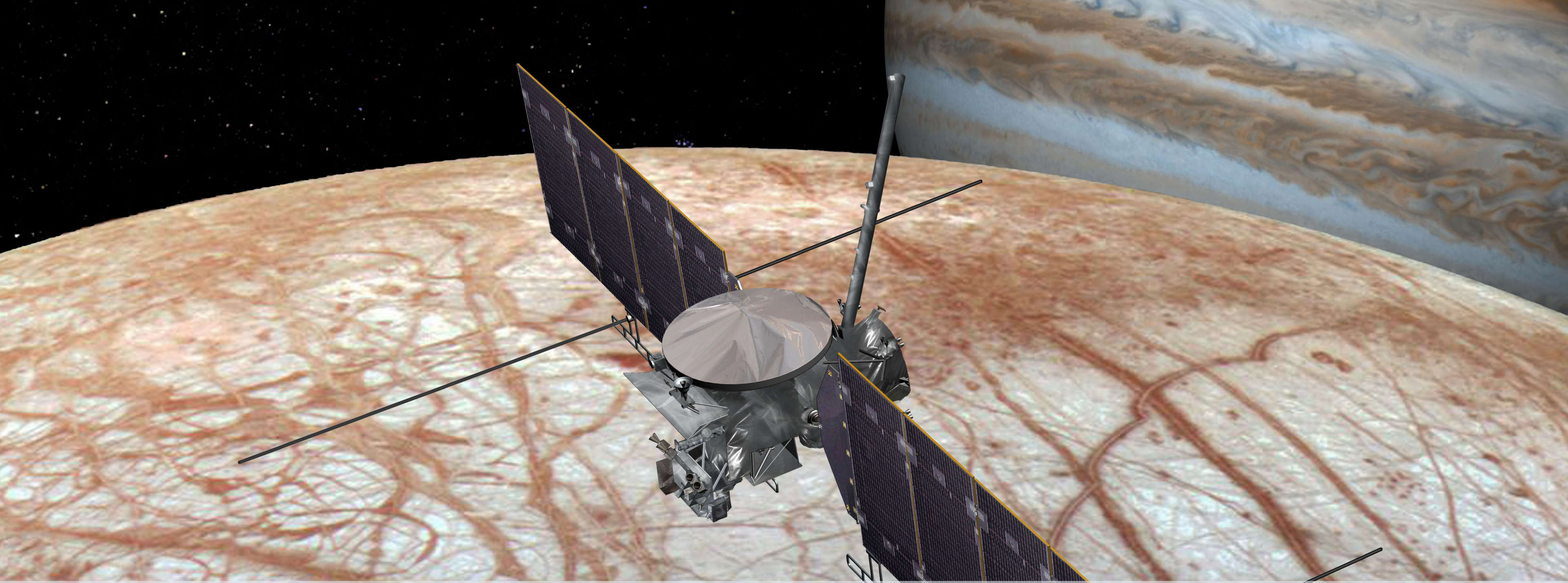

Virtual Research Presentation Conference

Responsive Onboard Science for the Europa Clipper Mission

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Program: Topics

RPC-129

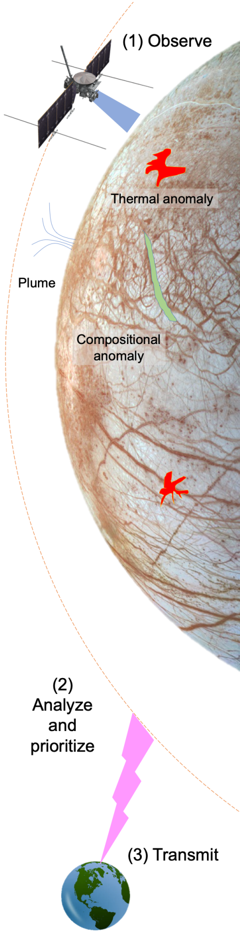
Introduction

Abstract

The **Europa Clipper** spacecraft will explore Jupiter's moon Europa to learn about its geology and potential habitability using a suite of scientific instruments. Answers to the many outstanding questions about Europa can be found by discovering certain **unexpected or unpredictable phenomena** such as thermal anomalies, compositional anomalies, or changes in its magnetic environment.

The baseline strategy for discovering such phenomena is through **systematic observation and serendipity**. However, the limited bandwidth and high latency in communication with the spacecraft make this strategy resource-intensive, and it precludes new observations being made quickly in response to discoveries not yet recognized by scientists on the ground. By developing tools to perform **detection and discovery onboard the spacecraft**, it is possible to increase the quality and quantity of science data collected by the mission through data summarization, downlink prioritization, and adaptive instrument mode switching.

