HASP Student Payload Application for 2018

Payload Title: **STRAINS - STratospheric RAdiation INstrumentS**

Institution:Sint-Pieterscollege Jette, Brussels, BELGIUM (High School)

Submit Date: December 14th, 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

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1. Payload description

The STRAINS payload consists primarily of two instruments:

1.) A Gamma Spectrometer to measure the energy distribution of the gamma photons and determine the altitude dependence of said distribution.
2.) A 3D Geiger-Müller Counter consisting of 3 mutually perpendicular Geiger tubes counting gammas in 3 (mutually perpendicular) planes.

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

- A Temperature sensor (allowing T-compensation of measurement results if tests should reveal the necessity)
- 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 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 Background

As a first 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 on the processes behind the occurrence of the Pfotzer maximum.

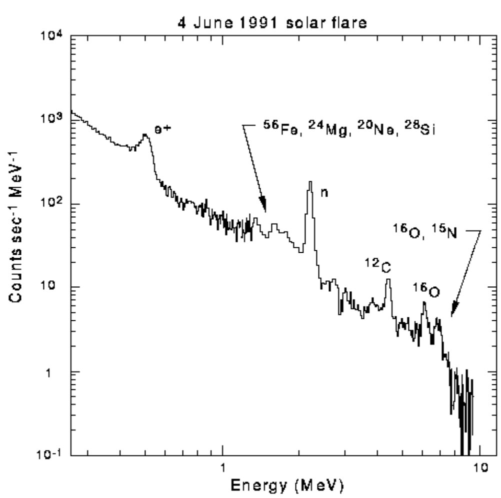
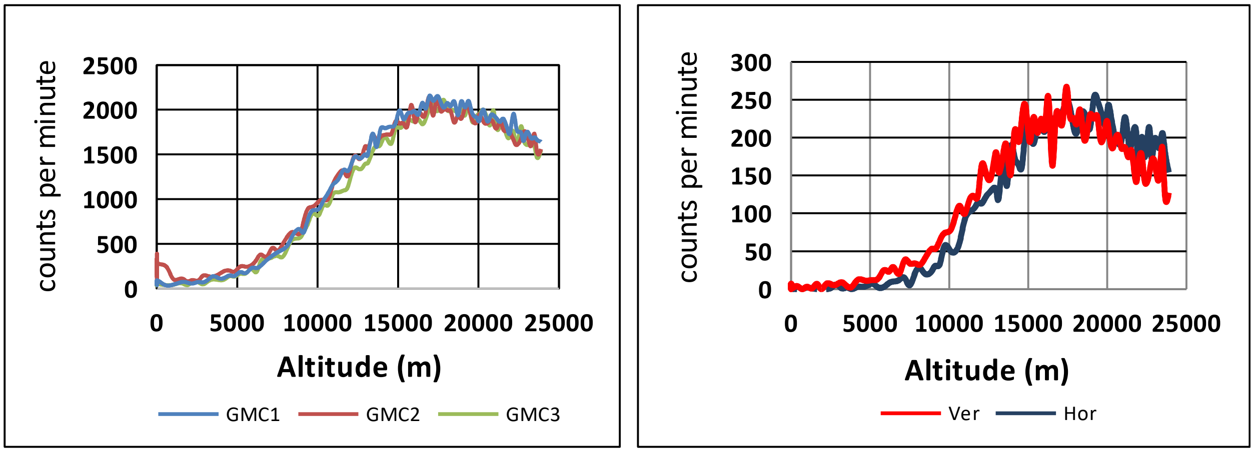


Fig.1 Gamma spectrum during a solar flare. While spectacular gamma events such as gamma ray bursts or solar flares cannot be predicted, it is hoped the instrument will be able to record a 'quiet conditions' gamma spectrum.

As a second instrument a ***2nd generation 3D Geiger counter*** is proposed to determine the ratio of vertical to horizontal radiation intensity as a function of altitude, in order to confirm that below the Pfotzer maximum vertically traveling gammas are more abundant than horizontally moving ones, as measured on an 'Asgard' sounding balloon flight in 2016 (with a first generation 3D Geiger counter). 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. While our and Univ. of Antwerp's data lead to the same conclusion, the difference between the horizontal and vertical CPM's (right figure below) barely exceeds the statistical error margin. The coincidence signal is just too small to assert the anisotropy is actually there. 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.



