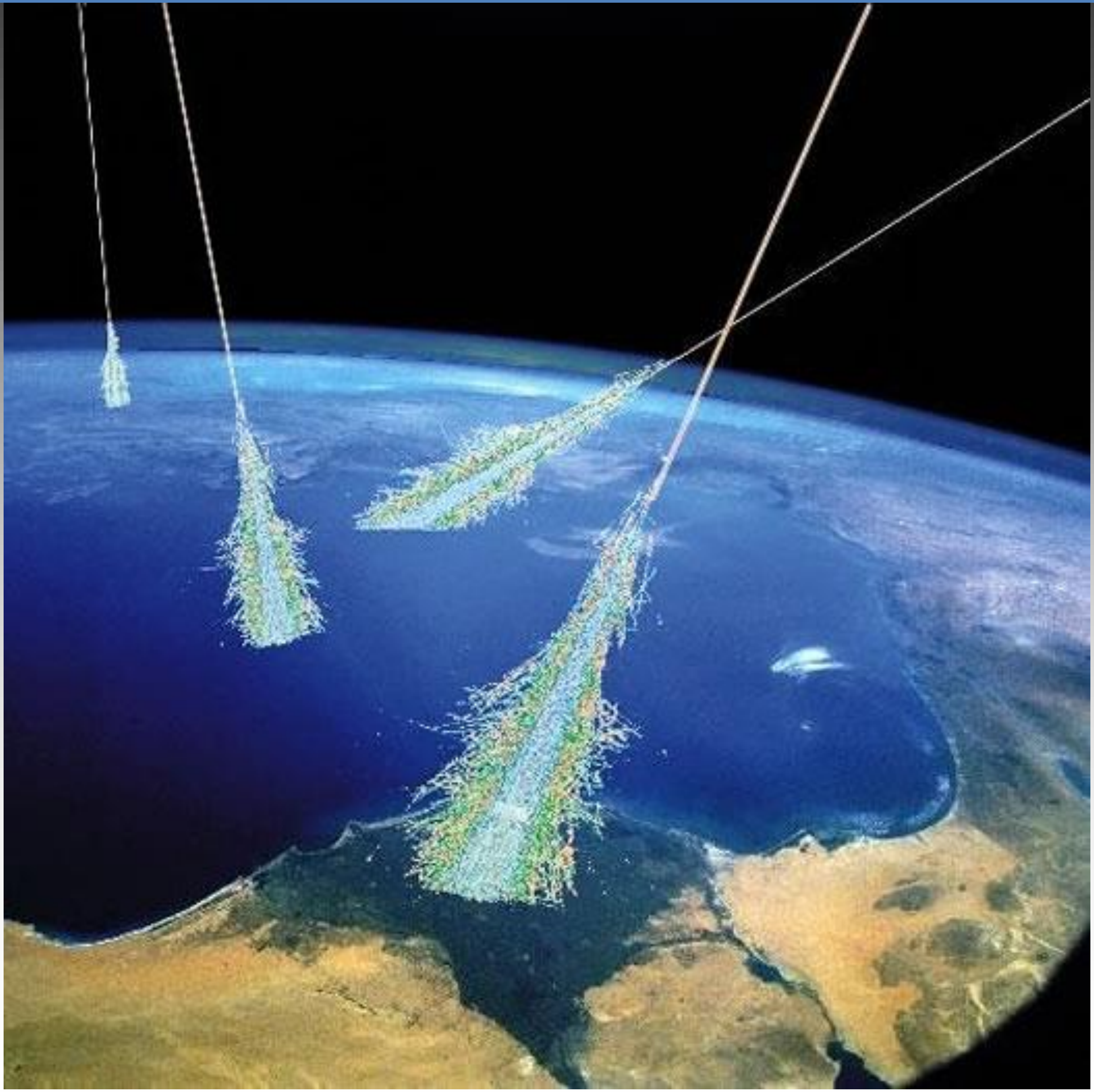
particle accelerator *in space*

Maximum energy of the protons of cosmic rays entering the Earth's atmosphere

$$10^{20}\ eV$$



Particle accelerator *in space*



cosmic rays

↓

gigantic natural accelerator

Muons counter at the Jungfraujoch near Bern

spark chamber

1. Bern *542m height*

2. Jungfraujoch *3571m height*

Are there any Muons?

What results are expected?

profile muon (Who ordered that?)

secondary radiation

larger mass than electrons

$$m_{Myon} = 206 \bullet m_{Elektron}$$

$$Q_{Myon} = -e$$

negatively charged, carries one elementary charge

Surprise!

unstable
average lifetime $= 2{,}2 \bullet 10^{-6}\, s$

a simple rollover

given:

v= $3 \bullet 10^{8} m \bullet s^{-1}$ movement with light speed

t=0,0000022 s average lifetime

h=20 km distance from the earth in production

wanted: s

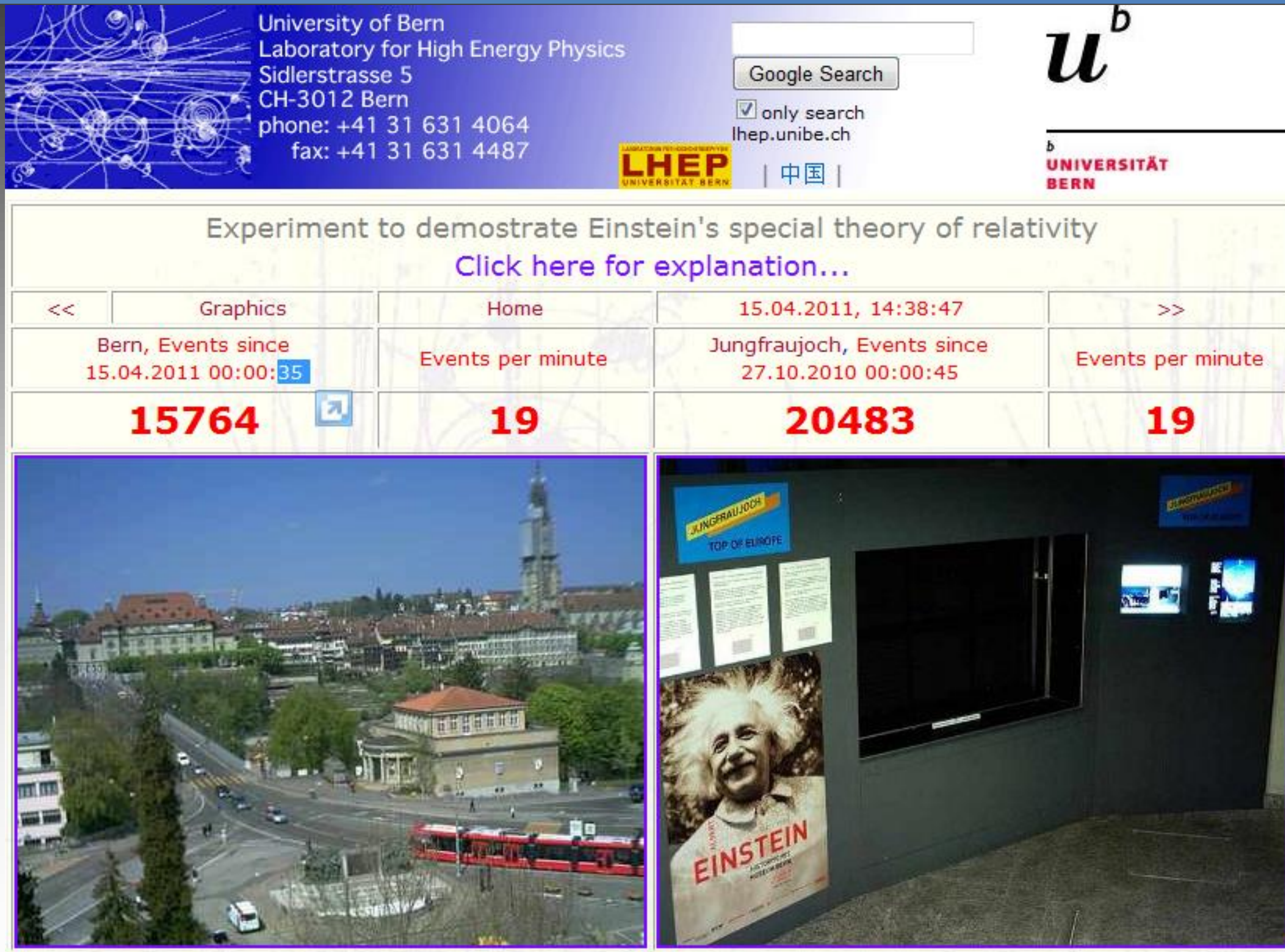
$$s = v \bullet t$$

$$s = 3 \bullet 10^{8} \bullet 2{,}2 \bullet 10^{-6} m \bullet s \bullet s^{-1}$$

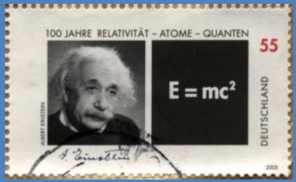
$$\underline{s = 660m}$$

distance that the muon can travel during
its average lifetime
Even if individual muons have a slightly longer life, they should not reach the earth(660m<<20000m)

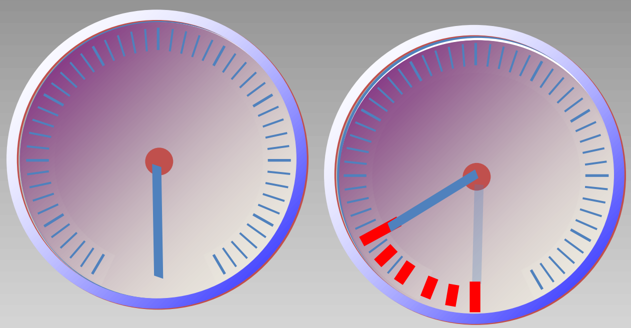
muon counter in Bern

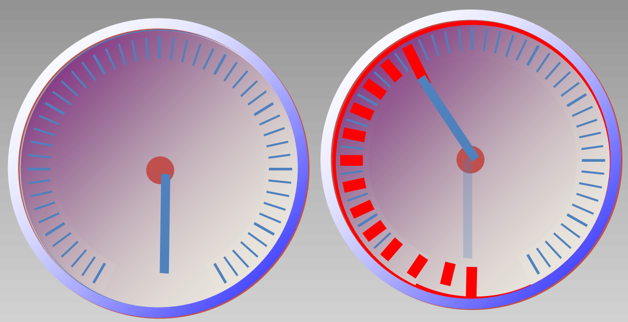


Reasoning with Einstein



For very fast moving particles the time passes very slowly.





resting muon	very fast muon
Does not reach the earth	reaches the earth

Why are the muons reaching the earth?

