Final Report: CPT-SCOPE

Report submitted to the NUUG Foundation, Norway.
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Summary

The objective of the Cosmic Particle Telescope (CPT-SCOPE) instrument was to study the altitude-dependent flux density of sub-atomic particles. The instrument used particle telescopes, a shielded stack of semiconductor sensors and absorber layers, and a radiation-hard application-specific integrated circuit (ASIC) for its readout. The novelty of this technology demonstration was the combination of inexpensive commercial off-the-shelf components with a space-rated ASIC. Two particle telescopes were used for the detection of different energy ranges. In this way the particle environment in the tropo- and stratosphere was investigated for a high latitude. The gathered data also helped to characterise the functionality and properties of the utilised ASIC. We were able to advance closer towards the implementation of a compact radiation monitor for nano- and picosatellites such as CubeSats. The CPT-SCOPE instrument has been accepted in December 2014 to fly aboard the BEXUS 20 student balloon mission. The flight was conducted on October 10, 2015 and science data was obtained. The project was concluded in May 2016. It was the first Norwegian-German project in the BEXUS programme, carried out by 11 students from Trondheim, Oslo and Berlin. Space outreach and education was a major component of the project involving over 100 school students. Several publications and conference presentations resulted from the project, and it is followed up with a new instrument development based on CPT-SCOPE within an Industrial-PhD project in Oslo.

Mission Statement

CPT-SCOPE shall measure the variable flux of energetic subatomic particles in the tropo- and stratosphere while demonstrating the capabilities of a new radiation-hard ASIC regarding future space missions.

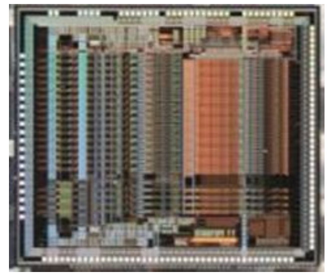
Objectives

Technology (primary):

- Build a functioning compact radiation monitor for (near) space applications,
- Test the readiness of the ASIC,
- Utilise the particle telescope geometry.

Science (secondary):

- Detection of energetic subatomic particles in the tropo- and stratosphere.



VATA465 ASIC - a space-rated component at the heart of CPT-SCOPE, image credit: IDEAS.

Meet the team

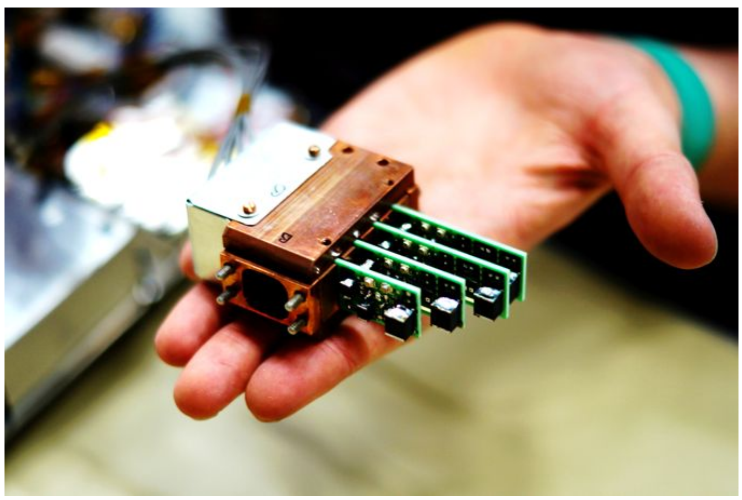
Team CPT-SCOPE during various milestones and events.

We are 11 students from Norway and Germany. Located in Trondheim, Oslo and Berlin, we worked together to make the first joint Norwegian-German BEXUS project happening. Our background is in Engineering, Pedagogics, and Natural Science. We are Timo A. Stein, Julian Petrasch, Anton Walter, Anastasiya Dykyy, Fabian Freyer, Michael Beermann, Patrick M. Schönberg, Grunde Wesenberg, Lucas Kempe, Johannes Stahn and Ron Wenzel. All B.Sc. and M.Sc. students (and some of us graduates by now).

