CHRIS HEIRWEGH **| he | him | his |** 04/2023

Jet Propulsion Laboratory, California Institute of Technology
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EDUCATION

Ph.D. Applied and Industrial Physics 2009 – 2014
Guelph-Waterloo Physics Institute (GWPI), Guelph, ON, Canada
Dissertation: Studies of Light Element X-ray Fundamental Parameters Used in PIXE
Supervisors: Profs. John L. (Iain) Campbell and Joanne O'Meara

M.Sc. Medical Physics 2006 – 2008
Department of Medical Physics, McMaster University, Hamilton, ON, Canada
Thesis: *In Vivo* Quantification of Bone Strontium Using X-Ray Fluorescence
Supervisor: Prof. David R. Chettle

Continuing Education Program 2004 – 2006
McMaster University, Hamilton, ON, Canada
English, economics, biology, chemistry and medical physics

B.Sc. Physical Science – *Honours degree* 2000 – 2004
McMaster University, Hamilton, ON, Canada

AWARDS AND CERTIFICATES

Plenary Speaker & Session Chair – 71st Denver X-ray Conference, Bethesda, Maryland 2022
Team Award – PIXL ops development and testing leading to successful commissioning, *JPL* 2021
Voyager Award – For exceptional achievement as Science-Engineering Liaison, *JPL* 2021
Invited Speaker – European X-ray Spec. Assoc. Virtual Meeting, *Budapest, Hungary* 2021
Invited Speaker – 70th Denver X-ray Conference (virtual), *Westminster, Colorado* 2021
Certificate of Recognition - Dedication to completion of PXL Flight Sensor Assembly, *JPL* 2020
Invited Speaker – Physics Dept. Colloquium, *University of Guelph, Guelph, Canada* 2020
Invited Speaker – 67th Denver X-ray Conference, *Westminster, Colorado* 2018
Best Poster Award – 2nd place, 14th PIXE conference, *Somerset West, South Africa* 2015

CHRIS HEIRWEGH | he | him | his | 04/2023

PROFESSIONAL EXPERIENCE

Research Scientist
Planetary Science Section, Jet Propulsion Laboratory, Pasadena CA, USA

Concept developer – In situ Microcalorimeter X-ray Detector	2023 –
Concept co-developer – uber PIXL & SHERLOC for Mars Sample return	2023 –
Operations Manager of the PIXL Science team for Mars 2020	2021 –
Research Collaborator and elemental calibration lead on PIXL	2021 –
Director of the PIXL Science Lab	2018 –
Team leader and co-developer of PIQUANT, PIXL's analytical software	2018 –
Consultant for development of PIXLISE, PIXL's GUI software	2018 –
Principle Investigator (PI) of a pyro-electric X-ray instrument, NASA R&TD	2018 – 2021
Engineering – Science Liaison for PIXL Integration and Testing (IT) program	2018 – 2019
Test development consultant and analyst for PIXL IT program	2018 – 2019

Caltech Postdoctoral Fellow & JPL Postdoctoral Scholar 2016 – 2018
Planetary Science Section, Jet Propulsion Laboratory, Pasadena CA, USA

PIXL Elemental Calibration Test Lead – developed framework for calibration plan
Researcher – Micro-focused XRF elemental calibration research
Software design consultant and alpha tester for PIQUANT software development

Postdoctoral Fellow 2014 – 2016
Guelph PIXE Group, Guelph-Waterloo Physics Institute, Guelph, ON, Canada

Researcher
Refined the elemental quantification procedure used to analyze light elements in geological materials using Proton Induced X-ray Emission (PIXE)
Influence of multi-vacancy X-rays satellite effects in analyzing alpha-particle X-ray spectrometer (APXS) spectra obtained from the Curiosity Rover - Mars Science Laboratory (MSL).
Beamline refurbishment – design and implementation of a magnetic proton deflection system
Instructor
Sessional Lecturer: Radiation and Radioactivity – 3rd year undergraduate course in physics

Graduate Student – Doctor of Philosophy 2009 – 2014
Guelph-Waterloo Physics Institute, Guelph, ON, Canada

Researcher
Investigated non-Gaussian line-shapes in semi-conductor spectra
Produced new measurement of the K X-ray fluorescence yield parameter of silicon
Assessed accuracy of light element mass attenuation coefficients used by proton-induced X-ray emission (PIXE) analysis of geological materials
Teaching Assistant
Courses in 1st year physics, class tutoring and lab supervision