Figs. 2 & 3. 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.

Moreover, 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 may vary over the course of the float phase, which could yield meaningful insights when combined with the results from the gamma spectrometer. In the 3D Geiger Counter project the students will improve both hard- and software of an existing experimental setup developed by their predecessors, using 3D printing techniques and improved testing equipment (including vacuum and low-temperature environments). A PCB with all necessary circuitry will be designed and dedicated software (Arduino: C++ language) written.

For the gamma spectrometer students will cooperate with PhD students at CERN (European Nuclear Physics Center in Geneva, Switzerland) to 'squeeze' the utmost sensitivity out of the available hardware (which includes a > 42cc research grade NaI scintillation crystal, Hamamatsu R6095 photomultiplier and Raspberry Pi3 computer). Here too, 3D printing will be required, along with PCB design and software (Raspberry Pi: programming in C or Python) engineering.

<u>1.2 Technical challenge</u>

For the Gamma spectrometer, simple challenges include the design of the 3D printed ABS container securing the key elements of the setup (the Th-doped NaI scintillation crystal and the Hamamatsu R6095 photomultiplier tube) in position. 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).

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, but the students will be required to design the 3D printed frame securing the 3 Geiger counters in their mutually perpendicular arrangement. They will also have to write the code for Arduino to count gammas, keep track of time and store the data on a µSD card. And they will have to design the PCB carrying all necessary components, and actually etch, drill and solder said PCB, before assessing its performance in proper testing.

1.3 Hypothesis

The gamma spectrometer, if sufficiently sensitive to determine the spectrum of atmospheric gammas during the ascent and descent phases is expected to yield insights in the processes involved in the generation of atmospheric gammas.

During the float phase, the gamma spectrometer is expected to yield information on the stability of the gamma radiation level, and its dependence on the time of day. It is hoped that the recorded gamma radiation (and possibly its variability) may be linked the sun or other known gamma sources.

As atmospheric gammas well above ground level but below the Pfotzer maximum are generated in atmospheric processes, a certain prevalence of vertically moving gammas over horizontally moving ones is to be expected. 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.

1.4 Payload systems and principle of operation

A high-level diagram of the payload's systems is shown in Figure 4 below. Subsystems are self-contained and draw their power directly from the DC/DC conversion&distribution system. These subsystems include

- a Raspberry Pi3 computer and the Hamamatsu R6095 Photomultiplier tube (PMT) it powers (annex signal acquisition and conversion electronics)
- 3 Arduino Nanos with µSD card modules and the Geiger Counter modules they are powering
- 1 or 2 Arduino Nanos with µSD card module(s) and the P,T sensor, IMU and GPS module they are powering

Power is provided by HASP and is regulated to +5 VDC to power all payload systems as seen in Figure 4. The power circuit also provides protection from reverse polarity and limits the current draw to 495mA to prevent inrush current spikes. The circuitry for this is based on the PT668X voltage regulator (and circuitry developed by University of Minnesota for previous HASP missions).

