HASP Student Payload Application for 2018

Payload Title: **STRAINS - STratospheric RAdiation INstrumentS**	
Institution:Sint-Pieterscollege Jette, Brussels, BELGIUM (High School)	
Submit Date: February 15th, 2017	
Payload Class (Enter SMALL, or LARGE): **SMALL**	

Project Abstract:

The intensity of gamma rays in Earth's atmosphere is strongly dependent on altitude. While intensity at sea level is low and the presence of gamma photons there predominantly due to radioactive decay of crustal isotopes, at altitude different other processes are at play. 'Atmospheric' gammas are generated when heavy ions or solar protons encounter atmospheric atoms and/or molecules. Such gammas are most numerous around 15-20km, which is sometimes referred to in the literature as the Pfotzer maximum. Rising above this maximum an ever increasing fraction of the gamma photons observed have non-terrestrial, often deep-space (and violent) origins: accretion of interstellar material on black holes, supernova explosions, tidal disruption events, etc. STRAINS intends to investigate the amount, direction, energy and (if possible) origin of gamma photons in the upper atmosphere.

Team Name: STRAINS		Team or Project Website: Under construction
	Student Leader Contact Information:	Faculty Advisor Contact Information:
Name:	Vincent Van den Moortel	Erik de Schrijver
Department:	Physical Sciences/Science-Math	Physical Sciences Department
Mailing Address:	Sint-Pieterscollege Jette Leon Theodorstraat 167	Sint-Pieterscollege Jette Leon Theodorstraat 167
City, State, Zip code:	1090, Brussels, BELGIUM	1090, Brussels, BELGIUM
e-mail:	vincent.vandenmoortel@sint-pieterscollege.be	eds@sint-pieterscollege.be
Office Telephone:	+32 2 426 85 15	+32 2 426 85 15
Mobile Telephone:		+32 486 78 70 63

Table of contents

I. Payload description

1. Scientific Instruments

The STRAINS payload consists primarily of two instruments:

a.) A 3D Geiger-Müller Counter consisting of 3 mutually perpendicular Geiger tubes counting gammas in 3 (mutually perpendicular) planes.

b.) A Gamma Spectrometer to measure the energy distribution of the gamma photons and determine – if possible - the altitude dependence of said distribution.

A number of smaller sensors are added to provide supporting/additional information:

- A Temperature sensor (for T-compensation of measurements if tests reveal the need)

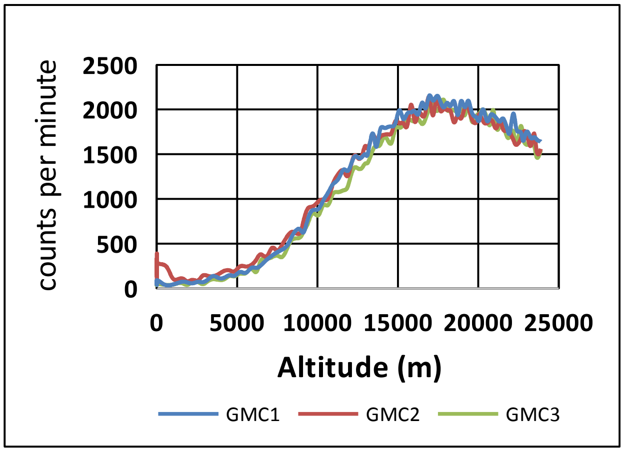
- A magnetometer to determine if the number of gamma photons detected in each of the 3 Geiger tubes is dependent on the equipments' orientation with respect to Earth's magnetic field and/or the sun's position in the sky.

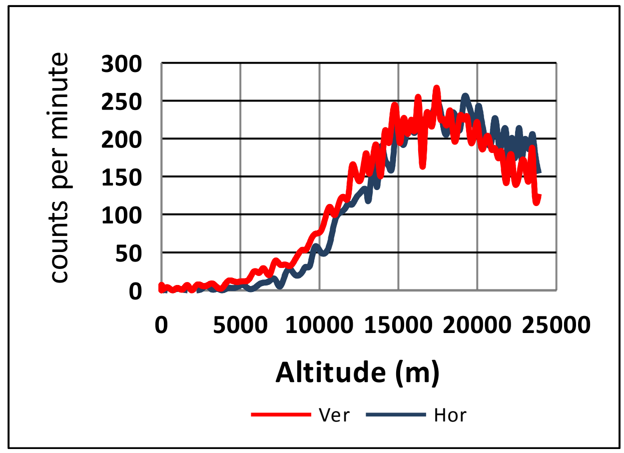
- A gps system to determine altitude, position and heading of the payload as a function of time (heading = backup for the magnetometer data)

- A Pressure sensor to determine altitude as a function of time (pressure derived altitude = backup for the gps-altitude)

1.1. The 3D Geiger Counter

A ***2nd generation 3D Geiger Counter*** is proposed to determine the ratio of vertical to horizontal radiation intensity as a function of altitude. On an Asgard sounding balloon flight in 2016, a 1st generation instrument found indications for a slight preponderance of vertically travelling gammas over horizontally moving ones below the Pfotzer maximum [1]. Further indications for such an anisotropy came from University of Antwerp's 2016-2017 Bexus team (BEXUS = Balloon Experiments for University Students = an ESA-program), but in both cases coincidence circuits were used on Geiger counters with their tubes stacked in parallel, which improves spatial resolution, but at the detriment of the S/N ratio. Both teams reached similar conclusions, but the difference between horizontal and vertical readings (right figure below) barely exceeds the statistical error margin.





Figs. 1 & 2: Results obtained by the 2015-2016-2017 student teams. The data were collected during the Asgard-VI balloon mission in 2016, and presented at the 23rd ESA Symposium on European Rocket and Balloon Programmes and Related Research, June 2017, Visby, Sweden.

The new design is based on the Geiger counter tube's low sensitivity along its axis and high sensitivity to particles coming in perpendicular to the axis. This limits angular resolution, but boosts the signal by an order of magnitude, i.e. well above the statistical error margin. Furthermore, above the Pfotzer maximum *solar* gammas are expected to dominate, and hence the angular distribution is expected to be time-dependent (as the sun moves across the sky during the day). The 3D Geiger counter will address these questions.

Fig. 3: The 3D Geiger counter is an assembly of 3 modules from RHElectronics:
http://www.rhelectronics.net/store/radiation-detector-geiger-counter-diy-kit-second-edition.html

1.1.1. Geometrical factor of the Geiger Tube

From: Private communication with doctoral candidate Wouter Gins, M. Sc, researcher at the Instituut voor Kern- en Stralingsfysica (Institute for Nuclear and Radiation Physics), Katholieke Universiteit Leuven, January 2017.

The Geiger counter's ability to detect a gamma photon is contingent on that photon interacting with the wall of the Geiger tube. A secondary electron is produced by that interaction. If this interaction takes place sufficiently close to the inner wall, the secondary electron can reach the fill gas and the Geiger counter will detect it. The efficiency for counting these gamma-rays thus depends on two factors: the probability that the incident gamma will interact with the wall and thus produce a secondary electron, and the probability that the secondary electron reaches the fill gas of the tube before it reaches the end of its track. Only the innermost layer of the tube wall can produce the secondary electrons required to detect the gamma photons, as shown in Figure 4.

A geiger tube has nonisotropic sensitivity, and so will give readings dependent on its orientation, even in a homogeneous flux of gamma radiation. There are two main reasons for this. First, the geiger counter's efficiency at detecting gammas is dependent on the gamma flux across the tube, which is – to first order approximation – proportional to $\cos\alpha$ (where α is the angle of incidence relative to the plane perpendicular to the Geiger tube's axis). Second, the tube's wall thickness impedes the secondary electrons' capability of reaching the fill gas and triggering a pulse. As the angle of incidence increases, the gammas are interacting with wall material at – on average – lower depths, and the thickness of the material the secondary electron has to move through to reach the fill gas increases. The thickness of wall material remaining to be crossed for the secondary electron is proportional to $1-\cos\alpha$, but the likelihood for the electrons to get through will be exponentially dependent on this thickness.

