How does Cosmic Radiation vary at Altitude?

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Abstract

During a time period of 6 months we prepared a mission called SPIDER whose goal it is to measure cosmic muon flux in correlation to altitude. In a probe suspended underneath a high-altitude balloon is the COMRADE KMP-1 muon detector, a custom-built optimisation of the AMD5 model sold by astroparticelle.it. The probe also includes a custom data logger (a device which logs atmospheric parameters) for the muon detector, two cameras and two GPS-trackers. As well as the scientific and technical challenges, we also handled organisational, legal and financial aspects as much as possible, however, we were constrained by our legal status as minors. In this paper we discuss the theoretical basis of cosmic radiation and report on our work on SPIDER. Unfortunately, the international lockdown resulting from the 2019-2020 coronavirus pandemic prevented the launch of SPIDER. As we were unable to collect our own data, we used results from similar studies.

SCIENTIFIC PLATFORM FOR INSTRUMENTS
DETECTING HIGH-ENERGY RADIATION

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Je déclare sur honneur avoir développé et rédigé ce mémoire sans l'aide abusive d'autrui.

Figure 1: Cosmic Radiation Cascade

1 Introduction

Throughout history, humans have always striven to reach higher and higher altitudes. From Leonardo da Vinci's advanced plans for flying contraptions and hot air balloons in the 18^{th} century to the first modern plane built by the Wright brothers at the beginning of the 20^{th} century and the supersonic fighter jets speeding through today's skies, huge strides have been made in quick succession. Today, it seems completely normal to us that every day thousands of planes fly at altitudes of 10 to 12 kilometres above the Earth's surface and that today's science fiction literature is full of cloud cities or habitats in orbit around Earth. Space agencies and private companies are setting themselves goals to land on the Moon and Mars. However, the human body has evolved for living in the conditions at Earth's surface. This raises a question: Might there be any threats to the human body at such high altitudes?

After performing studies on cosmic radiation, scientists have discovered that the surface of the Earth is shielded from this radiation by the planet's atmosphere and the magnetic field caused by its core. Furthermore, we know that large quantities of this radiation are very harmful to the human body. It is also known that pilots regularly flying aircraft at altitudes of around 10km are exposed to far more radiation than their friends on the ground. Does radiation flux actually increase at these altitudes or are there unknown parameters at play? Is the difference in radiation levels big enough to pose a threat to humans? To find out more about this variation of levels of cosmic radiation at different altitudes, we planned to launch SPIDER, a high-altitude balloon carrying a probe with a cosmic radiation detector onboard. It is SPIDER's mission is to gather data on how well we are shielded from this deadly radiation on Earth's surface and shed some light on this topic.

2 Cosmic Radiation [1]

2.1 Primary Particles

Cosmic radiation is a radiation consisting of high-energy particles circulating through space. The energy of these particles can reach astonishing values of up to 10^{20}eV. This radiation mainly consists of the following particles:

- 89% protons
- 10% nuclei of helium (2 protons; 2 neutrons)
- 1% heavier atomic nuclei: These nuclei can be of every naturally occurring element on the periodic table. The heaviest nucleus of these nuclei with the most protons in it (92) is uranium.

These particles originate from high-energy events in deep space. During these events, they are accelerated to speeds close to that of light. After traveling astounding distances, some of them hit Earth.

2.1.1 Origins

The origin of these highly energetic particles is still unclear. Firstly, this is due to the fact that on the Earth's surface, we are only able to detect the secondary particles. These secondary particles can't give us a directional indication, from where the primary particle came. Furthermore, even if we were able to detect primary particles and were able to find out from which direction they came, their origin would still be unclear. That is due to the fact that magnetic fields, which can affect the cosmic radiation's path, are very common throughout space. Due to the incredible vastness of space, only very slight deflections could completely change the particle's path. Therefore, we can mostly only theorise from where the cosmic rays are coming. One method is of course, due to the understanding we have about interstellar bodies, to predict that they probably emit some form of cosmic radiation. Furthermore, we can correlate different observations with a higher muon flux. If we measure for example on one day a lot of cosmic radiation and we observed a highly energetic extraordinary event during the same time, there is a high probability that the cosmic radiation originated from that event. Using these methods, we predict that cosmic rays have three main origins:

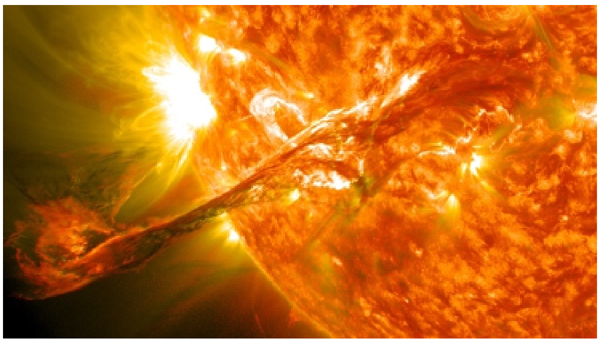


Figure 2: Solar Flares

Solar Flares One of the main origins of cosmic radiation is the Sun. When magnetic fields, which are caused by permanent interactions of particles on the Sun's surface, align in a specific way, a solar flare occurs. This is a process where the plasma (highly conductive gaseous state of matter), generally near the sunspots, is heated to tens of millions of Kelvin. This

causes electrons, protons and heavier nuclei to be accelerated to near the speed of light and electromagnetic waves over the whole spectrum are emitted. The accelerated particles are now what we call primary cosmic radiation. Solar flares can accelerate particles to energies of up to 100MeV. Even though that is an enormously high value, it is still the weakest source of the cosmic rays.

Supernovae Stars are essentially giant spheres of gas. Consequently, they should collapse due to their own gravity. However, this does not happen, because there is a force counteracting gravity called radiation pressure. This force is the result of a process called stellar fusion: The core of a young star is a hot and dense concentration of hydrogen atoms, the lightest element in the universe. Due to permanent collisions between these hydrogen atoms, they can fuse together to form the second element on the periodic table. After a long time, hydrogen will run low. This means, the core will get hotter and denser, which allows helium to fuse to carbon. This process repeats itself until only iron is left. At that point, nuclear fusion consumes too much energy for the process to be efficient. Depending on the size of the star, fusion already reaches its limit at lighter elements. Our sun for example can only go to carbon. This stellar fusion creates the radiation pressure, which counteracts gravity. Intuitively, when stellar fusion stops, there is nothing which prevents the star from collapsing. This collapse results in a giant explosion called a supernova. Depending on the mass of the star, this supernova leaves behind dwarfs (inactive very dense matter), neutron stars (very dense material, where electrons and protons are packed together and form neutrons), or black holes.
During a supernova, particles are accelerated to incredible speeds. They can reach energy values from 100MeV to 10GeV. Supernovae are probably the origin of most cosmic rays hitting our atmosphere.

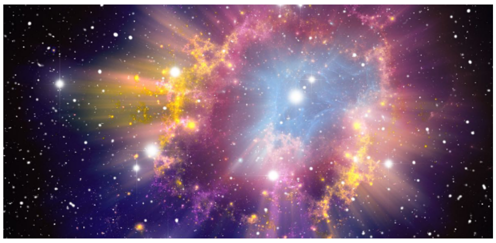


Figure 3: Supernova

Quasars Quasar is a term to describe the active centre of a galaxy. This name is derived from "quasi-stellar radio source". This means that a quasar is a star-like source of electromagnetic waves in the radio spectrum. Generally, these quasars consist of a black hole, with matter orbiting it. Matter falling in this black hole creates extreme amounts of energy accelerating particles to incredible energy values of up to 1,011GeV. The particles originating from quasars are by far the most energetic cosmic rays. However, the exact process how these particles are accelerated is still a mystery.

Figure 4: Quasar

2.2 Secondary Particles

When primary particles of the cosmic radiation hit the molecules in the Earth's upper atmosphere, a cascade of secondary particles is created. One single particle can create cascades of millions of secondary particles stretching over 40km^2. This involves a multitude of collisions and decays.

2.2.1 The Cascade

When a primary particle, i.e. single protons or atomic nuclei, hits a molecule in the upper atmosphere, a nuclear spallation occurs. Spallation reactions basically occur when a proton or any other atomic nucleus collides with another. Due to this collision a variety of secondary particles is created.

Generally, the most common particle resulting from this collision is the pion. Less commonly, light baryons (neutrons/protons) or even kaons can occur.

Due to the instability of the pions, they decay fast. This happens at an altitude of around 10 to 15km. However, charged pions and neutral pions decay very differently.

With a probability of 99.99%, the charged pions decay into muons and muon neutrinos:

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\pi^- \rightarrow \mu^- + \bar{\nu_\mu}$$

In short, this process happens due to the weak interaction. The two quarks in the pion emit a W boson. This boson almost immediately decays into a muon and a muon neutrino. Depending on the charge of the initial pion, the charge of the products changes.

However, there is a slight chance that they decay into lower energy particles:

$$\pi^+ \rightarrow e^+ + \nu_e$$

$$\pi^- \rightarrow e^- + \bar{\nu_e}$$

The neutral pions π^0 usually decay into two photons:

$$\pi^0 \rightarrow \gamma + \gamma$$

Nevertheless, there is chance of 1.2% that they decay into a photon, an electron and a positron.

$$\pi^0 \rightarrow \gamma + e^+ + e^-$$

The kaons decay most commonly into muons and muon neutrinos (about 60%) or into different pions, which once again decay into muons and muon neutrinos, respectively into photons and electrons.

In summary, the whole cascade can be divided into three sections. The leptonic component, the hadronic component and the electromagnetic component. The leptonic component starts with kaons and charged pions, which decay to muons and neutrinos and their respective antiparticles. The second component is the hadronic component. It contains hadrons which did not decay before reaching the surface. The third and last section is called electromagnetic component. It starts with kaons and pions, which either directly decay to photons or electrons, or decay to muons which decay due to energy loss to electrons. In the electromagnetic component, the

electrons, the photons and the positrons decay over and over again into each other.

Due to the instability of most of these particles, the majority reaching the surface of the Earth are the muons, the neutrinos, and the electrons. Electrons however are rather uninteresting, because it is a very common particle. Furthermore, neutrinos almost do not interact with any matter, due to their low energy and neutral charge. This makes them harder to detect. The muon, in contrast, often interacts with matter. This implies correlation with climate parameters and easier detection. This makes them the most interesting secondary particle of the cosmic radiation.

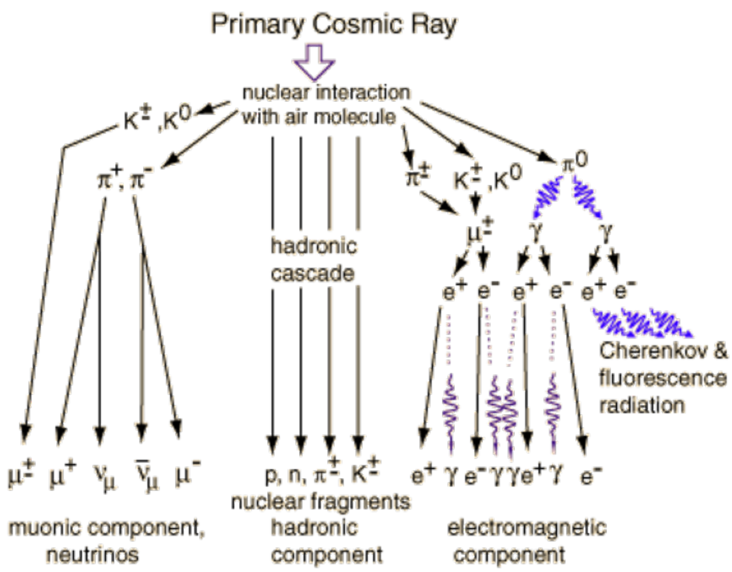


Figure 5: Cascade

2.2.2 Muon: Secondary Cosmic Ray

The muon is the second-generation particle of the electron. It is about 207 times heavier than its “light brother”. Moreover, it is one of the most interesting secondary particles of the cosmic radiation. In the cascade, it derives of the decay of pions and kaons. The creation process happens at an altitude of around 10 to 15km and they travel at speeds very close to that of light.

Temporal Dilation and Half-lives A muon has a half-life at rest of 1.56μs. They travel at 0.98 times the speed of light. They are formed at around 10km. We can calculate the time a muon needs to cover this distance:

$$T = \frac{10km}{0.98c} \approx \frac{10km}{0.98 \cdot 0.3\frac{km}{\mu s}} \approx 34\mu s$$

This would theoretically mean, that until muons reach the surface, $\frac{34}{1.56} = 21.8$ half-lives would have elapsed and therefore only $\frac{1}{2^{21.8}} \approx 0.00000027$ times the initial particles would be left. Out of a million particles, only 0.27 would reach the surface. This however is not right. Time dilation is at play. Special relativity, the world-famous theory of Albert Einstein, says that objects at the speed of light experience time much slower than an outside observer. The equation for time dilation is:

$$T' = \frac{T}{\sqrt{1-(\frac{v}{c})^2}}$$

where

- T' is the amount of time the outside observer experiences
- T is the amount time the moving object experiences
- v v is the speed of the moving object
- c is the speed of light

Hence, we can calculate the half-life of muons moving at 0.98c for an outside observer:

$$T' = \frac{1.56\mu s}{\sqrt{1 - (\frac{0.98c}{c})^2}}$$

$$\Leftrightarrow \; T' = \frac{1.56\mu s}{\sqrt{1 - (0.98)^2}}$$

$$\Leftrightarrow \; T' \approx 7.8\mu s$$

For a muon which travels at $0.98c$, the half-live for an outside observer lies around $7.8\mu s$. So, when travelling 10km, $\frac{34}{7.8} \approx 4.36$ half-lives of a muon elapse. Hence, we can calculate that after 4.36 half-lives only $\frac{1}{2^{4.36}} \approx 0.049$ times the initial amount of the muons remain. In conclusion, we have thus 49,000 muons remaining muons of 1,000,000 initially formed ones. In detecting muons, we actually prove time dilation because if time dilation did not exist, almost no muon would arrive at the surface of the Earth.