Graduate Student – Master of Science 2006 – 2008
Department of Medical Physics, McMaster University, Hamilton, ON, Canada

Research
Compared MRI, ultrasound, CT imaging methods to accurately measure soft-tissue thickness
Assessed feasibility of quantifying bone strontium *ex vivo* using XRF
Teaching Assistant
Courses in 1st year physics and 1st year statistics, class tutoring and lab supervision

Summer Intern 2003
Juravinski Cancer Centre, Department of Research, Hamilton, ON, Canada
Temporary Research Assistant - studied anti-angiogenetic properties of doxycycline on avian embryos *in vivo*

RESEARCH INTERESTS

Development of X-ray instrument concepts for use on spacecraft
Application of spectroscopic analysis techniques to planetary science research
Semiconductor detector physics and spectral line-shapes peak fitting
X-ray fundamental parameter accuracy refinement
Energy- and wavelength-dispersive X-ray analysis methods
Charge-induced multiple-shell vacancy effects on X-ray emission
Radiation and radioactivity
Medical physics applications of radiation

PUBLICATIONS

D. A. K. Pedersen, C. C. Liebe, J. Henneke, J. L. Jørgensen, R. Sharrow, T. Setterfield, L. Wade, M. Sondheim, M. Foote, W. T. Elam, C. M. Heirwegh, J. Hurowitz, A. Allwood, Pre-flight Geometric and Optical Calibration of the Planetary Instrument for X-ray Lithochemistry (PIXL), Space Sci. Rev. **219**, 11. doi:10.1007/s11214-023-00955-1

B. J. Orenstein, D. T. Flannery, L. W. Casey, W. T. Elam, C. M. Heirwegh, M. W. M. Jones, A statistical approach to removing diffraction from X-ray fluorescence spectra. *Spectrochimica Acta B*, **200**, 106603. doi:10.1016/j.sab.2022.106603

Y. Liu, M. M. Tice, M. E. Schmidt, A. H. Treiman, T. V. Kizovski, J. A. Hurowitz, J. Henneke, D. A. K. Pedersen, S. J. VanBommel, M. W. M. Jones, et al., An olivine cumulate outcrop on the floor of Jezero crater, Mars, *Science*, **377** (2022) 515 – 1519. 2022. doi:10.1126/science.abo2756

S. J. VanBommel, J. A. Berger, E. B. Rampe, C. M. Heirwegh, Chp. 11: In-Situ X-ray Spectrometers in Space Exploration, in Advances in Portable X-ray Fluorescence Spectrometry: Instrumentation, Application and Interpretation. Royal Society of Chemistry (2023). doi:10.1039/9781839162695-00298

C. M. Heirwegh, W. T. Elam, L. P. O'Neil, K. P. Sinclair, A. Das, The Focused Beam X-ray Fluorescence Elemental Quantification Software Package PIQUANT, *Spectrochim. Acta B*, **196** (2022) 106520. doi:10.1016/j.sab.2022.106520.

W.T. Elam, C.M. Heirwegh, PIQUANT (Version 3.2.11) [Open source computer software] Zenodo. (2022) doi:10.5281/zenodo.6959225

C. M. Heirwegh, M. Petric, S. Fazinić, M. Kavčič, I. Božičević Mihalić, J. Schneider, I. Zamboni, J. L. Campbell, Corrigendum to "Multiple ionization X-ray satellites of Mg, Al and Si in alpha particle PIXE" [Nucl. Inst. Methods Phys. Res., B 428C (2018) 9-16], *Nucl. Instrum. Meth. B.* **526** (2022) 60 – 61. doi:10.1016/j.nimb.2022.06.014

J. L. Campbell, D. J. T. Cureatz, E. L. Flannigan, C. M. Heirwegh, J. A. Maxwell, J. L. Russell, S. M. Taylor, The Guelph PIXE Software Package V. *Nucl. Instrum. Meth. B.*, **499** (2021) 77 – 88. doi:10.1016/j.nimb.2021.05.004

A. C. Allwood, L. A. Wade, M. C. Foote, et al., PIXL: Planetary Instrument for X-ray Lithochemistry (vol 216, 134, 2020), *Space Sci. Rev.* **217** (2021) 28. doi:10.1007/s11214-021-00801-2