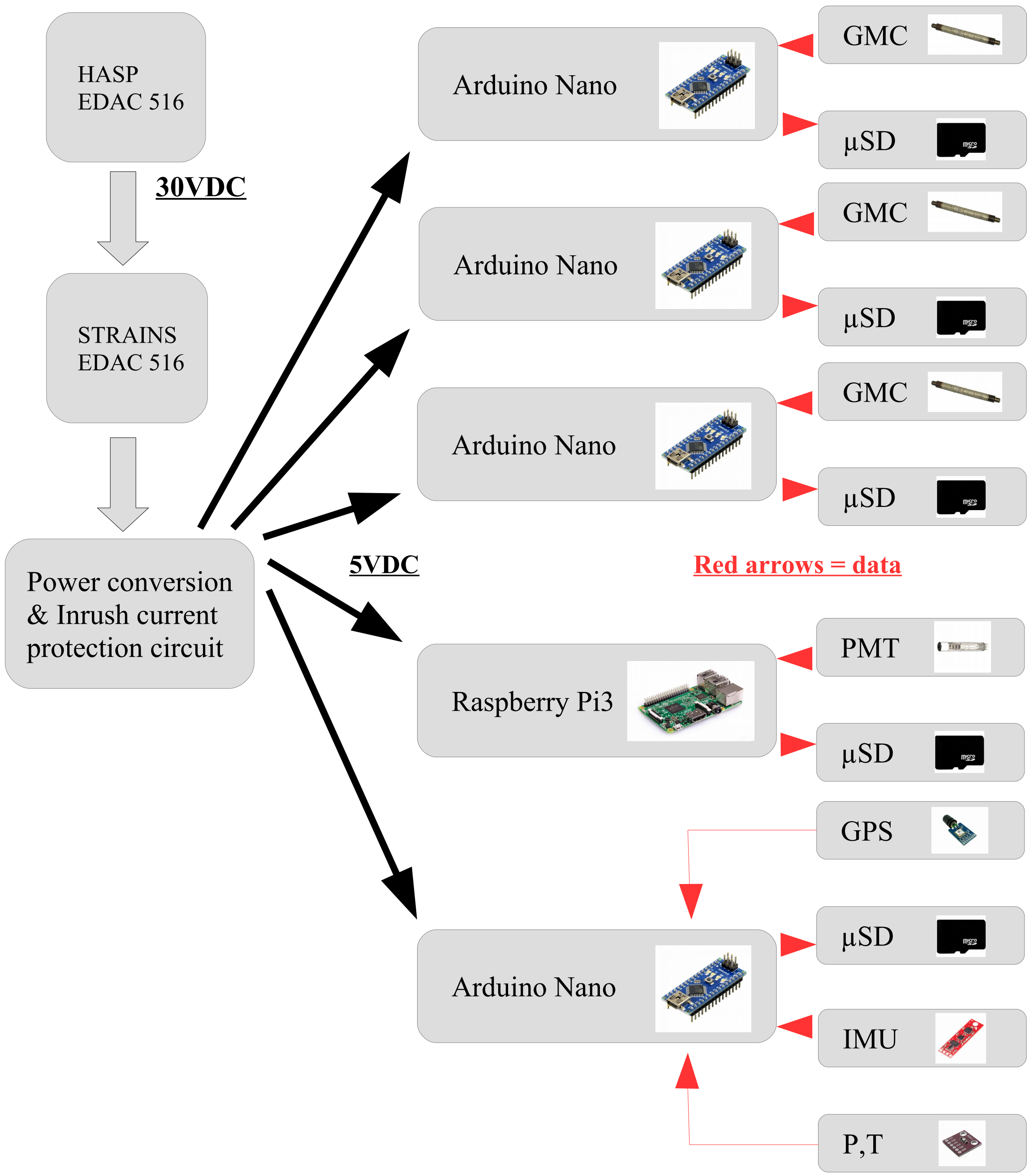


Fig. 4 Payload System Diagram

1.4.1 Sensor payload

The gamma spectrometer is an assembly of a Thallium doped NaI scintillation crystal (a material that gives excellent energy resolution in gamma spectroscopy), a Hamamatsu R6095 photomultiplier tube (surrounded by Mu-metal: Ultraperm 80 Metal Shielding Sheet 8" x 5.3": 80.3% Nickel, 14.3% Iron, 5.4% Molybdenum). Signal capturing and processing is done with RHElectronics' gamma spectrometer: http://www.rhelectronics.net/store/gamma-scintillator-driver-wired-socket-for-r6094-r6095-pmt.html). (See also: Preliminary drawings)

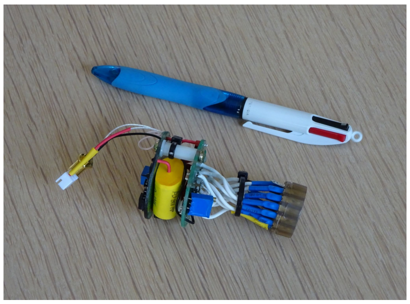


Fig. 5
Signal processing electronics

Fig. 6
Hamamatsu Photomultiplier

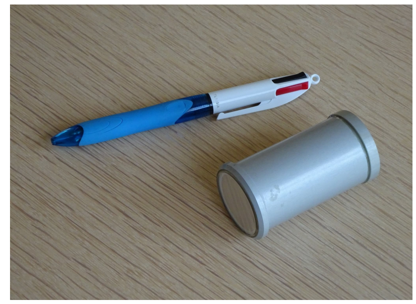


Fig. 7
Th-doped NaI scintillation crystal

Gamma Spectrometer data recording and storage is controlled by a Raspberry Pi3 computer. However, as the Pi3 draws significantly more current than a Raspberry Pi Zero, and is both bigger and heavier, an additional investigation into Pi Zero's applicability will be launched once Pi3's operation is certified. Whichever Pi is used, an additional heatsink (see Fig. 8) is included to improve cooling efficiency under low pressure. Tests will reveal whether that is sufficient and if additional cooling measures are called for.

