# Efficient Endmember Detection onboard the EO-1 Spacecraft

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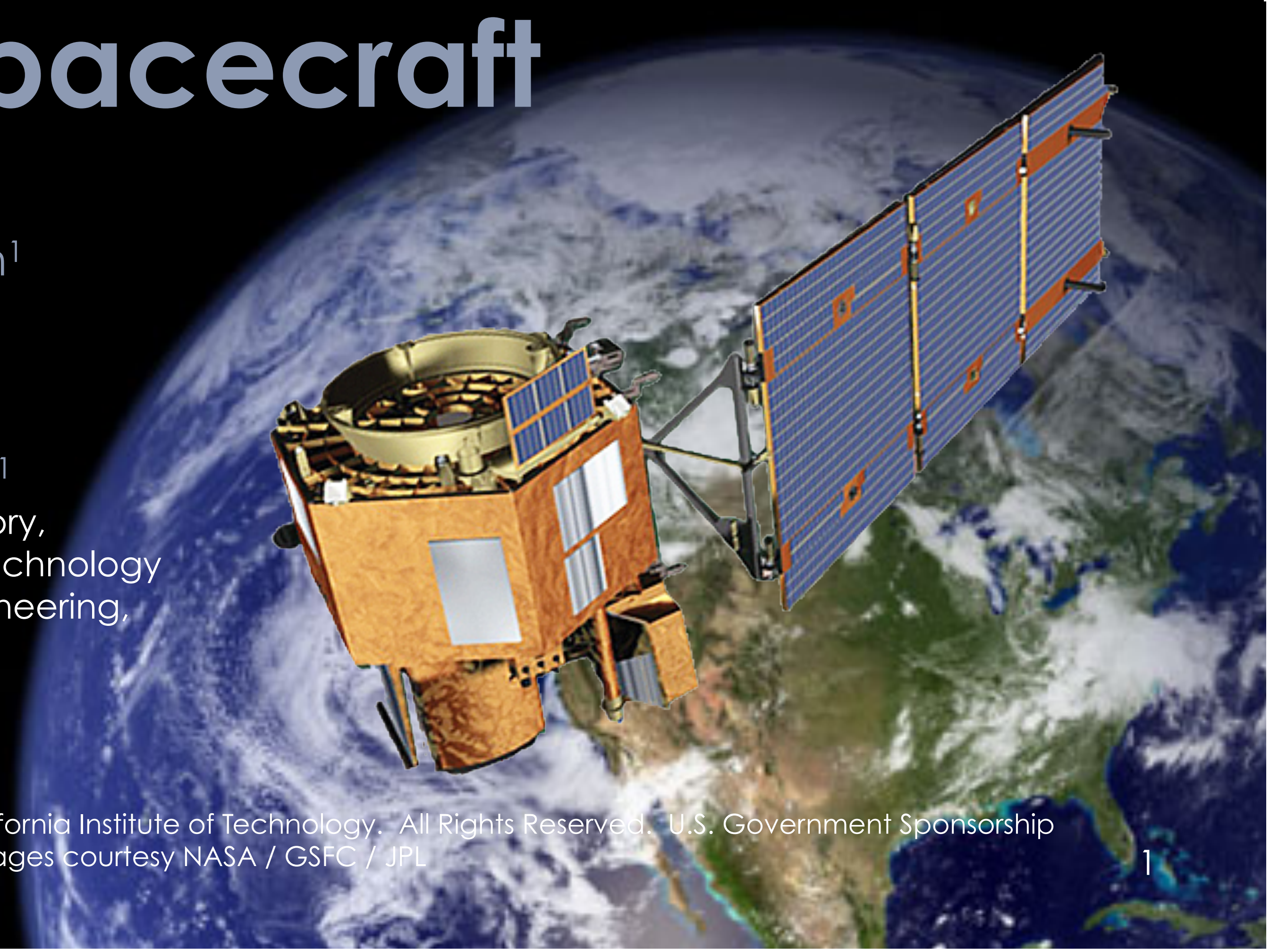
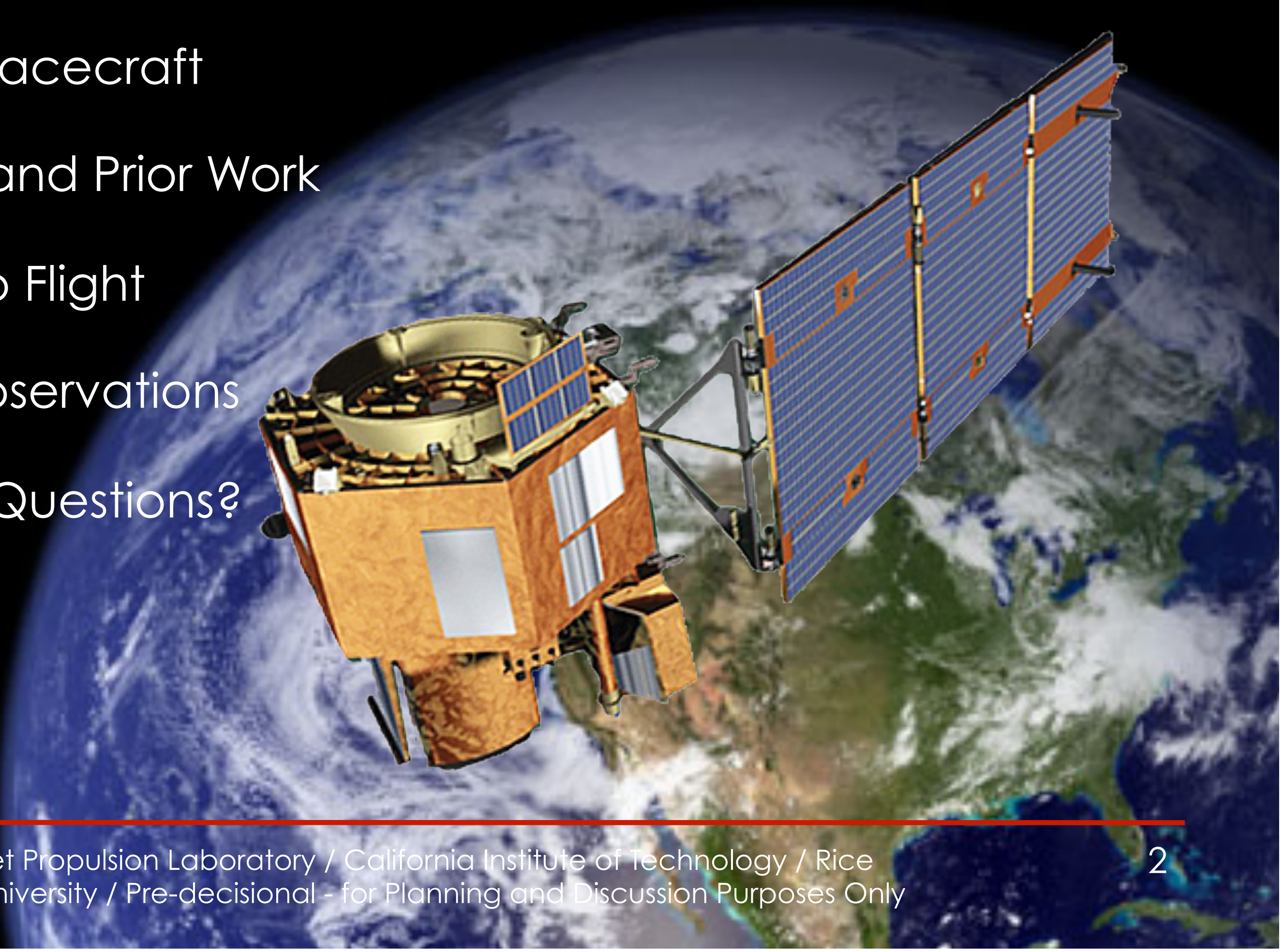


