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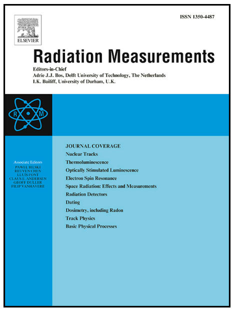

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Transforming education with the Timepix detector - ten years of CERN@school

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Abstract

The history and use of the Timepix detector as an educational tool is outlined. The CERN@school project which lends the Timepix technology to schools has been developing for the last ten years with over 300 schools involved and thousands of students. Resource materials and online support is available and schools have used the technology both to support curriculum activities and provide stimulus for student research. Student work includes research on radiation levels during a solar eclipse and a payload launched in space. Research projects with the Timepix technology have led to the development of the Langton Ultimate Cosmic ray Intensity Detector (LUCID) which has enabled students to develop an understanding of radiation in space and large scale data analysis. Feedback on the impact of these projects is discussed alongside plans for expansion of access to this technology. Possibilities for progress in the next ten years are suggested to include the gradual replacement of the Geiger-Müller tube in schools with this technology. This would make invisible ionising radiation visible and transform the understanding young people have of radiation. Alongside this transformation of the teaching and learning of radioactivity there is potential for further development of student expertise in analysing data from Timepix detectors in space. The opportunities this technology offers to students in school are vast and students have valuable roles to play in the use and application of the technology over the next ten years. It is hoped that not only are these developments in the UK but also across Europe and beyond.

Keywords: Timepix, Education, Space Radiation

1. History of the CERN@school project using Timepix technology

1.1. Meeting the Medipix collaboration

The connection between the Medipix detector and education grew out of a school visit to CERN in 2007. A group of fty students aged 16-17 from Simon Langton Grammar School for Boys[1] (SLGSB) was a test group for the CERN Visits Office. The Visits Office wanted to work with research groups at CERN so there could be places where school parties could go when it was no longer be possible to go down to the tunnel once the Large Hadron Collider (LHC) had started operation. This group had the huge fortune of having a visit to the Medipix Collaboration labs and a talk by Michael Campbell, Spokesperson for the Medipix Collaborations (now in their fourth generation, Medipix1 Amendolia et al., 1999, Medipix2 Llopart et al., 2002, Medipix3 Ballabriga et al., 2011, Medipix4 collaboration founded 2016). Medipix detectors are a family of photon counting pixel detectors (now in their 20th year, Bisogni et al., 1998, Campbell et al., 1998) for radiation detection that can detect and differentiate between all forms of ionizing radiation, and present many advantages compared to other detection methods.

Seeing the phenomenal potential of the Timepix detector with Pixelman software readout (Turecek et al., 2011) to visualise ionizing radiation and show young people what they would previously only have heard as clicks on a Geiger Müller (GM) tube was the initial impetus for the CERN@school project. There are now more than ten different projects done in schools that have arisen from this initial interaction. Most of the projects to date have involved students aged 13-18 although there is also a resource that helps students aged 8-12 years olds to understand frames from Timepix detectors measuring ionizing radiation in space in real-time.

1.2. Developing the Langton Ultimate Cosmic ray Intensity Detector (LUCID)

On returning from the school trip where they had rst encountered the Medipix Collaboration and seen the potential of the Timepix detector, students had the opportunity to enter a then British National Space Centre (now UK Space Agency) competition to put an experiment in space, taking care to take the radiation environment into account. Students suggested that the Timepix

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1 This group was mixed as the school is boys and girls for ages 16 and above.

that they had just seen at CERN, could measure the radiation and therefore provide a useful cosmic ray and radiation environment detector. This idea soon crystallised into a potential space experiment - named the Langton Ultimate Cosmic ray Intensity Detector (LUCID). At that time the Timepix detectors had not reached space qualification readiness 9 (see Hirshorn & Jefferies, 2016). The Medipix collaboration agreed to the competition entry going ahead and early designs for LUCID included more than a hundred detectors in a grid arrangement. As more realistic plans developed the students visited CERN again to talk with Michael Campbell and Professor Larry Pinsky (Lead astronaut dosimetry expert and member of the Medipix Collaboration) and decided on an arrangement of Timepix detectors around five sides of a cube. This was developed with Surrey Satellite Technology Limited (SSTL) and spearheaded by David Cooke (Project Engineer) with support from Dr Stuart Eves (SSTL Lead Mission Concepts Engineer and manager of the Space Experiment Competition). LUCID is discussed brie y in the appendix and in much greater detail, including an in depth analysis of data, in a recent paper by students who have worked on LUCID over the last ten years (Furnell et al., 2019). There have been over a hundred students work on LUCID from 2007 to the present (the instrument took data over 2014-2017), with the rst team being equal numbers of young men and women.