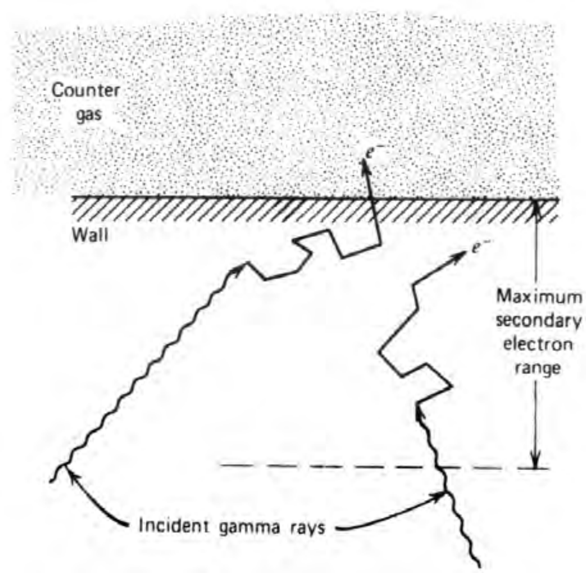


Fig. 4: The principal mechanism by which gas-filled counters are sensitive to gamma rays involves creation of secondary electrons in the counter wall. Only those interactions that occur within an electron range of the wall surface can result in a pulse.[2]

So, for gammas of equal energy, the angular dependence of the Geiger tube's sensitivity is at best cosα, assuming the characteristic track of the electrons in the tube's wall material far exceeds the wall's thickness. That will not be the case. The tube's material is stainless steel [3]. From [4] it can be seen that for electrons of 100keV in stainless steel (composition from [5]), the stopping power is between 1 and 2 MeVcm²/g.

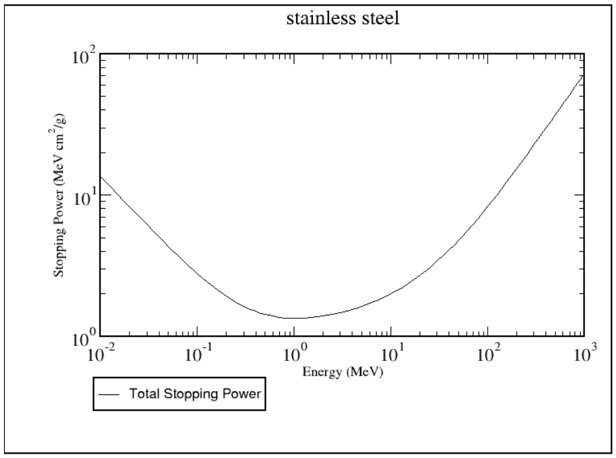


Fig. 5: Stopping power vs electron energy in stainless steel [4]

This stopping power means that, for a steel density of 8,00 g/cm³ [4], the characteristic track will be of the order of 0,06 – 0,13mm, much less than the wall thickness (estimated as >0,3mm from [3]) .

An even more accurate estimate of the distance an electron can cover can be obtained using the Continuous Slowing Down Approximation (CSDA). For stainless steel we obtain from [4] a range of about 2.10^{-2} g/cm². At a density of 8g/cm³ the penetration depth for electrons would be 25.10^{-3} mm.

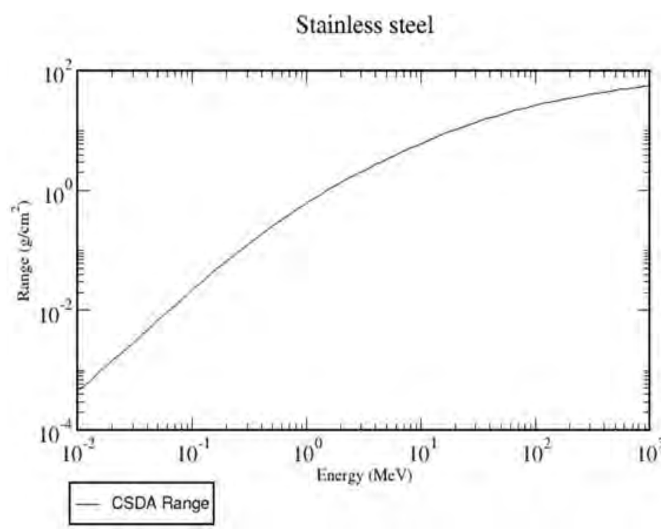


Fig. 6: CDSA electron range vs electron energy in stainless steel [4]

So the exponential function will be far from negligible, leading to an angular distribution of the sensitivity that is markedly skewed towards detecting gammas coming in more or less perpendicularly to the Geiger tube.

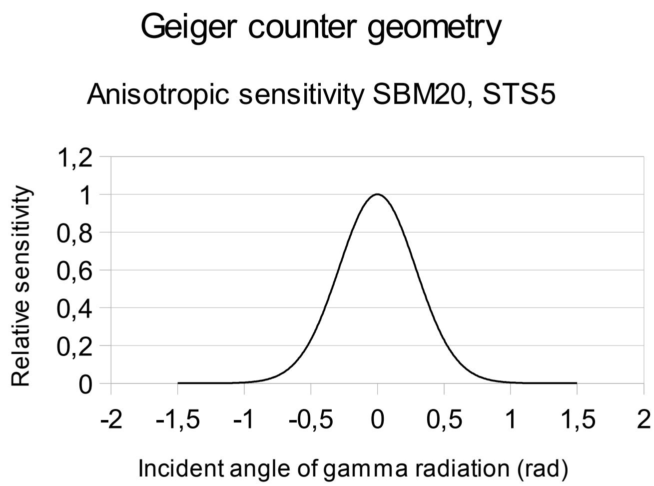
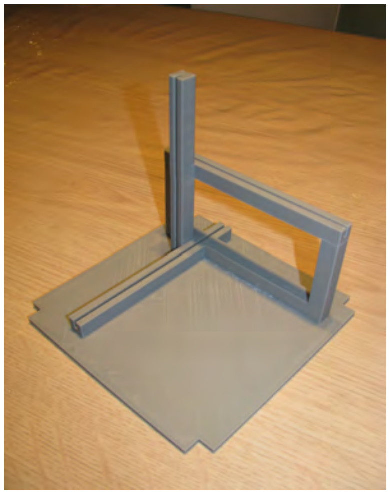
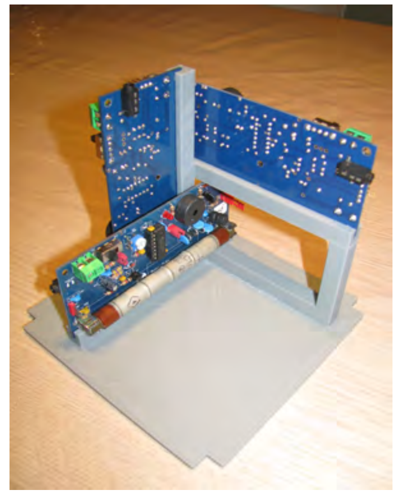


Fig. 7: Geiger Tube relative sensitivity vs angle of incident gamma radiation

1.1.2. Development status

For the 3D Geiger counter, the challenges are well within reach, as the setup builds on past experience (though with a new generation of students). All hard- and software needed is at hand, the students have designed the 3D printed frame securing the 3 Geiger counters in their mutually perpendicular arrangement. They have designed the circuit carrying all necessary components. Etching, drilling and soldering can start as of today (February 12th). The students will have to integrate the code for Arduino to count gammas, keep track of time and store the data on a µSD card.

Figs. 8&9: The redesigned support structure and base plate, now measuring 138 x 138mm, made-to-fit in the aluminum beam structure according to the HASP "Small Payloads" specifications.

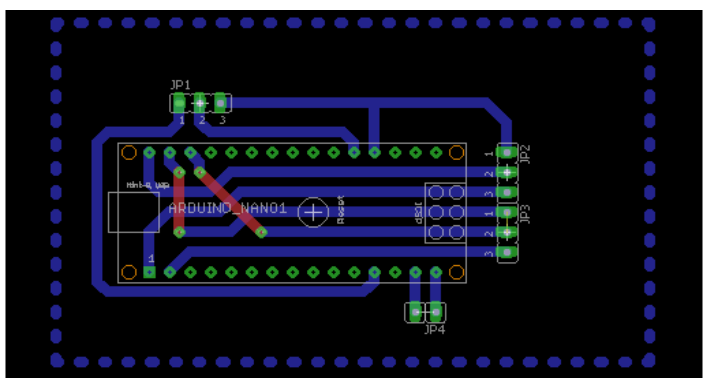
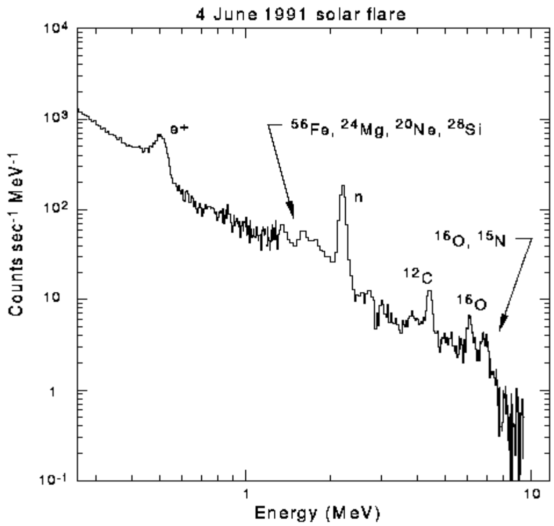


Fig. 10: Single-tube Geiger counter circuit for Arduino Nano, with power connector (top) and µSD card module (right). The 3D Geiger Counter has 3 of these circuits.