- The answer comes from the special theory of relativity, discovered by Einstein.
- For fast moving bodies, time passes slower (time dilation)
- For a muon travelling close to light speed the clock moves slower than for a resting muon.
- As a result the fast moving muon can reach the Earth.
- This effect is also known as the twin paradox.

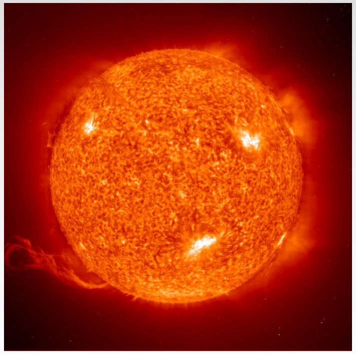
Where are current limits of our knowledge?

The protons from space have an extremely high energy.

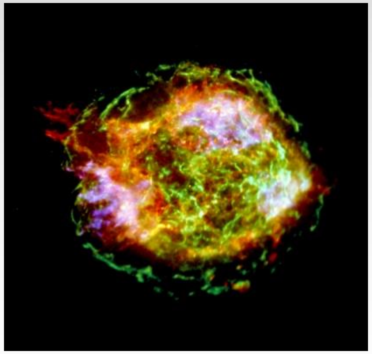
The mechanism by which they get this energy is still unknown.

There are many possibilities:

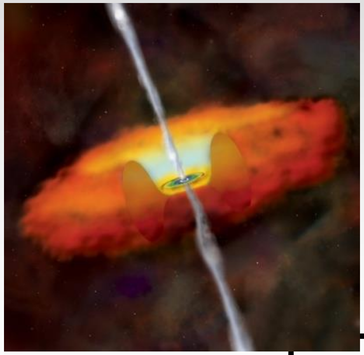
sun eruption



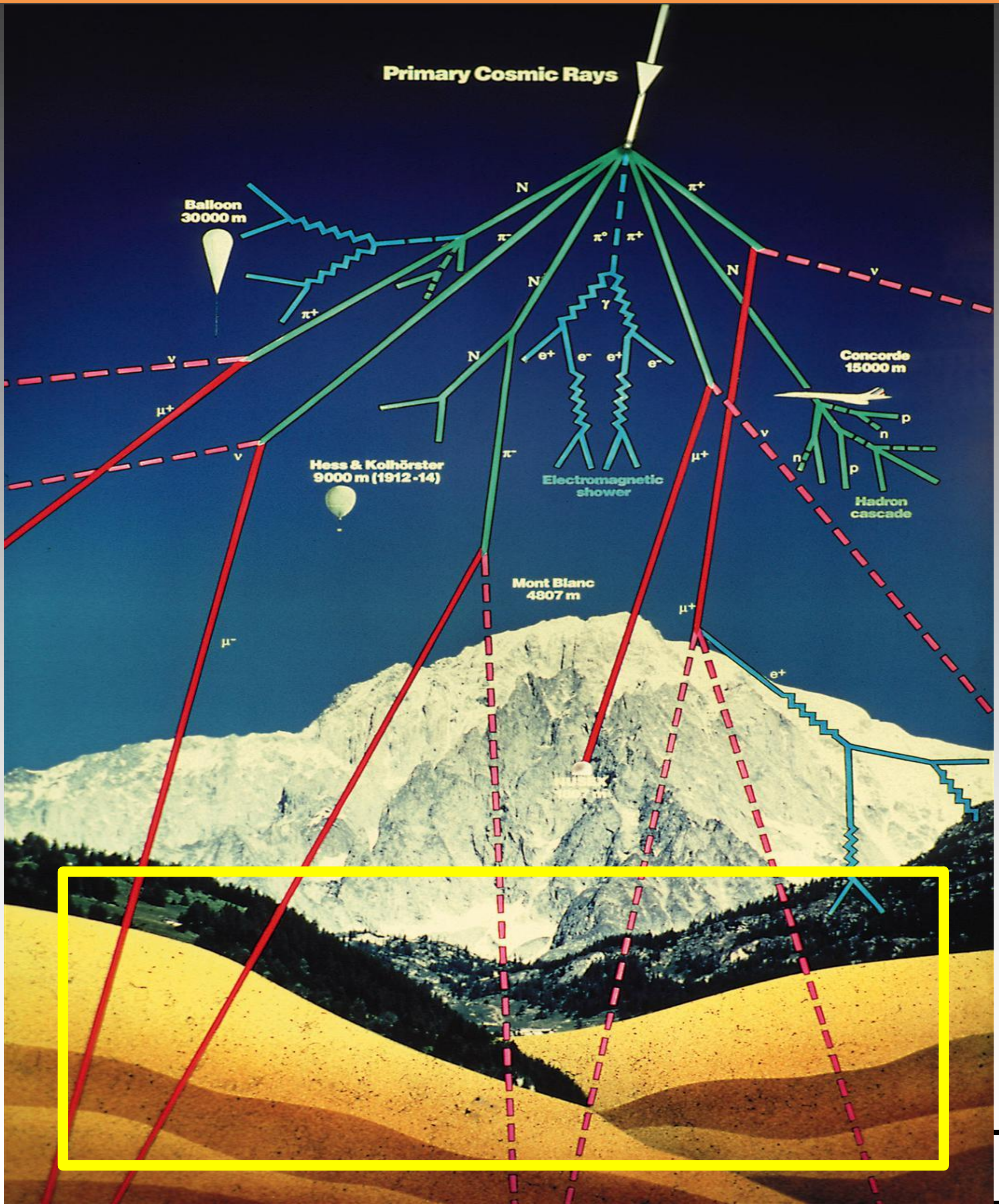
supernova



black hole



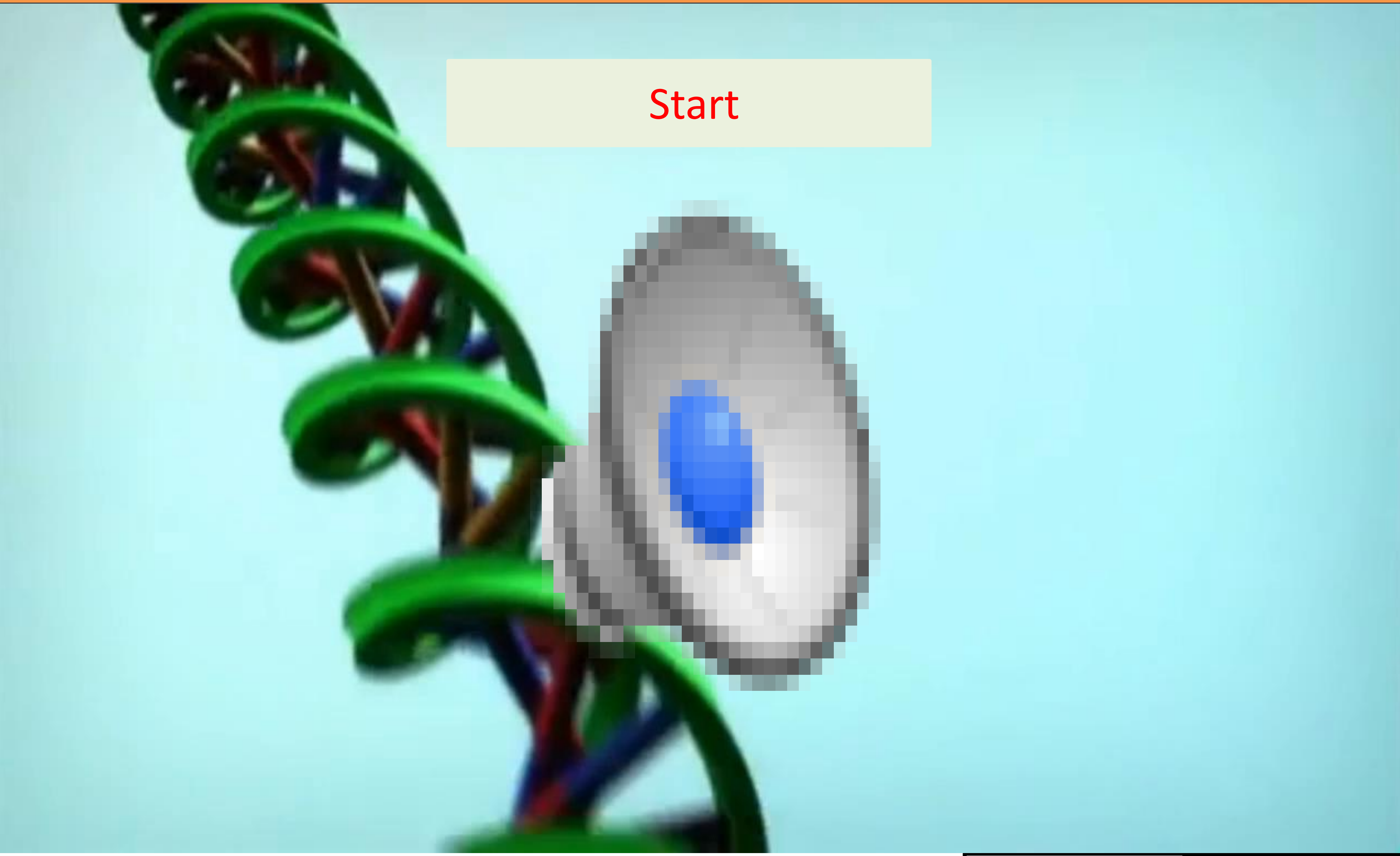
How does this radiation affect us?