1.3. Developing CERN@school

The plans to use Timepix detectors in schools arose in parallel with the development of LUCID, so that schools could measure background radiation and detect elementary particles in the laboratory - a programme known as CERN@school (see Whyntie et al., 2016 for an earlier description of the scheme). CERN@school was proposed as an inspirational way to bring particle physics into schools with the potential for school students to genuinely contribute to scientific research. The aim would be to allow project teams in schools to develop over time (compared with single day engagement events), and for teachers to be reenergized with their passion for the subject through connecting with contemporary research. This grid of school detectors, envisaged across the UK alongside LUCID, became reality when a pathfinder of CERN@school in Kent[2] received funding when sixteen-year-old students applied for support from Kent County Council (KCC). KCC had a Kent Youth Council comprised of young people who were able to allocate money to issues of concern to them and their peers. They were so impressed by the commitment the school students had to improving young people's and their understanding of radiation and the vision they had for what applications might emerge from young people working with this technology, that the students won an award of funding. This was not a typical use of the Kent Youth Fund[3] - yet many years later CERN@school involves more students than ever. Young secondary student researchers involved in the project continue to develop new ideas and applications, validating the decision of the young people choosing projects on the Kent Youth Council to take a risk funding an unusual project a little different from their usual remit. Handling the vast quantities of data was the next concern. It was clear that one school would struggle to support the computing infrastructure needed for this project and enquiries were made about the CERN Grid computing infrastructure.

1.4. Working with GridPP

Professor Steve Lloyd, Chair of the UK GridPP Collaboration Board gave the project access to grid computing. GridPP is the UK particle physics collaboration for participating in LHC Grid computing projects (GridPP et al., 2006, Britton et al., 2009).This was a phenomenal development and the support from Steve Lloyd was hugely valued. Dr Tom Whyntie (who worked as a researcher for CERN@school) developed the access to GridPP as part of GridPP's commitment to engaging with the wider re-search community and industry. Support was provided for non-LHC Virtual Organisations (VOs). Four out of the nineteen UK Tier-2 sites support the cernatschool.org VO. GridPP offers the cernatschool.org VO access to computing and opportunities for large-scale data analysis. This has proved invaluable for large scale analysis of data, for example the data sets from LUCID. It has also provided opportunities for school students to develop significant computing analysis projects under the CERN@school umbrella. Not only have students presented work on all aspects of CERN@school projects but students involved in using GridPP for data analysis have presented at CERN computing meetings (Furnell, 2018) With the school-based detectors linking with a larger detector in space and the accessibility of computing power the CERN@school project could expand.

2. CERN@school develops into a national project

Thanks to support from the Science and Technology Research Council (STFC), the Royal Commission for the Exhibition of 1851 and the UK Space Agency, CERN@school has grown to a major national project. There are now four sets of bespoke resources for teachers to use provided by CERN@school.

[2] The area in the UK in which SLGSB is located.

[3] More typical projects funded by this fund included a trip to Africa as part of a sexual health awareness project, a residential activity week for young people with physical and learning disabilities, a healthy eating project where young people learnt how to cook healthy food, the refurbishment of a voluntary sector youth centre, sports equipment for a local youth windsurfing club etc., O'Donnell et al., 2007

2.1. School resources

Sunny Spells and Solar Storms

Understanding Space Weather with LUCID - This guide is for Primary teachers and provides information on space weather and where it comes from. Three activities are included in this pack which is suitable for 8-12-year olds.

CERN@school Users' Guide

This guide provides information on the CERN@school detector and how to get started using it in class. It is part of a package of resources and the package includes a curriculum guide, this users' guide and suggested experiments.

CERN@school Curriculum Guide

The curriculum guide covers the relevant aspects of the curriculum. The suggested experiments are there to help get started using the detector in the classroom and are available to download from www.researchinschools.org.

TimPix Guide

Whatever the space weather - Monitoring Peake Radiation Levels with Timepix. This is the guide for the TimPix project, a CERN@school activity linked to the UK astronaut Tim Peake's trip to the International Space Station (ISS), (see section 3.1).