Atmospheric Interactions During its trajectory through the atmosphere, a muon experiences multiple interaction, resulting in constant energy loss. If the muon loses enough energy, it can decay. Therefore, these interactions also correlate with the muon flux on the Earth's surface. Every muon at an energy below 1 TeV loses energy through a process called ionisation. At higher energies, they can initiate stronger processes.

Ionisation Muons interact with the electrons of surrounding atoms, losing minimal energy, although enough to loosen an electron from its nucleus. Due to this process, the matter along the muon's trajectory gets ionized and the muon loses energy continuously. Ionisation does not only happen in the atmosphere but also occurs in every other material. Generally, the denser the material, the more energy the muon loses traveling through it. This process has a very important implication: Temperature has an effect on the cosmic muon flux.

Bremsstrahlung The phenomenon of "Bremsstrahlung" is the following: The muon interacts with a strong electromagnetic field, which can be natural (the electric field of a nucleus) or man-made (the magnet field in a particle accelerator). Electrons and positrons are, due to their high speeds, very easily affected by these fields, as are their higher-generation particles, the muons. During this interaction, the muon emits a photon that carries away part of its energy, hence energy loss. The muon is thus slowed down, and its trajectory modified.

This is actually the reason why particles in accelerators lose energy continuously. They are subjected to strong electromagnetic fields in order to keep them on their trajectory. This conclusively causes constant energy loss.

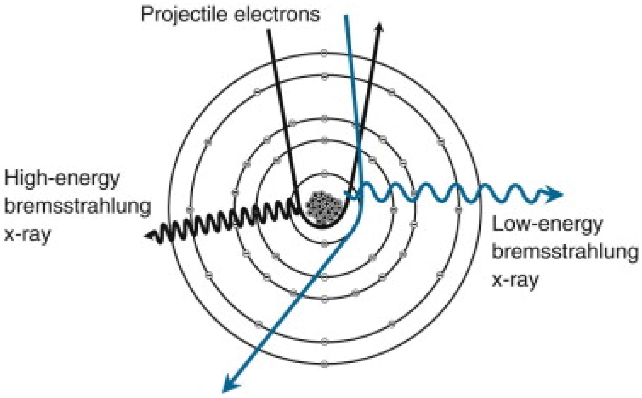


Figure 6: Bremsstrahlung

Pair production Pair production is essentially the creation of a particle-antiparticle pair from a neutral boson. Generally, when speaking of pair production, one refers to the creation of an electron positron pair from a photon. This always happens near an atomic nucleus. This is the dominating process in the electromagnetic component of the cascade. However, this process needs incoming energy to be initiated. This is where the muon comes into play. Because an amount of energy of the muon is used to initiate pair production, the muon loses energy. For muons with energies of over 1TeV, this is the main reason why muons lose energy. The muons continue to sustain the electromagnetic cascade along their whole trajectory.

3 SPIDER Project

The SPIDER Project uses a high-altitude balloon to measure cosmic radiation at different altitudes reaching a maximum of around 34km. To perform this task, the balloon carries a polystyrene box filled with various instruments.

3.1 Material

The high-altitude balloon together with the probe is called SPIDER (Scientific Platform for Instruments Detecting High-Energy Radiation). It is composed of various components which are described here in more detail.

3.1.1 High-Altitude Balloon and Scientific Platform

The high-altitude balloon we used is of the model "1600" of Stratoflghts GbR. It can carry a payload of 1.6kg to a maximum altitude of 36,000m at an ascent rate of 5m/s to 7m/s. It is made of a mixture of natural rubber and latex and weighs 1.6kg. The balloon's neck-diameter is 7.9cm with a deviation of plus/minus 0.4cm. When inflated, the high-altitude balloon has a diameter of 1.9m to 2.1m and when filled with 4.4m^3 of helium, it can carry its maximum payload [2]. Once the weather balloon is filled with helium, it is sealed with two cable ties. The first cable tie seals the top of the neck of the balloon and the second the lower end of the neck. Both cable ties are covered with duct tape to make sure that any sharp edges created by cutting off the excess cable tie length do not burst the high-altitude balloon [3].

Figure 7: High-Altitude Balloon

The high-altitude balloon's payload is the scientific platform. It consists of a parachute and a polystyrene box for the equipment and experiments. These are both connected with a special cord.

The parachute used for SPIDER is a "2500" model designed by Stratofligths GbR. It can safely lower a payload of 0.8kg to 2.5kg to the ground and is made out of light and tear-resistant fabric that does not wrinkle. It has a diameter of 1.2m and weighs 0.08kg. The material is red to make it easier to locate after landing. The parachute was specifically designed for high-altitude balloon flights in the stratosphere and is made in Germany. It opens automatically after the balloon bursts and has a hole in the middle to minimise that amount of time the parachute floats in the air, thus reducing the distance covered by the probe between the balloon bursting and landing [4].

The polystyrene box has a volume of 3.3l and a wall thickness of about 3cm. Its inside dimensions are 16cm by 16cm by 13cm with its outside dimensions being 22cm by 22cm by 18cm (both length by width by height). It is made out of a type of polystyrene called EPS (expanded

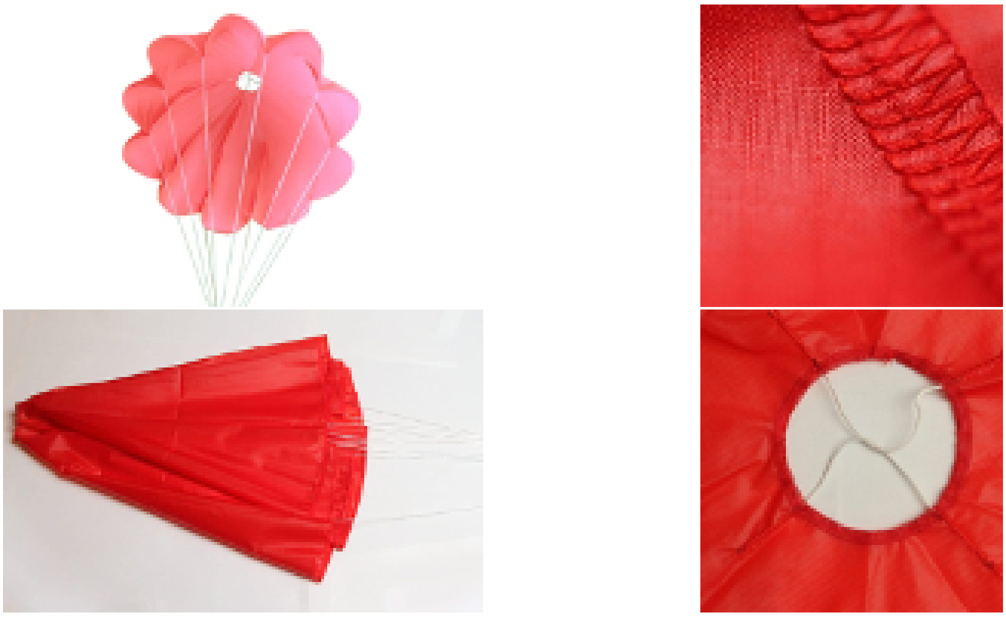


Figure 8: Parachute

polystyrene). The 200g box is robust and has a lid that fits snugly on top. The most important aspect of the polystyrene box is that it insulates the electronics from temperatures of -65 degrees Celsius. As temperatures in the stratosphere can drop to as low as -60 degrees Celsius, the batteries powering the electronics would fail quickly without the insulation from the outside. The polystyrene box comes with two wooden skewers and two 25cm by 20cm polystyrene panels. The skewers are poked through the box so that both ends are visible on the opposite sides, one above the other. The two panels are attached to the skewers with duct tape so that they are perpendicular to the ground. These panels minimise rotation caused by wind during the flight and stabilise the probe. We attached a card with our contact details on one of the sides of the probe in case someone found it after landing. Furthermore, German regulations require us to attach this card to the box. We laminated the card so that the paper would not be damaged by moisture during the flight [5].

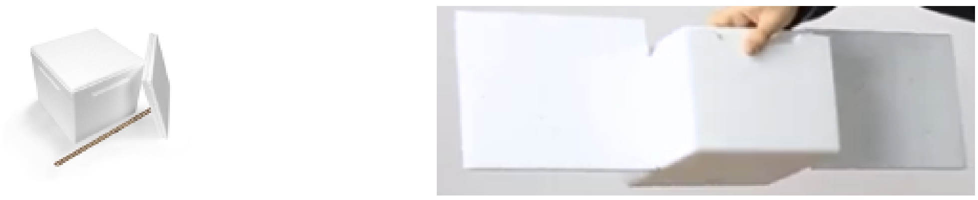


Figure 9: Polystyrene Box

To attach the polystyrene box to the parachute and the parachute to the high-altitude balloon, we purchased a 50m coil of polyethylene cord. The coil of cord weighs 30g and is only 1.2mm in diameter, yet it is tear-resistant and extremely durable, being able to withstand loads of 180N. This cord also conforms to the official German air traffic control and the German federal aviation authority regulations. These regulations do not permit cords with a tensile strength of above 230N [6].

To connect the polystyrene box with the parachute, first of all, four holes must be pierced into the lid of the box so that it is possible to attach some of the polyethylene cord on the underside of it and thread four equally long cord ends through to the other side. The cord is stuck down with duct tape. The four cord ends are knotted together at their extremities. The lid is then

sealed all the way around with duct tape and for extra security, it is wrapped around the top of the lid and the bottom of the box, so that the polystyrene box will not open in any situation. Furthermore, all holes pierced in the polystyrene box are sealed with more duct tape. A 10m long piece of cord is fastened with a knot under the existing knot keeping the four cord ends form the box together. This 10m long cord leads to the parachute. Next, the loops at the bottom of the parachute are knotted together making one big loop consisting of all the individual loops. The top end of the 10m long cord is attached to this one big loop with a knot [7].

To connect the high-altitude balloon to the probe, a 5m long bit of polyethylene cord is wrapped around the centre of the high-altitude balloon's neck between the two seals. The cord is attached with a knot. The neck of the balloon is then folded back to form a U-shape and a third cable tie is used to bind this together. One again, the cable tie is wrapped in duct tape to make sure that the sharp edge created by cutting of the excess cable tie length does not burst the balloon. The other end of the 5m long cord is knotted to the top of the parachute. In the centre of the hole in the top of the parachute, there is a cross consisting of two interlocking loops of thread. This thread is the same as the loops at the bottom of the parachute. For better security, multiple knots are made in all circumstances instead of just one. This makes sure that the cord does not disconnect from any other component of SPIDER, for example during launch, where there could be sudden tug when the high-altitude balloon is released [8].

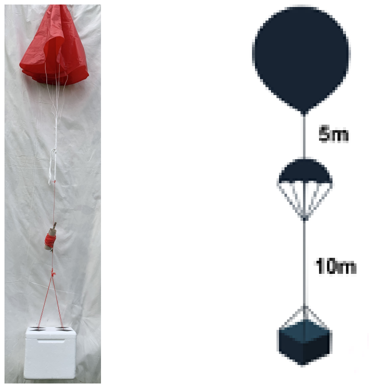


Figure 10: SPIDER

3.1.2 COMRADE KMP-1 Muon Detector

For our project, the most important part of SPIDER is the muon detector. Its design is based on that of the AMD5 muon detector. The AMD5 detector was designed by the ADA (Astroparticle Detector Array) project. This project is an Italian educational project created to detect high-energy cosmic rays, also known as UHE (Ultra High Energy) radiation.

As our science group did not have the electrical skills to build our detector, we worked closely with the FabLab science group that specialises in circuit boards, 3D printing and mill cutting. The muon counting detector is called COMRADE KMP-1 (Cosmic Muonic Radiation Detector Kooperatives Messprojekt 1) and is made out of two circuit boards, one for the electrical components and one for the detecting components. Both circuit boards are connected with cables. The electricals' circuit board is covered by a layer of plexiglass for protection. Its dimensions are 15cm by 10cm by 8cm (length by width by height). The main element of the detector though is the two 10.8cm long an 1cm wide cylindrical Geiger-Müller Tubes, GMTs (Geiger-Müller Tubes) for short, of the model SBM 20, placed one above the other. This model was originally produced in large quantities in the Soviet Union during the 80s and 90s and continues to be produced in all ex-Soviet countries. It works with a mixture of the noble gases

neon, argon and bromine (Br_2), and is one of the few models to have electronic features. The technology of the GMTs has not changed since the 80s and 90s and is still used today. Whenever an energetic particle passes through a GMT, the noble gases inside are ionised and send out an electric signal. After having lost a lot of their energy whilst passing through a GMT, most particles decay soon after, but as muons are created during high energetic events, they have very high energies, exceeding that of radioactive radiation by far. They are therefore the only particles that can pass through both GMTs almost simultaneously, travelling at 98% of the speed of light [9]. The GMTs are on the second circuit board. This circuit board has to placed vertically inside the polystyrene box to correctly measure the cosmic radiation, whereas the first circuit board can lie flat. The connectors of the GMTs are wrapped in copper wire which is soldered to pads on the circuit board. A 1.5mm^2 cable soldered on to a soldering pad next to the previous one connects the two circuit boards.

Our muon detector measures one detected muon when both GMTs are activated during a so-called coincidence time of 66ms. Using this coincidence time, we can exclude the majority of energetic particles that are not cosmic rays [10]. The detector is connected to an Arduino UNO single-board microcontroller via an analogue impulse cable. Every time a muon is detected, the detector sends an electric signal to the Arduino UNO that then saves the information onto an SD card.

3.1.3 Additional Instruments

In the following few paragraphs, some additional instruments needed for our mission are shortly presented. Please refer to chapter 3.2.5 Preflight Testing for more practical information.

Strato3 Aswell as the data gathered by the COMRADE KMP-1, we also need information about the position (especially altitude) of the probe and the climatic parameters of the probe's environment (temperature, air pressure, ...). We considered building a datalogger of this kind by ourselves, but we decided, due to the time frame, we'd rather use a tested and reliable model designed by Stratoflights GbR.