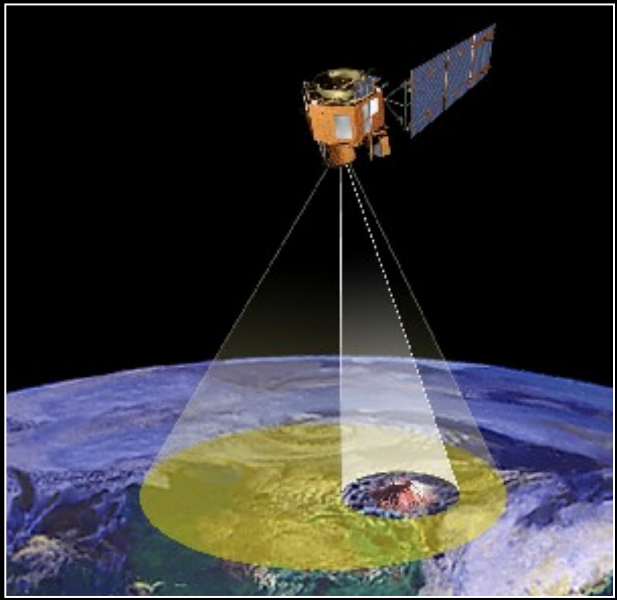
# Agenda

- Why analyze spectra onboard?
- The EO-1 spacecraft
- Algorithms and Prior Work
- Adapting to Flight
- Planned Observations
- Discussion, Questions?



# Why bother with onboard analysis?

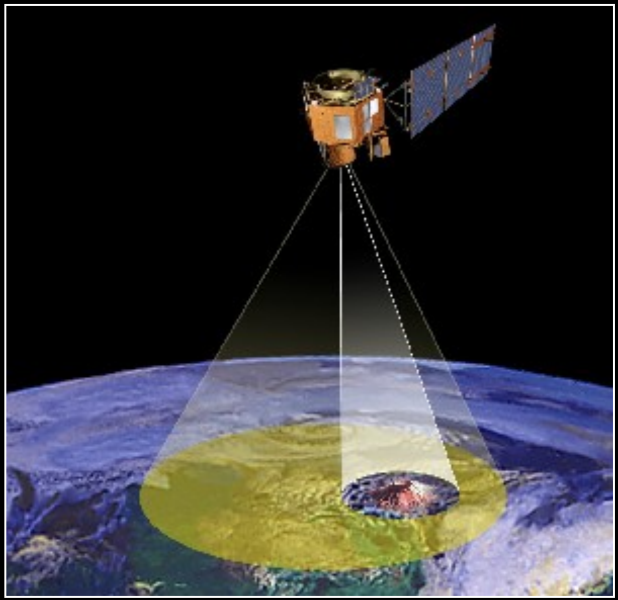
- Communications are intermittent and bandwidth constrained
- Onboard analysis can recognize target features for high-resolution data acquisition, followup measurements
- Provides onboard data summary for efficient downlink
- Particularly important for high-volume hyperspectral images
- **Endmember detection** helps when targets aren't known in advance



EO-1 Selective downlink of volcanic activity "hot spot" in thermal imagery [Davies et al. 2005]