1.2. The Gamma Spectrometer



As a 2nd instrument a ***gamma spectrometer*** is proposed to determine the energy distribution of the gamma photons observed during the float phase. As this instrument is a brand new project and its performance as yet unknown, it is unclear at this time whether the instrument will be sensitive enough to determine the gamma spectrum during the ascent and descent phases of the flight with sufficient temporal (and therefore spatial) resolution to allow significant insights to be gained in the processes of atmospheric gamma photon generation.

Fig.11: Gamma spectrum during a solar flare. While spectacular gamma events such as gamma ray bursts or solar flares cannot be predicted, it is hoped the instrument will be able to record a 'quiet conditions' gamma spectrum. [6,7,8]

As HASP is a long-duration balloon flight (LDB) long exposure times at altitude are available, as opposed to Asgard sounding balloons which rise to burst altitude and bring their payload down to the ground within a few hours (having spent less than an hour above 25km). The HASP-LDB would allow to investigate the stability of the radiation level at float altitude over the course of many hours. Also, the altitude of the Pfotzer maximum can be determined at two very different times in a single day, (once on ascent, once on descent). Furthermore, the ratio of horizontally to vertically moving gammas – as determined by the 3D Geiger Counter - may vary over the course of the float phase, which could yield meaningful insights when combined with the results from the gamma spectrometer.

1.2.1. Instrument

Instrument parts:

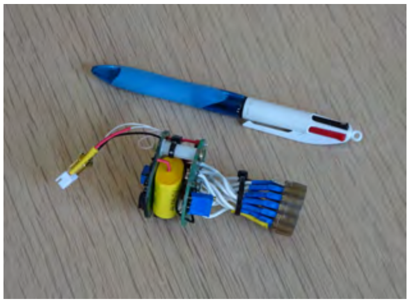


Fig. 12:
Signal processing electronics

Fig. 13:
Hamamatsu Photomultiplier

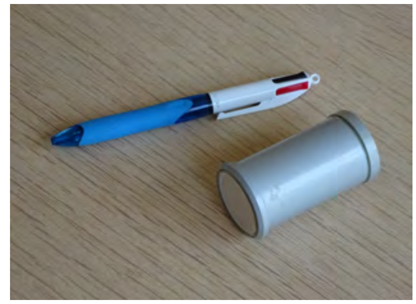


Fig. 14:
Th-doped NaI scintillation crystal

The gamma photons this instrument is to detect are captured in a Thallium(Iodide)-doped NaI (Sodium Iodide) crystal, a material well suited for spectroscopic work [2]. For HASP, a large crystal was considered desirable as the instrument's sensitivity was (and is) unknown, and a larger detector volume yields a larger signal at equal radiation intensities. As a secondary goal of the instrument is to investigate the gamma spectrum during the ascent and descent phases, every effort is to be made to increase sensitivity (within the mass constraints of the HASP “Small Payloads” format).

The photons generated when a gamma photon interacts with crystal material is converted to a sizeable electric signal by a photomultiplier tube (Hamamatsu type R6095). That signal is then to be processed.

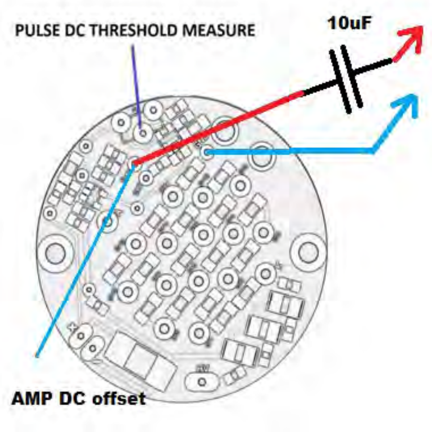
In order to keep development work within the capabilities of 12th grade students, the choice was made to purchase RH Electronics' Gamma Scintillator Driver Module wired with Socket for R6094 R6095 PMT [9]. Unfortunately, in it's default configuration this module is unfit for spectroscopic work. A small modification (see below) to the setup can reconfigure the module though, and it is in this modified configuration we propose to use the module.

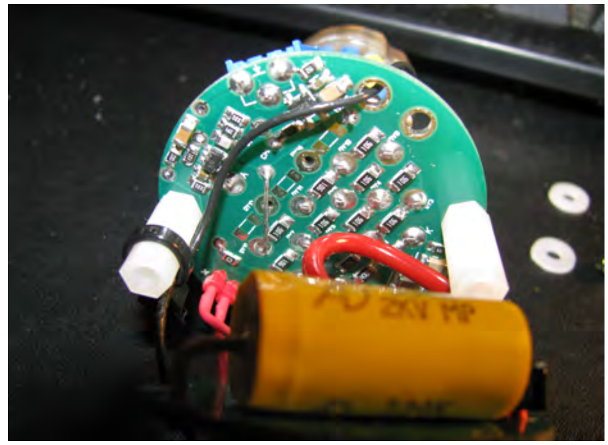
The signal from the module is then fed to an audio card and processed by a laptop (for benchtop applications) or Raspberry Pi3 (or Zero) in its HASP-flight configuration.

From: Private communications with RH Electronics, August 2017:

By default, the signal is taken from the comparator. For gamma spectroscopy applications, the signal needs to be taken right after the transimpedance amplifier. Check on the bottom PCB: you have a pad marked as "Spec" where you normally read "Amp DC offset". Take the signal from here via 10uF capacitor to the audio card input. Use a 10uF ceramic non-polar capacitor. Connect the capacitor from "Spec" to Audio cart input line In or Mic In. We suggest to connect an oscilloscope to the Spec pad and check the pulses first.

The R6095 can be used for spectroscopy with PRA or BqMoni software up to 1000CPS samples. It's limited by the audio card primarily.





Figs. 15 & 16: Modification as specified by the RH Electronics manufacturer to make the module suitable for spectroscopy applications.

The photomultiplier tube (Hamamatsu R6095) operates at high voltages (1500VDC between the anode and the cathode) [10].

HV Hazard

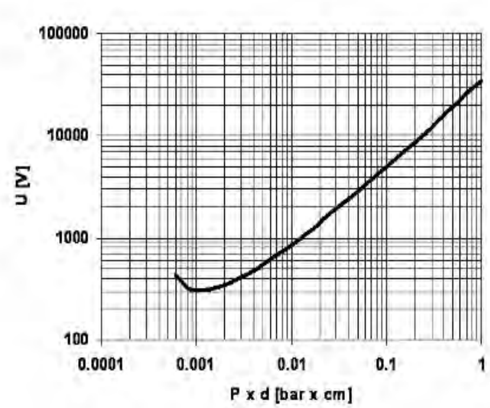
In order to prevent any HV accidents, the design will be configured in such a way as to make accidental contact with HV leads impossible. The circuit board is covered in insulating paint, lead wires are protected by appropriate shrink sleeve.

Furthermore all HV leads will be given additional protection (see below) with polyethylene hot glue, and mounted in a (non-pressurized vessel) that blocks direct access of personnel to the HV circuitry.

Corona Discharge, Arcing: mitigation measures

From: Dr. Stephen Patterson, PhD (Ph.D. thesis on the topic of very low pressure electrical breakdown), now at Saint Paul's School, London, UK, January 2017.

"The breakdown problem you sent looks very interesting but I think you should be ok with some extra insulation. The breakdown of air at low pressure is described by the Paschen curve:



So at atmospheric pressure (~1 bar) for a 1cm gap the breakdown voltage is about 30kV. At 1% of pressure at sea level breakdown for any exposed cold terminals at 1cm apart will be about 800V. Therefore anywhere on your kit where there is a pressure times distance not much greater than 0.01 bar.cm you will need electrical insulation. Any exposed points with a potential difference of 800V that are within less than 1cm (+ safety margin) of each other you will need to add some extra insulation.

While things stay cold there will be no breakdown as long as the voltage stays below ~300V even for smallish gaps. If there is heating then the Paschen curve will deform to allow breakdown at lower voltages. I have assumed DC which might not be true – if there is a high frequency component to the voltage this can cause a lower voltage breakdown or breakdown across a larger gap.

It would be also be good if you can demonstrate the setup is working properly in low pressure conditions to show the validity of your approach."

Answer: According to the Hamamatsu R6095 datasheet the voltage is 1500VDC between the anode and the cathode. At a current draw of 0,1mA though, things are not expected to heat up much. A combination of insulating paint, proper heat shrink sleeve and hot glue will be tested. The power supply board will be equipped with current surge protection.