Fig. 8 The Raspberry Pi3 controller will run a Linux kernel, WINE and PRA as dedicated gamma spectroscopy software, and homebread software for data storage.

Fig. 9 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

The Geiger Tube used is a Russian STS-5 (equivalent to the SBM-20) on all 3 modules. For data recording Arduino Nanos are used to save space, mass and power. Data are stored on µSD cards. The circuitry is designed in Eagle (Easily Applicable Graphics Layout Editor). The PCB's are etched by the students, drilled and soldered prior to extensive testing.

Fig. 10 The GPS module is Uputronics MAX M8 GPS module, flightproven 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

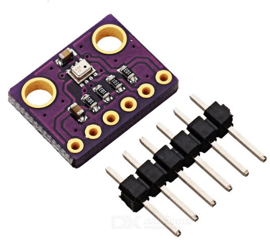


Fig. 11 For pressure and temperature, a single sensor is used: BMP280, flight proven on high altitude balloon missions throughout the world.
https://www.makerfabs.com/index.php?route=product/product&product_id=295

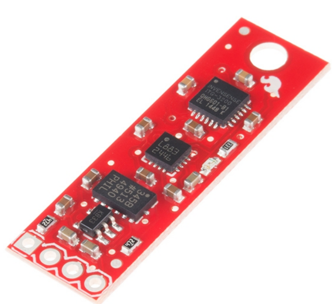


Fig. 12 The magnetometer is part of a 9 degrees-of-freedom inertial measurement unit: https://www.sparkfun.com/products/retired/10724. It was flown successfully by students on high altitude balloon missions from Brussels on several occasions

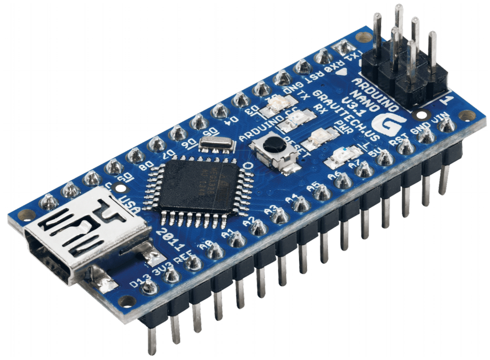


Fig. 13 Arduino Nano microcontrollers are used on all experiments except the gamma spectrometer, where the data rate and data processing complexity require the Raspberry Pi 3's (or Raspberry Pi Zero's) vastly greater capabilities.

Fig. 14 µSD card module for data storage. In use on our Arduino projects since 2015.

1.4.2 Structure

The structure is composed of 8020 type aluminum T-slot beams that have 15x15x30cm outer dimensions, polystyrene insulation included. The inner side of the aluminum walls is polished to assist in thermal protection as outlined below. There are four wall panels, a top plate, and a bottom plate all attached to the structural skeleton to increase the payload's strength and to give easier access to the components inside. The bottom plate is attached to the HASP Payload Mounting Plate with 1.25" long ATSM A307 ¼"-20 bolts. The exterior walls will be covered with 1cm thick extruded polystyrene carrying a thermal insulation foil to inhibit energy absorption, thus protecting the payload from overheating at float altitudes. The reflective interior will assist in keeping the payload warm as it passes through the extreme cold environment encountered in the tropopause.

1.4.3 Computer and Data Logger

GPS signals will be provided using a uBlox M8 based Uputronics module. The IMU is a Sparkfun 9DOF sensor stick that provides angular rates and accelerations as well as magnetic field data. Custom-designed daughter boards handle the hardware interface to the gamma spectrometer's Raspberry Pi3 computer or to the Arduino Nano microcontrollers. An accurate navigation solution is obtained by combining the IMU data with the GPS position estimate, though only altitude and orientation are relevant for science data processing. These can be obtained independently from either the gps or the pressure sensor + IMU (altitude can be derived from atmospheric pressure and orientation from magnetometer data). The data generated by the attitude determination system, the pressure and temperature sensors, the 3D Geiger Counter and the gamma spectrometer are placed in on-board storage (µSD cards) throughout the flight for post processing.