# EO-1 Experiment goals

- Demonstrate techniques for onboard hyperspectral image analysis
  - Segmentation
  - Feature detection
  - Endmember detection
- Motivate efficiency improvements for onboard algorithms
- Show fully-unsupervised anomaly discovery and scene summary
- Explore performance for Earth science and commercial application domains

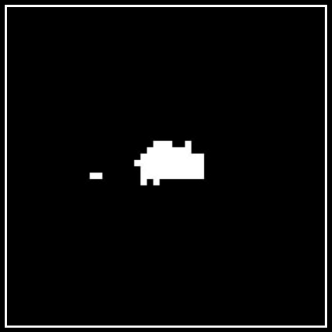


EO-1 Selective downlink of volcanic activity "hot spot" in thermal imagery [Davies et al. 2005]

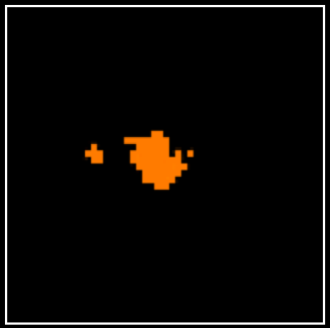
# The EO-1 Spacecraft

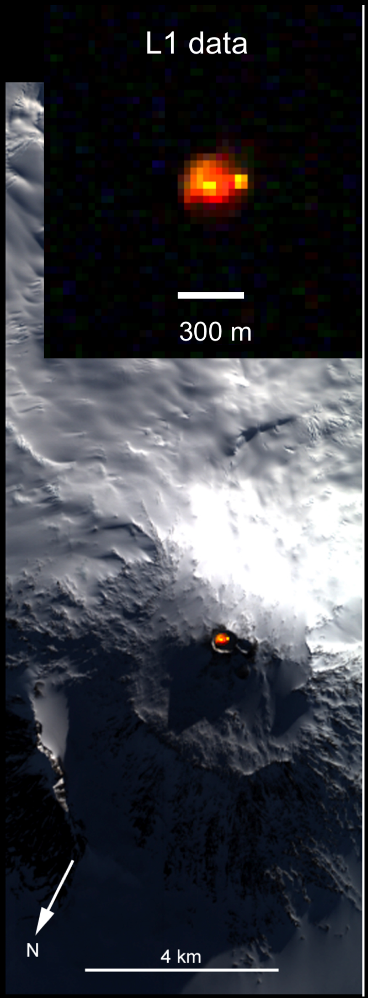
- Currently in an "extended mission" phase
- Used in sensorweb and autonomous science operations since 2004
  - Autonomous Sciencecraft Experiment (ASE) [Chien et al,. 2005]
- Detects transient events such as floods and volcanoes
- Mongoose-V 32-bit microprocessor for onboard data analysis
  - 12MHz clock speed
  - No hardware floating-point arithmetic
  - Limited memory (16 MB application max)

7 May 2004: ASE Thermal Classifier Thumbnail (Erebus Night)



7 May 2004: ASE Thermal Classifier (Erebus Day)






[Davies et al. 2005]