Summary of measures

- HV board painted with insulating paint, leads covered with proper shrink sleeve
- Power supply with current surge protection
- The boards were the 5V power supply converts to 1,5kV for the PMT will be enclosed in an insulating chamber (not pressurized) so as to avoid accidental contact. This way, the only contacts free to be touched will be 5V and GND.
- All free metal contacts inside will be covered in polyethylene hot glue

REMARK:

In the months since the purchase of our Gamma Spectrometer module from RH Eleectronics, the company has improved the performance of the module, and it is now available in a configuration that is defaulted for spectroscopic use. In this configuration, the module can be used in combination with a new module that records the spectra and stores the data on a µSD card, thereby eliminating the need for a Raspberry Pi. That module has press buttons for mode selection, making it unusable for stand alone operations. A modification with Arduino-steerable selections is possible. Should be decide on this option, both mass and power consumption as estimated will go down (not up) as the second module is smaller, lighter, and less power consuming than a Raspberry Pi3.

1.2.2. Development status

For this instrument, simple challenges included the design of the 3D printed ABS container securing the key elements of the setup (the ThI-doped NaI scintillation crystal and the Hamamatsu R6095 photomultiplier tube) in position. That work has been concluded succesfully.

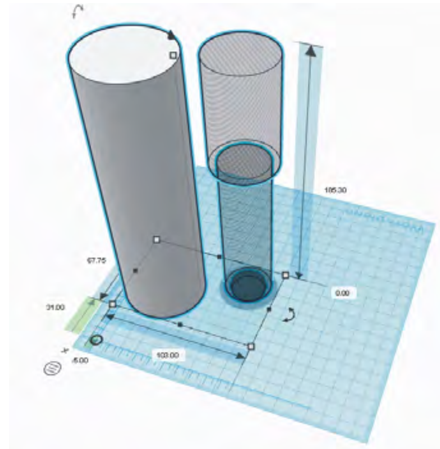



Fig. 17&18: The hollow casing aligning the photomultiplier tube and its μ-metal shielding (Ultraperm 80 Metal Shielding Sheet 8" x 5.3": 80.3% Nickel, 14.3% Iron, 5.4% Molybdenum) and the NaI scintillation crystal under development. A suitable base has been added to allow the setup to be properly secured to the experiment's base plate, while still allowing access to the setup if a problem should develop in testing.

Fig. 19: The Gamma Spectrometer support structure, with base for securing it to the experiment structure. Standing 18,5cm tall, it houses the NaI crystal, the PMT and the μmetal shielding. On top comes the HV supply and primary signal processing electronics [9].

Somewhat more challenging is the use of Raspberry Pi (a 'first' for our school) to collect and store the signals using existing PRA (Gamma Spectroscopy software- by Gamma Spectacular) software, and storing it on a μSD card.

Determining the setup's sensitivity will require equipment beyond our reach, but people at CERN have graciously offered assistance (which as a side effect offers our pre-university students a unique opportunity to learn about fundamental research at CERN from the researchers themselves). When operational, the setup will be shipped to CERN for fine-tuning of the HV supply to match the tube's optimal performance.

2. Additional sensors

2.1. GPS

Fig. 20: The GPS module is Uputronics MAX M8 GPS module, flight proven on high altitude balloon missions in both the USA and the UK: https://store.uputronics.com/index.php?route=product/product&path=60_64&product_id=83

2.2. P and T sensor

Fig. 21: For pressure and temperature, a single sensor is used: BMP280, flight proven on high altitude balloon missions throughout the world. https://www.makerfabs.com/index.php?route=product/product&product_id=295

2.3. IMU

Fig. 22: The magnetometer is part of a 9 degrees-of-freedom inertial measurement unit: https://www.sparkfun.com/products/retired/10724. It was flown successfully by our students on high altitude balloon missions from Brussels on several occasions

3. Control, data gathering/storage, telemetry

Data gathering and storage is decentralised. The 3D Geiger counter has 3 Arduino Nano's gathering a single tube's data each, storing it on a dedicated µSD card*. The Gamma Spectrometer, under control of a Raspberry Pi3 (or Raspberry Pi Zero) will store its data on the Pi's µSD card. The 'additional sensors' board will store its data on its dedicated µSD card.

The 'additional sensors' board will also be in control of power management and active thermal control. This means that this Arduino will check the temperature and be able to regulate the current to the heater pad. Should temperatures drop to extreme low values, this Arduino will also be able to power the Gamma Spectrometer OFF, thereby making more current avalailable for the heater pad. When temperatures are back within acceptable margins, the Gamma Spectrometer will be turned back ON**. This 'additional sensors' Arduino Nano will also be in charge of communications with the ground through HASP's downlink interface, following format instructions as per Hasp Payload Interface Manual.

*This is because the Arduino's circuitry doesn't allow interrupts on more than two pins. Furthermore, by having 3 independent circuits, any single circuit's malfunction (as observed on a single Geiger Tube's flight over Svalbard in 2016) would still allow valuable data to be collected (from the remaining two circuits) and significant conclusions to be drawn.

**This implies that the Raspberry Pi3 can reboot on the current that is available while the 4 Arduino's are running. This not an obvious proposition, and may force the team to drop the Raspberry Pi3 in favor of the less power hungry Raspberry Pi Zero. Should even Pi Zero draw too much current (@5V) to allow the Gamma Spectrometer to be rebooted in flight, then RH Electronics new spectroscopy model [12] will be considered.

Telemetry downlink

As specified in the HASP Interface manual, telemetry will be downlinked to HASP via a single RS-232 serial connection using **8 data bits, no parity, 1 stop bit and no flow control.** The serial port speed will be 1200 baud.

While the exact structure of the (packetized) telemetry data format has not been finalized, it will be transmitted every 5 seconds, and contain a header and footer of 2 bytes each, and contain GPS timestamp, longitude, latitude, altitude, heading, temperature, pressure, magnetic field along the x-axis, y-axis and z-axis. The status of the 3 Geiger Counter circuits, the Gamma Spectrometer and the heater circuit will also be presented.

4. Payload system diagram

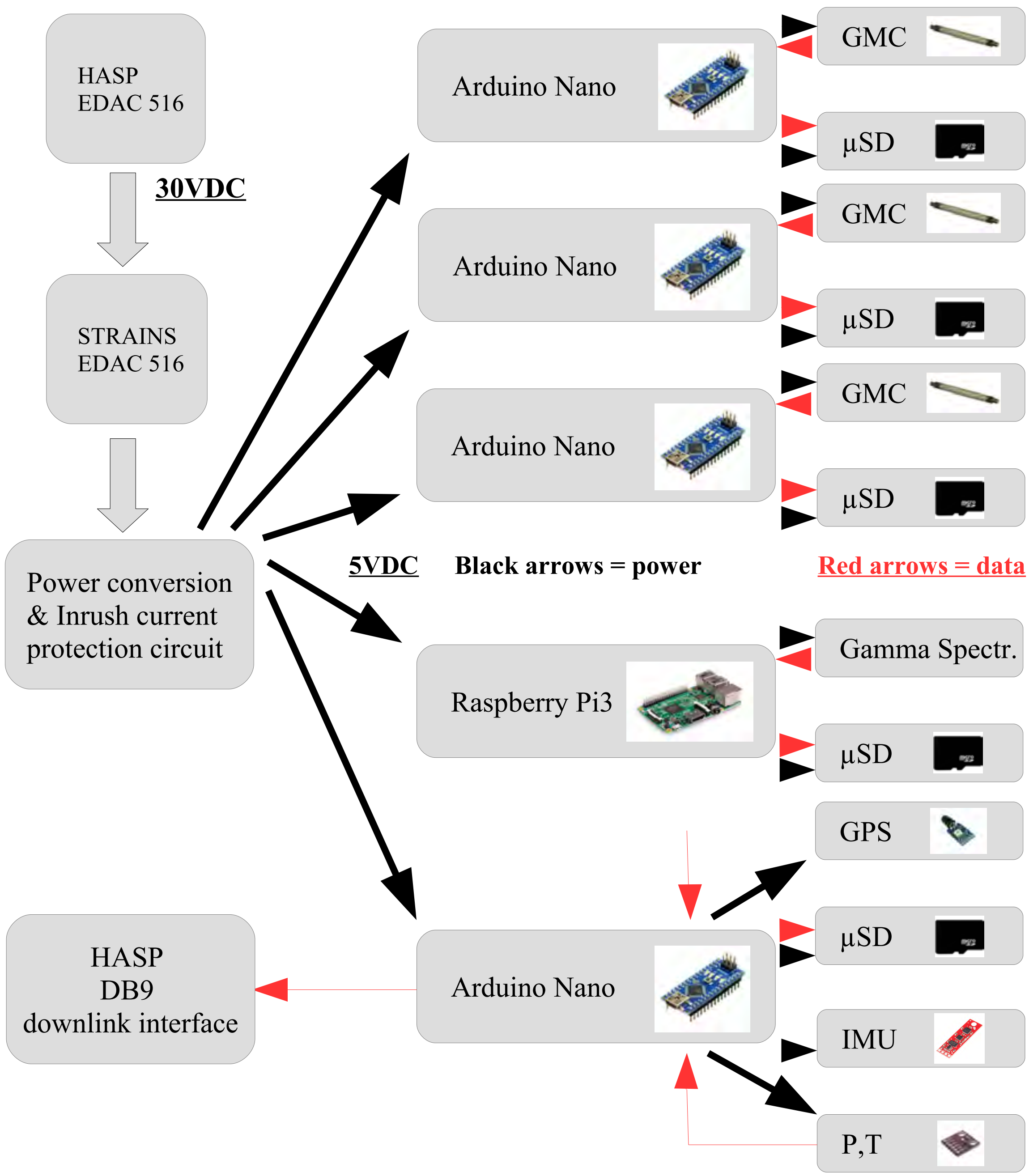


Fig. 23 Payload System Diagram

5. Power system

After contacting several former HASP teams, asking for advice, we settled on a Digikey buck convertor [11]. Its properties as per Digikey website:

Voltage - Input (Min):	9V
Voltage - Input (Max):	36V
Number of Outputs:	1
Voltage - Output 1:	5V
Current - Output (Max):	2A
Power (Watts):	10W
Operating Temperature:	-40°C ~ 85°C

As per the instructions, on the EDAC 516 power connector only pins A,B,C,D are wired to the payload as +30 VDC power supply and pins W,T,U,X are wired to payload as power ground to avoid failure to the power circuit or loss of payload.