Instrument

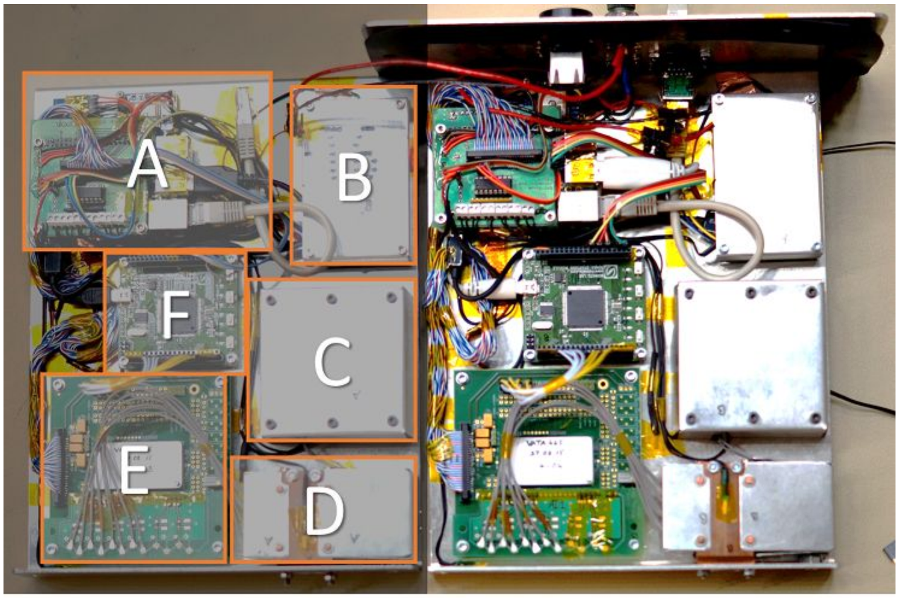
The instrument consisted of two electronically identical units (CPT-A and CPT-B), only differing in the geometry of the particle telescopes. This allowed to optimise the designs for different energies and provided a crude way of redundancy. The devices were programmed to run independently but remained connected to the ground station throughout the flight to transfer live data and provide the ability to command the units if actions of the operators were necessary.

Each unit was built around its particle telescope, a stack of absorbers and silicon sensors. By tuning the spacing between the sensors and the thickness of the absorbers one can control which particles will be detected and their energy. Roughly speaking, the deeper a particle penetrates the more energetic it is. An example of a CPT-SCOPE particle telescope is shown below.



The particle telescope showing the sensor-absorber stack. The four silicon detector modules (green) are mounted inside a copper housing and encapsulated by aluminium sheets for further protection.

The two units are shown in a the image below. One can see a variety of parts which are interconnected with each other. In summary there is a section for detecting the incoming energetic subatomic particles (C,D,E) including the space-rated ASIC on an evaluation card (E), the detected events are counted by means of a FPGA, a device which was programmed to act as a high-speed counter which can be read-out via a serial interface (F). The FPGA is connected to the on-board computer, a Raspberry Pi B+ running Raspbian Linux, via an interface card (A), and the whole unit is powered by a self-made power supply (B). In addition, various temperature sensors, a pressure sensor and GPS-unit were installed to track the payload and log environmental data throughout the flight. The ground station was run with laptops and a home-brew control and logging software written in Java and Python. The great majority of parts are commercially available at low cost and regularly used by hobbyists.



Opened CPT-SCOPE units before final assembly: CPT-A (left, labelled) and CPT-B (right) with exposed subsystems: A - on-board computer and interface card 1, B - power supply, C - reverse-bias generation, D - particle telescopes, E - front-end electronics and interface card 2, F - counter FPGA.

Each unit was connected to its own battery pack and via Ethernet to the BEXUS-communication system, called E-Link. This allowed us to connect to the payload in-flight. The entire instrument was housed in a solid aluminium structure and insulated from the harsh environment with thick thermal insulation material. The device weighed a little over 4 kg and had a size comparable to a shoe box.

BEXUS 20/21 Flight Campaign

BEXUS 20 balloon shortly before take-off. The gondola with CPT-SCOPE and two other payloads is mounted in the yellow assistance vehicle called “Hercules” (right).