# Approach

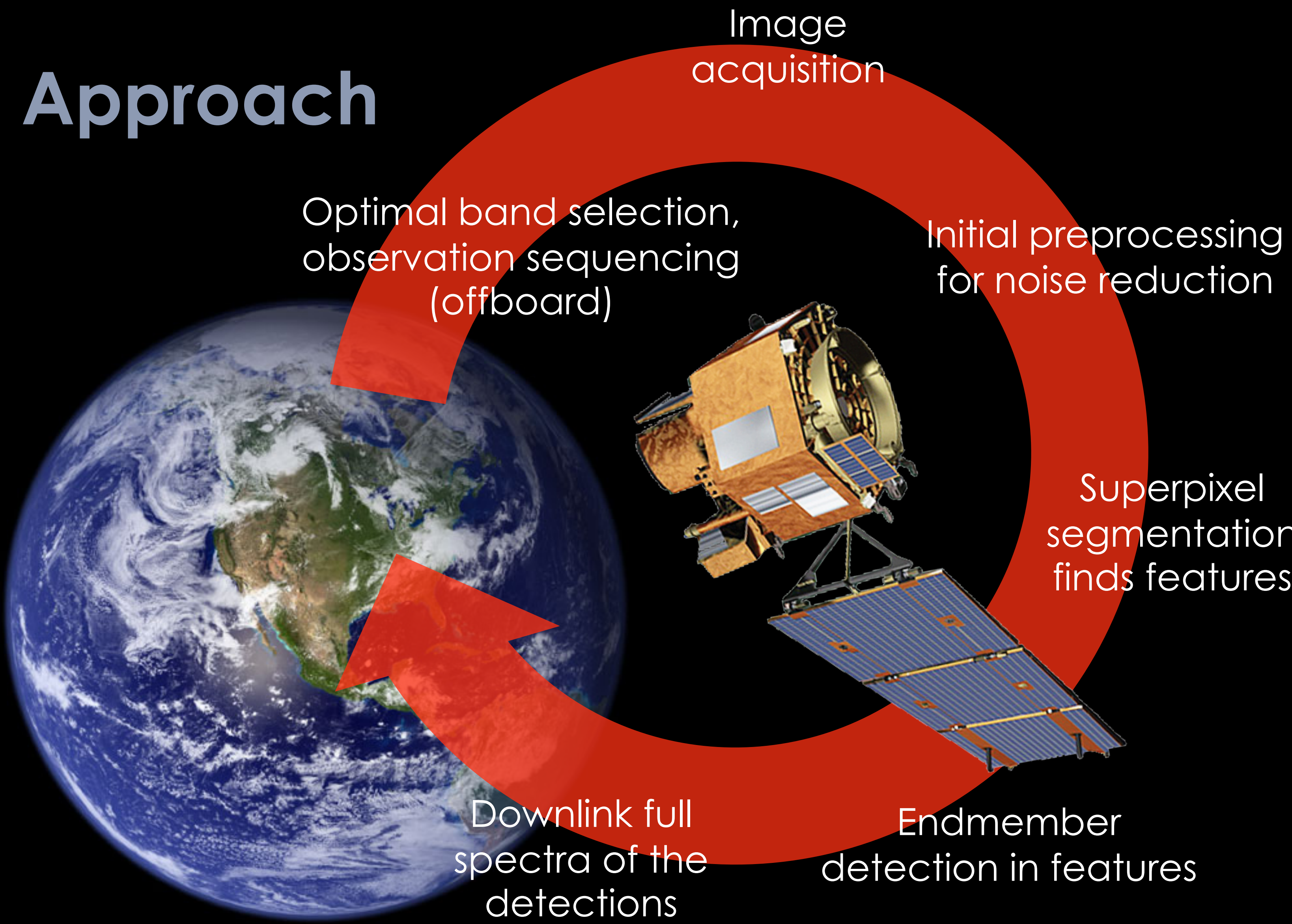


Image acquisition
Initial preprocessing for noise reduction
Superpixel segmentation finds features
Endmember detection in features
Downlink full spectra of the detections
Optimal band selection, observation sequencing (offboard)

# The Hyperion Hyperspectral Imager

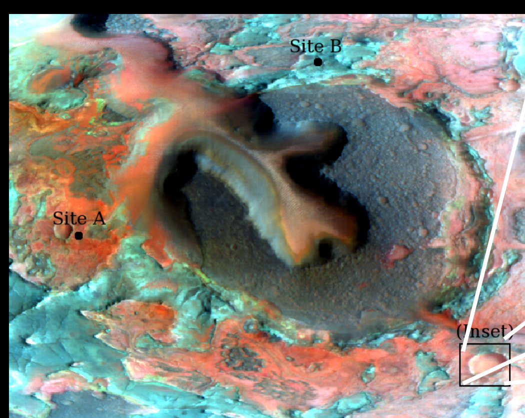
Hyperion view of Cuprite, NV

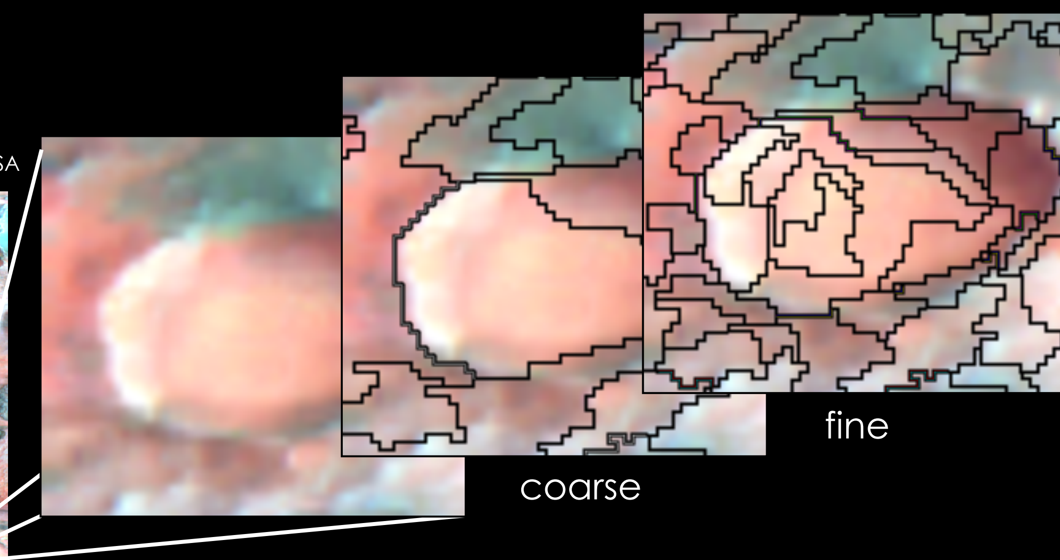
- High resolution hyperspectral imager
- 220 spectral bands from 0.4 to 2.5 μm
- 30 meter spatial resolution, provides 7.5 x 100 km land area per image
- A reflectance product is available for onboard use
  - 12 bands selected in advance (once per observation)
  - 256x1024 pixel subframe

# Superpixel segmentation

- Find spatially contiguous, spectrally homogeneous regions corresponding to physical features
- Reduces runtime, memory of later processing by 10-100x
- Users specify appropriate spatial scale
- O(n log n)