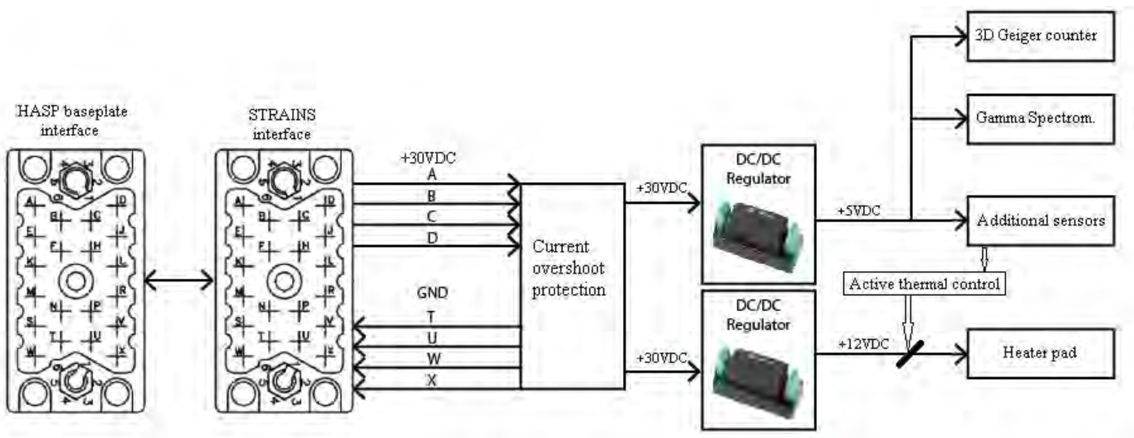


Fig. 24: STRAINS power diagram

Two issues will need to be tackled:

<u>First</u>: the current overshoot protection so as to avoid exceeding the HASP current limit of 500mA (@30VDC), while allowing STRAINS to restart in flight (Ground controlled).

<u>Second</u>: a circuit to allow the 'additional sensors' Arduino to regulate the current to the heater pad and power the Gamma Spectrometer ON and OFF as needed for active thermal control.

REMARK:
Should testing show that the Raspberry Pi3 draws too much current to reboot while 4 Arduino Nano's (and their sensors) are up and running, the team can switch to the less power hungry Raspberry Pi Zero. Should even Pi Zero draw too much current (@5V) to allow the Gamma Spectrometer to be rebooted in flight, then RH Electronics new spectroscopy model [12] will be considered

6. Thermal control

As part of managing the thermal properties of the payload, the team relied heavily on the school's past experience with sounding balloons. All materials and components used were selected with thermal constraints in mind.

The 3D printer plastic, ABS, has thermal properties making it suitable for use between -20 and +80°C, keeping its shock-resistant properties at those temperatures.

The Arduino Nano is claimed to be operational down to -40°C, whereas the information available for Raspberry Pi3 is less clear, some state -40°C is OK if the Pi is started at room temperatures so the components have the chance to warm up before the temperature drops. Testing will tell.

Thermal control will be both active and passive.

Passive

The payload will be insulated with white foamboard coated on both sides with MLI, for which thermal blanket will be used. On sounding balloons, a 2cm layer of styrofoam with a single layer of thermal blanket proved sufficient to keep the temperatures inside above -10°C even as outside temperatures in the tropopause plummeted to -70°C. At higher altitudes the problem becomes less severe (during the day at least) as actual temperatures go back up while atmospheric pressure continues to drop. That causes the cooling to shift towards an ever more purely radiative process (which is far less efficient than convection or conduction).

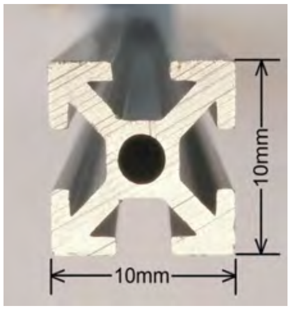
It is therefore expected that a thinner layer of styrofoam with multiple layers of thermal blanketing can do as good of job of keeping the heat inside (as a thicker layer of styrofoam with a single layer of thermal blanket), provided the layers of thermal blanketing do not allow conductive heat transfer. I.e. cold bridges should be avoided.

Tests will be perfomed to evaluate different styrofoam thickness & layer number combinations.

Active

Should the insulation provided and the power being dissipated by the electronics not suffice to keep the temperature inside withing acceptable limits, then the temperature sensor's data will trigger a heater (12V, 4W heating pad) to be turned on. As this may cause the overall power consumption to exceed the HASP “Small payloads” limitations, it may be necessary to switch the Gamma Spectrometer OFF. A procedure to switch the instrument back ON once the temperature is restored to acceptable values will be developed.

7. Mechanical structure



The structure of the STRAINS experiment is made of 10x10mm aluminum T-slot beams. The overall dimensions are 14x14x29cm, thereby allowing the addition of MLI on foamboard plates on the outside of the structure.

Fig. 25: Aluminum beams for the support structure of the STRAINS payload.

Custom made beams were ordered to ensure high quality cutoffs and precision sizing (to a degree far higher than could be achieved in-house). We also opted for adding proper treading in all endings of the beams, as that would allow to use non-protruding end cubes, thereby facilitating the fixation of the insulating foamboard-MLI panels, while at the same time eliminating all risk of dentures causing harm to personnel manipulating the payload.

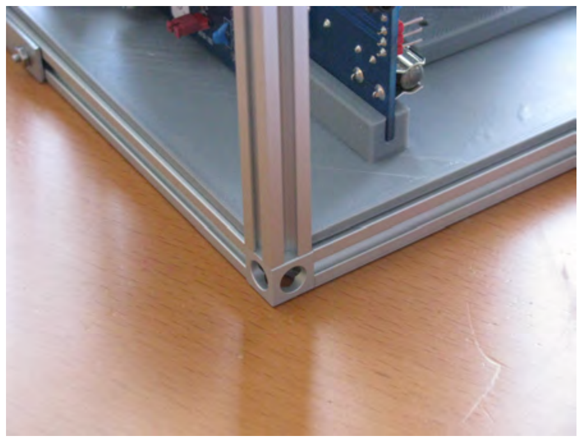


Fig. 26: The corners of the flight structure will be free of protruding parts (center). Because of delivery delays, it was decided to assemble a benchtop demonstration model with parts at hand, to prove that the different sensors and subsystems fitted together as planned. This benchtop model, while having the same footprint as the flight model, has some protruding screws though (as seen in the left upper corner of the picture).

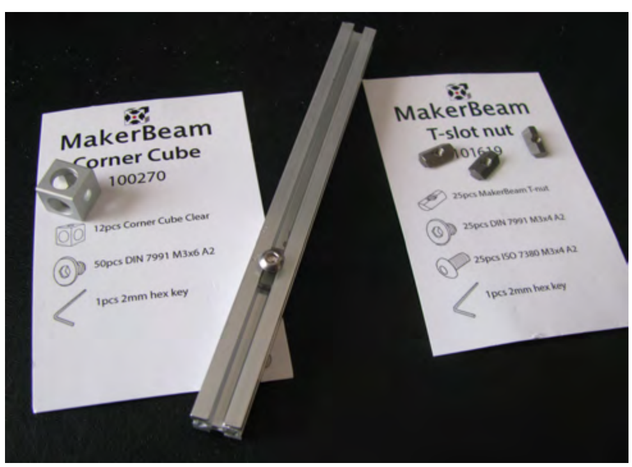


Fig. 27: Using T-slot aluminum beams also allows the easy fixation of homebread PCB's to the vertical sides of the structure, making late acess to the payload easier.