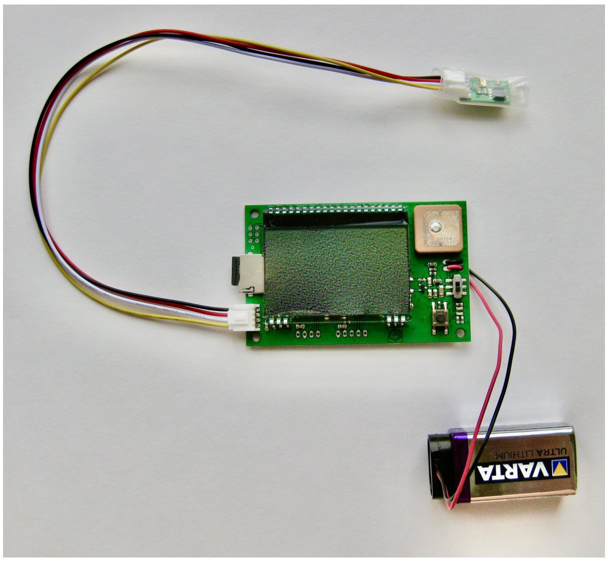


Figure 11: Strato3 (Display fuzzed out)

With a recording rate of 0.5Hz, this datalogger saves multiple parametrical informations to a MicroSD. StratoFlights GbR additionally provides an online data processing tool. However, as

we will need data in a format specifically adjusted to our main mission, we will write our own "VBA for Excel" script for that purpose.
For technical specifications, visit: https://www.stratoflights.com/en/shop/datalogger/

ApeMan Camera Weather balloon flights are famous for spectacular video material recorded during their mission. Therefore, we decided to gather our own footage during the flight and chose the camera "Apeman A79". This model is also recommended by Stratoflights GbR as it is sold at a low price and yet delivers high quality results. Most importantly, this camera is able to operate under the special conditions of the upper atmosphere.

Figure 12: Apeman A79

For technical specifications, visit: https://www.stratoflights.com/en/shop/space-cam-apeman/

GPS-Tracker TK-102 Finally, we need a way to receive live information about the probe's position in order to track it during and after the flight. For this, we chose the Xexun GPS-Tracker TK-102. It works with a SIM card. When you call the number of that SIM, the device will reply with an SMS message including its coordinates. As a potential failure of this device would render the mission a failure, we decided to buy a second tracker for redundancy.

Figure 13: GPS Tracker TK-102

For technical specifications, visit: https://www.stratoflights.com/en/shop/gps-tracker-tk102/

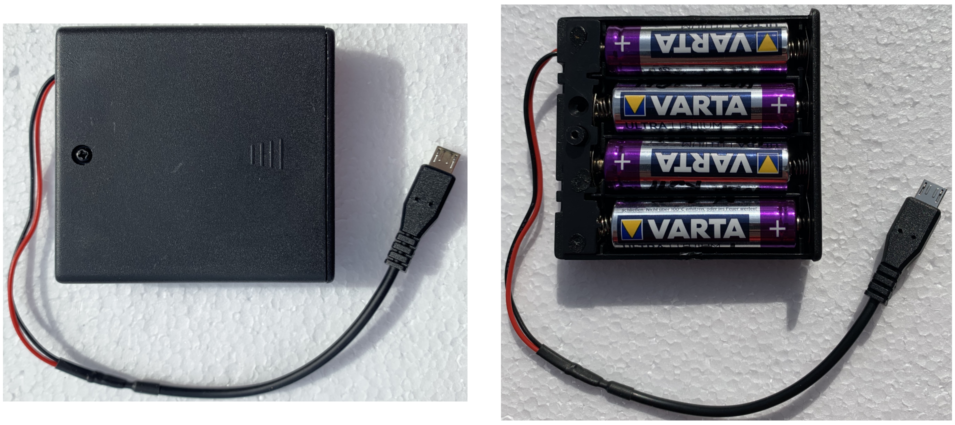


Figure 14: Battery Pack

Figure 15: All Equipment

3.2 Planning and Preparation

As SPIDER would fly through airspace often used for commercial aviation, we had to carefully plan how we would proceed and get sufficient authorisation from the different aviation governing bodies.

3.2.1 Schedule

To make sure that we executed our goals on time, we both sat down together on 18th October 2019 to create a schedule for our project. For this, we set certain deadlines for which attributes of the project had to be completed, along with a launch window in which we could launch SPIDER. We also planned that there might be some interest from other science groups at school to launch a project of their own on our flight. These are the deadlines and time frames we set right at the beginning:

21/10/2019	• pitch our ideas to the management group of the science department
08/11/2019	• all requests for experiments on our flight must be in
15/11/2019	• calculate weight to be lifted by the high-altitude balloon • pitch our ideas to the management group of the science department • request budget from the science department • order high-altitude balloon • first layout plan of the scientific platform
20/12/2019	• second layout plan of the scientific platform
07/02/2020	• apply for official authorisation at the required authorities
02/03/2020	• external experiments must be ready
09/03/2020	• SPIDER must be ready for launch
10/03/2020 to 02/04/2020	• Launch Window

On 21st October, we presented our ideas to the management group of the science department as planned. We explained how we would proceed with our project and our schedule. We also explained that we were open to requests for other experiments onboard our scientific platform. All requests however must have been made by 8th November. For this, we planned an extra week's time in case anyone did not get the message or forgot about the deadline. Nevertheless, we did not get any requests in that timeframe and we proceeded with our project alone. On 15th November we finalised our budget calculations and requested it from the science department who receive an annual budget from the school administration. We also estimated the available weight and planned a vague layout for the scientific platform. On 11th December, we ordered the Geiger-Müller tubes (GMTs) from Ukraine. As we did not get our budget until 21st January, we could not order the necessary equipment as early as planned and therefore all relevant deadlines were pushed back. When we did eventually get it, we received the total requested amount and ordered the equipment necessary for the flight on the same day. This equipment included the high-altitude balloon, the scientific platform and additional instruments. On 27th January, both science groups involved in the SPIDER project presented their half-year-progress reports to the head of the science department. The package containing the equipment was delivered on the same day, and the next day we opened it and checked if everything was in the package. As nothing was missing, we measured the weight of all the items the following week on 4th February and could therefore calculate the weight of the scientific platform with the experiments and instruments onboard. Knowing the approximate dimensions of the muon detector, we could also make a second more exact layout plan of the scientific platform. On the same day, we had a small meeting with multiple science and maths teachers about what our onboard camera setup should be. The problem was that the cameras needed a battery pack power supply as the cameras own batteries are quickly drained when exposed to the cold temperatures of the upper atmosphere that can be as low as -51 degrees Celsius [11]. We had the option to either build the cameras into the walls of the polystyrene box or in protective cases on the outside. If we built them into the walls, we would compromise the insulation capacity of the polystyrene box, but the cameras would not get as cold as they would outside, and the lens would not fog up with moisture due to the quick change in temperature during flight. On the other hand, if we placed them on the outside, it would be easier to mount them, and we would not use up as much of the limited space inside the polystyrene box. We decided that mounting the cameras on the outside was the better option, but we were not sure if we should use the camera cases with holes (to let the moisture out of the case during flight) or the ones without holes (to keep the temperature inside the cases from changing as quickly). We therefore performed an experiment (see under Preflight Testing) to test which option was better. For the flight, we decided to use the camera cases without holes because they offer better protection.

We also realised that there was a bit of plastic covering the charging port of the camera when in its case, so we asked the FabLab science group if they could drill holes in the cases just big enough to fit the charging cable through. A day or so before launch, we would seal these holes with silicon. On 29th January, we held an emergency meeting with the FabLab group, as we felt that their progress was too slow and that the detector would therefore not be finished in time for our launch window. There were many difficulties in designing the circuit board, and so far, this was the only thing that had been completed. Even though we did not yet have a fixed launch date, we decided this should be later in our launch window to give the FabLab science group some extra time to complete the detector. On the other hand, we asked if the group supervisor could work on the project outside of the science group's normal working hours. We also presented our backup ideas in case the detector could not be finished.

As the launch window was fast approaching and not all tasks had been completed, for example the application for the authorisation of the high-altitude balloon flight, we held a meeting with our teacher on 5th February to decide our launch date and our backup launch date in case something was not ready yet or if the weather conditions were not good enough to launch safely. We chose Wednesday 25th March in the last week of the original launch window as our primary launch day and Wednesday 22nd April as our backup launch day. Furthermore, we fixed the launch time on both dates at 13:00. The authorisation for the flight was requested the same day and was granted on 3rd March. By then our schedule looked like this:

21/10/2019	• pitch our ideas to the management group of the science department
15/11/2019	• all requests for experiments on our flight must be in • calculate weight to be lifted by the high-altitude balloon • finalise budget calculations • request budget from the science department • first layout plan of the scientific platform
21/01/2020	• order equipment necessary for the flight
27/01/2020	• second layout plan of the scientific platform
05/02/2020	• apply for official authorisation at the required authorities
24/03/2020	• SPIDER must be ready for launch
25/03/2020	• Launch Day
22/04/2020	• Backup Launch Day

On 26th February we prepared the camera cases for drilling by marking the areas that had to be removed, and, with just under a month to go until Launch Day, we decided to reorganise ourselves, check what still needed to be done, sort out or find solutions for problems and reschedule for the last month, as follows:

03/03/2020	• parachute test • evaluate parachute test • start battery pack/camera test • start scientific platform construction
04/03/2020	• finish battery pack/camera test • evaluate battery pack/camera test • finish scientific platform construction • finalise order list of remaining items needed
10/03/2020	• exact weight measurements • confirm muon detector power supply method
11/03/2020	• SIM card configurations • GPS tests • evaluate GPS tests • purchase remaining items needed
12/03/2020	• order Helium
17/03/2020	• calibrate GMTs
18/03/2020	• start muon detector test • start daily weather forecasting checks
20/03/2020	• end muon detector test • evaluate muon detector test
24/03/2020	• SPIDER must be ready for launch
25/03/2020	• Launch Day
22/04/2020	• Backup Launch Day

On 3rd March, we performed the parachute test and evaluated the results. We started the scientific platform construction, which consisted of attaching the lid of the polystyrene box to the parachute and the cord leading the high-altitude balloon to the top of the parachute. We also started the battery pack/camera test which we completed and evaluated the next day. That day, we also finished the construction of the scientific platform and made a list of all the remaining items we still needed for the flight. On 10th March, we made exact weight measurements of all of SPIDER's components, so that the FabLab science group knew what the maximum allowed weight of the detector was. This was also important to know when calculating the amount of helium required to fill the high-altitude balloon. Our two scientific groups also agreed that the power supply for the muon detector would be a 99mm long, 24mm in diameter, 5V, 2600mAh Li-Ion power bank and a 9V battery. On 11th March, we reconfigured the prepaid SIM cards because we needed them unlocked for our mission. We inserted them into a smartphone, and in the Settings menu, unlocked them and disabled their password function. We marked the GPS trackers with the SIM card's last two barcode numbers to be able to keeps both GPS sets separate. Furthermore, we tested both GPS trackers with the SIM cards and evaluated our results. We ordered the remaining items of our order list, completed the high-altitude authorisation application for the backup launch date, got it signed and we asked our contact from the airport for information about what procedures we needed to follow on the day of launch. Later, we sent a similar email to the DAC.

At this point, the only tasks that remained before launch were the calibration of the GMTs, testing the muon detector, ordering of the helium to fill the balloon with and checking the weather forecast. At this point though, we had to stop launch day preparations because of the

government's actions to fight the coronavirus disease (COVID-19) outbreak.

3.2.2 Budget

In order to afford all of the material for SPIDER, we needed financing from the school. At the beginning of the school year, we were informed, that we had to file a request for our budget before the 20th November 2019. Our school distinguishes between two categories of material they finance:

- Equipment: Everything that is more expensive and can be used multiple times, falls under the equipment category. To get this type of financing, a dedicated justification letter to the school administration that includes the exact price and seller of the equipment is necessary.
- Functioning: The functioning category includes all the one-time consumables or parts to build custom devices. A request for the functioning budget only requires conveying an approximation of the money required for one year to the head of the department (in our case, the science department).

As for the weather balloon and the probe, we decided to file an equipment request. This decision was based on the fact that it would be one single, big order from Stratoflights GbR and that almost everything in that order could be reused. The justification letter including the price list can be found in the appendix (5.3.2). It however excluded the muon detector as we would build it ourselves with parts falling into the functioning category. Moreover, our functioning budget would also have to include the price of the helium. We thus had to call Air Liquide S.A., a helium seller in Luxembourg, and ask for the cost of the helium we needed.

Finally, on the 20th November, we finished the justification letter and had approximated the functioning budget and filed everything with the corresponding persons. Our equipment budget amounted to €1,016.74 and the functioning budget to €500.

For more than two months, we waited for an answer. But finally, at the end of January, we were told that the board had decided that the risk of the weather balloon failing was too high and everything in the probe might be destroyed and therefore could not be considered equipment, but would fall under the consumable category. In conclusion, we were granted a functioning budget of €1,200. However, the head of the science department and a staff member offered to buy the helium with a part of the budget they usually use to buy chemicals for lessons, as there would be helium left for them. Therefore, we had no financial restrictions and could continue our project without budget cuts.