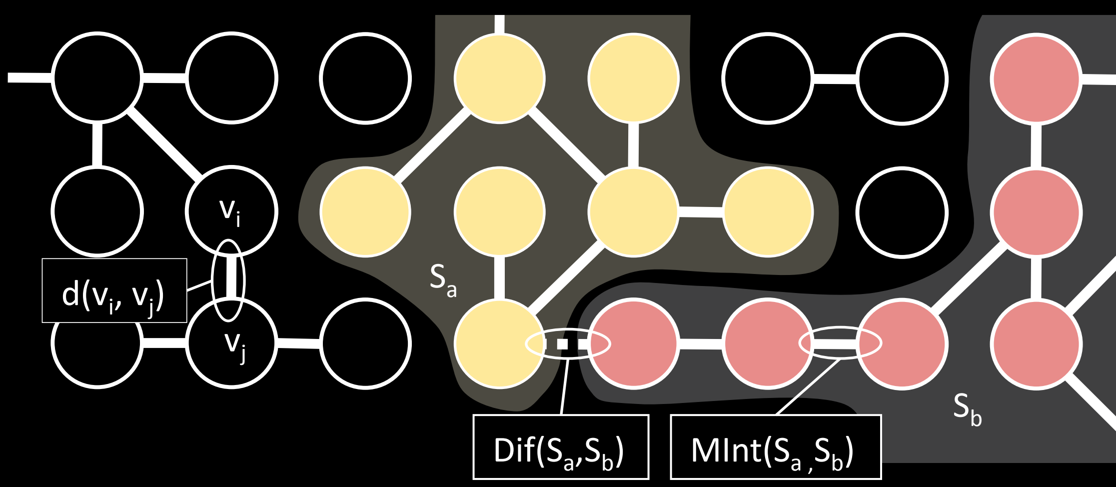
CRISM FRT00003e12, courtesy Brown University / NASA



# Superpixel segmentation

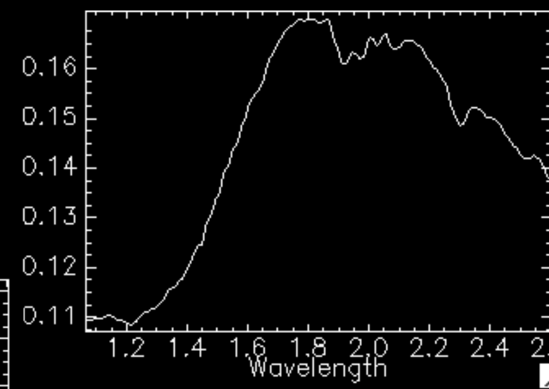
- A graph partitioning algorithm [Felzenszwalb et al., 2004] over-segments the image
- Compute spectral distances between neighbors
- Agglomerative clustering iteratively connects segments by growing minimum spanning trees



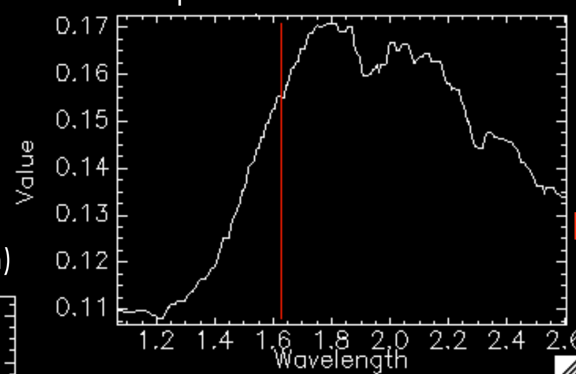
# Superpixel segmentation

- A superpixel's spectrum is the mean of its component pixels

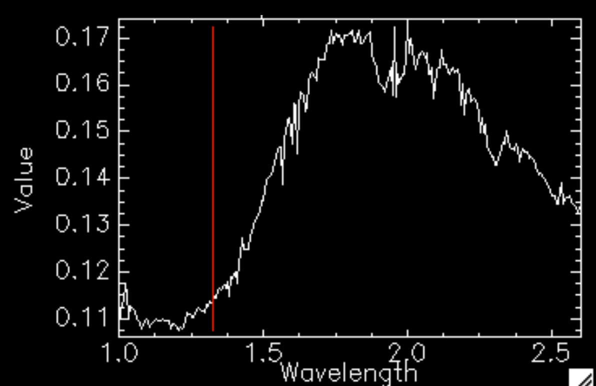
superpixel average




preprocessing with spectral median filter

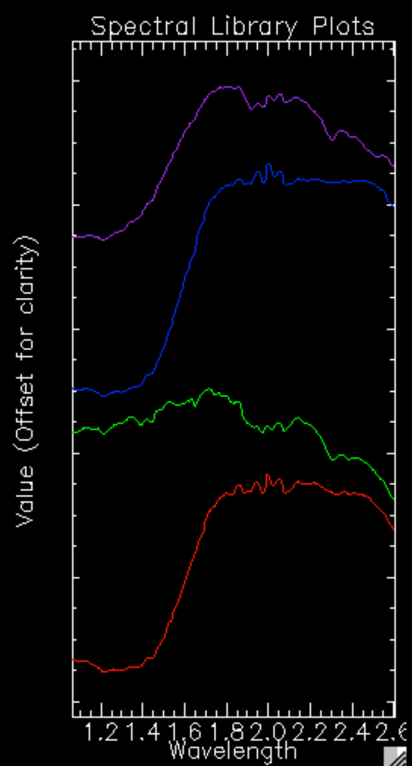



initial CRISM spectrum (NASA/Brown)




- Yields theoretical noise improvement of order $n^{1/2}$ for a superpixel of size n

# Previous work




CRISM data [Thompson et al., 2010]