These resources and associated webinars have all been developed by Laura Thomas, the Institute for Research in Schools' (IRIS, see section 3) Head of School Engagement.

The CERN@school kits (detector plus a laptop plus resources, see figure 1) are lent out for six week periods and with around forty units the kits are used by more than a hundred schools a year. SLGSB designed the initial housing for CERN@school - the Timepix detector with the USB device with laser etched CERN@school, but this assembly is now made commercially by Jablotron in the Czech Republic[4], called the MX10 device[5].

2.2. Seeing the invisible

Teachers report the benefits of using the visualization ability of the Timepix detectors and the modernity of the equipment. The principle for the GM tube was first invented by Hans Geiger in 1908 (Rutherford & Geiger, 1908) and developed with Walther Müller into the practical tube in 1928 (Geiger & Müller, 1928). This is still the practical approach for teaching radioactivity suggested by the Institute of Physics, but teachers now appreciate the cutting-edge nature of the CERN@school kit. Experiments can be performed using the CERN@school kit,

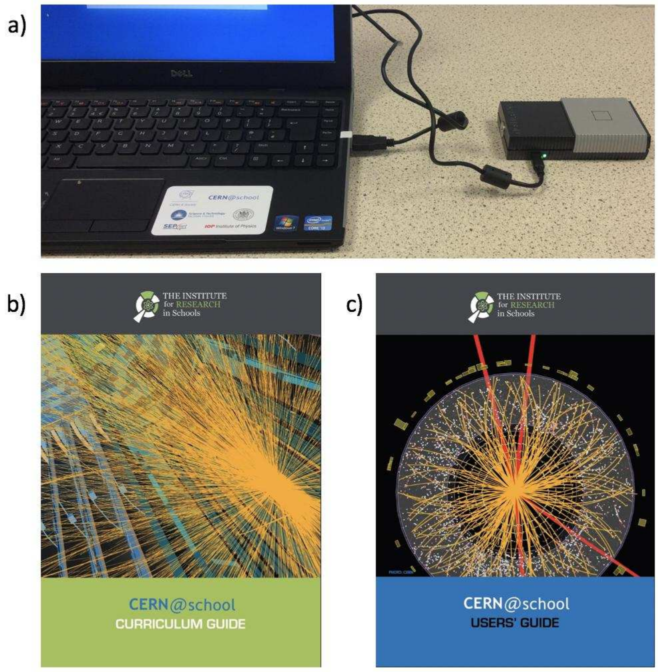

Figure 1: The CERN@school kits: a) The laptop and MX10 device in use today, and sample school guides, b) The Curriculum Guide and, c) the Users' Guide.

where the ability to see the tracks of ionizing particles makes the experiments relatable and understandable at a whole new level. For example, experiments to show the effect of different absorbers on a radioactive source clearly distinguish between alpha, beta and gamma radiation with their characteristic tracks. The teaching of special relativity and time dilation can be enhanced by showing tracks of muons arriving in the detector and principles of imaging can be demonstrated with an alpha source. Experiments can be done to find the banana equivalent dose with a banana - where with a GM tube it is terribly di cult to show a significant difference to background, a Timepix detector can clearly show the beta particles both from a banana or a pile of low sodium salt, which also contains naturally occurring radioactive potassium. The inverse square law for gamma radiation can also be clearly demonstrated using the Timepix detector (see Whyntie & Parker, 2013).

One of the most significant reactions to seeing radiation was from a physics teacher being introduced to the detector for the first time. Before going in to teaching he had been a submariner working on nuclear submarines for twenty years and seeing the nature of ionizing radiation displayed on the computer screen from the detector was incredibly illuminating and surprising to him - startling from someone who had worked close to radiation for most of his working life. Another teacher, Dr Andrew MacDonald from Stirling High School (the IRIS Central Scotland Hub), commented:

For four years we have had to teach radiation

4Jablotron Alarms a.s., Pod Skalkou 4567/33, 466 01 Jablonec nad Nisou, Czech Republic, http://www.particlecamera.com

[5] 256x256 55 m pixels, with 300 m Si sensor, USB 2.0 read-out interface.

without the aid of radioactive sources. This has limited the work to computer simulations and also a GM tube used to illustrate background radiation. This meant that the teaching did not have the immediacy and veracity of the observations. The main benefits from the detector was the very clear differentiation between the radiation types. The visual display showed the nature of the radiation in a way that a GM tube does not. Also, the tracks and the energy values emphasized the differences. Another bene-t was that the detector could be described as being similar to those used in particle accelerators (i.e. CERN) and being used on board the ISS - both adding credibility and aura of modernity. We were also able to have access to and to contribute to a wider database of observations through the TAPAS portal.