3.2.3 Authorisation and Insurance

As SPIDER would fly to an altitude much higher than the cruising altitudes of commercial airliners and other aircraft, an official authorisation from the aviation authorities was necessary. As we were launching SPIDER from Luxembourgish territory, we knew that we had to ask the home authorities for permission, but as Luxembourg is a small country, and high-altitude balloon flights cover distances of between 50km and 150km, it was most likely that the weather balloon would fly over the border and into a different country's airspace. After looking at a map, we concluded that there was a possibility of the probe landing in France, Belgium, the Netherlands and Germany. We did not know if we had to ask for permission in these countries as well. We started looking up the laws concerning high-altitude balloon flights in each country although this proved to be very difficult as we had not had any experience with legal texts. Therefore, we decided to ask a contact at the "Administration de la Navigation Aérienne" (ANA) for

help. ANA are the entity responsible for air traffic control in Luxembourgish airspace. We told our contact what we wanted to do and asked what regulations there were and who we had to contact to get permission. We got an answer back saying we needed to contact the "Direction de l'Aviation Civile" (DAC). He gave us an email address to contact them and mentioned that, if we sent them everything they needed, we would normally get an authorisation along with instructions about what to do on the day of launch. We promptly contacted the DAC explaining what we wanted to do. We got a reply stating that we had to fill in a form sent as an attachment. To fill in this form, we had to write down the reason why we were launching our high-altitude balloon and a description of SPIDER, including its weight. Along with this, we also had to state the launch date and time, the exact coordinates and address that we would be launching from, the maximum altitude SPIDER would reach and if we were using a balloon tethered to the ground or not. Furthermore, we needed written permission from the landowner and a contact person's details and signature (as we were still minors, we asked the head of the science department to help us out with this last point). We were not sure if this form would cover permission for Luxembourg as well as the surrounding countries or if we would also need to seek permission from EUROCONTROL, the European Organisation for the Safety of Air Navigation. Therefore we sent an email to our contact at ANA again regarding our queries. He replied saying that the form was sufficient as the ANA would be contacted first and that they would then have to ask the authorities in question for permission.

We were also kindly informed by a teacher at our school, who completed a similar project with multiple weather balloon flights five years beforehand, that we needed state insurance for SPIDER in case it caused any damage upon landing. We then contacted the governmental "Service National de la Sécurité dans la Fonction Publique" (SNSFP), explaining what our project was about as well as that we had been informed by a teacher who had completed a similar project and who had managed to get his probes insured with the SNSFP. We asked what the process was to be able to get our probe insured against any damage it may have caused upon landing. We were informed by the SNSFP that as our project was authorised by the school administrator, and that the material for the flight had been financed by the school, therefore by the state, we were already insured.

After speaking with our teacher about launch dates, the form was easy to fill in, but we did not know who the landowner was; the school is owned by the state, but the state was only leasing the land. We therefore contacted our school administration by email, explaining our project and telling them that we needed the landowner's written permission, but we did not know who to contact. They told us that they would try and find out who the landowner was and asked us if we had permission to launch SPIDER as well as insurance for the project. We sent them a scan of the filled-out form from the DAC and forwarded them our communications with the SNSFP. They further informed us that they were trying to get written permission from the landowner. In the end, it turned out that the school had the right to give us permission, which they did. The application was approved by the DAC and we received the authorisation on 3$^{\text{rd}}$ March. On 3$^{\text{rd}}$ April, we sent an email to the DAC asking for more information about what procedures had to be completed in the days leading up to the launch and the day itself. We got a reply back saying that we needed authorisations from Belgium, France and Germany, as there was a high probability that SPIDER would leave Luxembourgish Airspace, before we could decide on the coordinated arrangements for release.

3.2.4 Flight Predictions

Before our flight, we needed to know a few things about how the flight would probably play out.

Maximum Altitude A weather balloon floats up due to the small gas density (Helium) in the balloon. As it increases in altitude, the air pressure around it drops. Consequently, the balloon expands due to the lower pressure around it. The balloon bursts at a specific altitude in order to come back down to the surface.

The most important calculation for our flight was to predict what altitude SPIDER would reach. Stratoflights GbR offers a tool on their website which tells you exactly that, but we wanted to understand these calculations. This is why we wrote an e-mail to Stratoflights and asked them to provide us with some information. They referred us to a tool from a student society at Cambridge University where we found a downloadable spreadsheet which contained all the necessary calculations[12]. It needed some further research, but we figured it out eventually.

First of all, we need the relation between the outside pressure and the volume of the balloon. Simplified, we can say that the gas density outside of the balloon is proportional to the gas density inside the balloon [13]:

$$\frac{P}{P_0} = \frac{V_0}{V} \quad (1)$$

where

- P is the pressure at given height
- P_0 is the pressure at Earth's surface
- V is the volume of the balloon at a given height
- V_0 is the volume of the balloon at Earth's surface

Secondly, we need the relation between altitude and pressure. We know that, due to gravity, the pressure of a gas decreases exponentially over altitude[14]. We can express this change like this:

$$P = P_0 \cdot e^{k \cdot h} \quad or \quad \frac{P}{P_0} = e^{k \cdot h} \quad (2)$$

where

- h is the height
- k is an air density model constant ($k < 0$)

This air density model constant can theoretically be derived for an ideal gas. However, this is far from precise for Earth's irregular atmosphere. Furthermore, it depends on weather conditions and other various parameters. Nevertheless, you can use generalised values to approximate calculations. The value used in the spreadsheet by CUSF is $-\frac{1}{7{,}238.3}$.

By combining equations (1) and (2) and isolating h, we get:

$$\frac{V_0}{V} = e^{k \cdot h}$$

$$\Leftrightarrow h = \frac{1}{k} \cdot ln(\frac{V_0}{V})$$

$$\Leftrightarrow h = -7{,}238.3 \cdot ln(\frac{V_0}{V})$$

That is the final equation, we need. The only thing we need now are the initial volume of the balloon and the volume at which the balloon bursts. The seller provides the initial diameter and the burst diameter. For our balloon $d_0 = 2m$ and $d = 9.44m$. So, for our balloon:

$$h = -7,238.3 \cdot ln(\frac{\frac{4}{3}\pi(\frac{d_0}{2})^3}{\frac{4}{3}\pi(\frac{d}{2})^3})$$

$$\Leftrightarrow \; h = -7,238.3 \cdot ln(\frac{\frac{4}{3}\pi(\frac{2m}{2})^3}{\frac{4}{3}\pi(\frac{9.44m}{2})^3})$$

$$\Leftrightarrow \; h \approx 33,696m$$

Ascent Rate and Duration Another important prediction we have to calculate is the ascent rate of the balloon and the approximate duration of the flight. In order to calculate the ascent rate, we first want to find the free lift of the balloon:

$$F_{lift} = (V_0 \cdot (\rho_{air} - \rho_{helium}) - m) \cdot g$$

- F_{lift} is the free lift
- V_0 is the volume of the balloon on the Earth's surface
- ρ_{air} is the density of air
- ρ_{helium} is the density of helium
- m is the mass of balloon and the probe
- g is the local gravitational acceleration

Please not that we have not finished the construction of the probe and therefore can only estimate the weight.

Using the free lift, we can calculate the ascent rate with the following formula:

$$v = \sqrt{\frac{F_{lift}}{\frac{1}{2} \cdot \rho_{air} \cdot A_{balloon} \cdot c_d}}$$

where

- A_{probe} is the cross-sectional area of the balloon
- c_d is the drag coefficent of the balloon (provided by the seller - $c_d = 0.25$)

Putting in all the values, we get:

$$v = \sqrt{\frac{(\frac{4}{3}\pi * (\frac{2m}{2})^3 \cdot (1.205\frac{kg}{m^3} - 0.1786\frac{kg}{m^3}) - 3.1kg) \cdot 9.81\frac{m}{s^2}}{\frac{1}{2} \cdot 1.205\frac{kg}{m^3} \cdot \pi \cdot (\frac{2m}{2})^2 \cdot 0.25}}$$

$$\Leftrightarrow \; v \approx 4.97\frac{m}{s}$$

SPIDER will thus have an ascent rate of $4.97\frac{m}{s}$.

Finally, we can easily calculate the time the balloon needs to reach its burst altitude:

$$t = \frac{33,696m}{4.97\frac{m}{s}}$$

$$\Leftrightarrow t \approx 2.05h$$

We can conclude that SPIDER will take about 2 hours to reach its burst altitude.

Path Now that we know how high, how fast and how long SPIDER will fly, we want to know where it will fly. This is up to the wind conditions. Of course, we can't predict the exact wind conditions of a day far in the future, but there are general predictions we can make.

Prevailing winds Prevailing winds are winds which predominantly flow in one direction, caused by fixed high and low pressure areas [15]. The two areas which are most decisive for wind in Northern Europe are the Icelandic low, over the North Atlantic, and the Siberian High [16]. The Siberian High is centered over Central Asia but extends towards Eastern Europe. However, these winds do not flow in a straight line. Due to the rotation of the Earth, winds are curved to the right in the northern hemisphere and to the left in the southern hemisphere. In conclusion winds blow clockwise around high pressure areas and counterclockwise around low pressure areas [17]. Finally, considering the alignment of the Icelandic Low and the Siberian High, we know that the prevailing winds in Northern Europe blow from the west to the east. They have a dedicated name: "Westerlies".

For our weather balloon, the Westerlies mean that it will most likely travel to the east over Germany.

For more exact predictions, there are a few online tools which have access to weather forecasts and are able to precisely predict the path of a weather balloon. We can therefore simulate our balloon's path shortly before launch which makes it easier to track.

3.2.5 Preflight Testing

These are the results of the pre-flight tests that we performed before launching SPIDER.

To test which type of camera case would be better for the high-altitude balloon flight – the one with holes or the one without – we performed an experiment to see how much the lenses fogged up. For this, we placed two cameras overnight in a freezer at -20 degrees Celsius, one in a case with holes and the other one in a case without holes. With this experiment, we could also find out the cameras' operating time in the cold without a battery pack. The next day, both lenses were fogged up about the same amount and both cameras filmed for a time of between 75min and 90min. There was no real difference between the two cases, but we opted for the one without holes, reasoning that the one without holes would provide better protection.

For the parachute test, we filled the polystyrene box with iron, aluminium and wooden weights so that it weighed almost exactly 1.6kg, the maximum weight for our flight. We used string from the school's previous high-altitude balloon flight in 2015, and wrapped it around the polystyrene box and attached the parachute to the top with a series of knots. We then proceeded by dropping the probe from the 2nd floor to the ground level in the school staircase. To evaluate the test, we filmed the 10m flight from below. When let go, the parachute started opening immediately and was already fully open after falling about 3m. However, after falling 5m, there was an upwind from the 1st floor tilting the parachute to the side. As a consequence, the parachute brushed against the 1st floor stair guard rail causing the parachute to fold slightly and produce less drag. After passing the 1st floor, the parachute fully opened once again at an altitude of about 3m and slowed down before hitting the ground. Even though the test did no go perfectly, we were happy with the parachute's performance and did not feel the need to repeat the test.

We tested the two GPS devices at two different locations on the school campus. To initialise the GPS device, we had to text "begin" followed by a password to the SIM card by short message service (SMS). To obtain its coordinates, we phoned it and after it hung up, it sent us the

coordinates of its location along with a web link for Google Maps [18]. We repeated the process for the second GPS device. Both sets of results were the precise coordinates of the GPS devices at the time.

To test the Strato3 data logger, we went outside, and left the data logger running for a few minutes. Afterwards, we checked the data to see if everything worked fine and verfified the coordinates. There were no issues. The only thing that threw us off at first was that the coordinates are saved in a weird and unusual format, but after a few minutes, we figured it out.

Figure 16: A sequence of shots from the parachute test

3.2.6 Effects of the 2019-2020 Coronavirus Pandemic

In December 2019, an outbreak of a newly discovered coronavirus was reported in Wuhan, Hubei Province in China [19]. The disease, called Coronavirus Disease 2019 (COVID-19) [20], caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), spread around the world. The virus is spread through respiratory droplets expelled by those infected when coughing or sneezing as well as contact with contaminated surfaces following touching of the face [21]. Its most common symptoms are fever, cough and shortness of breath, similar to those of the flu (influenza) or the common cold [22]. The infection remains mild in 80% of cases but can cause pneumonia or breathing difficulties. For people with underlying health conditions, the infection can be deadly [23].

The first case in Luxembourg was reported on 29^{th} March 2020. On 12^{th} March, there were already 26 confirmed cases in the country. This meant there was a 371% increase from the previous day's count of 7 [24]. To try to slow the spread of the disease, the Luxembourgish government implemented restrictions later that day including a ban on all events of over 100 people and an initial two-week closure of schools from 16^{th} March to 27^{th} March [25]. Students would therefore work from home. This meant that we could not launch SPIDER on our planned date of 25^{th} March. Furthermore, because of the severity of the situation, it was expected that schools would remain closed for a further week, from 30^{th} March to 3^{rd} April, the week before the two-week Easter school holidays. Further development of the situation led to bans on nonessential social contact, unnecessary travel throughout the country and a large number of international border closures worldwide, including in the Schengen Area. All of this, including the closure of the German border with Luxembourg, meant that we would not be allowed to retrieve the probe in Germany after the high-altitude balloon flight.

At the time of the government's announcement, we estimated that we were two weeks away from being ready for launching SPIDER. We therefore decided to postpone the backup launch

date by a week on 13^{th} March, the last day of school before the closure. This meant the planned launch day was 29^{th} April. We sought permission to change the date on the flight authorisation form and asked the school administration to write another letter giving us permission to launch from their land. Our application was handed in to the DAC later that day and was approved on 21^{st} March. We spoke with our teacher and the head of the science department who both agreed that we could take the material for the mission back home. Our teacher translated the instructions for the GMT calibration from Italian to French and we asked the FabLab science group teacher, who would still be working in the school building during the closure, if he could calibrate the GMTs during this time. Unfortunately, he was not allowed to work on that, but the detector was otherwise finished. On 18^{th} March, the government announced its decision to extend the school closure to 19^{th} April [26]. On that day, there were 203 confirmed cases of COVID-19 in the country. On 25^{th} March, the day we had originally planned to launch SPIDER, there were 1,333 cases. On 1^{st} April, when there were 2,319 cases in the country, the government announced that schools would remain closed until 4^{th} May [27]. This meant we had to scrap the 29^{th} April launch date as well. On 17^{th} April, when there were 3,480 cases, the government announced that schools would reopen on 11^{th} May [28]. However, with much uncertainty about these plans, we decided to postpone the high-altitude balloon mission.