Overview in the video

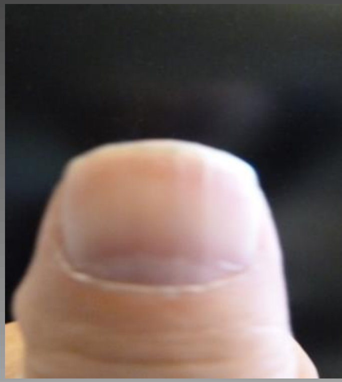
Next

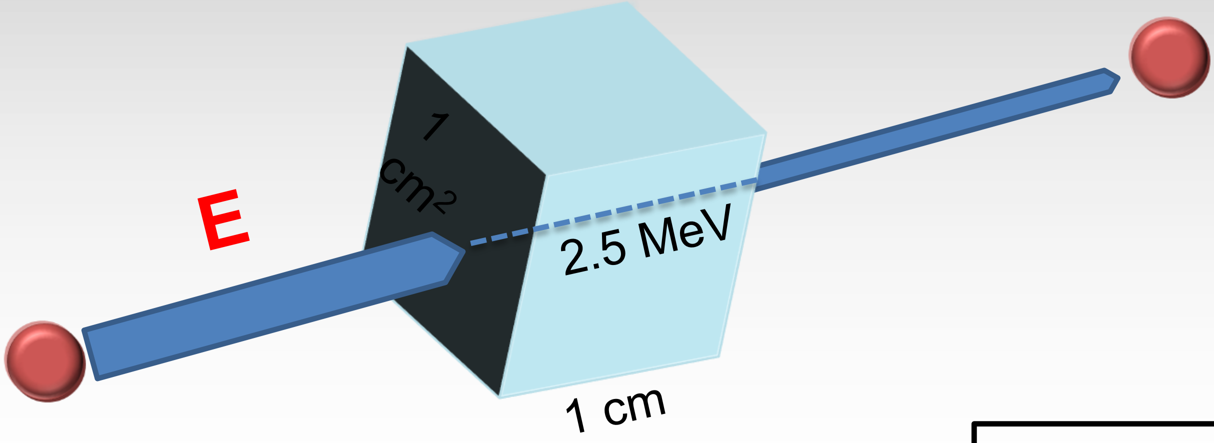
Start



Estimation of the cosmic radiation exposure

- typical energy of muons: E ~ 1 – 10 GeV
- particle flow: a muon per cm² per minute (fingernail)
- energy loss ~ 2.5 MeV per cm (in water)
- consider a volume of 1 cm³ of water:
- 1 g of water takes 2.5 MeV (ionisation-) energy per minute
- 1 year has ~ 526 000 minutes (60 x 24 x 365.25)
- 1 kg water absorbs 2.5 x 1000 x 526 000 MeV = $1.3 \cdot 10^9$ MeV = **0.00021 J**





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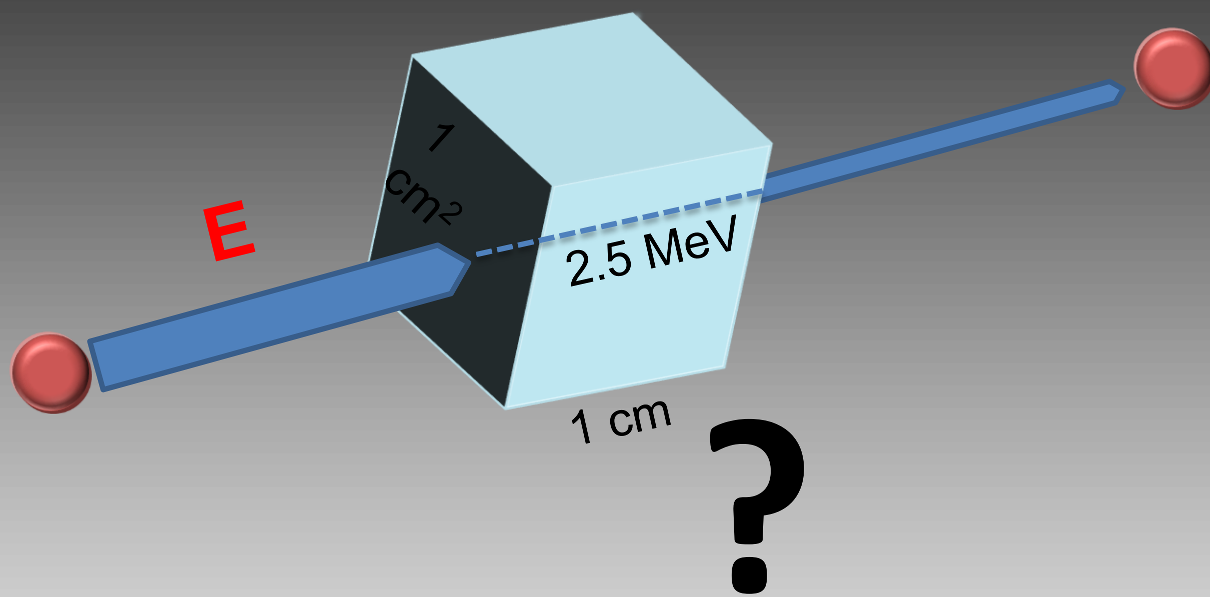
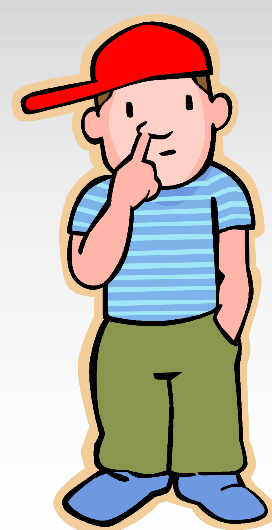
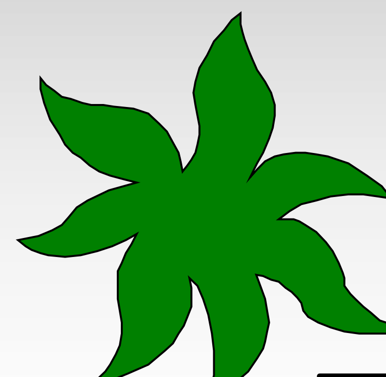
How does that effect us?







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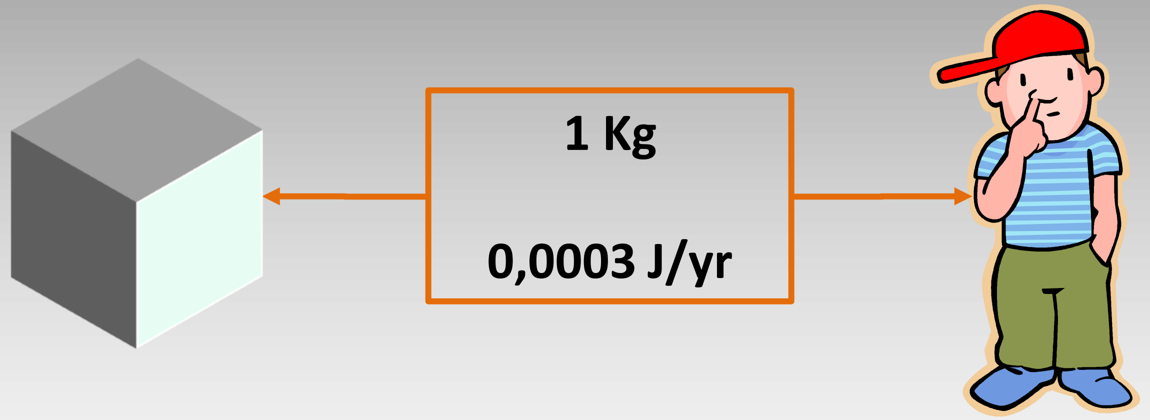
We consist………

- essentially of water
- Each kilogram of our body takes about the same amount of energy every year like a kilogram of water (in reality about 0.0003 J per year)



Comparison of loads: energy dose D

$$\frac{\text{absorbed energy}}{\text{1 kg of irradiated body}} = \text{energy dose [D]}$$

unit: $$\frac{\text{1 Joule}}{\text{1 Kilogram}} = \text{1 Sievert [1Sv]}$$

- Comparative value for radiation exposure
- Cover Size: 1 kg of the irradiated body