In this work, we evaluate the **technical and practical feasibility** of implementing a set of algorithms for use onboard Europa Clipper, which will require the use of a radiation-hardened processor with limited computational capability. Our proposed framework is **successfully used to evaluate several machine learning algorithms** and informs directions for future development and deployment to Europa Clipper.



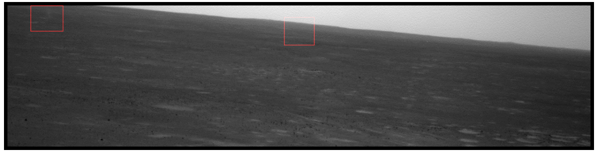
Problem Description

Increased spacecraft autonomy and automated ground-based processing can enable greater mission science productivity for Europa Clipper, set to launch in 2024.

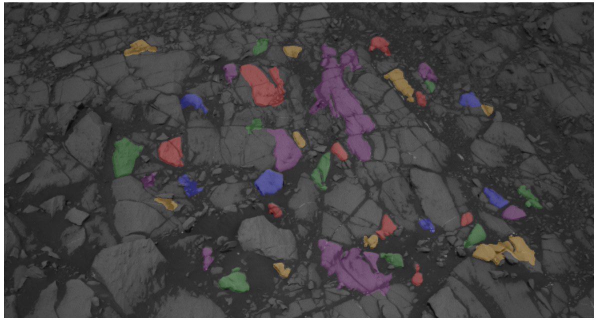
Relevant state of the art in spacecraft science autonomy includes:

- Dust Devil Detection (WATCH) on Mars Exploration Rovers (MER) [1]
- AEGIS Autonomous Targeting on MER and the Mars Science Laboratory (MSL) [2]
- Thermal and Spectral Anomaly Detection on the EO-1 Autonomous Sciencecraft Experiment [3, 4]

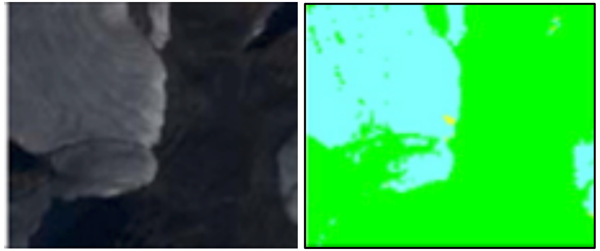
Dust Devil Detection



AEGIS Autonomous Targeting



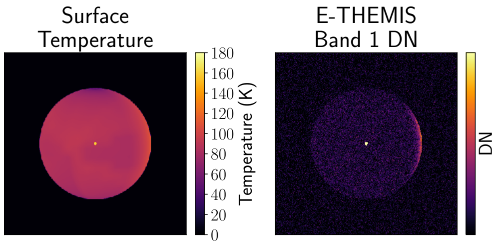
Sulfur Detection on EO-1



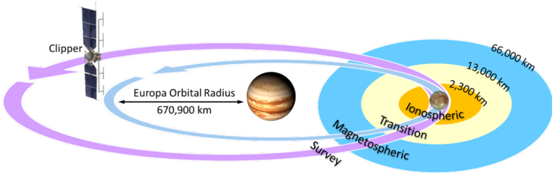
Background

Onboard data analysis algorithms previously developed and tested:

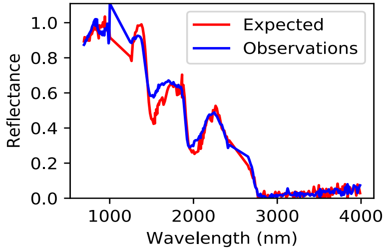
- Europa Thermal Emission Imaging System (E-THEMIS):
  - 3-Band Infrared Imager
  - Thermal Anomaly Detection [A]
- Plasma Instrument for Magnetic Sounding (PIMS):
  - Measures the counts of charged particles within energy bins
  - Ionosphere-Magnetosphere Boundary Detection [B]
- Mapping Imaging Spectrometer for Europa (MISE):
  - 421-band Imaging Spectrometer
  - Spectral Anomaly Detection [C]



Thermal Anomalies



Changes in Magnetic Environment



Compositional Anomalies

Methodology

Algorithms ported from Python to C and evaluated using:

1. Benchmarking (Computational and Memory Requirements)
   - Uses VxWorks running on a PowerPC 750 processor, an analogue to the RAD750 used by Europa Clipper
   - Record runtime and memory
2. Radiation Robustness Analysis
   - Uses BITFLIPS [5] running in the Linux Environment
   - Injects single-event upsets (SEUs), flipped bits in memory during program execution
   - Expected SEU rate at Jupiter: 10^{-19} SEU/KB-instruction