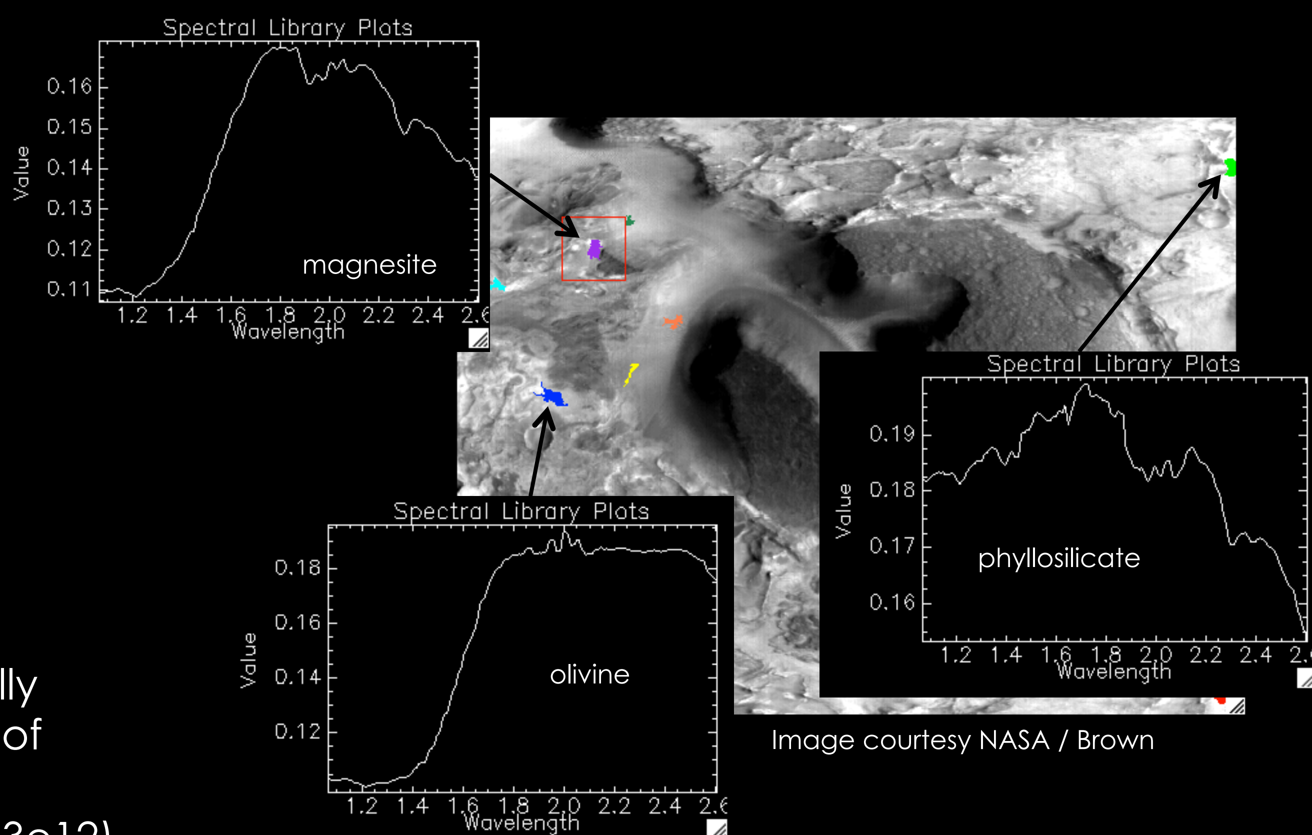


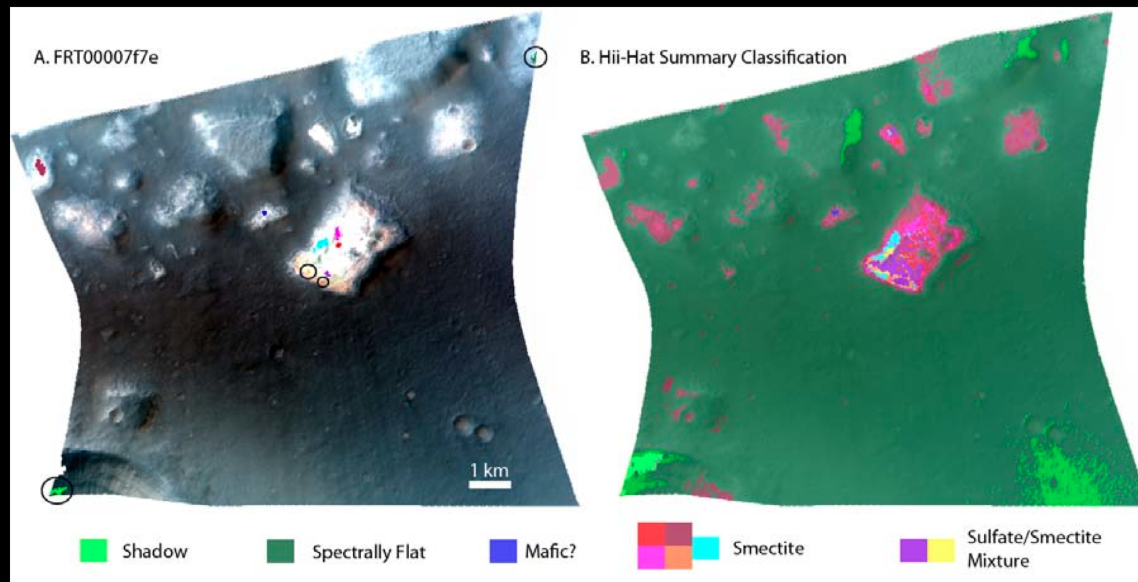

Image courtesy NASA / Brown

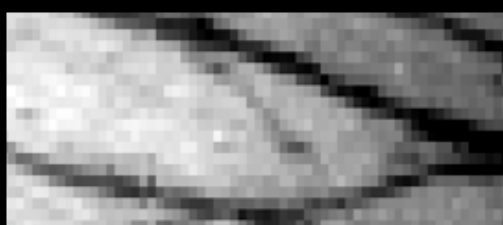
Top 4 automatically detected regions of interest (all known minerals in CRISM 3e12)