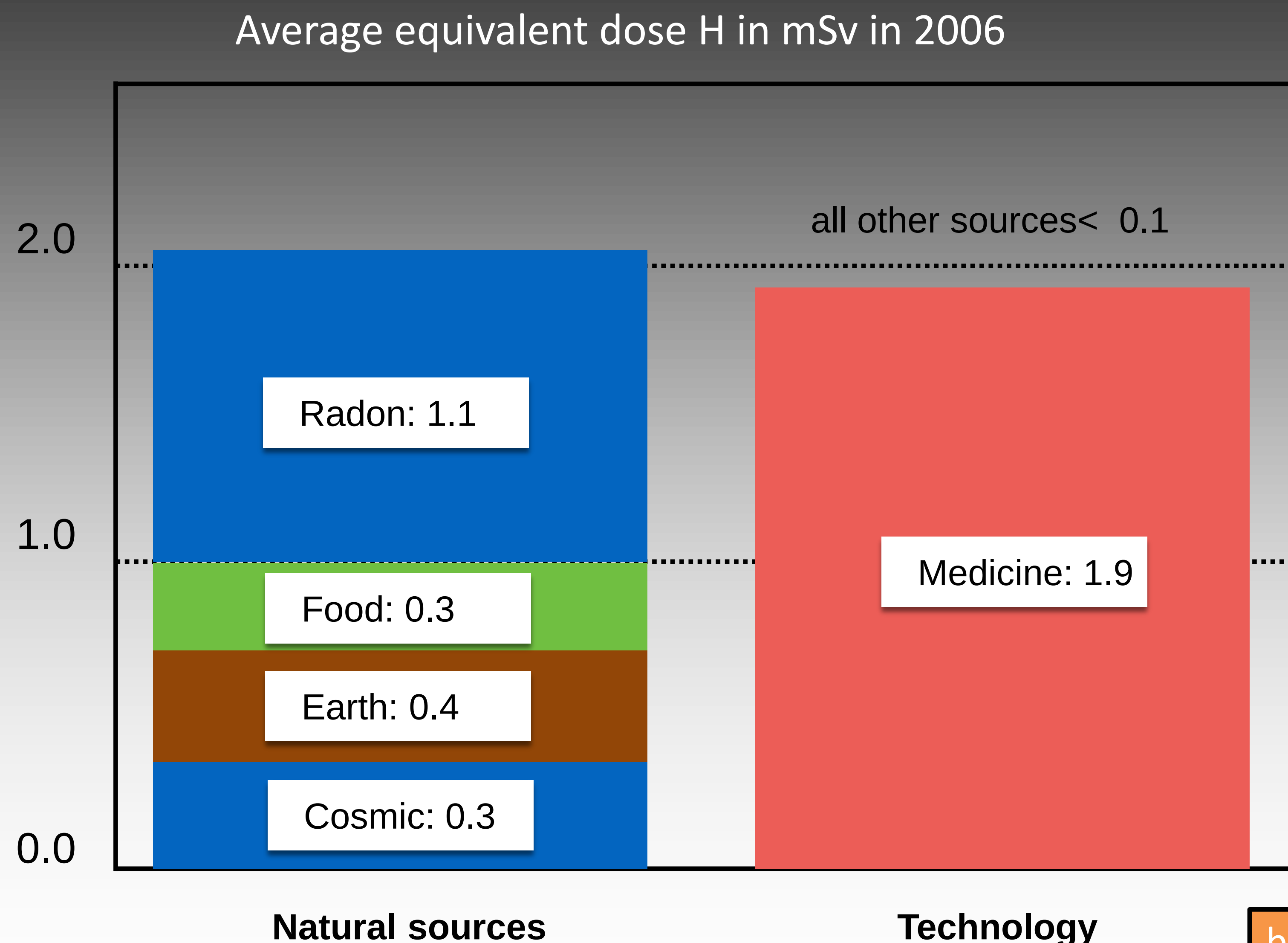
Additions...

- Annually each kilogram of our body absorbs about 0.0003 J energy from cosmic radiation. The absorbed dose D is:

$$0{,}0003\ Sv/yr = 0{,}3\ mSv/yr$$

- The equivalent dose H makes adjustments for different forms of is radiation by applying a factor Q: **H=D•Q**
- Q=1 for gamma-ray and muons, Q= 1-30 for alpha radiation, protons and neutrons
- The sizes D and H are also used to assess the danger of other forms of radiation.

artificial and natural radiation exposure



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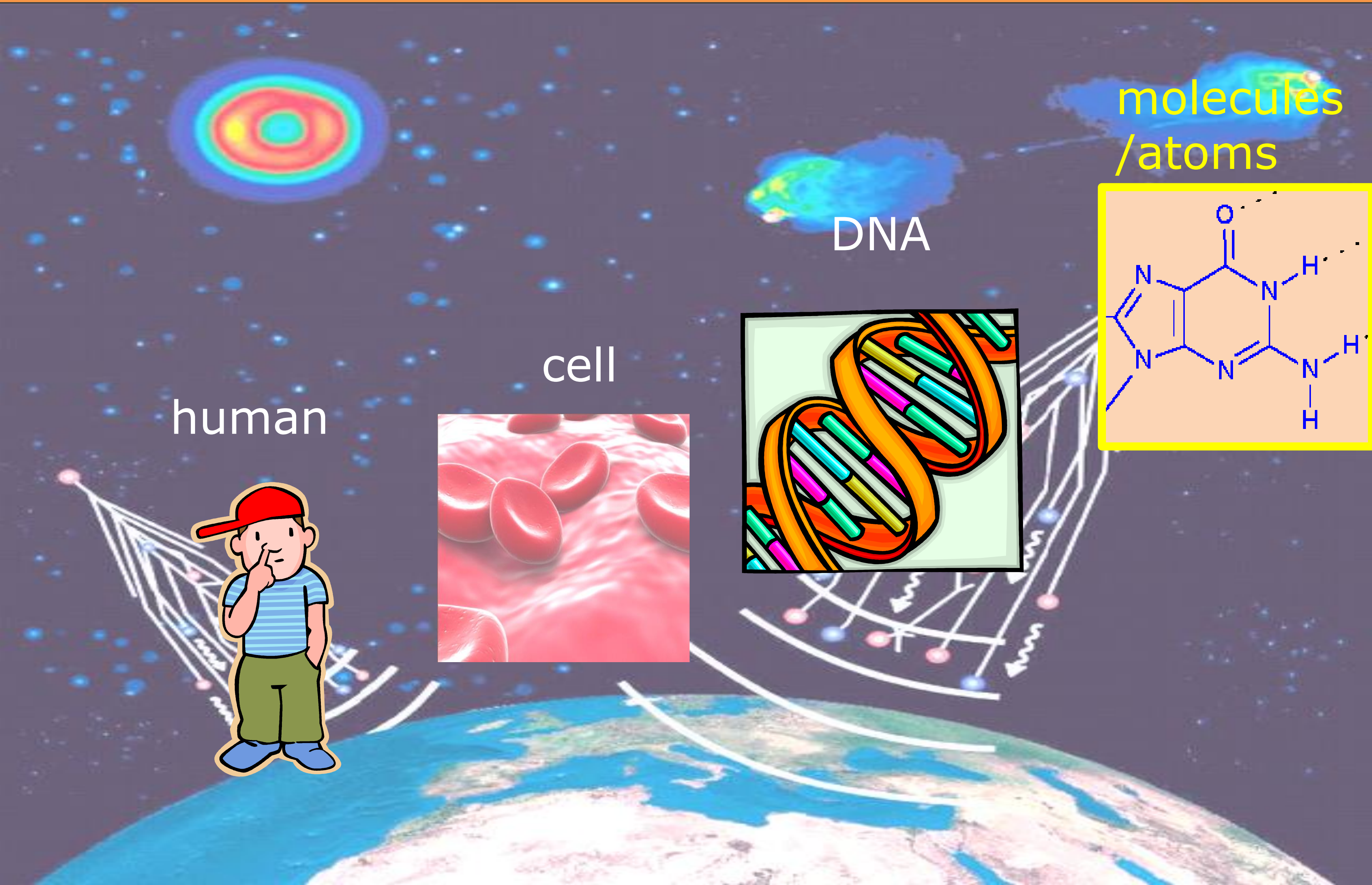
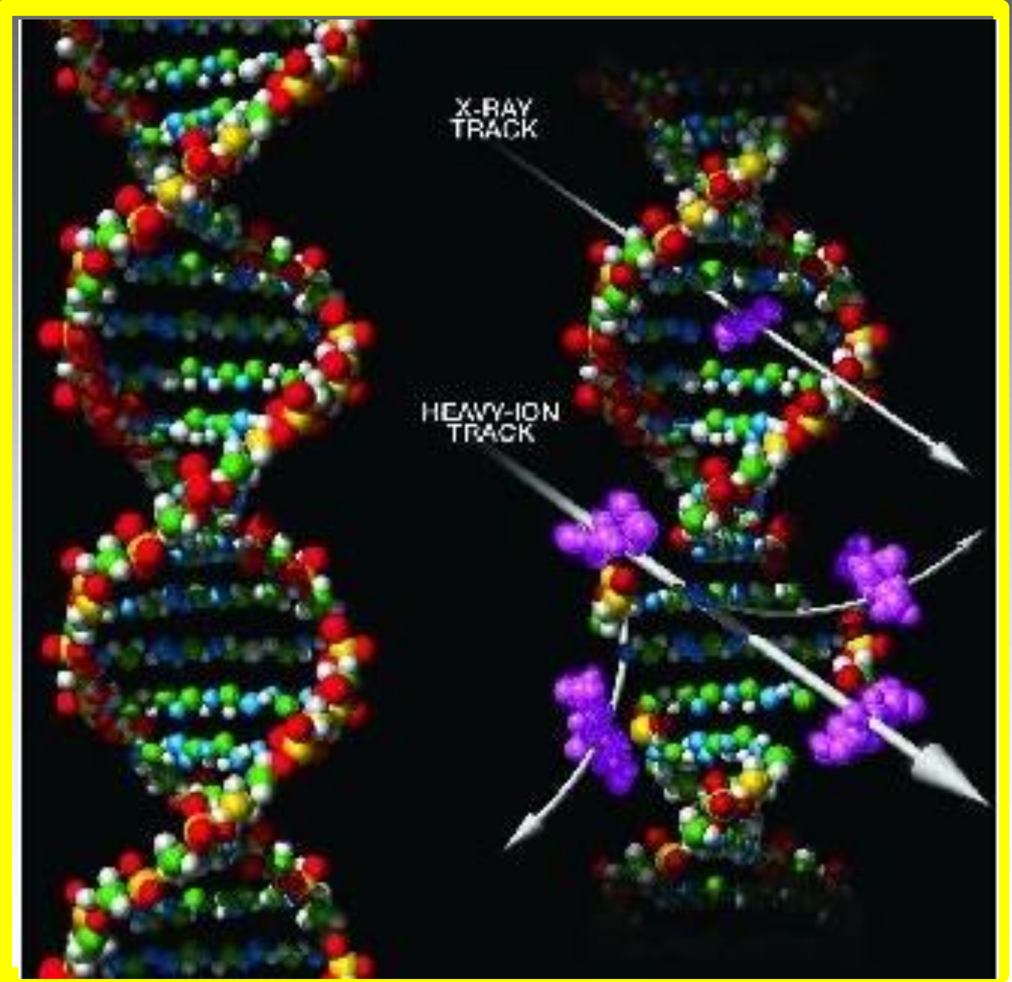
What is the effect of the radiation on our bodies?