A. C. Allwood, L. A. Wade, M. C. Foote, et al., PIXL: Planetary Instrument for X-ray Lithochemistry, *Space Sci. Rev.* **216** (2020) 134. doi:10.1007/s11214-020-00767-7

A. C. Allwood, M. T. Rosing, D. T. Flannery, J. A. Hurowitz, C. M. Heirwegh, "Reassessing Evidence of Life in 3,700 million year old rocks of Greenland," *Nature* **563** (2018) 241 – 244. doi:10.1038/s41586-018-0759-x

C. M. Heirwegh, W. T. Elam, D. T. Flannery, A. C. Allwood, An empirical derivation of the x-ray optic transmission profile used in calibrating the Planetary Instrument for X-ray Lithochemistry (PIXL) for Mars 2020, *Powder Diffraction Journal* **33** (2018) 162 – 165. doi:10.1017/S0885715618000416

C. M. Heirwegh, M. Petric, S. Fazinić, M. Kavčič, I. Božičević Mihalić, J. Schneider, I. Zamboni, J. L. Campbell, Multiple ionization X-ray satellites of Mg, Al and Si in alpha particle PIXE, *Nucl. Instrum. Meth. B.* **428** (2018) 9 – 16. doi:10.1016/j.nimb.2018.05.005

S. Menachekanian, D. T. Flannery, C. M. Heirwegh, M. L. Tuite, C. S. Jamieson, R. Hodyss, K. Williford, "Investigating photochemical effects of micro-XRF analysis on common geochemical compounds," *Advances in X-Ray Analysis* (2018) 61.

J. L. Campbell, B. Ganly, C. M. Heirwegh, J. A. Maxwell, Separation of detector non-linearity issues and multiple ionization satellites in alpha-particle PIXE, *Nucl. Instrum. Meth. B.* 414 (2018) 38 – 44. doi:10.1016/j.nimb.2017.10.001

E. L. Flannigan, C. M. Heirwegh, J. L. Campbell, Role of the mass attenuation coefficient database in

standardization of a silicon drift X-ray detector for PIXE analysis, *X-Ray Spectrom.* 47 (2018) 63 - 71. doi:10.1002/xrs.2812

J. L. Campbell, C. M. Heirwegh, B. Ganly, Non-linearity issues and multiple ionization satellites in the PIXE portion of spectra from the Mars alpha particle X-ray spectrometer, *Nucl. Instrum. Meth. B* **383** (2016) 143 – 151. doi:10.1016/j.nimb.2016.07.004

C. M. Heirwegh, J. L. Campbell, G. K. Czamanske, Refinement of major- and minor-element PIXE analysis of rocks and minerals, *Nucl. Instrum. Meth. B* **336** (2016) 40 - 50. doi:10.1016/j.nimb.2015.10.018

C. M. Heirwegh, I. Pradler, J. L. Campbell, Choice of mass attenuation coefficients for PIXE analysis of silicate minerals and rocks, *X-ray Spectrom.* **44** (2015) 63 - 68. doi:10.1002/xrs.2583

C. M. Heirwegh, I. Pradler, J. L. Campbell, An accuracy assessment of photo-ionization cross-section databases for 1-2 keV x-rays in light elements using PIXE, *J. Phys. B: At. Mol. Opt. Phys.* **46** (2013) 185602. doi:10.1088/0953-4075/46/18/185602

T. L. Hopman, C. M. Heirwegh, J. L. Campbell, M. Krumrey, F. Scholze, An accurate determination of the K-shell fluorescence yield of silicon, *X-ray Spectrom.* **41** (2012) 164 - 171. doi:10.1002/xrs.2378

C. M. Heirwegh, D. R. Chettle, A. Pejović-Milić, *Ex vivo* evaluation of a coherent normalization procedure to quantify *in vivo* finger strontium XRS measurements, *Med. Phys.* **39** (2012) 832 - 841. doi:10.1118/1.3673787

C. M. Heirwegh, D. R. Chettle, A. Pejović-Milić, Evaluation of imaging technologies to correct for photon attenuation in the overlying tissue for *in vivo* bone strontium measurements, *Phys. Med. Biol.* **55** (2010) 1083 - 1098. doi:10.1088/0031-9155/55/4/012

MEDIA AND OUTREACH

Interviews

The Scientists Behind the Science on Mars, Applied Spectroscopy on Mars, Society for Applied Spectroscopy, 2022.