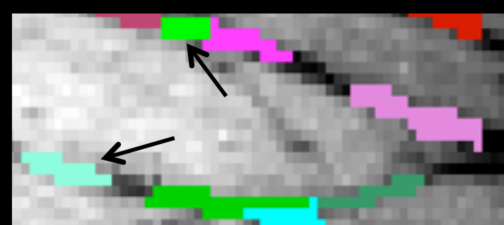
# Previous work

Detected Sulfates, Smectites and Mafics in Ariadnes Chaos, Mars using several CRISM images [Gilmore et. al., 2011]

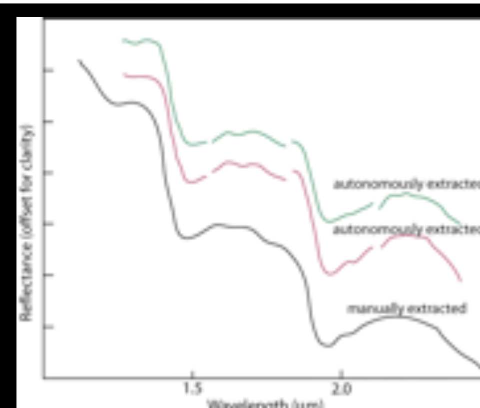
All known minerals, and several previously-unreported phyllosilicates and sulfate materials, were discovered





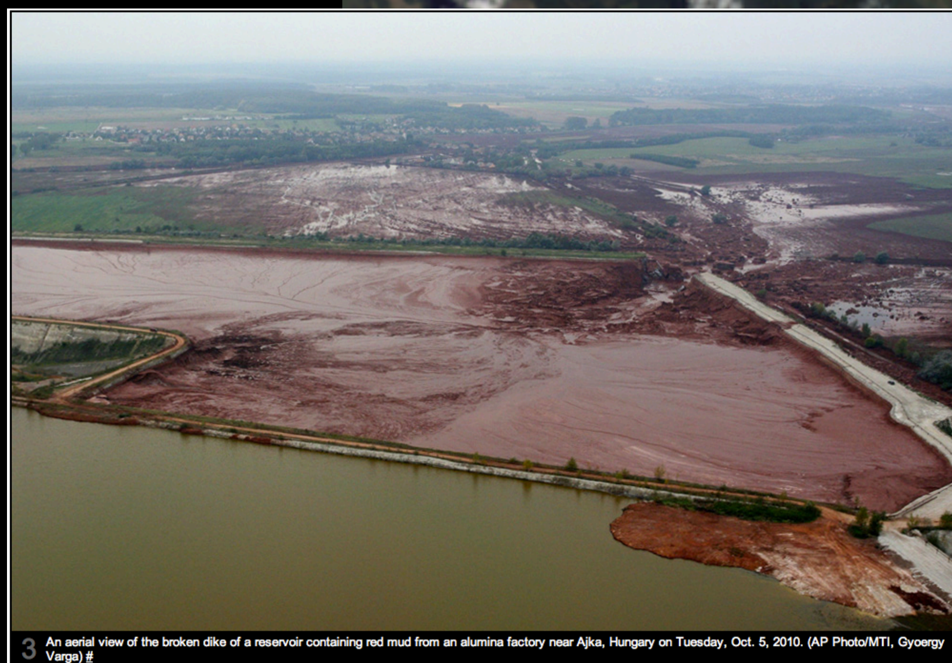
Low-spatial-resolution NIMS features showing ices, possible amides on Europa [Bunte et al., 2011]



# Previous work

Kolontar toxic sludge spill
Hyperion ALI (9 bands)


Hyperion ALI image
(courtesy NASA/GSFC)



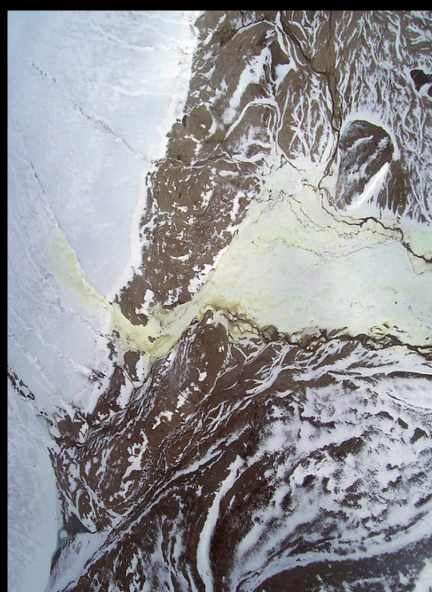
3 An aerial view of the broken dike of a reservoir containing red mud from an alumina factory near Ajka, Hungary on Tuesday, Oct. 5, 2010. (AP Photo/MTI, Gyoergy Varga) #

TEXT: BOSTON GLOBE; IMAGE: AP

# Previous work

Sulfur outflow at Borup Fiord, Canada is a candidate for onboard detection due to astrobiology implications [Mandrake et al., 2009]

Here it is detected automatically in Hyperion images



Helicopter photo showing sulfur outflow (courtesy NASA)