The significance of the output of the detector making invisible ionising radiation visible cannot be under-estimated. The use of the GM tube relies completely on students taking their teacher's word for it that a reduction in counts from a source as absorbers are added represents a loss of alpha, then beta and then gamma radiation. Notably, anecdotally students often don't think about this leap of faith - they accept facts told to them at face value. When there exists a better mechanism to improve genuine understanding of an area of science critical to mod-ern society it must be grasped - particularly for a field like comprehension of radiation which is so regularly poorly understood, and often feared.

2.3. The Timepix Analysis Platform at School (TAPAS)

Initially the plan was to encourage schools to collabo-rate on data from CERN@school kits by downloading data from different schools via their IT infrastructure. This proved to be very problematic. A student doing an Ex-tended Project Qualification[6] (this is a 6000 word extended piece of independent work a student can undertake aged 17) developed a solution to this - the Timepix Analysis Platform at School (TAPAS) (Furnell et al., 2019). This makes uploaded data from any of the detectors accessible to all schools. It is available at https://tapas. researchinschools.org. TAPAS is a platform for students and teachers to upload, analyse and share radiation imaging data from Timepix detectors in space, on Earth and at sea. The platform allows users to upload their own data, taken with the Timepix detectors or data which has been provided to them, such as the TimPix ISS Timepix data. A web application was chosen instead of a desk-top application because it is very easy to access. Once a user has uploaded a dataset, a cron job is used to run the analysis service every 10 minutes to process the data. The service also generates an image of every frame processed. TAPAS has also been used to analyse small amounts of the LUCID data (the whole LUCID data set required the resources of GridPP). TAPAS is programmed to allow students to download CSV les with particle count data, al-lowing them to conduct further analysis using their own choice of software packages - or even by choosing to write their own, in a programming language they are most comfortable with using.

CERN@school benefited from collaboration with the South East Physics Network (SEPnet) organisation (Thomas, 2018), who helped in gaining University support for schools across the South East.

[6] See Edexcel course specifications, https:// qualifications.pearson.com/en/qualifications/ edexcel-project-qualification/level-3.html

3. The development of the Institute for Research in Schools

CERN@school was a key impetus for creating a new national charity, the Institute for Research in Schools (IRIS) to support and develop research projects in schools across the country and it remains its leading physics research project.

The IRIS Vision:

Where research is a key element of learning STEM[7] such that both the teacher and student are contributing valued members of the Scientific Community.

IRIS' Key Aims::

1. To increase the number of young people and teachers who engage with STEM research at school in a way that raises aspiration, participation and attainment so that more young people, especially those from dis-advantaged groups, continue with careers in STEM.
2. To establish within the teaching profession the model of the `teacher scientist' as opposed to the science teacher so that a role within a school of Leader in STEM research and development is integral to the delivery of STEM Education in the school.
3. To enable teachers to be connected as key partners in STEM research with Universities, Industry and Research Councils and so retain them in the profession.

The IRIS Approach:

IRIS makes cutting edge research projects open to school students and their teachers so that they can experience the excitement and challenge of science. We do this by making data accessible to schools, providing teacher training and resources, and by lending out scientific research equipment (Parker & Rushton, 2018b,a). CERN@school now

[7] Science, Technology, Engineering and Mathematics

encompasses a range of research projects associated with the Timepix detector. It provides a framework for secondary school pupils in the UK to use the Medipix technology. LUCID is now just one of a larger multi-disciplinary suite of projects and experiments using Medipix technology being tested and applied in schools. Other projects have included Radiation Around You (RAY), a country-wide survey of radiation, which was runner up in the Rolls Royce Science Prize 2013, and the Radiation In Soil Experiment (RISE) which has measured the radiation in different geological samples across the UK and been cited by the Institute of Physics as an exemplar of good practice in improving gender balance (Institute of Physics, 2017). One notable example of a student proposed and lead project - students wanted to investigate whether the radiation back-ground count changed during the 20th May 2015 eclipse. Eighteen schools across the country took readings over the full duration of the partial eclipse and it was analysed by a student and written up as an extended project[8]. It was for many schools the highlight of the eclipse event since clouds across most of the UK prevented observations!