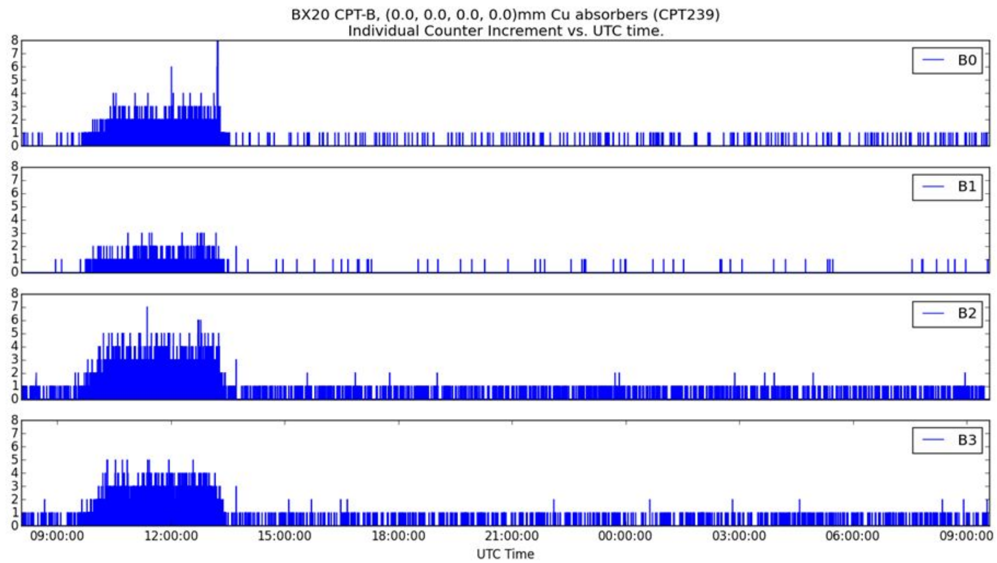
The BEXUS 20/21 flight campaign took place in Kiruna, Sweden, October 2-12, 2015. This milestone was the climax for the CPT-SCOPE project to which all members contributed during the prior year of instrument design, manufacturing and testing. There were two balloon launches, namely BEXUS 21 with three experiments from Poland, Germany and Spain, and BEXUS 20 with instruments from Belgium, Germany and Norway. The Belgium payload, called HACORD, was also a radiation detector based on Geiger-Müller tubes. Four CPT-SCOPE members took part in the campaign (Lucas, Anton, Julian and Timo). After the first few days of assembly and testing, CPT-SCOPE was ready for take-off. A picture of the final instrument mounted in the gondola is shown below.

CPT-SCOPE with thermal insulation mounted inside the BEXUS 20 gondola.

Due to delays in other payloads the BEXUS 20 balloon was delayed but launched on October 10, 2016. The flight took over 2 hours and the balloon reached a floating altitude of some 28 km. Flying eastwards, the gondola was cut loose from the balloon and a parachute was deployed for a soft landing in Finland. The CPT-SCOPE instrument operated nominally only suffering the loss of one redundant GPS-unit. In fact, it operated even after landing leading to a total operational period exceeding 25 hours. The BEXUS 20 gondola with all instruments was recovered on October 11 and returned to base. After the first post-flight data analysis preliminary data was shown in the post-flight debriefing and all teams left for home the following day. We had a great time and got to know the other teams and its members better. A great experience!

Ground station operations during the flight preparations.

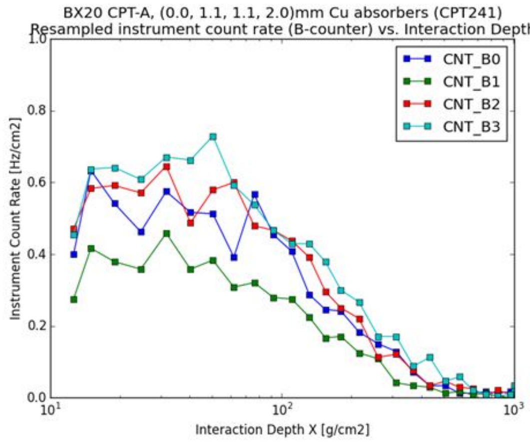
Flight Results

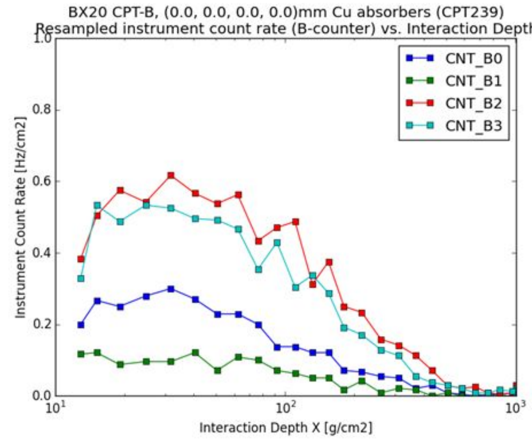


Raw data from unit CPT-B showing the increased number of events during flight (left) and the total operating time exceeding 25 hours, mostly spent at ground level (low activity). From top to bottom are the four sensors of the particle telescope denoted (top to bottom)).