Perseverance Mars Mission Interview: Abigail Allwood and Chris Heirwegh – SAS eNews, Society for Applied Spectroscopy, Newmarket, MD, USA, 07/2021

Ancient Life on Mars? U of G Grad Aims to Find Out – Portico, University of Guelph, Guelph, ON Canada, 04/02/2021

***Simcoe scientist helping NASA find signs of ancient life on* Mars** – The Hamilton Spectator, Hamilton, ON Canada, 03/02/2021

NASA's New Mars Rover Will Use X-Rays to Hunt Fossils – JPL Media Coverage, JPL, Pasadena, CA USA, 09/22/2020

Simcoe native helps prepare Mars Perseverance – The Simcoe Reformer, Simcoe, ON Canada, 08/12/2020

Public Speaking Engagements

Exploration of Mars using Physics and X-ray Fluorescence Spectroscopy, Simcoe Lions Club, Simcoe, ON Canada, 01/20/2022.

The Role of X-ray Spectroscopy in Investigating the Red Planet – 6th grade class, Grimsby Elementary School, Grimsby, ON Canada, 12/17/2020.

The Role of X-ray Spectroscopy in Investigating the Red Planet, Simcoe Rotary Club, Simcoe, ON Canada, 11/03/2020

MENTORSHIP AND TEACHING

Host of JPL Visiting Scientist (3 mos.)
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
Brianna Ganly (CSIRO, AUS) – Perseverance rover calibration of PIXL 2023

Postdoc Advisor
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
Anusheela Das – Micro-XRF X-ray optics and quantification research 2022 - Present

Sessional Lecturer
Guelph-Waterloo Physics Institute, Guelph, ON, Canada
Clinical Applications of Physics in Medicine – senior undergraduate/graduate course 2021
Radioactivity and Radiation Interactions - 3rd year undergraduate physics course. 2015

Intern Advisor 2017 – 2019
Early career JPL employee and undergraduate university students participating in the JPL summer research internship opportunities. Two students in 2017, four in 2018, one in 2019.

Academic Co-Supervisor 2015 - 2016
M.Sc. student in applied physics – University of Guelph, Guelph, Canada
Dept. of Physics, University of Guelph, Guelph, Ontario

Teaching Assistant
Year 1 physics labs and tutorials, Physics, University of Guelph, Guelph, Canada 2009 – 2012

Year 1 statistics labs and tutorials, Math, McMaster University, Hamilton, Canada 2008
Year 1 physics labs, Physics, McMaster University, Hamilton, Canada 2004 – 2008

CONFERENCES, POSTERS AND WORKSHOPS (* - presenter)

C. M. Heirwegh, A. Das, B. P. Ganly, W. T. Elam, Y. Liu, L. A. Wade, N. Gao, XRF Research Developments for the Calibration of PIXL. *54th LPSC* (2023) Abstract 1708.

C. M. Heirwegh*. PIXL's Recent X-Ray Data and Findings from the Red Planet (Plenary) Denver X-ray Conference, August 2022, Bethesda, Mayland, USA.

E. C. Fayolle, A. C. Noell, P. V. Johnson, R. P. Hodyss, C. Heirwegh, M. Braun, J. Hein, Viability of Bacterial Spores Under Icy World Surface Conditions. *53rd LPSC* (2022) Abstract 1785.

C. M. Heirwegh*. The Mars 2020 Mission and the Elemental Calibration of the Planetary Instrument for X-ray Lithochemistry (PIXL) (Invited Talk) Denver X-ray Conference, August 2021, Virtual.

C. M. Heirwegh, Y. Liu, B. C. Clark, W. T. Elam, L. P. O'Neil, K. P. Sinclair, M. Tice, J. A. Hurowitz, A. C. Allwood, Calibrating the PIXL Instrument for Elemental Analysis of Mars, *52nd LPSC* (2021) Abstract 1260.

C. M. Heirwegh*, N. Tallarida, L. A. Wade. Positioning capabilities of the Planetary Instrument for X-ray Lithochemistry (Presentation) Joint meeting – 68th Denver X-ray Conference and 25th International Congress of X-ray Optics and Microanalysis, August 2019, Chicago, Illinois, USA.