3.1. TimPix

There has been a close relationship with the team at NASA developing Timepix for radiation environment monitoring for astronauts on the International Space Station (Pinsky et al., 2012) and CERN@school. An application to the UK Space Agency for support for a project to access the frames of data from the Timepix detectors (see Stoffle et al., 2015) on board the ISS during British ESA astronaut Tim Peake's mission led to the TimPix project (a project within the CERN@school scheme). The TimPix project developed and showcased by IRIS has been tackled by over a thousand students. Starter activities with guidance introduce students to the data format and encourage them to investigate the science underpinning the measurements. As part of this project students develop their data analysis and communication skills. Students have investigated and reported on a variety of aspects including the South Atlantic Anomaly and how it changes over time. Students have compared measurements on the ISS with the behaviour of the Sun and have also made comparisons with ground-based measurements. TimPix was part of Mission Principia, a larger scheme of school and educational projects linked to Tim Peake's trip to the ISS 15th December 2015 to 18th June 2016 as part of Expeditions 46 and 47.

3.2. The wider schools programme

Student researchers have also been involved with efforts to detect magnetic monopoles in the Monopole and Exotics Detector at the LHC (MoEDAL) experiment (Pinfold, 2009) at the Large Hadron Collider (CERN Bulletin 2013)., and in CERN@sea, a project that has deployed Medipix RasPix detectors on a wave propelled Unmanned Surface Vessel, `AutoNaut'. AutoNauts generate energy through wave power and thus do not require recharging, permitting long deployment times and radiation measurements at sea-level over large areas of the oceans over time.

Collectively these projects show the ability for school based scientific projects to successfully develop new applications and techniques for new technology in a range of environments, alongside playing a key role in education (Colthurst et al., 2015; Parker, 2017; Parker & Rushton, 2018b). These projects are managed through the same data storage and reduction pipeline TAPAS.

There are many bene ts of working on CERN@school. We have run four CERN@school conferences; the first tied to the 10th Position Sensitive Detector Conference at the University of Surrey in September 2014, followed by a symposium at Queen Mary University of London, and two at the Rutherford Appleton Laboratory in the years following (see figure 2). Students have presented talks and posters at international conferences including Medipix collaboration meetings at CERN and National Astronomy Meetings in 2015 and 2016. These opportunities develop communication skills (Rushton & Charters, 2018), and projects develop research, collaboration and data analysis skills. When in a school, the detector can be used as the basis of a research project. Students set a research question and design a set of experiments to investigate it. For example, a student at Liberton High School presented to the Medipix collaboration meeting in Glasgow on `Producing Protons from Bombardment of Polythene with Alpha Particles'. The CERN@school project fits easily into enhancing the physics curriculum as well as providing equipment that is stimulating for students to use which allows them to develop research projects.

One student from a school in Bedford wrote:

> The most amazing opportunity from the project that I had, if I was to pick only one, would be opportunity to use the equipment. It would never have occurred to me that I would be us-ing equipment as advanced as the Timepix in school.

Former CERN@school student Dr Chantal Nobs (now a radiometric researcher at the Culham Centre for Fusion Energy), who spoke at the last CERN@school symposium, said of CERN@school:

> Being exposed to this project, and visiting CERN were two major contributing factors to my decision to study physics at University. This exposure showed me that physics research is happening, even today, and it can be an exciting job. It was the first time I had considered a job exciting. I certainly developed communication skills more than anything else, and the confidence to ask questions.

8See http://www.researchinschools.org/HowTo/Example_EPQs.html for the eclipse EPQ and other sample EPQ reports.

Figure 2: Photographs from the CERN@school Symposium, Rutherford Appleton Laboratory, 16th November 2017: a) Students presenting on the Radiation in Soil Experiment, b) Student presenting on the CERN@sea experiment, c) Student presenting on LUCID, d) Dr Chantal Nobs presenting

4. Other uses of the Timepix detector in education

CERN@school was featured in the CERN Courier (Del Rosso, 2010) and there was interest in how the Timepix detector could be part of the new educational experience S'Cool. S'Cool LAB is a Physics Education Research facility at CERN. They offer high school students and their teachers the chance to take part in hands-on and minds-on particle physics experiment sessions on-site at CERN. Timepix is now part of this. CERN@school is also being presented at the next Teacher and Student Forum at CERN run by Sascha Schmeling, Head of Teacher and Students Programmes. There have also been trials of using Timepix with a iPad mini interface as an educational tool (Keller et al., 2016), see also Kvita et al. (2018) for a description of using the MX-10 with the public and with school students. CERN@school is just one of many school linked cosmic ray projects, proving that it is an area ripe for collaboration between schools and researchers:

HiSPARC which originated in the Netherlands (http://www.hisparc.nl/en/) Secondary schools purchase and install HiSPARC detectors on the roofs of their school and take measurements of cosmic rays. They collaborate with University partners and present research ndings at an annual conference.

