Institution: Aberystwyth University		
Unit of Assessment: 9: Physics		
Title of case study: Enabling ExoMars 2022 through instrument calibration and testing.		
Period when the underpinning research was undertaken: 2008- 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Dr Matt Gunn	**Role(s) (e.g. job title):** Research Technician; Senior Research Technician; Research Fellow; Lecturer	**Period(s) employed by submitting HEI:** 1 August 2006- present
Period when the claimed impact occurred: 2014- 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

The Department of Physics at Aberystwyth University is heavily involved in the ESA/Roscosmos ExoMars 2022 rover mission, and Dr Matt Gunn is responsible for the radiometric and colorimetric calibration and image processing for the primary remote-sensing science camera system during mission operations. An emulator for the camera system has been developed, which has provided the data for industry partners to develop and validate operational procedures and data processing software systems. The research has also led to impact in the area of society, culture and creativity, and will ultimately provide a foundation for answering the question of whether there is life beyond Earth.

2. Underpinning research (indicative maximum 500 words)

The ExoMars 2022 mission will place a rover developed by the European Space Agency and a landing platform developed by Roscosmos on the surface of Mars in June 2023 with the objective of finding out if Mars does, or has ever, harboured life. This is the second of a two-part mission which has received a total investment of over EUR1,300,000,000. The Department of Physics (in collaboration with the Department of Computer Science) at Aberystwyth University (AU) is contributing to the objectives of the mission through involvement with three of the key remote sensing instruments – PanCam [3.1], ISEM [3.2] and CLUPI [3.3]. These instruments will be used to identify the best locations to use the limited resources of the life detection instruments on board the rover, and so the success of the mission is dependent on the accuracy and precision of their results.

AU personnel have worked on several streams of research which are key to ensuring the success of the remote sensing instruments and mission:

1. ***Aberystwyth University PanCam Emulator (AUPE).*** The long development cycle of a space instrument and the delicate nature of flight hardware means all the testing and rehearsals leading up to the mission must be carried out with emulator instruments. AUPE was designed and built at AU, providing representative PanCam data from rugged and reliable field portable instruments. It has been used for numerous international field trials [3.4] and mission simulations [3.5].

2. ***Flight Hardware.*** The Aberystwyth team designed, manufactured and characterised the Pancam Calibration Target (PCT) which will be used for in-situ radiometric calibration activities of both PanCam and ISEM on Mars [3.1; 3.2]. The PCT provides a set of eight calibrated reflectance standards which will be used to:

i. measure the incident solar illumination,
ii. obtain reflectance measurements
iii. provide a colour reference.

The PCT is also duplicated in miniature for the CLUPI instrument [3.3].

3. ***Data Processing and Visualisation.*** The AU Team are leading [3.11] and collaborating [3.8; 3.9] on several projects which are developing both the radiometric and geometric data processing pipelines, analysis software and visualisation tools. AU are responsible for developing the radiometric processing pipeline, and lead the radiometric and spectral analysis software development team. They work closely with the Johanneum Research geometric processing team, as well as the analysis and visualisation teams [3.1].

4. ***Calibration and cross calibration.*** AU personnel lead the PanCam calibration team responsible for pre-flight calibration of the instrument and cross calibration with the other remote sensing payload instruments. This calibration will ensure the instrument teams will be able to work together to achieve the mission objectives [3.1; 3.2; 3.3].

3. References to the research (indicative maximum of six references)

3.1 AJ Coates, R Jaumann, AD Griffiths, CE Leff, N Schmitz, J-L Josset, G Paar, **M Gunn**, E Hauber, CR Cousins, RE Cross, P Grindrod, JC Bridges, M Balme, S Gupta, IA Crawford, P Irwin, R Stabbins, D Tirsch, JL Vago, T Theodorou, M Caballo-Perucha, GR Osinski, and the PanCam Team. “The PanCam Instrument for the ExoMars Rover.” Astrobiology. July 2017, 17(6-7): 511-541. DOI: 10.1089/ast.2016.1548

3.2 OI Korablev, Y Dobrolensky, N Evdokimova, AA Fedorova, RO Kuzmin, SN Mantsevich, EA Cloutis, J Carter, F Poulet, J Flahaut, A Griffiths, **M Gunn**, N Schmitz, J Martín-Torres, M-P Zorzano, DS Rodionov, JL Vago, AV Stepanov, AY Titov, NA Vyazovetsky, AY Trokhimovskiy, AG Sapgir, YK Kalinnikov, YS Ivanov, AA Shapkin, AY Ivanov. “Infrared Spectrometer for ExoMars: A Mast-Mounted Instrument for the Rover.” Astrobiology. July 2017, 17(6-7): 542-564. DOI: 10.1089/ast.2016.1543