H. Munguia-Flores, B. H. Zhong, K. Uckert, R. P. Hodyss, C. M. Heirwegh*, Concept testing of a low power pyroelectric X-ray source for application in planetary explorations (Poster - DXC) Joint meeting – 68th Denver X-ray Conference and 25th International Congress of X-ray Optics and Microanalysis, August 2019, Chicago, Illinois, USA.

C. M. Heirwegh*, B. C. Clark, A. C. Allwood, D. T. Flannery, J. A. Hurowitz, W. T. Elam, Evaluating perspectives from past missions to shape future investigations using the Mars 2020 Planetary Instrument for X-ray Lithochemistry (Invited talk) 67th Denver X-ray Conference, August 2018, Westminster, Colorado, USA.

M. Kavčič, M. Petric, S. Fazinić*, I. Božičević Mihalić, I. Zamboni, C. M. Heirwegh, J. Schneider, J. L. Campbell, Multiple ionization of K X-ray satellites of Mg, Al, Si in alpha particle PIXE. (Poster) EXRS 2018 – European Conf. on X-ray Spectrometry, June 2018, Ljubljana, Slovena.

C. M. Heirwegh*, W. T. Elam, D. T. Flannery, A. C. Allwood, A first look at the quantification

capabilities of the prototype Mars 2020 Planetary Instrument for X-ray Lithochemistry. (Presentation) 24th International Congress on X-ray Optics and Microanalysis, September 2017, Trieste, Italy.

S. Menachekanian*, D. T. Flannery, M. L. Tuite, C. M. Heirwegh, A. C. Allwood, C. S. Jamieson, R. Hodyss, K. Williford, Investigating photochemical effects of micro-XRF analysis on common geochemical compounds. (Poster) 66th Denver X-ray Conference, July 2017, Big Sky, Montana, USA.

C. M. Heirwegh*, W. T. Elam, D. T. Flannery, A. C. Allwood, Calibration of a μ-XRF prototype instrument used in modelling the performance of the Planetary Instrument for X-Ray Lithochemistry (PIXL) for Mars 2020. (Presentation) 66th Denver X-ray Conference, July 2017, Big Sky, Montana, USA.

E. L. Flannigan*, J. L. Campbell, C. M. Heirwegh, Standardization of a silicon drift detector using PIXE. (Poster) 15th International Conference on Particle Induced X-Ray Emission, April 2017, Split, Croatia.

C. M. Heirwegh, J. L. Campbell J L*. Spectrum artefacts due to non-linear response in silicon drift detector systems (Poster) 15th International Conference on Particle Induced X-Ray Emission, April 2017, Split, Croatia.

C. M. Heirwegh*. Improvement to Major Element PIXE Analysis through Accuracy Assessment of Mass Attenuation Coefficients (Presentation) Symposium on Applications of Fundamental Parameters in X-ray Analysis, June 3-4, 2016, University of Western Ontario, London, Canada.

C. M. Heirwegh*, J. L. Campbell. Refinement of major and minor element PIXE analysis of rocks and minerals (Presentation) 14th International Conference on Particle Induced X-Ray Emission, February 2015, Somerset West, South Africa.

J. L. Campbell, J. L. Russell, J. A. Maxwell, C. M. Heirwegh*, GUPIX and GUMAP (Presentation) 14th International Conference on Particle Induced X-Ray Emission, February 2015, Somerset West, South Africa.

C. M. Heirwegh*, I. Pradler, J. L. Campbell, Comparison of x-ray mass attenuation coefficients used in PIXE analysis of silicate minerals and glasses. (Poster) 14th International Conference on Particle Induced X-Ray Emission, February 2015, Somerset West, South Africa.

C. M. Heirwegh*, I. Pradler, J. L. Campbell, A comparison of attenuation coefficient databases used in μ-PIXE analysis – XCOM, Chantler or…? (Presentation) 13th International Conference on Particle Induced X-Ray Emission, March 2013, Gramado, Brazil.

C. M. Heirwegh, I. Pradler, J. L. Campbell, A comparison of attenuation coefficient databases used in PIXE analysis – XCOM, Chantler or…? (Presented by M.-C. Lépy) 7th Workshop, International

Initiative on X-Ray Fundamental Parameters, March 25-26th, 2014, Paris, France.