effect on DNA

DNA molecule



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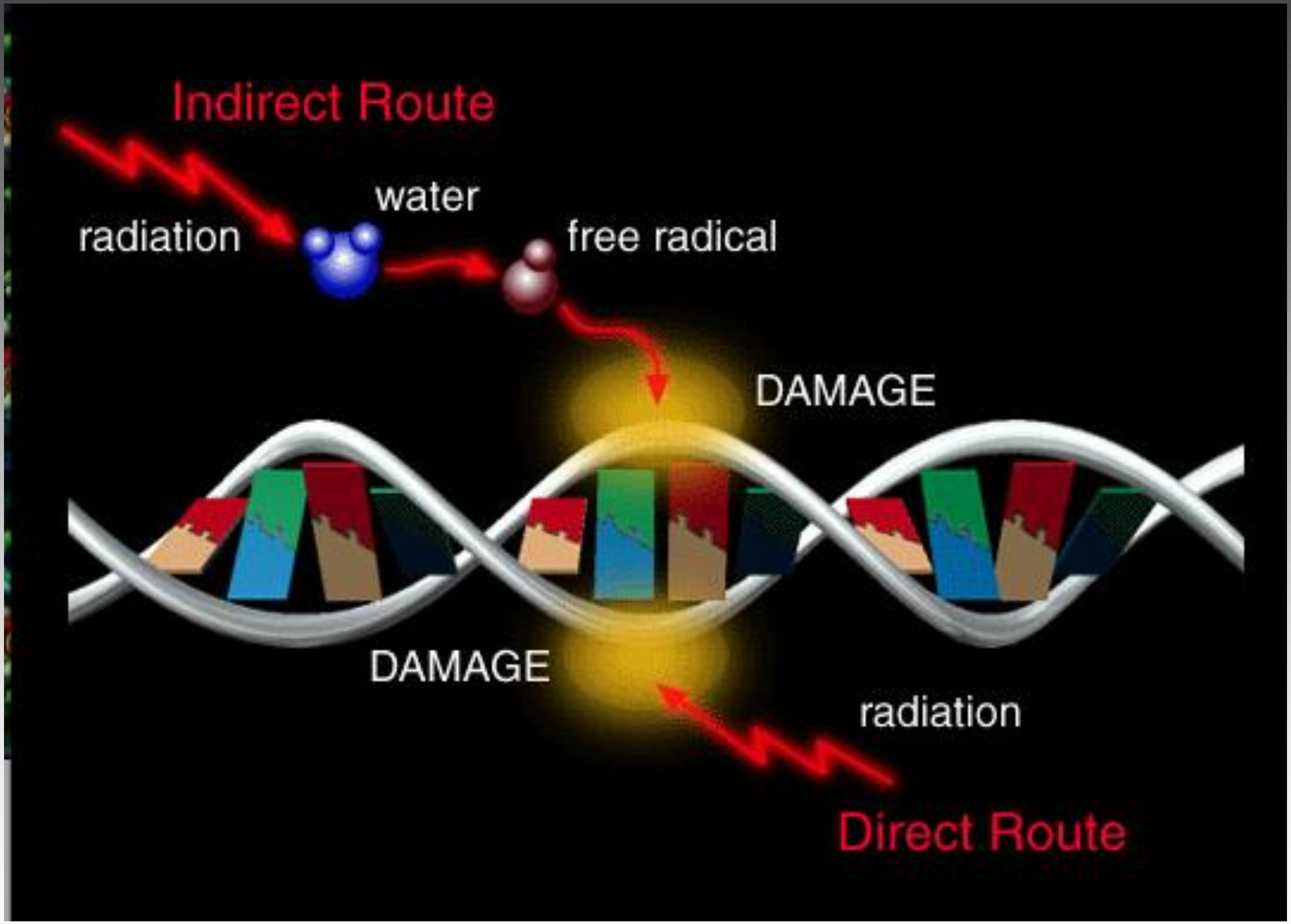
Emergence of defects in DNA



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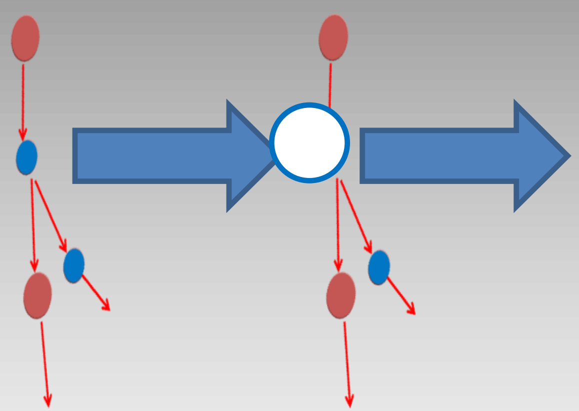
What exactly is happening?

Ionization, free radical



bug in DNA

Repair by the body?

yes

fixed bug

no

bug not fixed

Mutations and cancer

What exactly is happening?

The energy of the particles in cosmic radiation releases electrons from their correct place in the molecule (ionization). A defect is created in the molecule.

The body can usually repair itself because humans have adapted to the presence of natural radiation in the course of evolution. However, the possibilities for repairing are limited.

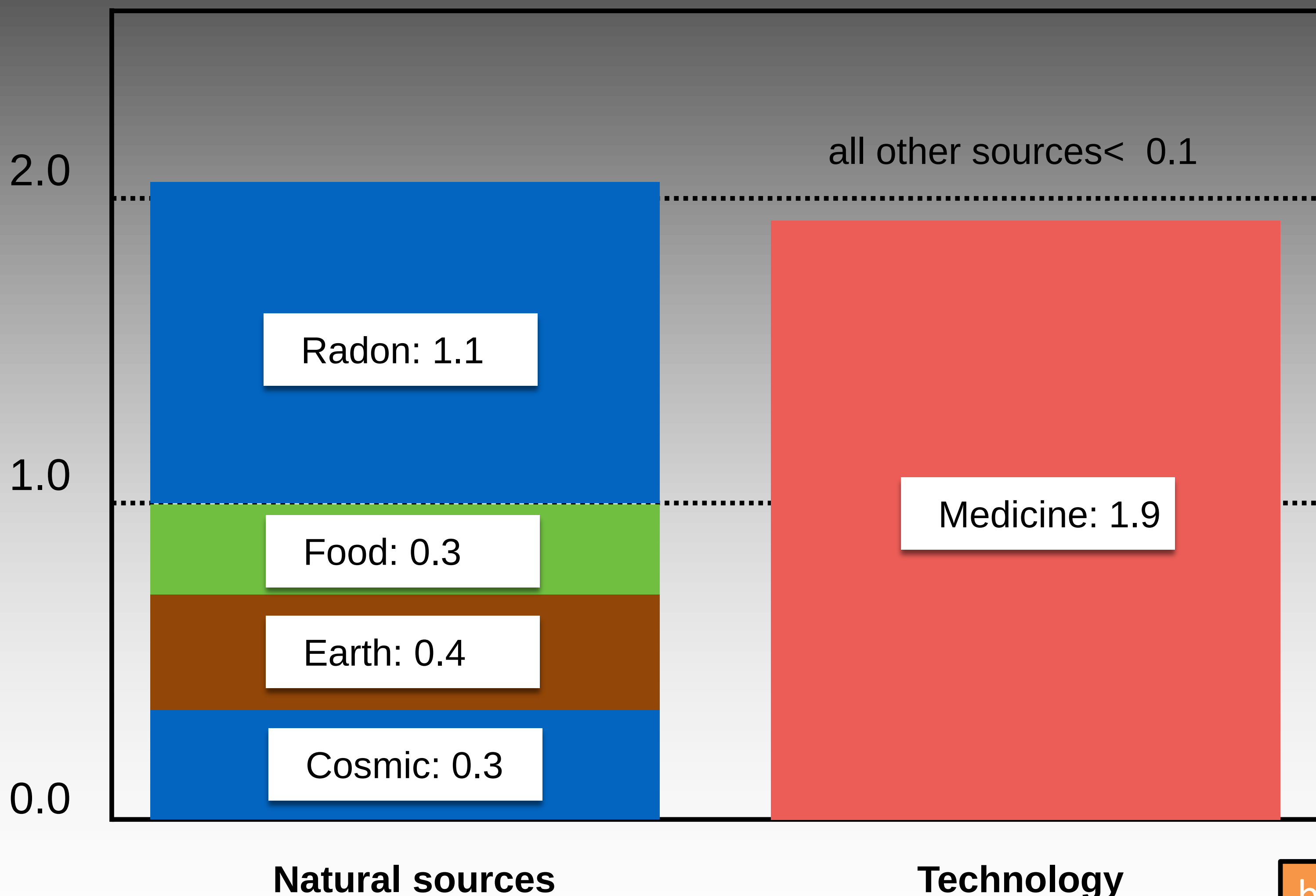
If the number of defective places is too great due to caused a high energy dose then permanently altered sections of the DNA may result. These alterations are responsible for genetic changes (mutations) as well as for development of cancer cells.