Quarknet (https://quarknet.org/) is a collaboration between Fermilab and the University of Notre Dame and they aim to support teachers bringing research into the classroom. The original programme used cosmic ray detectors to do this and now the programme is broader. The group Quarknet Cymru (https://blogs.cardiff.ac.uk/physicsoutreach/quarknet-cymru/) is a group using these detectors in Wales.

The Alberta Large-area Time-coincidence Array (ALTA) and the CZEch Large-area Time- coincidence Array (CZELTA) are sparse networks of cosmic ray detectors. At present, the detector system covers areas in Canada and the Czech Republic. The key aim is to search for a non-random high energy cosmic ray phenomena and the studies involve school students because the detectors tend to be placed like HiSPARC on school roofs.

There is an increasing amount of research being done to measure the impact of genuine research in education. The majority of work done in this area is with respect to University education and learning (University Alliance, 2016), who suggest that the approach to learning develops soft skills including self-esteem. This is consistent with IRIS' findings across a range of projects (Parker & Rushton, 2018b; Rushton & Charters, 2018).

5. Conclusion

Over the last ten years the idea of Medipix technology in schools has led to the CERN@school project with a number of associated projects, TimPix, LUCID, CERN@sea and work with the MoEDAL collaboration. Four major research conferences have enabled over a thousand students to present their work. Projects have involved hundreds of interested teachers, and thousands of students. Research is being done on the advantages of using the Timepix detector as a replacement for the Geiger Müller tube, highlighting how an understanding of radiation is improved with the visualisation of ionizing radiation the Timepix detector provides, as opposed to sonification from a GM tube. IRIS has plans to extend the CERN@school programme and also wishes to maintain a programme of school student payloads in space. The benefits to CERN member states are clear with this sustained access to particle physics and associated support material and guidance. Schools are very keen to work with Timepix3 technology (Poikela et al., 2014) on a number of cutting-edge experiments. The key advantages of CERN@school are bringing particle and radiation physics into schools in a clear and inspiring way associated with the potential for young people to genuinely contribute to research. CERN@school allows project teams to develop and grow in confidence and teachers to be reinvigorated with the subject and this distinguishes it from single day initiatives which are currently the norm for particle physics interactions. It's recommended that CERN embraces the experience, evidence and resources available in the CERN@school project to scale up this initiative for the bene t of more students across the UK, Europe and beyond.

Acknowledgements

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Thanks to all the IRIS team also to Elizabeth Cunningham and the teams at the University of Surrey, Queen Mary University of London and the Rutherford Appleton Laboratory for hosting the CERN@school conferences. Thanks to the many hundreds of teachers and thousands of students who have been so committed to the project.

Appendix: LUCID and TechDemoSat-1

LUCID is a payload on the technology demonstration satellite TechDemoSat-1. (TDS-1) TDS-1 launched on 8 July 2014 (15:58:28 UTC) on a Soyuz-2-1b launch vehicle with Fregat-M upper stage from the Baikonur Cosmodrome in Kazakhstan, into a 635 km, 98.4 degrees Sun-synchronous orbit. Data collection began shortly after launch, and data collection ceased on the 4th July 2017. The detectors used in LUCID are based on the Timepix ASIC detector (Llopart et al., 2007; Plackett et al., 2010), part of the second generation of Medipix (Medipix2, Llopart et al., 2002, 2007; Ballabriga et al., 2011). The payload has five Timepix radiation detectors in a cube-like configuration and has been of significant interest to the community investigating the use of Medipix detectors in Space (Pinsky et al., 2016). The detectors are surrounded by a 0.75mm thick aluminium dome which blocks intense light, plasma and low-energy charged particles. LUCID is mounted on the `Earthside' of TDS-1. The detectors were calibrated by the Institute of Experimental and Applied Physics (IEAP) at the Czech Technical University in Prague. The performance and expected measurements of LUCID were simulated in Whyntie & Harrison (2014) and Whyntie & Harrison (2015), Matt Harrison being a secondary school student who was the project leader for LUCID at the time.

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