1.4.4 System Operation

Once the payload is fired up, it will continue running for the duration of the flight. There are no control capabilities included on the payload so there are no commands to be sent to the payload during flight. Therefore, a single power up command will be sufficient for payload operation. All data will be stored on board for post-flight processing. The downlink will be utilized solely for telemetry. If data collection is not proceeding as expected, then a request to power the payload off and then back on will be made.

2.Team structure and Management

Team members and duties:

Gamma Spectrometer		
Vincent Van den Moortel	Team Leader, Principal Investigator	12^{th} grade Science-Math
Jennifer Pham Van	Mechanical engineer	12^{th} grade Science-Math
Ellen Van den Bossche	Integration engineer, Outreach	12^{th} grade Science-Languages
Elie Kochuyt	Electronical engineer, Outreach	12^{th} grade Science-Languages
3D Geiger Counter		
Jerome Sleewaegen	Mechanical engineer	11^{th} grade Science-Math
Emilie Sanvito	Electronical engineer	11^{th} grade Science-Math
Elise Van den Bossche	Electronical engineer	11^{th} grade Science-Math
Ebe Coomans	Software engineer	11^{th} grade Science-Math
Sarkis Mellk	Software engineer	11^{th} grade Latin-Math
Jeff Van den Bossche	Software engineer	11^{th} grade Science-Math
Additional sensors		
Elie Kochuyt	Electronical engineer, Outreach	12^{th} grade Science-Languages
Jerome Sleewaegen	Mechanical engineer	11^{th} grade Science-Math
Emilie Sanvito	Electronical engineer	11^{th} grade Science-Math
Elise Van den Bossche	Electronical engineer	11^{th} grade Science-Math
Ebe Coomans	Software engineer	11^{th} grade Science-Math
Sarkis Mellk	Software engineer	11^{th} grade Latin-Math
Jeff Van den Bossche	Software engineer	11^{th} grade Science-Math

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.
Timeline 2018	**To Do**
January	Redesign of 3D Geiger counter support structure. Design of Geiger counter PCB. Software integration for 3D Geiger counter. Construction of Al-beam casing. Final design of Gamma Spectrometer 3D print. Preliminary mechanical integration, validation of mechanical design.
February	Mechanical & electrical integration of Gamma Spectrometer. Software testing. Instrument calibration. Hard & software test of GPS. Additional sensor PCB manufacture. Additional sensor software integration.
March	3D Geiger Counter full system's tests. Additional sensor full system's tests. Gamma Spectrometer full system's tests.
April 28	**Preliminary PSIP document deadline.**
April	Power and interface systems development. Gamma Spectrometer and GPS in-flight test on a sounding balloon flight. 3D Geiger Counter and additional sensor 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 23	**Final PSIP document deadline.**
July 28	**Final FLOP document deadline.**
July 30 - August 4	**Student payload integration.**
August	Correct unforeseen issues found during payload integration if needed.
September 7	**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'.

3.Payload Specifications

The STRAINS payload is designed to falls within the HASP guidelines for the **small payload** classification, i.e. 15x15x30cm.

At this time there are no uplink or additional commands anticipated for the payload. However, some downlink bandwidth will be required for system health monitoring. The serial link will be connected at 1200 baud using 8 data bits, no parity, and 1 stop bit as described in the HASP Student Payload Interface Manual. If the data received via the downlink indicates that data collection is not proceeding as planned, then a power on/power off command will be requested. Thus, the only discrete line required is the default line that powers the payload on and off.

The integration procedure should verify that the interface with the HASP gondola through the EDAC 516 connector is suitable, that power is being delivered and does not exceed the allowed current draw, and that the payload transmits telemetry and stores science data without issues. Assuming successful integration, flight preparation procedures should be limited to powering up the payload and verifying proper startup. It should be noted that STRAINS will undergo thorough systems testing as well as thermal/vacuum testing at St Pieterscollege or 'Klimaatkast', a company specialized in such testing for industrial applications.

3.1 Payload Mass and Power Budget

The payload will use the EDAC 516 connector to provide power to all systems as indicated in Figure 4. Voltage will be regulated and distributed to each subsystem. Both Raspberry Pi and Arduino should be able to run on 5V (4,75-5,25V), though for Arduino this is tbc (to be confirmed). The table below outlines the power and mass budgets for the payload components.