3.3 COMRADE KMP-1 Muon Detector

The detector is key to the mission as it is the component that measures the radiation. There is limited space in the polystyrene box, meaning that we cannot use any of our much larger detectors. We therefore worked together with a different science group to build a new detector from scratch. For this, communication between the two science groups was key.

3.3.1 Construction

Detector On 1^{st} October, we asked the FabLab science group, who specialise in designing electronics, 3D printing and mill cutting, if they could build a detector from scratch for us. We explained that we needed a smaller version of our AMD5 muon detector for our stratospheric flight later in the year. They accepted the challenge and the next day, 2^{nd} October, both science groups held a meeting so that we could take photos of the AMD5 circuit boards and, with the help of a copy of the original electrical network diagram, start a list of the electrical components of the circuit board. On 7^{th} October and 8^{th} October, the FabLab science group analysed the electrical circuit network and compared it with the circuit board of the AMD5 detector to get an idea of how it works. On 9^{th} October, they started a material list of things needed to build the detector. From 16^{th} October to 22^{nd} October, they further analysed the electrical network diagram and on the latter date, they disassembled the AMD5 detector to make more accurate assessments of the electronic components. The main goal of this operation was to find out the voltages of the capacitors. From 30^{th} October to 11^{th} December they finished the material list and started designing the circuit board. This was difficult, as it was the most complex thing they had yet designed. On 18^{th} December we updated them on our schedule and gave them a target date for completion. On 8^{th} January they changed the design method for the circuit board as the way they were doing it was too complicated. We held another meeting together on 29^{th} January to discuss their progress and to make sure everything could be completed for our launch window. We also told them about our alternative ideas for the muon detector in case they could not complete COMRADE KMP-1. They also made it clear that it was difficult to design such a complex circuit board without an idea of how it should look, given the AMD5 design was not space-saving and the electronic components were different sizes to theirs. We managed to obtain illustrations from Mr. Marco Arcani, the inventor of the AMD5 detector, which we forwarded to the FabLab science group. On the same day, they started measuring the material for the detector. Using the illustrations as an aid, they again started designing

the circuit board in the school holidays, from 8th February to 11th February. There were still problems with this design meaning that from 24th February to 29th February these problems had be solved and a new design was made. From 2nd March to 7th March, an etching bath was prepared for the circuit board in which it was etched. They also cut a plexiglass panel to attach to the corners of circuit board for protection. However, there were issues with the circuit board, meaning they had to order new parts and correct the problems with the circuit board by slightly changing the design. From 9th March to 15th March, they attempted to etch the circuit board again, but there was a problem with the etching bath, so they tried it again and this time it worked. They then drilled the holes in the circuit board and soldered the electrical components in. They made a new heat sink and cut a new plexiglass panel, both of which they attached to the circuit board. They had to order new components which they also mounted on the circuit board. Afterwards, they wired the detector and designed a far simpler circuit board for the GMTs. Both circuit boards are linked together with four cables. The GMT-circuit-board was completed, without the GMTs soldered on, on Friday 13th March. With this, the only remaining task was the setup, which included GMT calibration, testing and troubleshooting.

3.3.2 Data Logger

The COMRADE KMP-1 only detects the muons. We needed a device which can store the measurements of the detector.

Construction And Programming The muon detector's output consists of two wires. One of them is a GND (Ground) wire and the other is one that transmits an impulse signal (high increase in voltage) every time a muon is measured. In order to log these impulses, we needed to build a device with the capabilities to measure voltage changes, keep precise track of time and write data to an output file.

To build this data logger, we used the following components:

- Arduino UNO The "Arduino UNO" is an open-source microcontroller board, which is equipped with various I/O pins. This allows it to be interfaced with various devices.
  We chose this particular board due to its powerful simplicity and lightweight resources. Furthermore, it has analog pins, which will easily allow communication between the muon detector and the Arduino.

- MicroSD Card Adapter In order to write and store data, we chose a MicroSD card adapter. This item communicates with the Arduino and allows it to write to a MicroSD card.

- DS3231 Real Time Clock As the Arduino UNO's built-in timekeeping device does not meet the required precision for our project, we bought this additional module, sold by Adafruit. Powered by a small battery, this high precision clock interfaces via I2C to the board and allows it to read the current time.

- Jumper Wires (12) Some wires are required to connect the different devices.

First, we needed to wire the components together. The wiring of the MicroSD card adapter and the DS3231 Real Time Clock is rather easy. Specific instructions came with them. Then, we added two wires which connect to the muon detector. One of course occupies a GND pin, and the other wire we connected to the A0 analog pin.

As this microcontroller board was just a jumble of parts without the corresponding software, the next step was to program it. Via USB, the Arduino UNO can interface with a computer.

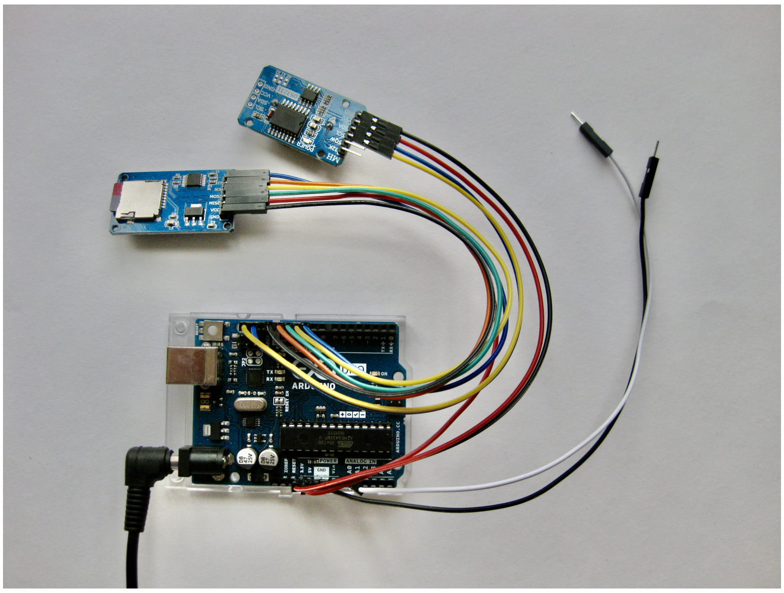


Figure 17: Arduino UNO (Bottom) and attachements (left to right): MicroSD card adapter, DS3231 Real Tim Clock, Wires for connection with COMRADE KMP-1

Using the Arduino SDK, the user is able to upload scripts to the board. Our final script can be found in the appendix (5.1.1).

Essentially, after initialising the different devices, the Arduino reads from the A0 analog pin. As soon the base signal noise is exceeded, the Arduino reads the Time from the Real Time Clock and opens a text file on the MicroSD card. For every muon it measures, the device writes a line in the following format:

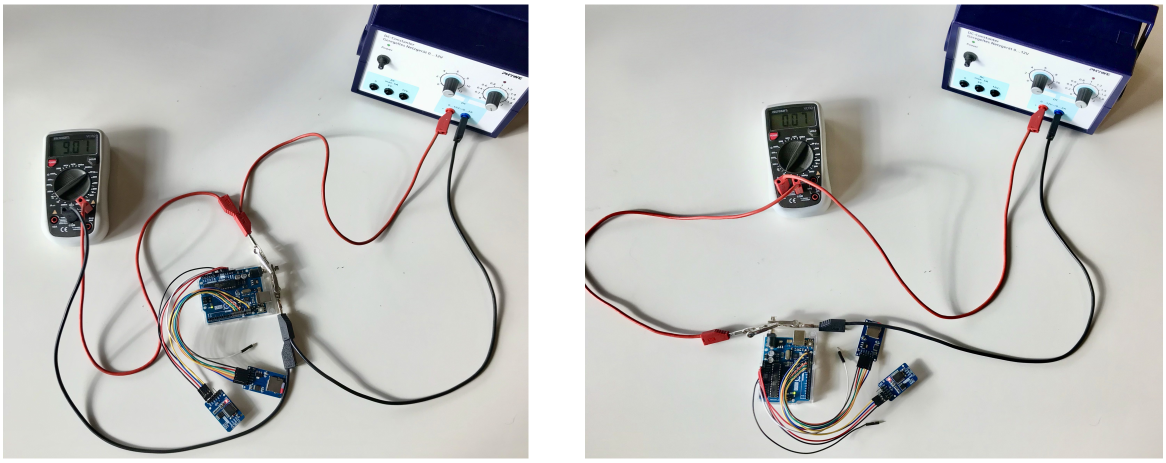
```
yyyy/mm/dd; hh:mm:ss; muon measured;
```

Using this data format, all the information is stored and we will be flexible with our data analysis, as we can convert this information to any format we might need.

Testing Before launching the balloon, this device also needed to be tested. In order to do that, we connected the Arduino to the AMD5, the working muon detector at our school. Additionally, we connected a multimeter in parallel to the communication wires. Finally, we connected the Arduino to a PC and set up the PC to show us every time the Arduino recorded a measurement. Hence, we were able to monitor the output of the detector and the output of the Arduino. Finally, when we saw that the outputs matched, we knew that the Arduino worked and was ready for the mission.

Power Supply One last issue we had with the data logger was the power supply. We had no idea how much power the board, with its additional components, consumed. The only thing we knew was that the Arduino operates at 5V or 9V. We first decided to measure the power consumption at 9V, as Stratoflights GbR sells rather light 9V brick batteries which are adapted for the conditions in the upper atmosphere. Furthermore, we programmed the Arduino to read from the Real Time Clock and write to the SD card non-stop, in order to simulate the highest consumption possible.

We measured that at 9V, the Arduino operates at a current of 0.07A or (70mA). The battery we considered has a capacity of 1.2Ah (or 1,200mAh). Conclusively, connected to this battery,



(a) Voltage (9.01V) (b) Current (0.07A)

Figure 18: Power Consumption Test

the Arduino has a minumum run time of $\frac{1200mAh}{70mA} \approx 17.1h$. As the flight will probably have a duration of about 3 to 4 hours, 17 hours are more than enough. Hence, we will use the 9V Varta Lithium brick sold by Stratoflights GbR.

3.3.3 Difficulties

The COMRADE KMP-1 detector was the FabLab science group's most complex build to date. This meant that they ran into a fair share of problems before being able to complete the build. The first problem was that this was the biggest circuit board they had designed. Although they had pictures of the AMD5 circuit boards, they had to try to keep the design as compact as possible. They originally started their design by freestyling. This was too complicated though, so they changed their designing method to a more methodical approach. This was still difficult, so they asked us for illustrations of what it could look like. We therefore contacted the AMD5 detector designer who kindly sent us illustrations of his circuit boards. We sent these to the FabLab science group who managed to complete the first design of the COMRADE KMP-1 circuit board. However, as the design was not drawn to the same scale as the actual circuit board, some problems were discovered: The design was too compact with some of the components, which had different sizes to those on the illustrations, not fitting and the conducting paths had to be made thicker because of the cold temperatures it would encounter in the stratosphere. Furthermore, as the detector would be powered by batteries, the rectifiers were removed from the design. They etched a circuit board with the second design but there were still problems: Some of the electrical components still did not fit and the soldering joints were too small. They adjusted the design again and etched it onto a new circuit board. However, there was a malfunction of the etching bath, meaning this process had to be repeated. After this, the electrical components could finally be mounted correctly.

The multitude of unexpected problems caused delays, making it a challenge to get the detector ready for the launch date. Towards the end, it was planned to do the detector setup in the week before the launch.

3.3.4 Backup Ideas

As we had no guarantee that COMRADE KMP-1 would work, we came up with a backup idea. We knew that the output of the GMTs we would use was an impulse signal. Therefore, it would be possible to connect them directly to the Arduino and create a software-based coincidence.

The reason why we did not build this to begin with is the fact that this would be less precise than a dedicated circuit board. Nevertheless, it would likely work and could be a replacement in case COMRADE KMP-1 did not work.

3.3.5 Setup

The setup is the last key step for getting the detector ready for its mission. For this, the GMTs have to be calibrated to give proper readings. Once this has been completed, we still need to test the detector over a period of a few days and compare its data with that of our other detector. If the data provided is not similar to that of the other detector, there is a problem with COMRADE KMP-1 that has to be rectified. Once the detector has been corrected and passes the test, it is ready for launch.

3.4 Launch Day

The most important day for our mission is, of course, the launch day. Before launch, we will assemble the probe, which means switching on all the electronics and carefully balancing them in the polystyrene box so that the weight is spread out evenly. Furthermore, the panels still have to be attached. One hour before launch, we will phone air traffic control to make sure everything is ready and it is safe to launch. Shortly before launch, the high-altitude balloon will be filled with the calculated amount of helium and the probe will be attached to it [29]. Whilst launching the high-altitude balloon, it is important to gently launch it in a fashion that does not result in a tug on the probe which causes stress on the cord and may cause it to break, letting the balloon fly away without the probe [30]. SPIDER will be scheduled to launch at 13:00 so that there is enough time to retrieve the probe in the same day. To make a retrieval possible, we will have to leave straight after launch to go to the predicted landing coordinates and retrieve the probe along with the data it gathered.

3.5 Results and Analysis

As we were not able to launch the weather balloon, due to the 2019-2020 coronavirus pandemic, we do not have the data we hoped to gather with SPIDER. However, there are some groups of scientists who have conducted similar missions.