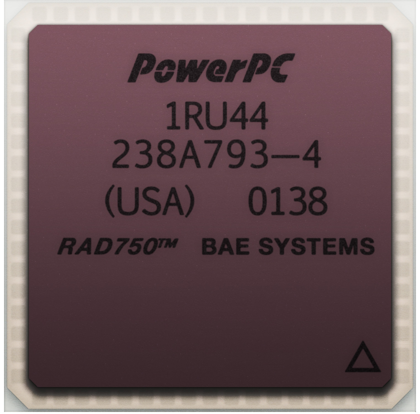
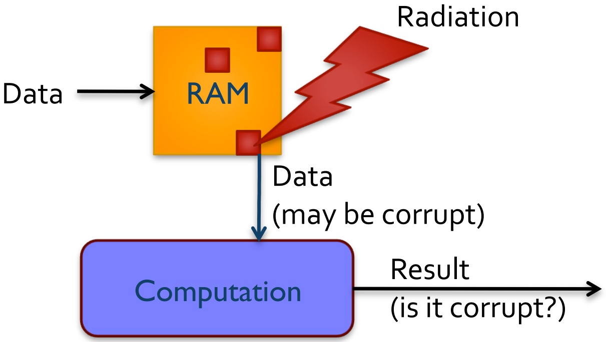
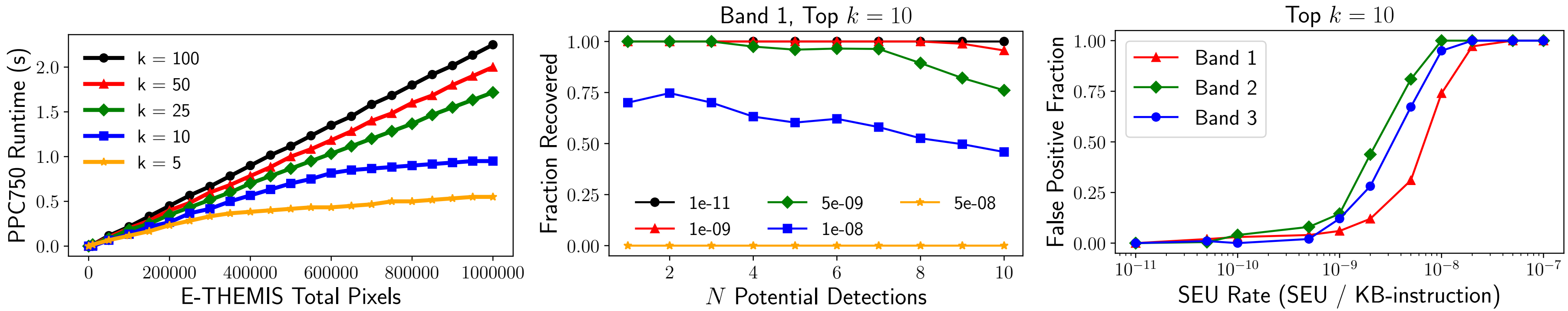


Image Credit: Henriok



Results: E-THEMIS Thermal Anomaly Detection



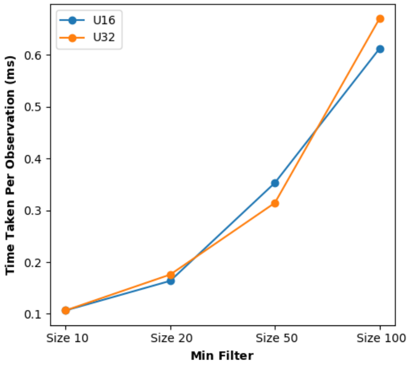
Left: E-THEMIS runtime (PPC750) as a function of number of pixels in the observation (x-axis) and maximum number of anomalies to record (k).

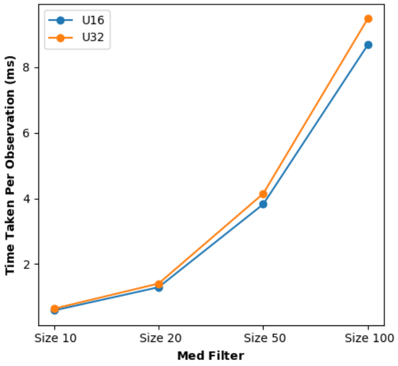
Center: Results showing the average fraction of top k = 10 thermal anomalies in E- THEMIS observations that are still recoverable as SEUs are introduced at various rates.