Structural components include the payload walls, mounting hardware, and GPS antenna embedded in the top plate (with care taken not to exceed the 30 cm restriction).

The mass requirements for the passive thermal protection system are unknown, and allowed a large amount of uncertainty compared to other known hardware components. Regardless of the design changes which may yet be made (addition of active thermal control, internal battery, ...), the mass and power specifications of the payload will remain within the limits of +30 VDC at 0.5 amps (15 Watts) and 3 kg, respectively, for the small payload classification.

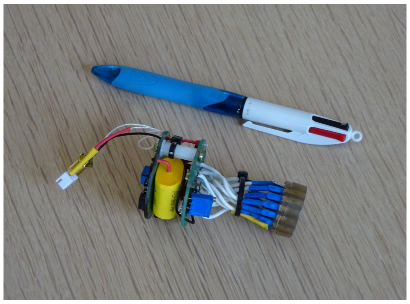
Component	**Mass (g)**	**Mass uncertainty (g)**	**Power (W)**	**Power uncertainty (W)**
Structure	800	400	-	-
Thermal protection	100	50	-	-
Raspberry Pi3	200	30	5	2
Arduino Nanos	100	25	1	0,5
Power conversion	200	50	0,8	0,2
Gamma Spectrometer	500	50	1,5	0,5
3D Geiger Counter	170	30	1,5	0,3
P,T Sensor	30	10	0,3	0,1
IMU	20	5	0,4	0,1
GPS	30	10	0,5	0,1
Total	**2150**	**660**	**11**	**3,8**

3.2 Payload Location and Orientation

Any a small payload location or orientation will do. Location is unimportant, and as for orientation, the on board GPS and magnetometer will provide the information required for data processing and interpretation.

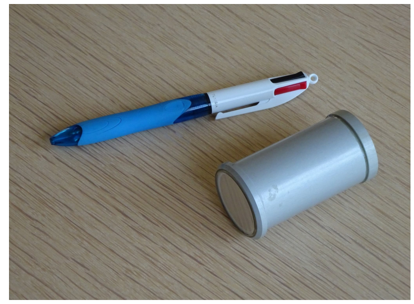
4. Preliminary Drawings

4.1 The Gamma spectrometer

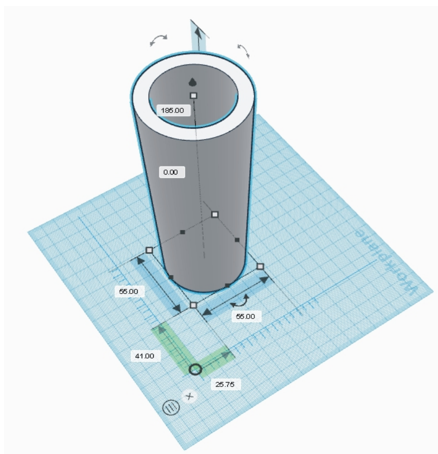


Signal processing electronics

Hamamatsu Photomultiplier



Th-doped NaI scintillation crystal



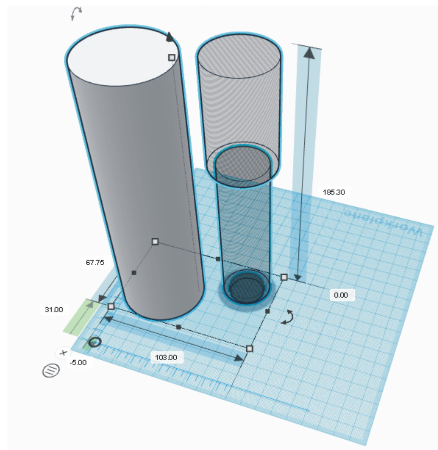
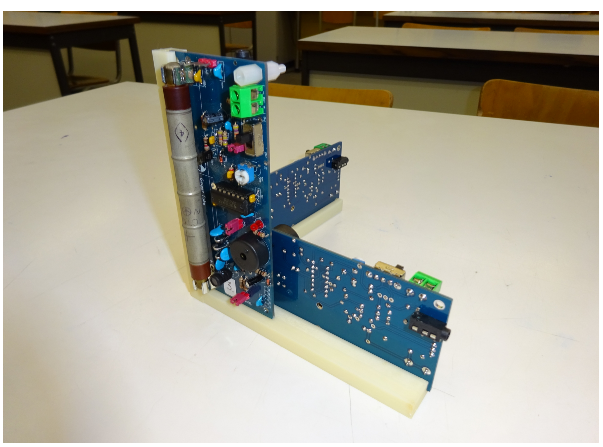


Fig. 15&16 The hollow casing aligning the photomultiplier tube (and its mu-metal shielding) and the NaI scintillation crystal under development. A suitable base will need to be added to allow the setup to be properly secured to the experiment's base plate.