In October 2018, a research group from Pozzuoli, Italy, launched a weather balloon with a muon detector similar to ours[31]. Like us, this research group participates in the ADA project (Astroparticle Detector Array), overseen by the astroparticelle.it organisation. They obtained the following results:

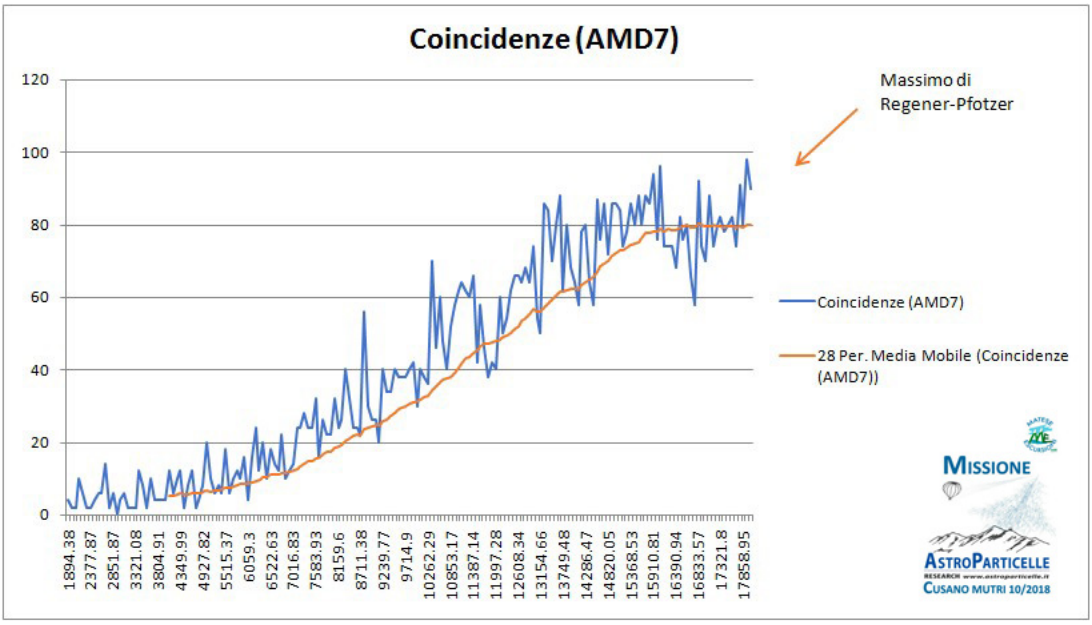


Figure 19: Astroparticelle.it Results

The y-axis shows the “amount” of cosmic radiation measured and the x-axis shows the altitude. As expected, we see a very clear increase of radiation over altitude. However, at about 15 kilometers, the curve flattens. This “plateau” is called the Regener-Pfotzer Maximum [32]. We know that primary cosmic particles create cascades of secondary particles as they hit the stratosphere. These cascades are most intense at their altitude of origin. We therefore find the Regener-Pfotzer Maximum at that altitude.

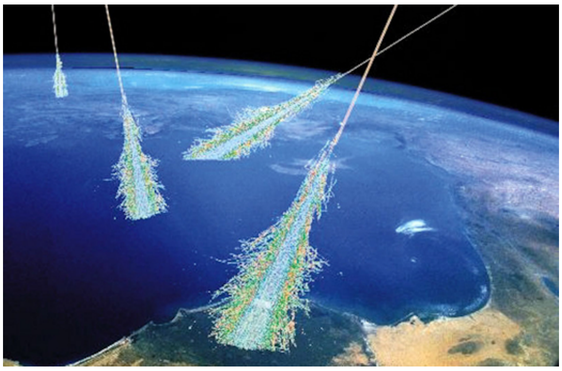


Figure 20: Secondary Particles Cascade

Furthermore, as studies from spaceweather.com based in California show, the radiation dose decreases as expected when the measuring device reaches higher altitudes than the Regener-Pfotzer Maximum [32].

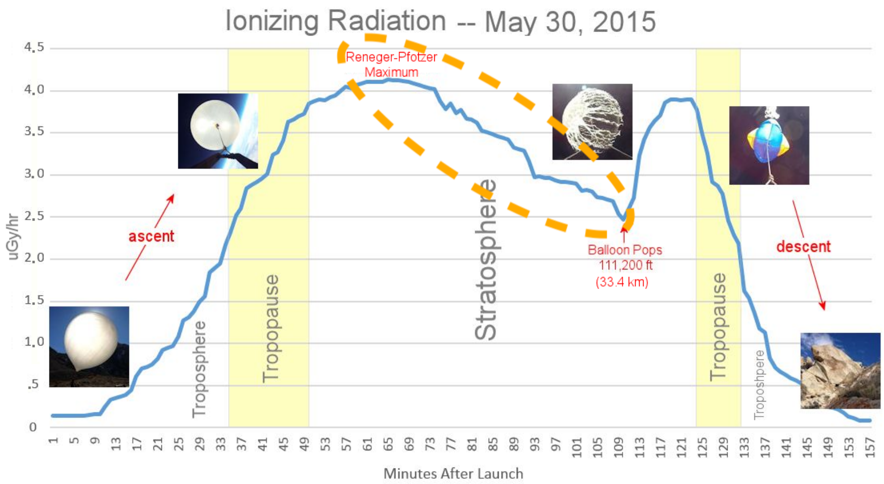


Figure 21: Spaceweather.com Results

As for SPIDER, we plan to launch it as soon as the restrictions put in place because of the coronavirus pandemic are lifted and the situation allows it. Firstly, we aim to confirm this data concerning the Regener-Pfotzer Maximum. Moreover, due to the unevenness of the atmosphere and its seasonal dependency the altitude of the Regener-Pfotzer Maximum varies with location and season. We want to study this altitude variation, especially since we found no northern European study about the Regener-Pfotzer Maximum during our research.

4 Conclusion

To conclude, we can now answer the questions we asked ourselves at the beginning of our work. Does radiation flux actually increase at altitude and if it does, is the difference in radiation levels big enough to pose a threat to humans?

Sadly, as we were not able to collect our own data for this work, we had to use other people's research. As already explained under Results and Analysis, there is a steady increase in radiation the higher the altitude gets due to the shielding effect of the atmosphere, until at a height of around 15km where the secondary cosmic radiation is at its most intense because of the formation of the particle cascades.

To fully understand if this increase in radiation poses a threat to people who spend longer amounts of time at higher altitudes, like pilots and flight attendants, we have to compare the average radiation exposure of a pilot with that of a "regular" person. The average dose of radiation of someone living in the United States is 3.1 millisieverts (mSv) per year. This number excludes radiation absorbed during medical procedures like x-ray imaging [33]. 1mSv is equivalent to three chest x-rays. In comparison, the average US American pilot or flight attendant absorbs 5mSv per year [34] . This means a pilot is generally exposed to 1.6 times as much radiation than someone on the ground. Even though pilots should be aware of this increased amount of radiation, it is not very dangerous. For comparison, the dose of a typical computerised tomography (CT) scan is 10mSv. This means that after one CT scan, someone can absorb as much radiation as a pilot in two years.

However, astronauts on space missions are exposed to radiation levels ranging from 50 to 2,000mSv [35]. For there to be the possibility of long-duration human spaceflight to different celestial bodies like the Moon and Mars, we have to come up with a good solution to this difficult problem.

Bibliography

[1] Christophe Luis. *Cosmic Radiation - Theoretical Physics and Detection Project*. Travil Personnel - Lycée Ermesinde, 2019.

[2] Stratoflights GbR. Wetterballon 1600, . URL https://www.stratoflights.com/shop/wetterballon/. Last accessed 02/05/2020.

[3] Stratoflights GbR. Konstruktion der sonde, . URL https://www.stratoflights.com/tutorial/konstruktion-der-sonde/. Last accessed 02/05/2020.

[4] Stratoflights GbR. Fallschirm 2500, . URL https://www.stratoflights.com/shop/fallschirm/. Last accessed 02/05/2020.

[5] Stratoflights GbR. Styroporsonde, . URL https://www.stratoflights.com/shop/styroporsonde/. Last accessed 02/05/2020.

[6] Stratoflights GbR. Spezialschnur, . URL https://www.stratoflights.com/shop/spezialschnur/. Last accessed 02/05/2020.

[7] Stratoflights GbR. Tips for the construction of your weather balloon probe - stratoflights, . URL https://www.youtube.com/watch?v=p27KLpFZEzA. Last accessed 02/05/2020.

[8] Stratoflights GbR. How to fill a weather balloon with helium., . URL https://www.youtube.com/watch?v=dNnj4z_q-TY. Last accessed 02/05/2020.

[9] Christophe Luis and Noah Stevens. *Analysis of the Blackett effect based on the detected cosmic muon flux with the AMD5 detector*. Entreprise Sciences - Lycée Ermesinde, 2019.

[10] Marco Arcani. *AMD5 an educational cosmic ray detector*. ResearchGate GmbH, 2016.

[11] USA National Weather Service. Layers of the atmosphere. URL https://www.weather.gov/jetstream/layers. Last accessed 02/05/2020.

[12] CUSF. Burst calculator app github. URL https://github.com/cuspaceflight/cusf-burst-calc. Last accessed 01/05/2020.

[13] BV-Westfalen. Berechnungen zum aufstieg des wetterballons. URL http://www.bv-westfalen.de/stratosphaerenballon/theorie/berechnungen-zum-aufstieg-des-wetterballons/. Last accessed 01/05/2020.

[14] Math24. Barometric formula. URL https://www.math24.net/barometric-formula/. Last accessed 01/05/2020.

[15] Wikipedia. Prevailing winds. URL https://en.wikipedia.org/wiki/Prevailing_winds. Last accessed 01/05/2020.

[16] Britannica. Climate - air pressure belts. URL https://www.britannica.com/place/Europe/Climate. Last accessed 01/05/2020.

[17] Nick Walker. Wind & air pressure. URL http://www.wxdude.com/singalongcompanion/windandairpressure/. Last accessed 01/05/2020.

[18] Stratoflights GbR. Gps tracker tk 102-2, . URL https://www.stratoflights.com/downloads/anleitung_gps_tracker.pdf. Last accessed 02/05/2020.

[19] World Health Organisation. Coronavirus disease (covid-19) pandemic, . URL https://www.who.int/emergencies/diseases/novel-coronavirus-2019. Last accessed 02/04/2020.

[20] World Health Organisation. Naming the coronavirus disease (covid-19) and the virus that causes it, . URL https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-(covid-2019)-and-the-virus-that-causes-it. Last accessed 02/04/2020.

[21] Luxembourg Ministry of Health. Coronavirus covid-19 informations et directives, . URL https://msan.gouvernement.lu/dam-assets/covid-19/02-coronavirus-affiches/en/AFF-Coronoa-A2-vertical-EN.jpg. Last accessed 02/04/2020.

[22] World Health Organisation. Key messages and actions for covid-19 prevention and control in schools, . URL https://www.who.int/docs/default-source/coronaviruse/key-messages-and-actions-for-covid-19-prevention-and-control-in-schools-march-2020.pdf. Last accessed 02/04/2020.

[23] World Health Organisation. Coronavirus, . URL https://www.who.int/health-topics/coronavirus#tab=tab_1. Last accessed 02/04/2020.

[24] Luxembourg Ministry of Health. Coronavirus: Covid-19, . URL https://msan.gouvernement.lu/en/dossiers/2020/corona-virus.html. Last accessed 02/04/2020.

[25] RTL Luxembourg. Fighting coronavirus: Luxembourg implements drastic measures, . URL https://today.rtl.lu/news/luxembourg/a/1482367.html. Last accessed 02/04/2020.

[26] RTL Luxembourg. Schoulen, crèchen, maisons relais bleiwe bis den 19. abrëll zou, . URL https://www.rtl.lu/news/national/a/1485798.html. Last accessed 02/04/2020.

[27] RTL Luxembourg. All d'schoule bleiwe bis de 4. mee zou, . URL https://www.rtl.lu/news/national/a/1494261.html. Last accessed 02/04/2020.

[28] RTL Luxembourg. Opsplécke vu klassen net nëmmen am lycée, mä och am fondamental, . URL https://www.rtl.lu/news/national/a/1502548.html. Last accessed 02/04/2020.

[29] Stratoflights GbR. Wetterballonstart, . URL https://www.stratoflights.com/tutorial/wetterballonstart/. Last accessed 02/05/2020.

[30] Stratoflights GbR. Stratoflights - präsentieren sie ihre marke der welt, . URL https://www.youtube.com/watch?v=R5XsiVWVPv0. Last accessed 02/04/2020.

[31] Astroparticelle.it. Missione stratosfera targata astroparticelle. URL https://www.astroparticelle.it/missione-stratosfera.asp. Last accessed 02/05/2020.

[32] Dr. Tony Phillips. What is the regener-pfotzer maximum? URL https://spaceweatherarchive.com/2018/06/07/what-is-the-regener-pfotzer-maximum/. Last accessed 02/05/2020.

[33] USA Centers for Disease Control and Prevention. Radiation thermometer. URL https://www.cdc.gov/nceh/radiation/emergencies/radiationthermometer.htm. Last accessed 02/05/2020.

[34] Skift. Super long-haul trips exspode flight crews and passengers to cosmic radiation. URL https://skift.com/2018/03/12/super-long-haul-trips-expose-flight-crews-and-passengers-to-cosmic-radiation/. Last accessed 02/05/2020.

[35] National Aeronautics and Space Administration. Why space radiation matters. URL https://www.nasa.gov/analogs/nsrl/why-space-radiation-matters. Last accessed 02/05/2020.

List of Figures

Acknowledgements

To conclude, we would like to thank all of people who helped us with the mission. Without them, this whole project would not have been possible. First of all, we are extremely grateful to Andrea Grana who provided us with huge amounts of help and guidance throughout the six months. We are also thankful for the hours of work that Max Reuter and Ken Vallender put in to design and build our muon detector in time for the originally planned launch date as well as for their technical support. We would also like to thank Anabela Ramada Dias and Ken Vallender (again) for their support and helpful ideas. Thank you also to Nicolas Aschman for supporting the SPIDER project, helping with the budget application and encouraging us. We wish to thank Marco Arcani for giving us free access to the original designs of the AMD5 detector and letting us use them for our own detector. Finally we also want to show gratitude to the school administration for financially supporting the project. Thank you to you all.