8. Mass and power budget

MASS budget

Green =Measured / Blue = estimated (by datasheet or calculation) / guess

Component	Mass (g)	Mass uncertainty (g)
Aluminum structure(1)	367	50
Thermal protection (foamboard(2)100g, MLI:100g)	200	50
3D Geiger Counter support structure	67	1
3 Geiger Counter boards	120	1
4 Arduino Nanos (with µSD card modules and cards)	80	30
Power/signal cables	20	10
PCB for Geiger counter + additional sensors(3)	60	5
DB9 connectors + cable	150	100
Power conversion (2 buck convertors 58g each)	116	20
Power conversion board	60	5
EDAC516 connectors + cable	150	100
Gamma Spectrometer support structure(4)	118	50
NaI scintillation crystal	215	1
Photomultiplier	42	1
µMetal shielding	28	1
HV and Signal Processing Electronics (HVSPE)	40	1
Connector power-HVSPE	20	5
Raspberry Pi3	73	1
Sound card	13	1
Connector soundcard-HVSPE	17	1
P,T Sensor	30	10
IMU	20	5
GPS	30	10
Heater pad (RS245-590 12V, 4W)	13	1
Total	**2049**	**460**

(1) Not included: fixation to the HASP baseplate. Uncertainty is provision for aluminum S-profiles & screws + screws to attach PCB's to the frame.
(2) 3mm foamboard has surface gravity of 460g/m² at ~0,225m² is 104g
(3) Not included: DB9 connector for data downlink
(4) Uncertainty is provision for the HV protection enclosure

POWER budget

All figures based on datasheets

Component	Power consumption(W)	Power uncertainty (W)
3 Geiger Counter boards[(1)]	0,03	0,01
4 Arduino nano[(2)]	0,5	0,1
4 µSD card modules&cards[(3)]	0,5	0,3
GPS[(4)]	0,13	0,02
P,T sensor[(5)]	0,05	0,01
IMU[(6)]	0,25	0,1
Buck DCDC convertor 30VDC to 5VDC[(7)]	1,4	0,3
Buck DCDC convertor 30VDC to 12VDC[(7)]	1,4	0,3
Raspberry Pi3[(8)]	3,75	2
Gamma Spectrometer HVSPE [(9)]	0,23	0,1
Heater pad	4	< 0 (4W is the max.)
Total	**12,24**	**4,23**

COMMENT: As mentioned before: the heater pad's use is contingent on power being avalaible, or else the Gamma Spectrometer will have to be shut down. So under no circumstances will power consumption exceed the 15W available under the HASP Small Payloads specifications.

(1) As per datasheet the current draw (@5V) is 0,03-0,06mA at background radiation level. Comparing data obtained on sounding balloon flights over Brussels (Fig. 1), the radiation level is expected to rise to about 2000CPM, from a sea level value of about 20CPM. That is a 100 fold increase, so current is expected to rise (first approximation) to about 6mA (@5V) or 0,03W.
(2) Current draw of the Arduino while running code (but without peripherals) is about 215mA. Times 4 is 100mA @5V so 0,5W.
(3) µSD cards draw 20mA @3,3V and the modules something similar (according to the Arduino forum) so 4 times 20+20mA is 160mA @3,3V is 528mW.
(4) As per Uputronics website,current draw varies between 25mA at acquisition of signal and 21mA in operation (@5V), hence 0,13W with a 0,02W uncertainty.
(5) As per datasheet the current draw is 3µA @5V so 15µW, butb that is the sensor, not the breakout board. We 'll count 10mA @5V = 50mW for safety
(6) As measured at maximum sampling rate: 50mA @5V = 0,25W
(7) As the buck convertors have a 10W rating and are 88% efficient, their consumption rate is estimated at 11,36W, 10W available for the experiments, the difference being dissipated in the convertor.
(8) The Raspberry Pi3 is slated to draw a current in operation of about 750mA @5V so 3,75W
(9) As per communications with RH Elelectronics, current should be below 25mA @5V

9. HASP Small Payloads constraints & mounting

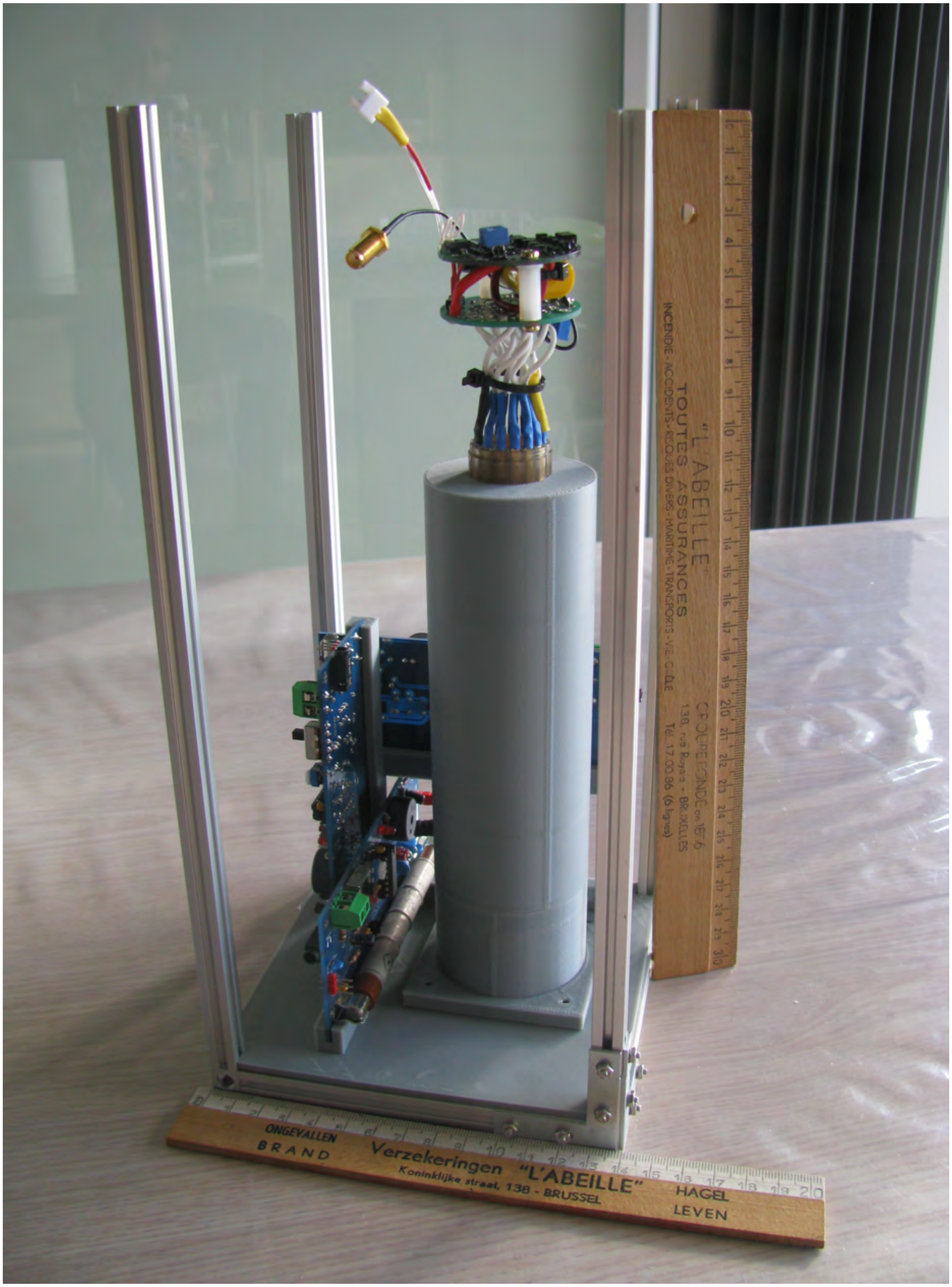


Fig. 28: Benchtop structure of 14x14x31cm holding the 3D geiger counter support structure and boards as well as the gamma spectrometer support structure and primary signal processing electronics.

Clearly, the footprint of both experiments is compliant with both the benchtop 3D Geiger counter/Gamma Spectrometer structure and HASP specifications. As can also be seen from the picture, the benchtop model is not finished at the top, but the height of the Gamma Spectrometer's HV and primary signal processing electronics does NOT exceed a height of 26,5cm, so the flight model's height was fixed at 29cm when the parts for the flight model's structure were ordered. The HV and primary signal processing electronics of the Gamma Spectrometer will be enclosed in a 3D printed cylinder for HV protection, with the flexible cables visible at the top of the picture protruding from the sides and connecting the apparatus to the sound card, and from there to the Raspberry Pi3 (or Pi Zero).