What consequences does it have for us?

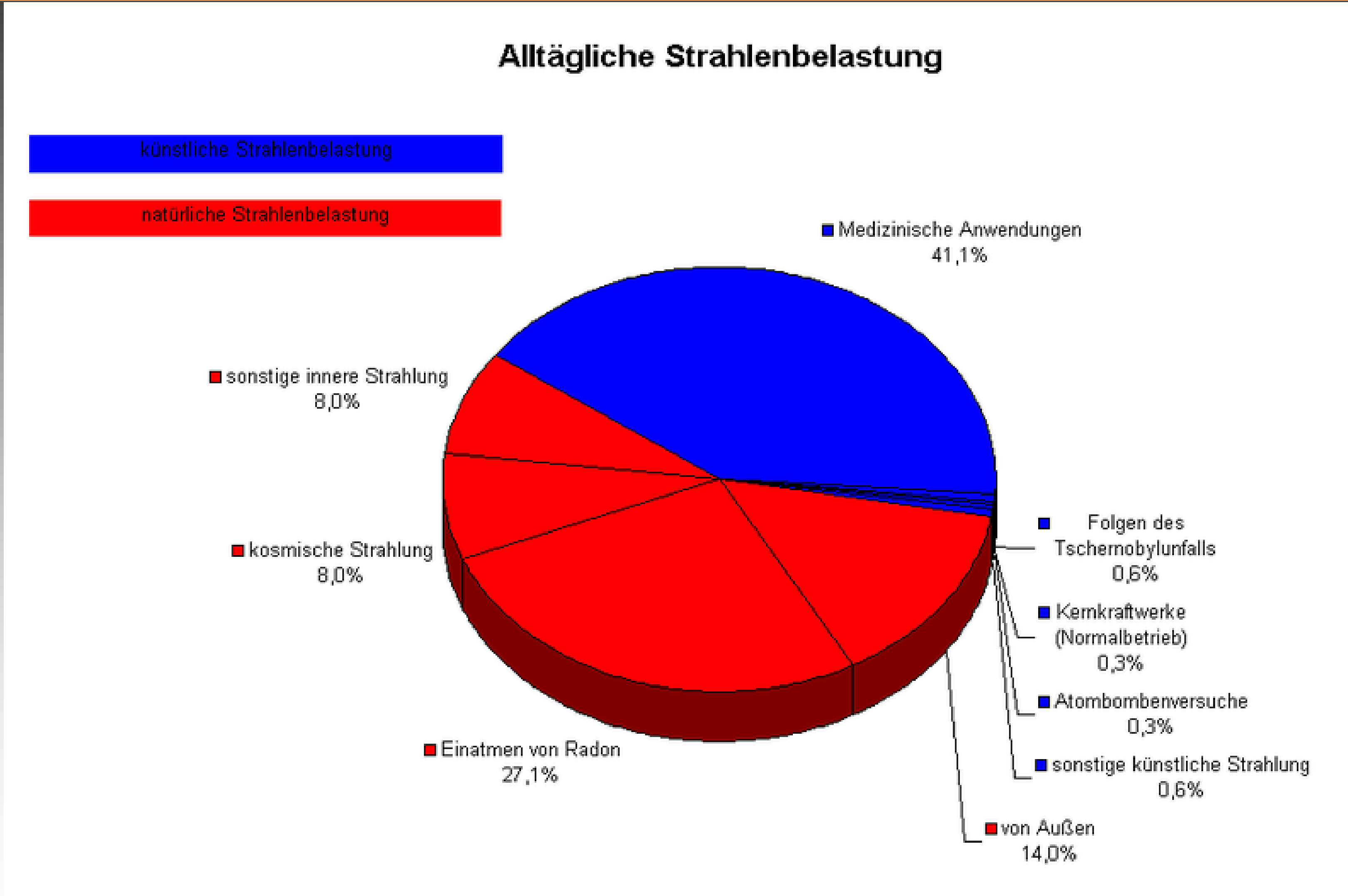
- Cosmic radiation is part of nature
- The human body can deal with a natural dose of radiation
- An estimation of any specific health risk requires the consideration of any additional sources of ionizing radiation
- Currently a limit of 1 millisievert per year has been established by law in Germany as an upper limit for any additional radiation dose .

to remember .....

Average equivalent dose H in mSv in 2006



artificial vs. natural radiation



Altitude dependence of cosmic rays

height above the earth	effective dose per year
300 km (outside of the Space Shuttle)	400...500 mSv (quiet sun)
300 km (in Space Shuttle)	100...200 mSv (quiet sun)
10 km (plane cruising altitude)	40 mSv (with permanent residence)
3800 m	1,8 mSv
3000 m	1 mSv
2000 m	0,6 mSv cosmic + ca. 1 mSv terrestrial
0 m	0,3 mSv cosmic + 2 mSv terrestrial

Load at different heights

Click on Address

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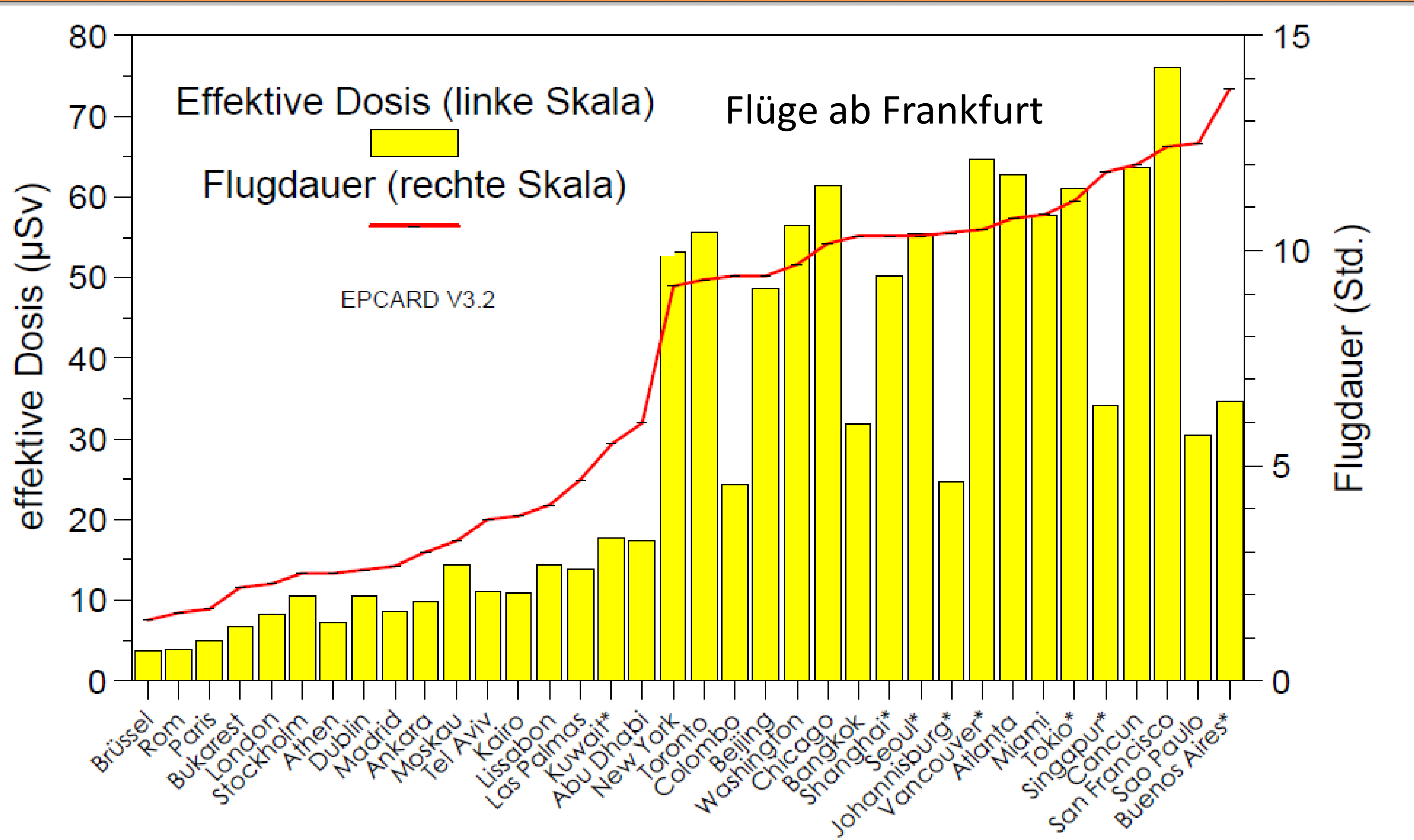
Risk during flying?



load at the next flight

Click on adress

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Risk during flying?