3.3 J-L Josset, F Westall, BA Hofmann, J Spray, C Cockell, S Kempe, AD Griffiths, MC De Sanctis, L Colangeli, D Koschny, K Föllmi, E Verrecchia, L Diamond, M Josset, EJ Javaux, F Esposito, **M Gunn**, AL Souchon-Leitner, TRR Bontognali, O Korablev, S Erkman, G Paar, S Ulamec, F Foucher, P Martin, A Verhaeghe, M Tanevski, JL Vago. “The Close-Up Imager Onboard the ESA ExoMars Rover: Objectives, Description, Operations, and Science Validation Activities.” Astrobiology. July 2017, 17(6-7): 595-611. DOI: 10.1089/ast.2016.1546

3.4 JK Harris, CR Cousins, **M Gunn**, PM Grindrod, D Barnes, IA Crawford, RE Cross, AJ Coates. “Remote detection of past habitability at Mars-analogue hydrothermal alteration terrains using an ExoMars Panoramic Camera emulator.” Icarus 2015, 252 : 284-300. DOI: 10.1016/j.icarus.2015.02.004

3.5 Balme, MC Curtis-Rouse, S Banham, D Barnes, R Barnes, A Bauer, CC Bedford, JC Bridges, FEG Butcher, P Caballo, A Caldwell, AJ Coates, C Cousins, JM Davis, J Dequaire, P Edwards, P Fawdon, K Furuya, M Gadd, P Get, A Griffiths, PM Grindrod, **M Gunn**, S Gupta, R Hansen, JK Harris, LJ Hicks, J Holt, B Huber, C Huntly, I Hutchinson, L Jackson, S Kay, S Kyberd, HN Lerman, M McHugh, WJ McMahon, J-P Muller, T Ortner, G Osinski, G Paar, LJ Preston, SP Schwenzer, R Stabbins, Y Tao, C Traxler, S Turner, LG Tyler, S Venn, H Walker, T Wilcox, J Wright, B Yeomans. "The 2016 UK Space Agency Mars Utah Rover Field Investigation (MURFI)." Planetary and Space Science. 2019, 165 : 31-56. DOI: 10.1016/j.pss.2018.12.003

Research Grants

3.6 M Gunn, (PI),Stereo Wide-Angle Cameras for the ExoMars PanCam Instrument – Parts D-G; UK Space Agency; 2015-2020; GBP435,000 [(D) 2015; GBP40,000, (E) 2015-2018; GBP200,000, (F) 2018-2019, GBP67,000, (G) 2019-2020; GBP128,000].

3.7 M Gunn (PI with Imperial College London); Quantitative 3D analysis and validation of terrestrial analogues for ancient Martian habitable environments in preparation for the 2018 ExoMars Rover; UK Space Agency; 2016-2019; GBP42,000

3.8 M Gunn (PI with University of St Andrews); Scientific integration and exploitation of ExoMars PanCam, CLUPI and ISEM; UK Space Agency; 2017-2020; GBP180,000

3.9 M Gunn (PI with Imperial College London); 3-D analysis of fracture networks and fine-scale sedimentary structures for reconstructing ancient Martian habitable environments; UK Space Agency; 2019-2022; GBP20,000

3.10 M Gunn (PI with the Open University); Martian aeolian processes and landforms at the ExoMars Rover site: from orbit to surface; UK Space Agency; 2019-2022; GBP8,000

3.11 M Gunn; Post launch radiometric calibration and data processing for the ExoMars PanCam instrument through compensation for atmospheric and deposited dust; UK Space Agency; 2020-2021; GBP137,000

4. Details of the impact (indicative maximum 750 words)

Impacts on the ExoMars mission and the search for life on Mars

The ExoMars rover will be the first to search directly for signs of life*: "Key to this quest will be the context instruments PanCam (a multiscale camera system) and ISEM (an infrared spectrometer for determining bulk mineralogy composition), both mounted on the rover mast."* [5.2]. According to a leading ExoMars project Scientist at the European Space Agency (ESA*): "The Departments of Physics and Computer Science at Aberystwyth University (AU) have played a key role in the development, calibration, and testing of PanCam and ISEM."* [5.2].

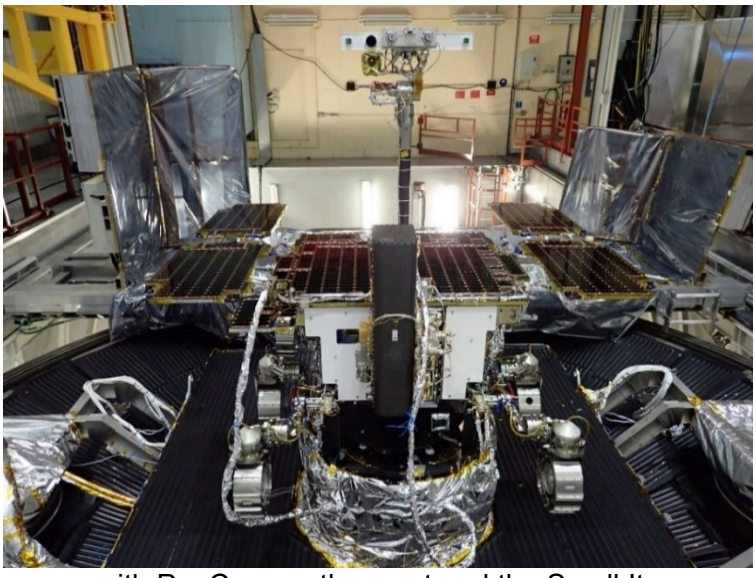

Figure 1: ExoMars rover with PanCam on the mast and the Small Items mounted on the deck (image courtesy of ESA)

Our research has validated the performance of the science payload instruments: *"thanks to the results obtained by AU, we have great confidence in the flight instruments' ability to fulfil their mission objectives."* [5.2].