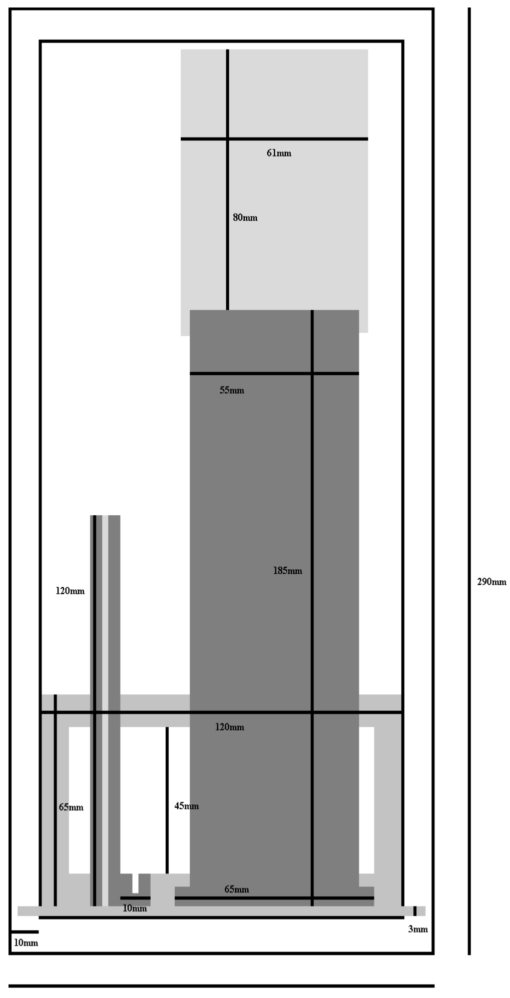


Fig. 29: Front view of the STRAINS payload without the thermal insulation.
The aluminum casing's outer dimensions are 14x14x29cm.

Mounting

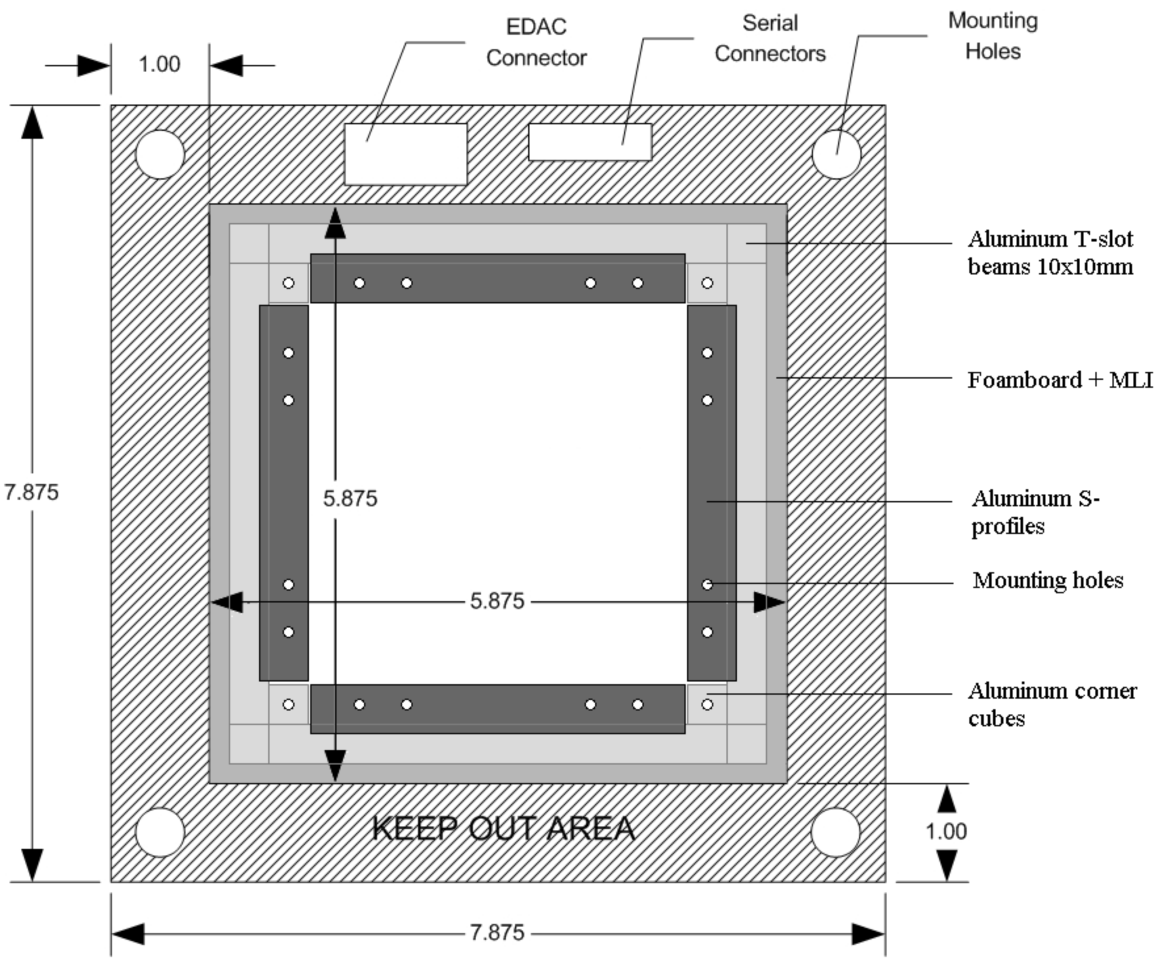


Fig. 30: HASP mounting plate (courtesy HASP Interface manual)

The base of the STRAINS aluminum frame is a 14x14cm square made of 10x10mm aluminum T-slot beams. In each of the corners a so-called 'corner cube' is fastened. Each carries 3 screws, one in each of the square's sides, one to the HASP baseplate. In the grooves of the side beams of the square, an aluminum S-profile is slit (see cross-section in fig. 2 below), each secured to the HASP baseplate with another 4 screws.

The 14x14cm base square is located on top of a foamboard and MLI (multi layer insulation made of thermal blanket) cover, so as to provide insulation on the lower surface of the STRAINS apparatus.

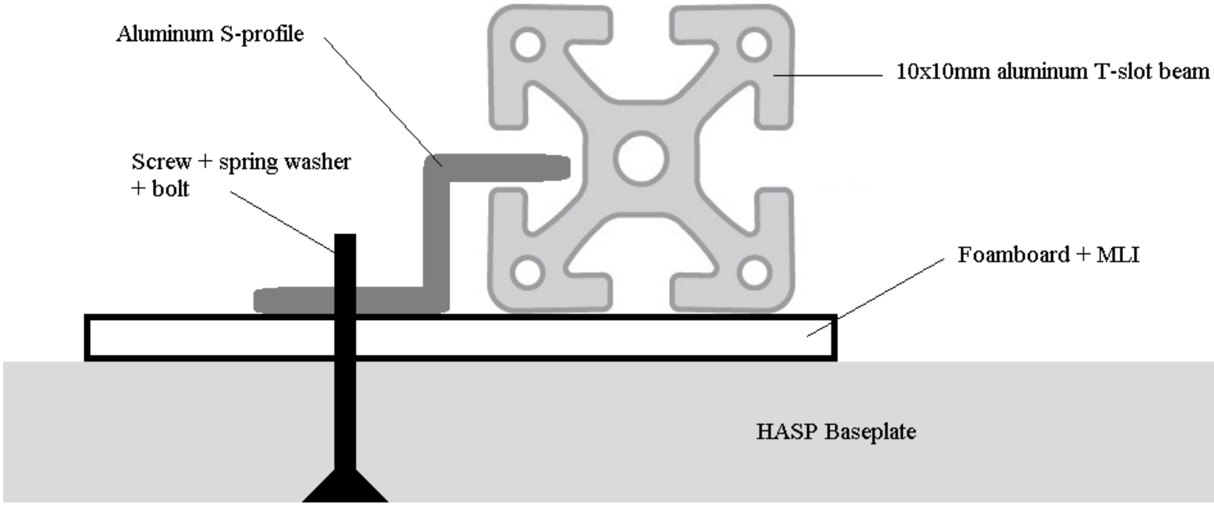


Fig. 31: Cross section of S-profile in the T-slot groove securing the setup to the HASP-baseplate. If the foamboard between the aluminum beams and the baseplate should deform, it will be replaced by additional layers of thermal blanket for equivalent insulating properties.