5 Appendix

5.1 Code

5.1.1 Data Logger Script

```
#include <SPI.h>
#include <SD.h>
#include <Wire.h>
#include "RTClib.h"

RTC_DS3231 rtc;

File myFile;

int analogPin = A0;
unsigned long miliTime;
float secTime;
int voltState;

void setup() {
  pinMode(LED_BUILTIN, OUTPUT);
  randomSeed(analogRead(1));
  if (!SD.begin(10)) {
    digitalWrite(LED_BUILTIN, HIGH);
    while (1);
  }
  if (!rtc.begin()) {
    digitalWrite(LED_BUILTIN, HIGH);
    while (1);
  }
}

void loop() {
  voltState = analogRead(analogPin);
  if (voltState > 50) {
    while (analogRead(analogPin) > 50) {
      ;
    }
    DateTime now = rtc.now();
    myFile = SD.open("muons.txt", FILE_WRITE);
    if (myFile) {
      myFile.print(now.year(), DEC);
      myFile.print('/');
      myFile.print(now.month(), DEC);
      myFile.print('/');
      myFile.print(now.day(), DEC);
      myFile.print(';');
      myFile.print(' ');
      myFile.print(now.hour(), DEC);
      myFile.print(':');
      myFile.print(now.minute(), DEC);
      myFile.print(':');
      myFile.print(now.second(), DEC);
      myFile.println("; muon measured;");
      myFile.close();
    } else {
      digitalWrite(LED_BUILTIN, HIGH);
    }
  }
}
```

Listing 1: Datalogger Code

5.2 E-Mails

5.2.1 School Administration

The following document is a series of emails sent to the school administration and is about us informing them about the progress of our project.

From: LUIS Christophe (LEM)
Sent: Wednesday, January 29, 2020 2:48:48 PM
To: Direction (LEM); Secretariat (LEM)
Subject: Autorisation - Lâcher d'un ballon méteorologique

Chers Madames, Messieurs,

Dans le cadre de l'entreprise LEM.SCIENCE, on réalise un projet dont le but est de lâcher un ballon météorologique qui atteindra une altitude de 36 km. La mission principale de ce ballon sera de mesurer la variation du flux des muons mesurés en corrélation avec l'altitude de l'appareil de mesure. En outre, ce ballon aura une mission annexe qui consiste à recueillir des données atmosphériques.

Pour faire autoriser ce vol, nous devons renvoyer le formulaire ci-joint à la DAC (Direction de l'Aviation Civile). En ce qui concerne la plus grande partie du document, nous sommes en mesure de le compléter sans complications. Cependant, pour la section D (Documents d'accompagnement), nous aurons besoin d'une autorisation écrite du propriétaire légal du terrain du Lycée Ermesinde Mersch permettant le lancement du ballon météo.

C'est la raison pour laquelle nous vous écrivons. Devrons-nous soumettre une demande formelle à la direction du LEM, ou même au ministère de l'éducation? Ou le propriétaire légal est-il une autre tierce partie?

Veuillez agréer, Madame, Monsieur, nos salutations distinguées,
LUIS Christophe - 3CLB
STEVENS Noah - 3CLB

From: LUIS Christophe (LEM)
Sent: Wednesday, February 5, 2020 4:19:04 PM
To: Direction (LEM); Secretariat (LEM)
Subject: Re: Autorisation - Lâcher d'un ballon méteorologique

Madame, Monsieur,

Comme nous en avons discuté jeudi (04/02/2020), nous avons rempli le formulaire pour la DAC et préparé une lettre d'autorisation du propriétaire légal du terrain, prête à être signée. Puisque nous n'avons aucune expérience concernant la forme des lettres écrites par la direction, elle pourrait nécessiter de légers ajustements.
Ces deux documents sont joints à la présente.

En ce qui concerne l'assurance de l'SNSFP, nous avons envoyé une demande ce matin.

Avec nos meilleurs salutations,
LUIS Christophe - 3CLB
STEVENS Noah - 3CLB

From: LUIS Christophe (LEM)
Sent: Friday, February 7, 2020 1:16 PM
To: Secretariat (LEM); Direction (LEM)
Subject: Autorisation - Lâcher d'un ballon météorologique

Mesdames, Messieurs,

Ci-joint les documents dont on a parlé; la lettre du propriétaire légal du terrain et notre communication avec le SNSFP.

Nos meilleurs salutations,
LUIS Christophe - 3CLB
STEVENS Noah - 3CLB

5.2.2 DAC

The following email correspondence is with the DAC concerning the authorisation of our high-altitude balloon flight.

From: LUIS Christophe (LEM)
Sent: Tuesday, November 12, 2019 12:46 PM
To: AV Civilair (DAC)
Subject: Weather Balloon Launch

Dear Mr/Mrs,

We are two students from the Lycée Ermesinde in Mersch in charge of a project to send a weather balloon into the stratosphere. A contact of ours informed us that it would be necessary to contact you.

We plan to launch the balloon sometime between the 9th of March and the 3rd of April to an altitude of between 35 and 40 kilometers. The main mission is to measure cosmic muon flux at high altitudes. Other smaller experiments will be on-board as well.

Due to fact that we don't have much experience in the legal sector, we would be pleased if you could provide us with instructions on how to file a formal request for a permit, allowing the launch of this weather balloon.

Furthermore, we are also not sure on whether or not we have to contact any other agencies in Europe? All information will be helpful.

Thank you very much in advance,
LUIS Christophe

STEVENS Noah
Lycée Ermesinde Mersch - 3e classique section B

From: AV Civilair (DAC)
Sent: Wednesday, November 13, 2019 9:52 AM
To: LUIS Christophe (LEM)
Cc: RAUS Marc (DAC)
Subject: Lâcher d'un ballon météorologique - 2019-93504

Messieurs Luis et Stevens,

J'ai l'honneur de vous envoyer en annexe le courrier réf. : 2019-93504 concernant le sujet émargé.

Veuillez agréer, Messieurs Luis et Stevens, l'expression de mes salutations distinguées,

Evelyne SCHONS-LAEMMEL
Secrétariat de Direction

LE GOUVERNEMENT DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de la Mobilité et des Travaux publics
Direction de l'Aviation Civile

4, rue Lou Hemmer . L-1748 Luxembourg
www.gouvernement.lu . www.luxembourg.lu
www.dac.lu

Save a tree...please don't print this e-mail unless you really need to

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From: STEVENS Noah (LEM)
Sent: Tuesday, January 14, 2020 1:59 PM
To: AV Civilair (DAC)
Subject: Lâchage d'un ballon météo

Madame, Monsieur,

En ce qui concerne le lâchage d'un ballon météo que nous voulons effectuer en avril, nous voulons savoir si nous devons demander une autorisation pour notre vol autre que la Demande d'autorisation de lâcher de ballons (https://dac.public.lu/formulaires/navigation-aerienne/ADM220-1-Demande-d_autorisation-de-lacher-de-ballons.pdf) que nous avons déjà. Notre ballon météo volera très probablement dans l'espace aérien allemand à une altitude maximale de 40 km, bien qu'il soit possible que le ballon vole dans l'espace aérien belge, l'espace aérien néerlandais et l'espace aérien français.

Je vous prie d'agréer, Madame, Monsieur, l'expression de mes salutations distinguées,
Noah Stevens

Lycée Ermesinde Mersch (LEM)

From: CZERWONKA Tonia (DAC)
Sent: Thursday, January 16, 2020 1:43 PM
To: STEVENS Noah (LEM)
Cc: RAUS Marc (DAC); KEUP Luc (DAC)
Subject: Lâcher d'un ballon météorologique

Monsieur Stevens,

J'ai l'honneur de vous envoyer en annexe le courrier ref.2020-95036 concernant le sujet émargé.

Veuillez agréer, Monsieur Stevens, l'expression de mes considérations respectueuses.

Tonia CZERWONKA
Agent administratif - Département espace aérien, aérodromes et ATM/ANS

LE GOUVERNEMENT DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de la Mobilité et des Travaux publics
Direction de l'Aviation Civile

4, rue Lou Hemmer . L-1748 Luxembourg
www.mmtp.lu . www.dac.lu

From: STEVENS Noah (LEM)
Sent: Friday, April 3, 2020 9:22 AM
To: AV Civilair (DAC)
Subject: Informations pour lâcher un ballon météorologie

Madame/Monsieur,

Nous sommes deux élèves du "Lycée Ermesinde Mersch" et on est en train de réaliser un projet dont le but est de lâcher un ballon météorologique. Nous avons déjà l'autorisation nécessaire pour cela (référence : 2020-96586). Nous savons qu'il est peu probable que le lancement ait lieu en raison de la pandémie de coronavirus, mais nous n'avons toujours pas reçu d'instructions sur les procédures à suivre le jour du lancement. Même si le lancement n'aura pas lieu, nous en avons besoin pour rédiger un rapport sur notre projet pour l'école. Pourriez vous s'il vous plaît envoyer ces informations à mon adresse électronique?

Merci d'avance,

STEVENS Noah - 3e classique section B
LUIS Christophe - 3e classique section B

From: OSSANT Régis (DAC)

Sent: Friday, April 10, 2020 9:32 AM
To: ASCHMAN Nicolas
Cc: STEVENS Noah
Subject: Votre demande de renseignements complémentaires concernant le lâcher d'un ballon-sonde

Bonjour,

Conformément au Règlement d'exécution (UE) No 923/2012 de la Commission européenne établissant les règles de l'air communes et des dispositions opérationnelles relatives aux services et procédures de navigation aérienne (https://eur-lex.europa.eu/legal-content/FR/TXT/PDF/?uri=CELEX:32012R0923&from=FR), Annexe 2, point 2.4, "Un ballon libre non habité sera exploité conformément aux conditions spécifiées par l'État d'immatriculation et l'État ou les États qui seront en principe survolés."

Etant donné qu'il est plus que probable que le ballon dérivera hors de l'espace aérien luxembourgeois, il est nécessaire d'assurer une certaine coordination avec les pays voisins.

A ce titre, il vous faut donc obtenir, si ce n'est déjà le cas, une autorisation de la part de la France, de la Belgique et de l'Allemagne.

Ces autorisations peuvent être demandées:

- Pour la Belgique : https://mobilit.belgium.be/fr/Resources/form/aerien/form_luchtruim_activ_stratosfeerballon
- Pour l'Allemagne : https://www.dfs.de/dfs_homepage/de/Services/Luftsport%20&%20Freizeit/Kontakt/ (Aufstieg eines unbemannten Freiballons ("Wetterballon") der Klasse leicht, mittelschwer oder schwer)
- Pour la France : formulaire https://www.formulaires.service-public.fr/gf/cerfa_15915.do à renvoyer à l'adresse dsac-ne-espaces-aeriens-bf@aviation-civile.gouv.fr (l'adresse dans le formulaire pour la DSAC Nord-Est est erronée)

Une fois ces autorisations obtenues, que je vous serai reconnaissant de bien vouloir nous faire parvenir, nous pourrons alors décider des modalités coordonnées de lâcher.

Meilleures salutations,

Régis Ossant
Direction de l'aviation civile

5.2.3 SNSFP

The following email correspondence is with the SNSFP concerning how to get insurance for SPIDER.

From: LUIS Christophe (LEM)

Sent: Wednesday, February 5, 2020 2:00 PM
To: SNSFP (SNSFP)
Subject: Demande d'assurance - Ballon météorologique

Bonjour Madame, Monsieur,

Nous sommes deux élèves du 'Lycée Ermesinde Mersch', et on est en train de réaliser un projet dont le but est de lâcher un ballon météorologique qui atteindra une altitude de 36 km. La mission principale de ce ballon sera de mesurer la variation du flux des muons mesurés en corrélation avec l'altitude de l'appareil de mesure. En outre, ce ballon aura une mission annexe qui consiste à recueillir des données atmosphériques. Le dispositif consiste en un ballon de 4,4 mêt d'une sonde en styropore contenant l'équipement avec parachute.

Nous avons été informés par M. Goedert Tom qu'il y a cinq ans, lorsqu'il a réalisé au Lycée Ermesinde un projet similaire avec ses élèves, il a pu assurer le ballon météo auprès de votre service.

C'est la raison pour laquelle nous vous écrivions. Dans quelle mesure pouvons-nous assurer ce ballon météo à l'SNSFP? Quelle est la procédure à suivre pour déposer une demande officielle d'assurance de ce type?

Veuillez agréer, Madame, Monsieur, nos salutations distinguées,
LUIS Christophe - 3e classique section B
STEVENS Noah - 3e classique section B

From: SNSFP (SNSFP)
Sent: Wednesday, February 5, 2020 5:12 PM
To: LUIS Christophe (LEM)
Cc: SNSFP (SNSFP)
Subject: RE: Demande d'assurance - Ballon météorologique

Bonjour,

Comme il s'agit d'un projet scolaire autorisé par votre directeur de lycée, si j'ai bien compris, la responsabilité civile de l'Etat légale est engagée, le cas échéant que votre projet cause des dégâts à des tiers.
Il ne s'agit pas d'un contrat d'assurance comme vous le connaissez généralement, mais d'une obligation légale de l'Etat.
SNSFP gère les dossiers de déclaration de dégâts.
Le matériel-sonde est mis à disposition par le lycée ?

Meilleures salutations

Camille Strottner
inspecteur général de la sécurité dans la fonction publique

LE GOUVERNEMENT DU GRAND-DUCHÉ DE LUXEMBOURG
Service national de la sécurité dans la fonction publique
www.snsfp.public.lu

Please consider the environment before printing this email.

5.2.4 ANA

The following email correspondence is with our contact from the ANA about information concerning high-altitude balloon flight regulations.

From: STEVENS Noah (LEM)
Sent: Friday, October 18, 2019 12:07 PM
To: **** Steve (ANA)
Subject: Fro iwert de Loftraum

Moien Steve,

Ech wees net obst du dech nach drun erennerst, mee ech war 2017 am Fréijoer fir eng Woch bei der ANA am Stage. Mir haten eis am Radarraum kennegeléiert woust du mir deng Emailsadress ginn hues, falls ich eng Fro hätt iwert de Loftraum. Dat ass lo genau de Fall.