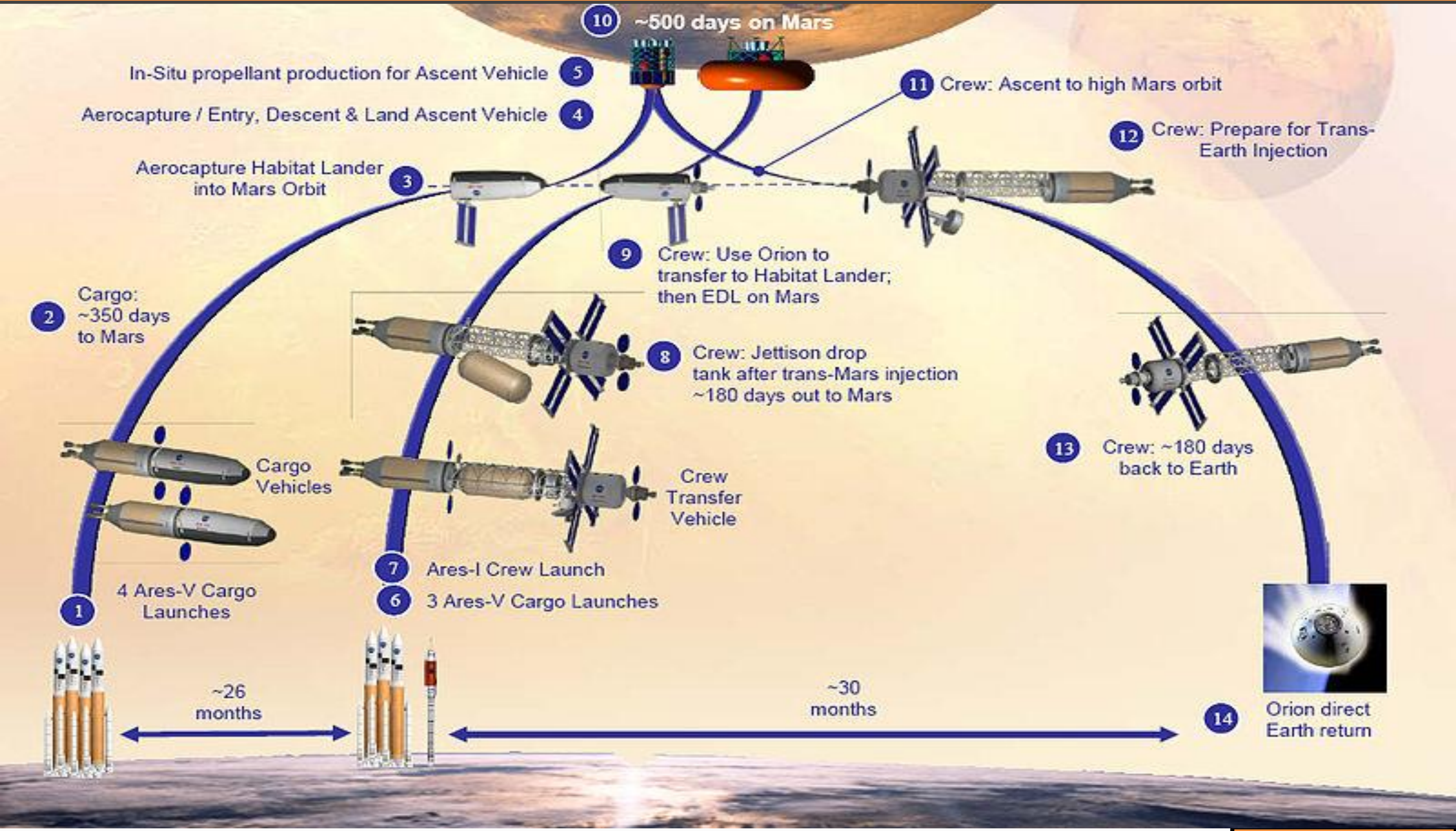
Flugdosimetrie

- Short distance flight: less than 1% of the annual natural load
- Long-haul flight: Approx. 5% of the annual natural load
- "Occasional flyer": very low risk
- Risk control necessary for „frequent flyers" and aircrews

Reiseziel	Dosisbereich* [µSv], etwa
Rom	3 – 6
Gran Canaria	10 – 18
Rio de Janeiro	17 – 28
Johannesburg	18 – 30
Singapur	28 – 50
New York	32 – 75
San Francisco	45 – 110

(flights from Frankfurt)

Manned flight to Mars - a reality soon?



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Challenges

- Flight duration: over 2 years
- Distance: > 200,000,000 km
- Massive exposure to cosmic radiation
- Tremendous driving power required
- No reversal possible
- No assistance from Earth
- Cancer risk
- Psychological distress (isolation)

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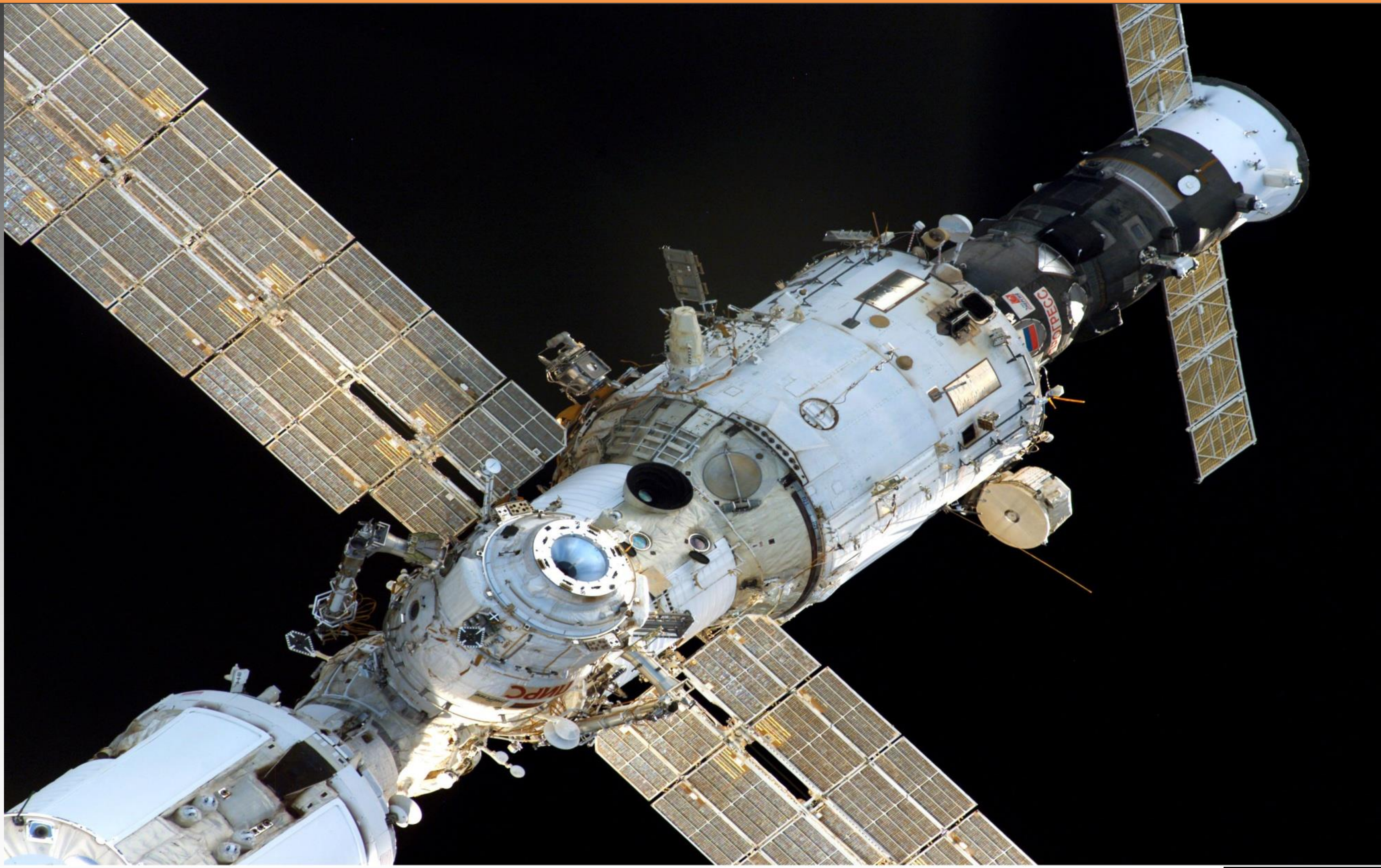
Test of radiation exposure on ISS



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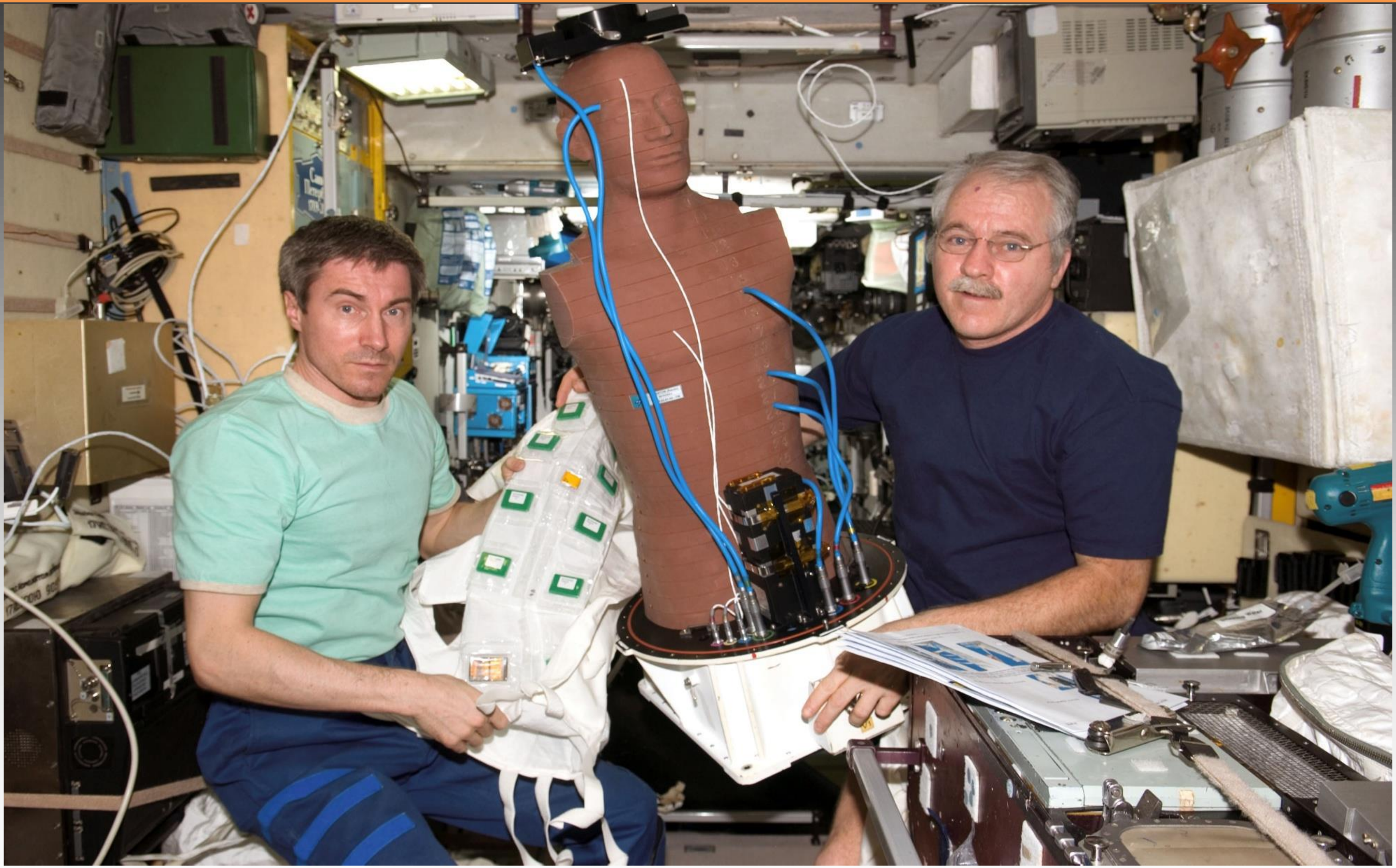
Doll gets suit with hundreds of sensors!