II. Team structure and management

Team members and duties:

Gamma Spectrometer		
Vincent Van den Moortel	Team Leader, Principal Investigator	12th grade Science-Math
Jennifer Pham Van	Mechanical engineer	12th grade Science-Math
Ellen Van den Bossche	Integration engineer, Outreach	12th grade Science-Languages
Elie Kochuyt	Electronical engineer, Outreach	12th grade Science-Languages
3D Geiger Counter		
Jerome Sleewaegen	Mechanical engineer	11th grade Science-Math
Emilie Sanvito	Electronical engineer	11th grade Science-Math
Elise Van den Bossche	Electronical engineer	11th grade Science-Math
Ebe Coomans	Software engineer	11th grade Science-Math
Sarkis Mellk	Software engineer	11th grade Latin-Math
Jeff Van den Bossche	Software engineer	11th grade Science-Math
Additional sensors		
Jerome Sleewaegen	Electronical engineer	11th grade Science-Math
Ebe Coomans	Electronical engineer	11th grade Science-Math
Emilie Sanvito	Software engineer	11th grade Science-Math
Elise Van den Bossche	Software engineer	11th grade Science-Math
Sarkis Mellk	Software engineer	11th grade Latin-Math
Jeff Van den Bossche	Software engineer	11th grade Science-Math
Louis Bonte	Software/Electronics (beginner)	11th grade Latin-Math
Max Van Den Bosch	Software/Electronics (beginner)	11th grade Latin-Math

'Faculty advisor' is **Erik de Schrijver**, M. Sc. Is our Science Teacher (Physics). He has been engaged in hands-on space education projects for secondary school students since 2004 and is considered an expert in the field. He has also launched about a dozen sounding balloons carrying over a hundred high school student experiments.

For lack of experience, the team consults with the teacher (aka 'faculty advisor') twice per week, when a (40minute) lunch-break meeting is held to discuss progress/problems.

Any technical questions the teacher can't handle is passed on to former students, now in college studying engineering (or professionally active as engineers).

Any scientific questions the teacher can't handle is passed on to former students, now in college studying physics (or preparing a PhD in Physics, such as **Wouter Gins**), or to Dr. Engineer Viscount **Dirk Frimout**, former astronaut (STS-45, 1992), specialized in instrument development for atmospheric research (incl. high altitude balloons).

Once the instruments are finished, CERN personnel will verify proper functioning and evaluate performance.

Management structure:

The Gamma Spectrometer will be developed by Mr. **Vincent Van den Moortel** as part of his work on building research competences (mandatory part of secondary education in the graduation year). Mr. Van den Moortel will be in charge of team management, the monthly teleconferences and the production of reports and other documents for HASP organizers.

Subteams of volunteers are formed working on different hard- and software subsystems, and outreach. These teams do not have formal team leaders and this tends to reduce overall involvement of other team members. To compensate for the students lack of experience with teamwork and communication, meetings are held twice a week to discuss progress and identify show stoppers. This has proven efficient as it allows breaking down projects into small incremental tasks that can be performed by a single student on a single evening.

The subteams working on STRAINS are as follows:

<u>Gamma Spectrometer</u>: **Vincent Van den Moortel** works on electronics, connections, data gathering and storage. **Jennifer Pham Van** works on the mechanics of the instrument, including the 3D printed parts, and mitigating any risks or problems associated with the HV. **Ellen Van den Bossche** is in charge of securing this instrument (and others) to the base plate. **Elie Kochuyt** is in charge of power management and distribution over the entire STRAINS setup.

<u>3D Geiger Counter</u>: **Jerôme Sleewaegen** has designed the 3D printed support structure securing the 3 Geiger Counter boards in mutually perpendicular directions. **Elise Van den Bossche** and **Emilie Sanvito** are in charge of designing the PCB that will carry the Geiger Counter circuitry. **Ebe Coomans**, **Sarkis Mellk** and **Jeff Van den Bossche** have working software to store numbers on a µSD card and working software counting Geiger events and displaying the CPS on a terminal. They are now working on the integration of both sets of code.

<u>Additional Sensors</u>: **Jerôme Sleewaegen** and **Ebe Coomans** are in charge of designing the PCB that will carry the Additional Sensors circuitry. It should be noted that this circuit will be on the same physical PCB as the Geiger Counter circuitry. **Elise Van den Bossche** and **Emilie Sanvito** are working on software for collecting GPS data. **Ebe Coomans**, **Sarkis Mellk** and **Jeff Van den Bossche** have working software to store numbers on a µSD card and working software collecting P, T and IMU data. They are now working on the integration of both sets of code. **Louis Bonte** and **Max Van Den Bosch** recently joined our group and are observing the workings of the hard- and software development efforts.

<u>Overall integration</u>: is the responsibility of **Ellen Van den Bossche**. Ordering the aluminum beams, screws, corner cubes, etc. Making sure the pieces fit together and HASP specifications are met.

Power management: **Elie Kochuyt** is in charge of power management (and therefore has frequent contact with the people designing the circuitry, and with Ellen for overall integration of cables connectors), parts procurement (EDAC516 connectors and cables, buck convertors, etc).

Thermal control: **Vincent Van den Moortel** is in charge of designing, developing and testing the passive and active thermal control systems. For the active control system, he will be working closely with Elie, as the current draw of the heater pad may throw the STRAINS power consumption over budget, in which case measures will have to be taken (i.e. a power OFF on the Geiger Counter may be necessary).

III. Calendar

Status Dec. 2017	
Gamma Spectrometer	All hardware at hand, except the connector from signal capture electronics to Raspberry Pi3. It is ordered though. Software installation on Raspberry Pi3 underway.
3D Geiger Counter	All hardware at hand, except the final version of the 3D print support structure. Software for signal collection available. Software for data inscription on µSD card available. Software integration remains to be done. Circuit is operational at benchtop level. PCB design and manufacture remains to be done.
Additional sensors	All hardware at hand. Software for signal collection available. Software for data inscription on µSD card available. Software integration remains to be done. Circuit is operational at benchtop level. PCB design and manufacture remains to be done.
Status Jan. 2018	
	Redesign of 3D Geiger counter support structure completed. Mechanical design validated. Design of 3D Geiger counter circuit completed. Software integration for 3D Geiger counter underway. Construction of benchtop Al-beam casing completed. Design of Gamma Spectrometer 3D print support structure completed. Mechanical design validated.
Timeline 2018	
February	Parts for the flight model ordered. HV casing being designed. 3D Geiger Counter PCB manufacture and testing. Software integration and testing. Electrical integration of Gamma Spectrometer. Functional modification. Testing at laptop level. Hard & software test of GPS. Additional sensors' PCB manufacture. Additional sensors software integration.
March	3D Geiger Counter full system's tests. Additional sensor full system's tests. Gamma Spectrometer full system's tests at laptop level. Power and interface systems development.
April 27	**Preliminary PSIP document deadline.**
April	Gamma Spectrometer and GPS in-flight test on a sounding balloon flight. 3D Geiger Counter and additional sensors in-flight test on Asgard-8 sounding balloon flight.
May	Power & interface systems tests. Full payload integration & tests. **Finalize flight operations plan. Verify all systems go for launch.**
June 22	**Final PSIP document deadline.**

July 19	**Final FLOP document deadline.**
July 23	**Flight Ready Payload due.**
July 23 - 27	**Student payload integration.**
August	Correct unforeseen issues found during payload integration if needed.
01/09/03	**Target launch date.**
October	Analyze results and begin science report.
November	**Complete data analysis and final report.**
December	**Submit final report (Dec 8th)** and prepare abstract(s) for the '24th ESA Symposium on European Rocket and Balloon Programmes and Related Research, Germany, June 2019'.

IV. References

[1] Behe, N. et al. "Secondary School Students Designing, Testing and Flying Geiger Counter Equipment to Study Atmospheric Gammas over Europe and Svalbard", 23rd ESA Symposium on European Rocket and Balloon Programmes and Related Research, June 2017, Visby, Sweden.

[2] Glenn F. Knoll, Radiation Detection and Measurement. John Wiley & Sons, Inc., USA, 3rd Edition, 2000.

[3] Geiger tube materials: http://www.sovtube.com/content/2-geiger-counter

[4] https://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html

[5] http://www.espimetals.com/index.php/technical-data/202-stainless-steel-316-alloy-composition

[6] Smith, Joseph; David M. Smith (August 2012). "Deadly Rays From Clouds". Scientific American. Vol. 307 no. 2. pp. 55–59.

[7] Domínguez, Alberto; et al. (2015-06-01). "All the Light There Ever Was". Scientific American. Vol. 312 no. 6. pp. 38–43. ISSN 0036-8075

[8] Mryan, J. et al. 'Atmospheric Gamma-Ray Angle and Energy Distributions from 2 to 25 MeV', 15th International Cosmic Ray Conference, Vol. 1. Published: Budapest : Dept. of Cosmic Rays, Central Research Institute for Physics of the Hungarian Academy of Sciences, 1977.

[9] http://www.rhelectronics.net/store/gamma-scintillator-driver-wired-socket-for-r6094-r6095-pmt.html

[10] http://www.sphere.bc.ca/test/phototubes2/ham/r6095.pdf

[11] https://www.digikey.com/product-detail/en/cui-inc/PYB10-Q24-S5-T/102-3138-ND/4477396

[12] http://www.rhelectronics.net/store/diy-pic18-mca-kit-for-gamma-spectroscopy.html