Am Kader vun engem Schoulprojet wollt ech matt enger Grupp von anere Schüler ee Wiederballon op eng Héicht vun ongeféier 40km an d'Stratosphere schecken. Wat fir eng Regulatiounen ginn et dofir an wen müssen mir kontaktéieren?

Matt beschten Gréiß,
Noah Stevens

From: **** Steve (ANA)
Sent: Friday, October 18, 2019 1:25 PM
To: STEVENS Noah (LEM)
Subject: RE: Fro iwert de Loftraum

Moien Noah,

Fir en Wiederballon sou héich an d'Loft ze schécken brauchs de eng Authorisatioun vun der DAC (Direction de l'Aviation Civile).

Am beschten schreiws de hinnen en Email iwwert daat waat der wëllt maachen, sie froen iech dann all Detailer déi se brauchen.
Wann sie dann alles hun kritt der normalerweis eng Authorisatioun an daer genau Instruktiounen dranstin.

Hei as d'Emailadress vun der DAC: info@dac.public.lu¡mail**To:**info@dac.public.lu¿

Wanns de nach weider froen hues oder eppes onkloer as dann mell dech roueg nach eng Kéier.

Bis dann,

Steve *.

Steve ****
Deputy Safety Officer
Service ATC/APP

LE GOUVERNEMENT DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de la Mobilité et des Travaux publics
Administration de la navigation aérienne

** ***** ** ****** * ****** ******
www.ana.public.lu

From: STEVENS Noah (LEM)
Sent: Monday, October 21, 2019 08:24
To: **** Steve (ANA)
Subject: RE: Fro iwert de Loftraum

Moien Steve,

Merci villmols fir d'séier Antwert. Dat helleft eis schon gudd virun.

Matt beschten Gréiß,
Noah Stevens

From: STEVENS Noah (LEM)
Sent: Tuesday, January 7, 2020 2:12 PM
To: **** Steve (ANA)
Subject: RE: Fro iwert de Loftraum

Moien Steve,

Ech schreiwen Dir well ech nach weider Froen iwwert d'Authorisatioun fir eisen Wiederballon fluch. Mir hunn schon d'DAC kontaktéiert an kruten vun hinen den Formuläire gescheckt. Do get et kee Problem.

Eise Wiederballon wärt awer mat gréißter Wahrscheinlechkeet an den däitschen Loftraum fléien. Außerdem, wann ech mech nach gudd drun erenneren kann, huest Du mer erzielt, dass ab enger bestemmter Altitude get den Loftraum vun EUROCONTROL iwwerwaach (eise Wiederballon flit bis ob ongeféier 35km Héischt). Wat mussen mir dofir maachen?

Villmols merci,
Noah Stevens

From: **** Steve (ANA)

Sent: Thursday, January 30, 2020 10:39 AM
To: STEVENS Noah (LEM)
Subject: RE: Fro iwert de Loftraum

Salut Noah,

Sorry fir déi spéit Äntwert... Hutt dir schon d'Authorisatioun kritt?
Ech wees dass soss mol dran stoung dass mir als éischt musse kontaktéiert gin an mir dann déi aaner Unitéiten froen fir d'Erlaabnis.

Steve ****
Deputy Safety Officer
Service ATC/APP

LE GOUVERNEMENT DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de la Mobilité et des Travaux publics
Administration de la navigation aérienne

** ***** ** ****** * ****** ******
www.ana.public.lu
Administration de la navigation aérienne // Le gouvernement luxembourgeois
Administration de la navigation aérienne
www.ana.public.lu

From: STEVENS Noah (LEM)
Sent: Tuesday, February 4, 2020 2:25 PM
To: **** Steve (ANA)
Subject: RE: Fro iwert de Loftraum

Moien Steve,

Kee Problem, ech sinn einfach frou dass ech eng Persoun kennen déi mer an sou Situatiounen hellefen kann.

Mir préparéieren grad eis Demande an wärten se och demnächst eranschecken. Un sech war d'Fro just waat mir nach ufroen missten, well mir waren eis net secher ob mir nach déi bei den aneren Unitéiten ufroen missten. Lo ass awer alles vill méi kloer.

Villmols merci,
Noah Stevens

From: STEVENS Noah (LEM)
Sent: Tuesday, March 31, 2020 12:17 PM
To: **** Steve (ANA)
Subject: RE: Fro iwwert de Loftraum

Moien Steve,

Mir hunn fir de Wiederballon eng net Demande gemaach. Ob dat eppes gett wees ech nett, mee ech muss eng Schoularbescht iwwert de Projet schreiwen. Dofir froen ech rem no obst du bei der DAC fir d'Instruktiounen, déi eis soen wat mir den Daag selwer maachen mussen (z.B.: zu Bréissel uruffen), nofroen kannst.

D'Nummer (Référence) vun eiser Authorisatioun ass: "2020-96586".

Villmols merci an matt beschten Gréiß,
Noah Stevens

5.3 Documents

5.3.1 Letter and Form DAC

The following documents are two letters and a form we received from the DAC. Upon request of the authorisation, we were sent the first letter and the form. After filling in the form and sending it back, we received the second letter.

LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de la Mobilité
et des Travaux publics

Direction de l'aviation civile

Luxembourg, le 13 NOV. 2019

Référence : 2019 – 93504
Dossier suivi par : M. Marc RAUS
Tél : (+352) 247-74946
Courriel : marc.raus@av.etat.lu

Lycée Ermesinde Mersch
Monsieur Christophe LUIS et
Monsieur Noah STEVENS

Par courriel : *luich893@school.lu*

V/Réf : *Votre courriel en date du 12 novembre 2019*
Objet : *Lâcher d'un ballon météorologique*
P.J. : *Formulaire ADM221 - 2*

Messieurs,

Suite à votre courriel sous rubrique, la Direction de l'Aviation Civile du Grand – Duché de Luxembourg (DAC) a l'honneur de vous informer que le Règlement ministériel du 1er mars 1988 déterminant les conditions d'utilisation et d'exploitation des aérostats et des cerfs-volants couvre le volet des lâchers de ballons – sonde ou ballons météorologiques dans l'espace aérien luxembourgeois.

Veuillez introduire votre demande d'autorisation d'un ballon-sonde ou ballon météorologique, avec l'aide du formulaire ADM221 - 2 joint à la présente, avec prière de porter une attention particulière aux points C. et D. du formulaire précité.

Veuillez agréer, Messieurs, l'expression de mes considérations respectueuses.

DIRECTION DE L'AVIATION CIVILE

Pierre JAEGER
Directeur de l'Aviation Civile

4, rue Lou Hemmer
L-1748 Luxembourg

Tél (+352) 247 74900
Fax (+352) 46 77 90

info@dac.public.lu

www.dac.public.lu
www.mt.public.lu

DAC

Direction de l'Aviation Civile
Grand-Duché de Luxembourg

DEMANDE D'AUTORISATION DE BALLON-SONDE
AUFSTIEGSGENEHMIGUNG FÜR VERSUCHSBALLONS

A. Informations générales / *Allgemeine Informationen*

Occasion :
Gelegenheit : Recherche scientifique en Astrophysique

Date et heure:
Datum und Uhrzeit: 25/03/2020 13:00

Coordonnées WGS84
WGS84 Koordinaten
49°45'25.1"N
06°06'41.9"E

Adresse ou n° parcelle cadastrale :
Ort oder Flurstück Nr.:
45, rue de la Gare
L-7590 Mersch

Description et poids:
Beschreibung und Gewicht : vol stratosphérique
Poids : 3,2 kg (1,6 kg ballon + 1,6 kg sonde)
Diamètre : 2 m
Vitesse d'ascension : 5 à 7 $\frac{m}{s}$
Parachute : oui

Altitude maximale (le cas échéant):
Maximale Flughöhe (ggf.) : 40 000 m

Ballon captif : Oui/Non
Fesselballon : Ja/Nein Non

B. Contacts / *Kontaktangaben*

Nom /prénom de la personne de contact :
Name/Vorname der Kontaktperson : ASCHMAN NICOLAS

Adresse de la personne de contact:
Adresse der Kontaktperson :
LYCÉE ERMESINDE
45, RUE DE LA GARE
L-7590 MERSCH

N° Téléphone
Tel. Nr. : 671 500432

E-mail : NICOLAS.ASCHMAN@LEM.LU

C. Généralités / *Allgemeinheiten*

La présente demande d'autorisation est à introduire au plus tard 3 semaines au préalable à la date de l'évènement / *Vorliegender Antrag muss mindestens 3 Wochen vor dem Termin eingereicht werden*

Toute demande introduite passé ce délai pourra ne pas être autorisée / *Anträge bei denen der Antrag verspätet eingereicht wurde, riskieren abgelehnt zu werden*

Le déroulement de l'évènement relève entièrement de la responsabilité du demandeur / *Der Ablauf der Veranstaltung obliegt der Verantwortung des Antragstellers*

D. Documents d'accompagnement / *Begleitdokumente*

- Autorisation écrite du (des) propriétaire(s) du terrain / *Genehmigung des Grundstückeigners*

E. Le soussigné certifie / *Der Unterzeichnete bescheinigt*

que tous les renseignements fournis dans le présent formulaire sont corrects et complets / *dass die in diesem Formblatt gemachten Angaben vollständig und wahrheitsgetreu sind*

Fait à / ***Erstellt*** MERSCH, **le** / ***am*** 7/2/2020

Nom du signataire :
Name : ASCHMAN

Signature
Unterschrift

DAC-ADM221-2 – Demande d'autorisation de ballon-sonde – 03/2017

LE GOUVERNEMENT
DU GRAND-DUCHÉ DE LUXEMBOURG
Ministère de la Mobilité
et des Travaux publics

Direction de l'aviation civile

Luxembourg, le 18 MARS 2020

Référence : 2020 – 96586
Dossier suivi par : M. Marc RAUS
Tél : (+352) 247-74946
Courriel : marc.raus@av.etat.lu

LYCÉE ERMESINDE
Monsieur Jeannot MEDINGER
Directeur
45, rue de la Gare

L – 7590 MERSCH

Par courriel : direction@lem.lu
& nicolas.aschman@lem.lu

V/Réf : *Votre courriel en date du 13 mars 2020*
Objet : *Autorisation pour un lâcher de ballon – sonde léger*

Monsieur Medinger,

J'ai l'honneur de me référer à votre courriel sous rubrique relatif à un lâcher de ballon - sonde léger prévu pour le 29 avril 2020 à 13.00 heures (LT) à Mersch (49° 45' 25.1" N et 06° 06' 41.9" E).

Par la présente la Direction de l'Aviation Civile du Grand – Duché de Luxembourg (DAC) ne voit pas d'objection à l'autorisation de ce lâcher de ballon – sonde léger ne dépassant pas le poids et les conditions de lancement prévues dans votre demande initiale.

Veuillez agréer, Monsieur Medinger, l'expression de mes considérations respectueuses.

DIRECTION DE L'AVIATION CIVILE

Pierre JAEGER
Directeur de l'Aviation Civile

Copies : Monsieur le Directeur de l'Administration de la Navigation aérienne
Monsieur le Directeur général de la Police Grand-Ducale
Monsieur le Bourgmestre de Mersch
LAA

4, rue Lou Hemmer
L-1748 Luxembourg
Tél (+352) 247 74900
Fax (+352) 46 77 90
info@dac.public.lu
www.dac.public.lu
www.mt.public.lu

5.3.2 Budget Justification Letter

We wrote the following letter in order to request equipment financing for SPIDER.

Mersch, le 20 novembre 2019

Madame, Monsieur,

Pendant l'année scolaire précédente, l'activité 'Astronomie' de l'entreprise LEM.SCIENCE, a eu un grand succès avec les recherches sur le flux des muons cosmiques (particules élémentaires provenant de l'espace) en relation avec des paramètres climatiques. Ce projet a été, entre autre, présenté dans trois différents lycées et les élèves qui ont rendu ceci possible ont même étés interviewés pour l' « Asteroid Day » - Livestream qui a été diffusé dans le monde entier. Faisant partie du groupe d'élèves qui ont rendu cela possible et basant sur le succès de nos recherches, nous espérons réaliser un projet encore plus audacieux seulement possible avec votre aide financière.

Ce projet, géré par nous, Christophe Luis et Noah Stevens, sera réalisé dans le cadre de notre mémoire collectif. Le but de ce projet est de lâcher un ballon météorologique qui atteindra une altitude de 36 km. La mission principale de ce ballon sera de mesurer la variation du flux des muons mesurés en corrélation avec l'altitude de l'appareil de mesure. En outre, ce ballon aura deux missions annexes. L'une sera de recueillir des données atmosphériques et l'autre sera d'effectuer des recherches sur un matériel particulier permettant de visualiser chaque impact de quelques espèces de particules élémentaires.

Ce ballon nous aidera pour ce projet, mais il nous permettra également de filmer des séquences magnifiques de haute définition en premier plan de notre planète et même aussi du site de notre école.

Ci-joint, vous trouverez une liste de l'équipement nécessaire pour le ballon météo. Le prix total de l'équipement pour réaliser ce projet s'établit à 1016,74 €.

En attente d'une réponse de votre part, je vous prie de croire, Madame, Monsieur, à l'expression de nos salutations distinguées,

LUIS Christophe,
STEVENS Noah

		Price	
Datalogger		**268,9**	**€**
	self	249	€
	Datalogger Battery (9V)	9,95	€
	SD Card	9,95	€
2x SpaceCam "Apeman"		**249,84**	**€**
1x	self	89,99	€
1x	MicroSD Card 32GB	9,95	€
1x	MicroUSB Battery Pack + Batteries	24,98	€
Weather Ballon Kit		**478**	**€**
	Balloon 1600		
	Parachute 2000		
	Polystyrene Probe		
	Special Cord		
	Gloves!!!		
	Micro/Mini USB Batterypack + Batteries		
	Primary GPS Tracker TK 102-2	99	€
	BackUp GPS Tracker TK 102-2	89	€
2x SIM Card for GPS Tracker (Post TIPTOP)		**20**	**€**
1x	self	0	€
1x	Charge	10	€
Total		1016,74	€