Our research and development of the PanCam emulator has made key contributions to the preparations for the surface mission:

> *"(AUPE) has underpinned over a decade of field trials in preparation for Rosalind Franklin's mission. AUPE has allowed developing analysis tools and techniques,*

rehearsing operations, and training investigators. The AU lead on the development of an instrument for field testing has proven critical for the design and success of the mission." [5.2].

This view is shared by the Space Robotics & Instruments Team Lead at Joanneum Research (JR):

"As an important jointly used asset, the Aberystwyth University PanCam Emulator (AUPE) system has been used for numerous laboratory and field trials over the last decade, which have provided test and reference data for our processing pipelines and analysis tools, provided benchmark data for end-to-end validation of workflows and support for field test campaigns to rehearse mission operations and train operators, and enabled industry to calibrate rover instruments, validate the calibration assets, and verify the instruments' performance." [5.1]

Figure 2: ExoMars PanCam 'Small Items' Engineering Model (image courtesy of M. de la Nougerede, UCL/MSSL)

Ongoing development of software and processes for operations ensure maximum return from the surface mission:

"the involvement of AU staff in preparing ExoMars has and continues to be fundamental for improving mission design, processes, streamlining operations, and getting us closer, in the not too distant future, to hopefully being able to find traces of life on Mars……..The contributions of the Aberystwyth team to the data processing pipelines and to data archiving will ensure that high quality data will be available when required for tactical (short term, day-to-day) rover operations, as well as for detailed scientific analysis for decades in the future." [5.2]

Impact on Commerce and Industry

We have worked closely with ESA and industry, applying our expertise to minimise costs associated with instrument testing and calibration and maximise the accuracy of results: *"Their quick and efficient work on the ExoMars rover, both when performing individual instrument calibration as well as Pan-Cam/ISEM cross calibration, has enabled industrial contractors to maintain their tight schedule."* [5.2]

The ongoing research at AU complements that of our industrial collaborators:

"JR implementing the stereovision chain and geometric calibration for the Beagle2 camera, whilst the Aberystwyth University departments of Physics and Computer Science provided robotic calibration & planning and radiometric calibration." [5.1]

Through our work on ExoMars we continue a long-standing partnership with international industrial collaborators:

> *"The JR Space Robotics and Instruments team has been working closely with researchers in the departments of Physics and Computer Science for more than 20 years, and their research has had a direct impact on our work on technical, scientific, strategic and economic level."* [5.1]

The impact of our research on JRs business is borne out by their commitment to future collaboration:

> *"I can conclude that the collaborators Aberystwyth University continues to be one of the most important international R&D partners of the JR Space Robotics and Instruments team. New challenges faced in forthcoming and planned planetary missions to Mars & other planets, Moon, Asteroids and Comets will be jointly tackled in good complement and synergy between the research entities, with JR emphasizing 3D vision & visualization, and Aberystwyth University being center of excellence in radiometry & calibration, instrument development, computer science and robotics*." [5.1]

Impact on Society

The ExoMars mission may be the first able to directly answer the long-standing question of whether we are alone in the universe: *"The Rosalind Franklin rover will be able to acquire —for the first time— subsurface samples and analyze them to search for molecular biosignatures of possible martian lifeforms."* [5.2].

Our role in the imaging instruments has enabled us to contribute to national outreach activities which have reached more than 310,000 people [5.3]:

> *"The research carried out by the departments of Physics and Computer Science at Aberystwyth University (AU) was a key part of the content in Destination Space Phase 2. The AU researchers provided crucial expertise on the Mars elements of the activities and workshops." "The descriptions of how a camera is built, tested, and operated on another planet will help the public to relate to the images when the ExoMars mission is underway."* [5.3]

Using our research on the Martian environment, we developed exhibits to improve public engagement. Significant use has been made by the UK Association for Science Discovery Centres, according to their Space & Physics project Manager:

> *"The Mars surface models developed and produced by Aberystwyth were very popular and provided a great, hands-on way to show people what Mars looks like, and where various mission have landed and explored. Visitor feedback has been overwhelmingly positive, and the exhibits have greatly increased public awareness of ExoMars."* [5.3]

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 Testimonial from Space Robotics & Instruments Team Lead, Joanneum Research
5.2 Testimonial from ExoMars Project Scientist, ESA
5.3 Testimonial from the Space & Physics Project Manager, Association of Science Discovery Centres