C. M. Heirwegh*, R. Butler, D. R. Chettle, A. Pejović-Milić, Evaluation of MR, CT and ultrasound imaging modalities for estimation of finger soft-tissue thickness: efforts to improve normalization of in vivo strontium x-ray fluorescence measurements. (Presentation) June 2008, 7th Industrial Radiation and Radioisotopes Measurement Applications meeting, Prague, Czech Republic.

E. Da Silva*, C. Heirwegh, A. Pejović-Milić, V. Heyd. Use of hydroxyapatite bone composites for the calibration of in vivo EDXRF – based systems for bone strontium quantification. (Poster) June 2008, European Conference on X-ray Spectrometry, Cavtat, Dubrovnik, Croatia.

C. M. Heirwegh*. The use of chick chorioallantoic membranes in cancer research. (Presentation) November 2003, Canadian Undergraduate Physics Conference, McGill University, Montreal, Quebec, Canada.

SCHOLARLY AND PROFESSIONAL ACTIVITIES

Publication Peer Reviewer 2015 – 2022

Articles – Journal of Synchrotron Radiation
Articles – Advances in X-ray Analysis – Denver X-ray Conference Proceedings
Articles – Icarus
Articles – Journal of X-Ray Spectrometry
Communication - Nuclear Instruments and Methods A
Article - The Journal of Biological Trace Element Research
Conference proceeding - Nuclear Instruments and Methods B

Project Principle Investigator

NASA Research and Technological Development (R&TD) funded proposal

A Pyroelectric Instrument for Elemental Lithochemistry 2019 – 2021
Micro Focus XRF Quantification for Applications in Planetary Science (acting 3 mos.) 2018

Academic Supervisor

JPL Postdoctoral Fellow 2022
Undergraduate students of the JPL Summer Internship Program, JPL 2017 – 2019
Students in undergraduate and graduate research projects, U of Guelph 2015 – 2016

NASA new technology contributions

PIQUANT software release to open source 2022
PIXELATE, an Astrobiology visualization tool Software, NTR #50960 2018
PIQUANT X-ray Fluorescence Quantification Software. v.2, NTR #50887 2018

Accelerator Group Committee member

Accelerator Management Committee (AMC), University of Guelph, Canada 2012 – 2016

Quarterly meeting participation on accelerator operations, projects, upgrades, safety and funding.

Collaborations and Field work

University of Guelph – Emeritus Prof. Iain Campbell 2016 – present
Consultation on GUPIX software development and PIXE spectroscopy fitting issues

University of Western Ontario - guest of Prof. Lyudmila Goncharova. 2015
Feasibility study using Rutherford backscatter to measure thickness of thin Ti layers.

J. Stefan Institute, Ljubjlana, Slovenia – guest of Dr. M. Kavčič. 2014
Wavelength dispersive x-ray fluorescence measurements of Si satellite intensity

Soleil Synchrotron, St. Aubin, France – guest of Dr. M.-C. Lépy (CEA). 2013
Observed measurements of mass-attenuation coefficients in the soft x-ray region.

Xstrata Zinc Inc., Belldune, New Brunswick – supervisor: Dr. D. R. Chettle 2008
Performed bone lead XRF measurements on smelter workers as part of a multi-institutional project to monitor occupational lead levels *in vivo*.

JPL INTERNAL REPORTS

C. M. Heirwegh, W. T. Elam, "PIXL Flight Unit Elemental ReqID 76420 – Elemental Calibration Accuracy Report," *Bravo-Doc-2373632.* (June 24, 2020) 15 pages.

C. M. Heirwegh, M. C. Foote, W. T. Elam, "PIXL Elemental Composition Accuracy. ReqID 704208," *D-94107.* (June 9, 2020) 12 pages.

C. M. Heirwegh, W. T. Elam, K. P. Sinclair, "PIXL Flight Unit Detectable Elements 76419 Report," *Bravo-Doc-410.* (June 20, 2019) 16 pages.

C. M. Heirwegh, W. T. Elam, K. P. Sinclair, "PIXL Flight Unit Detectable Elements 76418 Report," *Bravo-Doc-2306924.* (June 10, 2019) 16 pages.