4.2 The 3D Geiger Counter



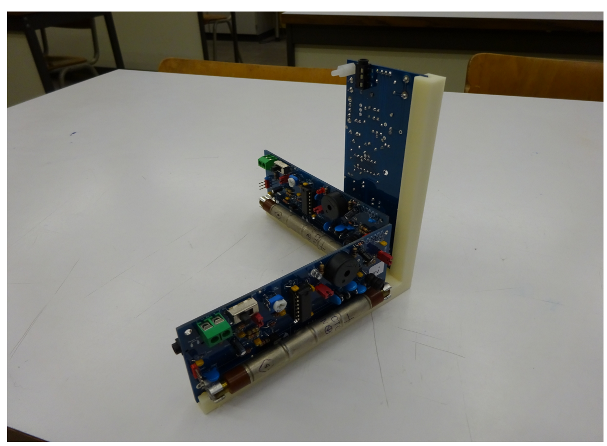


Fig. 17&18 A 12x12x12 cm 3D printed ABS frame holds the Geiger counter modules in place, their tubes neatly perpendicular to one another. Each Geiger counter is connected to an Arduino Nano that carries a µSD card module for data storage. This arrangement will have to be modified to ensure a nice fit within the aluminum structure, and to optimize the use of available space.

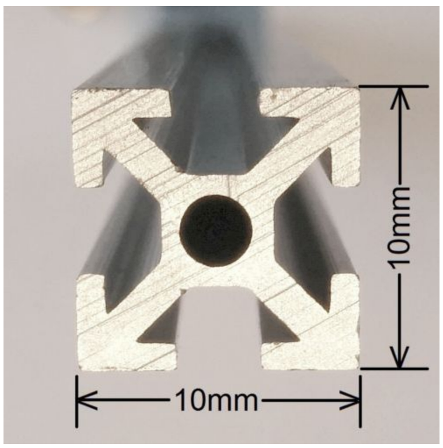
The Geiger counter circuit and initial software has been demonstrated and is operational at benchtop level. The circuit be translated to PCB using EAGLE-CAD software when Xmas exams and holidays are over.

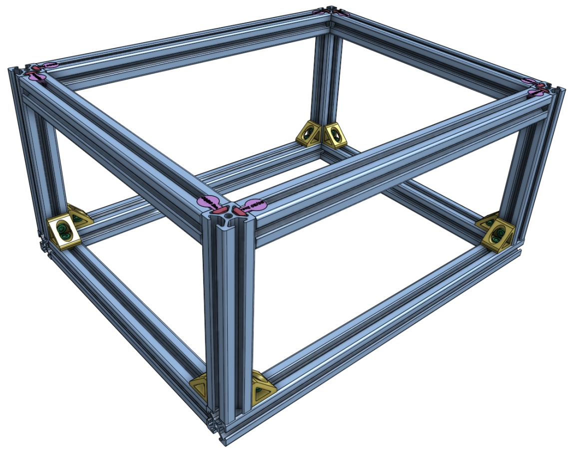
4.3 Additional sensors

The 'additional sensors' PCB will be secured to a side or to the top payload wall, so as to allow the GPS antenna to protrude through the top panel (whilst respecting the overall outside dimensions specified for the 'small' payload classification.

4.4 The supporting structure

Structural strength evaluation is underway, but at this time an extrusion Aluminum T-slot frame (8020 Inc.) of 10x10mm (0.39"x0.39") is being considered.





Figs. 19&20 A T-slot Aluminum beam cross section and example casing (Google images). Actual casing is approx (wxdxh) 13x13x28cm (without polystyrene insulation).

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. *Smith, Joseph; David M. Smith (August 2012). "Deadly Rays From Clouds". Scientific American. Vol. 307 no. 2. pp. 55–59.*
3. *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*
4. *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.*