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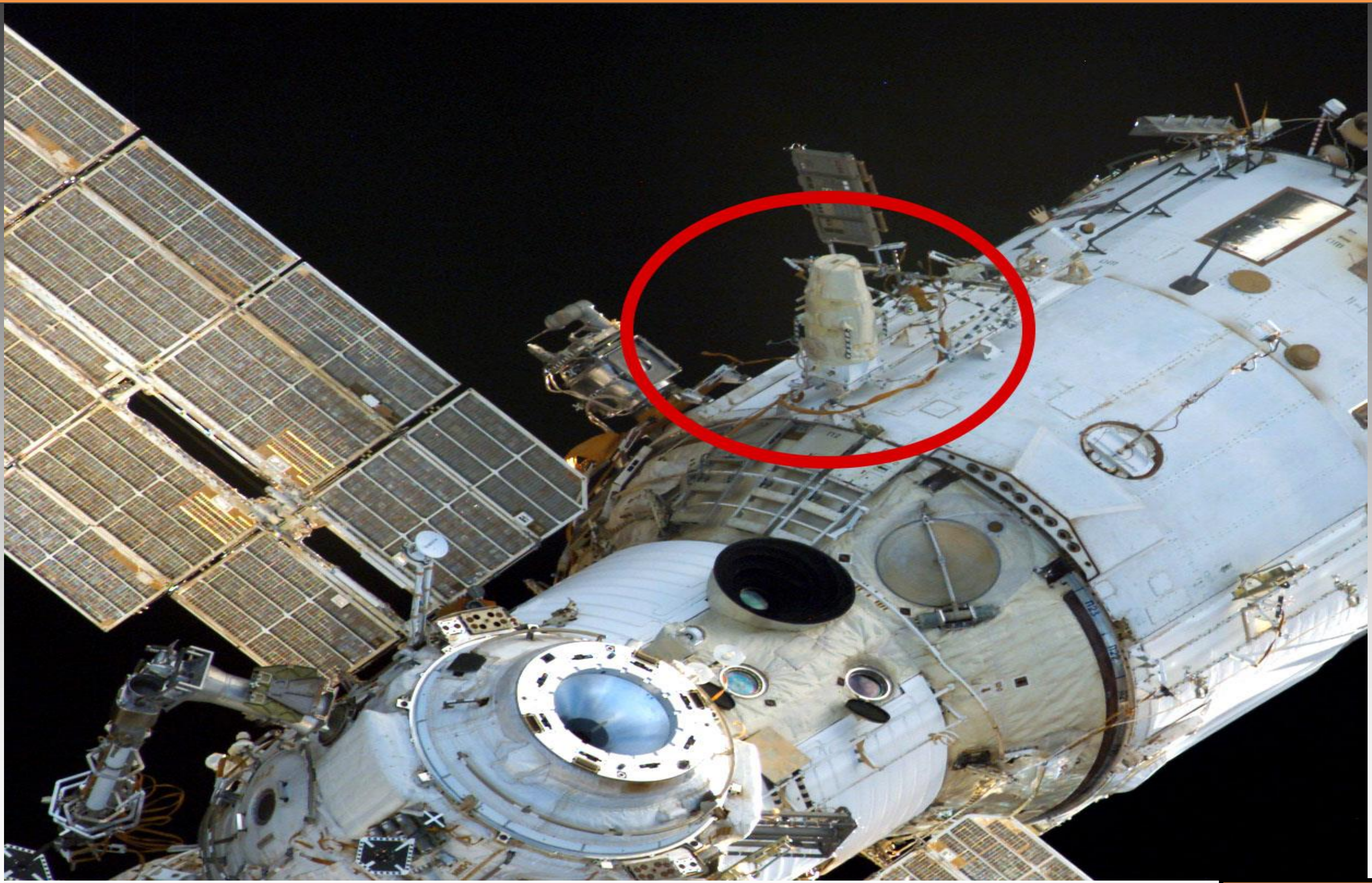
... and is fixed at the outside of the station



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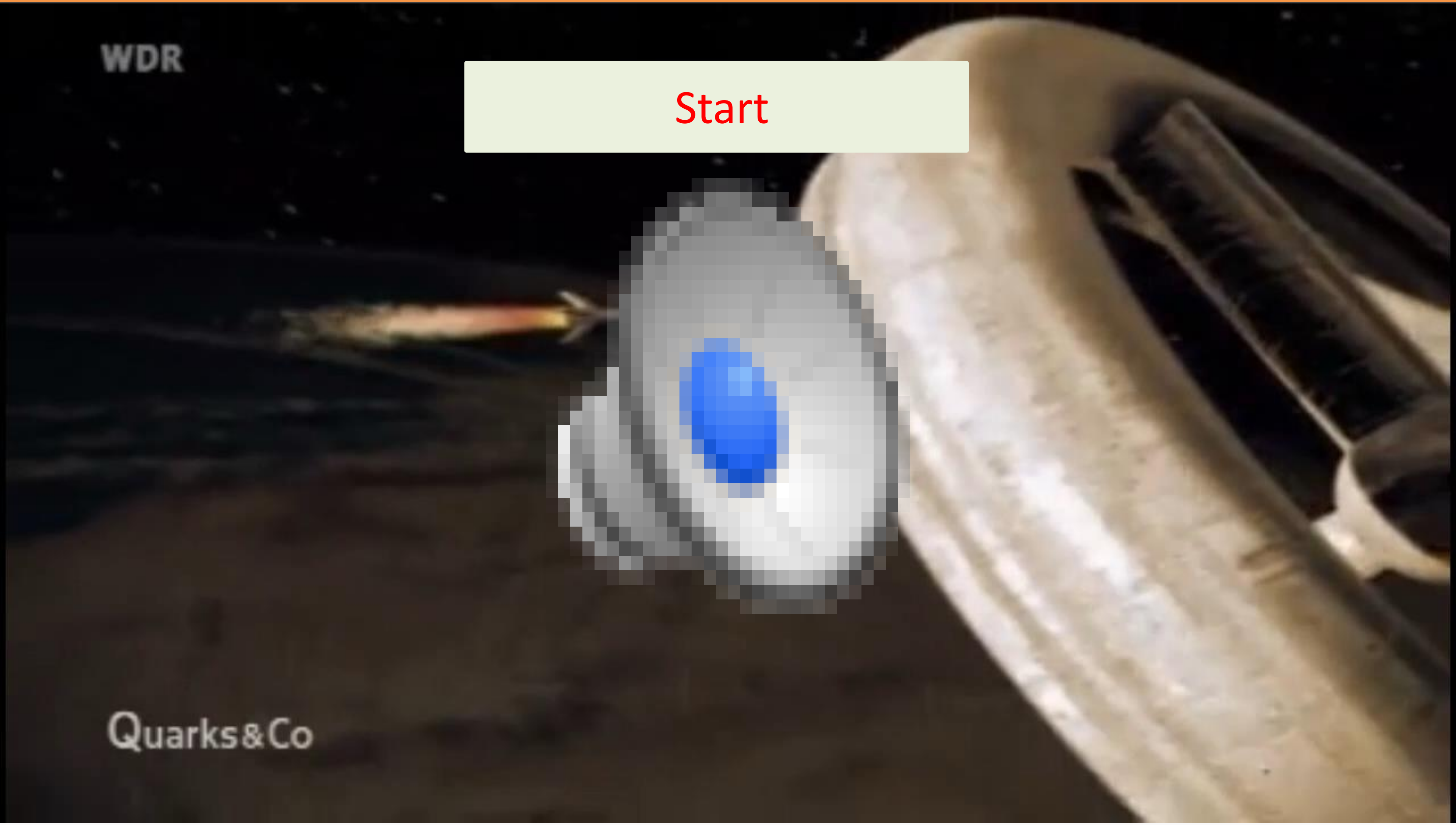
Manned flight to Mars - a reality soon?

Next



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Thanks…

To the members of the „Physic- Education“ group at CERN for their help and support

One special „Thank You“to Rolf Landua for his ideas and critical coaching during the project!