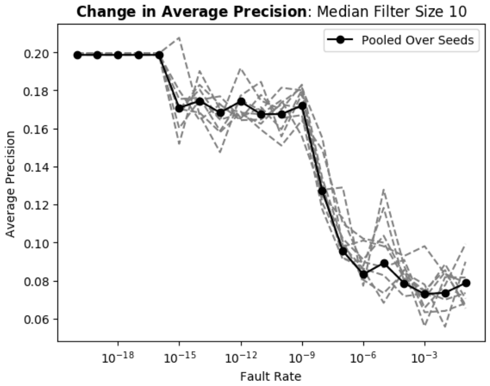
Right: The fraction of false positives within the top k = 10 identified anomalies in E-THEMIS observations for each band as a function of SEU rate.

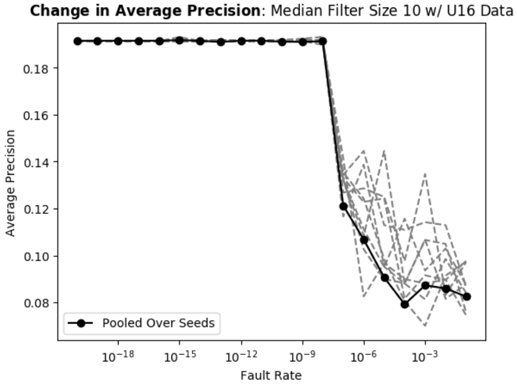
Algorithm can process E-THEMIS data with minimal computational and memory requirements, and is robust to radiation at many orders of magnitude above the expected rate (10^{-19} SEU/KB-instruction).

Results: PIMS Environmental Transition Detection







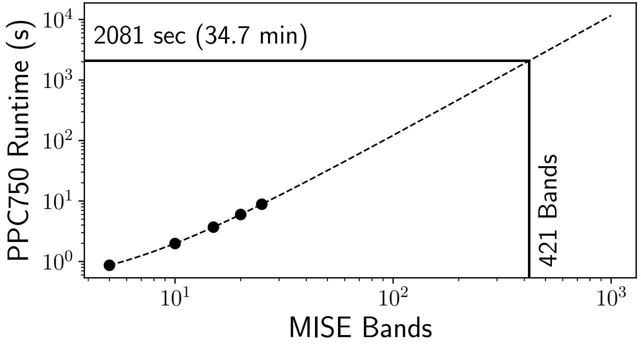


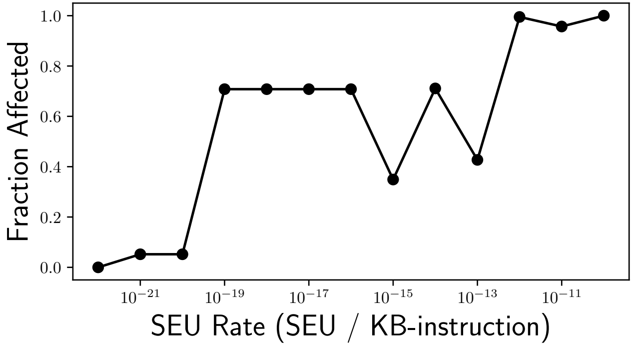
Left: PIMS L2-Diff algorithm runtime (PPC750) as a function of the filter window size, across various filters. A comparison using 16- and 32-bit representations of the data is also shown.

Right: Results showing how average precision is affected by SEU rate for them PIMS L2-Diff detection algorithm with a median filter. The left shows the effect for data in a 32-bit representation, and the right shows the same for data in a 16-bit representation. Dashed lines show variations across random seeds.

The L2-Diff algorithm can process data fast enough to accommodate the rate of data generation (2 Hz), and is robust to SEU rates exceeding those expected (10^{-19} SEU/KB-instruction).

Results: MISE Spectral Anomaly Detection





Left: MISE RX algorithm runtime (PPC750) as a function of the number of spectral channels. Runtime is extrapolated to full-sized observations with 421 channels.

Right: The fraction of the top k = 10 identified anomalies in MISE observations affected by radiation as a function of SEU rate.

The existing RX implementation requires improvements to reduce memory footprint and increase algorithm efficiency. It is currently sensitive to radiation at SEU rates expected at Europa (10^{-19} SEU/KB-instruction).

Conclusions and Future Work

- E-THEMIS and PIMS algorithms can be feasibly implemented onboard.
- The RX algorithm for MISE spectral anomaly detection requires future improvements to run efficiently and robustly onboard.
- Our evaluation methodology can be applied to other algorithms and missions.
- In the future, we will seek pathways for infusion into mission flight software as well as ground systems for automated analysis to assist scientists.

Acknowledgements

Special thanks to Ameya Daigavane, an intern who joined us to work on this project for two consecutive summers to make key contributions to PIMS algorithm development, analysis, implementation, and benchmarking.

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