Both units worked well and recorded data continuously for more than one day. We were able to fulfil all primary objectives in particular operating a functional technology demonstrator. This resulted in 53,489 and 53,679 data packages for CPT-A and CPT-B, respectively. Of these were valid 53477 (>99.9%) for CPT-A and 53568 (>99.7%) for CPT-B providing useful telemetry and science data. Each package contained a unique ID, system time, ambient pressure, several temperature readings from in- and outside the instrument, GPS location and time, test register readings and the science data i.e. counter register values. The period between packages was 1,723 ms and 1,732 ms for CPT-A and CPT-B, respectively. The raw count rates for unit CPT-B, counters B is shown on top.

The science data was noisy and hence re-sampled to 4 minute intervals in order to reduce noise by adding registered events within each time bin. This is shown in the figure below.





Count rate (number of registered particles per time unit) as function of interaction depth for unit CPT-A.

Count rate (number of registered particles per time unit) as function of interaction depth for unit CPT-B.

Here the number of detected particles per time unit is displayed on the y-axis (count rate) and the interaction depth is shown logarithmically on the x-axis. The interaction depth tells how much air the particles had to traverse to reach the detector. Hence, the left hand side shows the balloon at its highest altitude at around 28 km (~10 g/cm^2), the the right hand side on the ground (~1 kg/cm^2). One can see that the number of events strongly increases with altitude until a maximum is reached around 22 km (~ 40 g/cm^2). This is known as Pfotzer maximum where the most secondary particles are present. These are the results from collisions between the initial particles with such high energies that their interaction can create (multiple) new particles. From the present data we understand that the instrument was rather looking at these particles than the initial, fewer but highly energetic particles originating from our sun or the depth of the cosmos.

Furthermore, we can see how much protection our thin atmosphere provides for life on earth given the fact that there is just about 1 kg of material between space and the ground per square centimetre (less than 1 litre of water!). At first a number of secondary particles are produced which contribute most to the radiation dose people are exposed to during flights but on the ground the rate is remarkably low.

In addition, to the presented data there was numerous data points obtained for the housekeeping systems and other detector outputs which are not shown for brevity.

Achievements

More than 20 months into the CPT-SCOPE project our achievements can be summarised as follows: A functioning technology demonstrator of a radiation monitor has been conceive, designed, built, tested and successfully flown aboard BEXUS 20. The instrument delivered scientific data on the particle precipitation in the tropo- and stratosphere. Within this project a total of 11 students from Norway and Germany participated. Two of them were able to write either their Bachelor or Master thesis based on their contribution. So far two papers have been published on CPT-SCOPE and its findings. A total of 11 project presentations were held of which 5 were at conferences. Our outreach team reached several hundred school students, and over 180 followers on social media.

Outlook

The project will be continued within an Industrial-PhD project by the project leader at the University of Oslo and the Integrated Detector Electronics AS. The application of the updated device will be either for CubeSats or for high-energy physics experiments. CPT-SCOPE has been an important milestone for this.

Your contribution ...

… has helped us significantly to reach our aim. We were able to fund travel and accomodation, parts and manufacture for the CPT-SCOPE. Without your financial we would not have gotten to where we are. On behalf of the entire CPT-SCOPE team I would like to express my gratitude. Thank you!

Sincerely,

Timo A. Stein
CPT-SCOPE project leader

References, Media and Web Links

REXUS/BEXUS webpage:
http://rexusbexus.net/

Final CPT-SCOPE report to the European Space Agency:
http://rexusbexus.net/wp-content/uploads/2016/05/BX20_CPT-SCOPE_SEDv5-0_18May16_reducedFileSize.pdf

CPT-SCOPE webpage:
http://www.cpt-scope.com/

CPT-SCOPE Facebook page:
https://www.facebook.com/CPTSCOPE/

Article on Forskning.no on CPT-SCOPE's initial phase:
http://forskning.no/blogg/berit-ellingsens-blogg/ntnu-studenter-skal-undersoke-kosmisk-straling-med-esa-ballong

Article on Forskning.no on CPT-SCOPE's final phase:
http://forskning.no/blogg/berit-ellingsens-blogg/studentprosjekt-med-esa-ga-jobb-i-romindustrien

CPT-SCOPE presentation at the 1st SSSA symposium in Padova, Dec. 2015:
http://cisas.unipd.it/sites/cisas.unipd.it/files/E3-Stein-PRESENTATION.pdf