Original hyperion image

spectral angle map

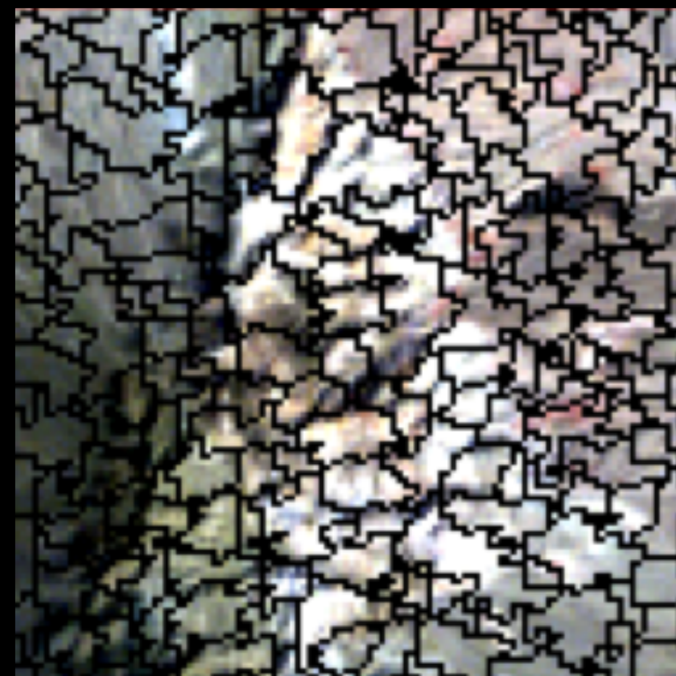
# Adapting to Flight

- SMACC algorithm [Gruninger et al., 2004] favored for speed, computational simplicity, test set performance
- Segmentation reduces number of spectra from ~$10^5$ to ~$10^3$
  - Trades for an O(n log n) segmentation for polynomial time endmember detection
- In practice, edge weight (distance) computations a bottleneck
  - 256x1024x12 image: ~36 million floating-point operations
- Maximum memory usage is just 15MB

# Adapting to Flight

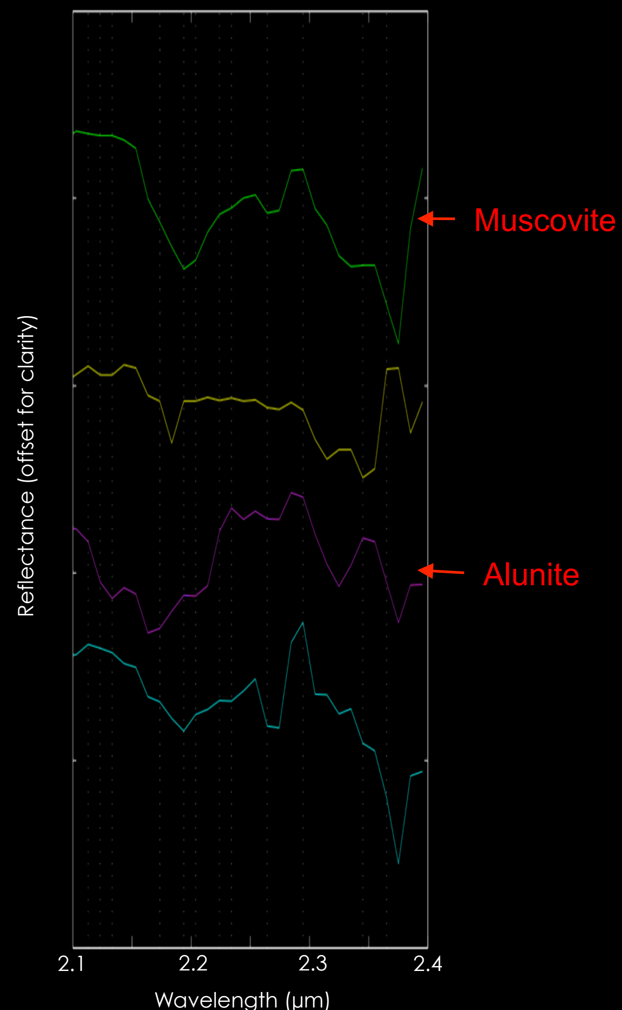
- Full unit test coverage of all code
- Regression test suite for performance evaluations
- Validation on lab testbed currently in progress

# Cuprite ground test

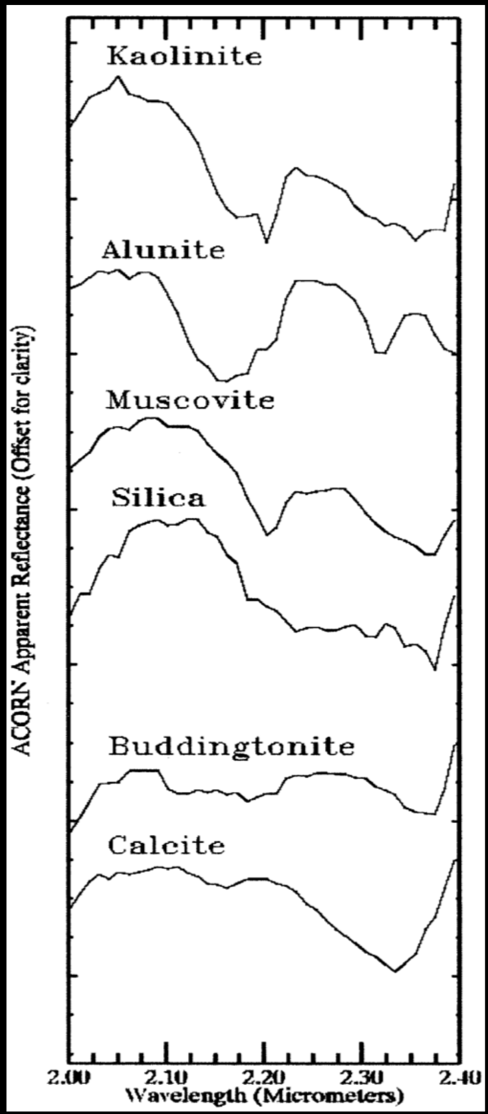


A virtually cloudless scene!
Targeting successful; most of the classic Cuprite scene is visible

# Cuprite ground test

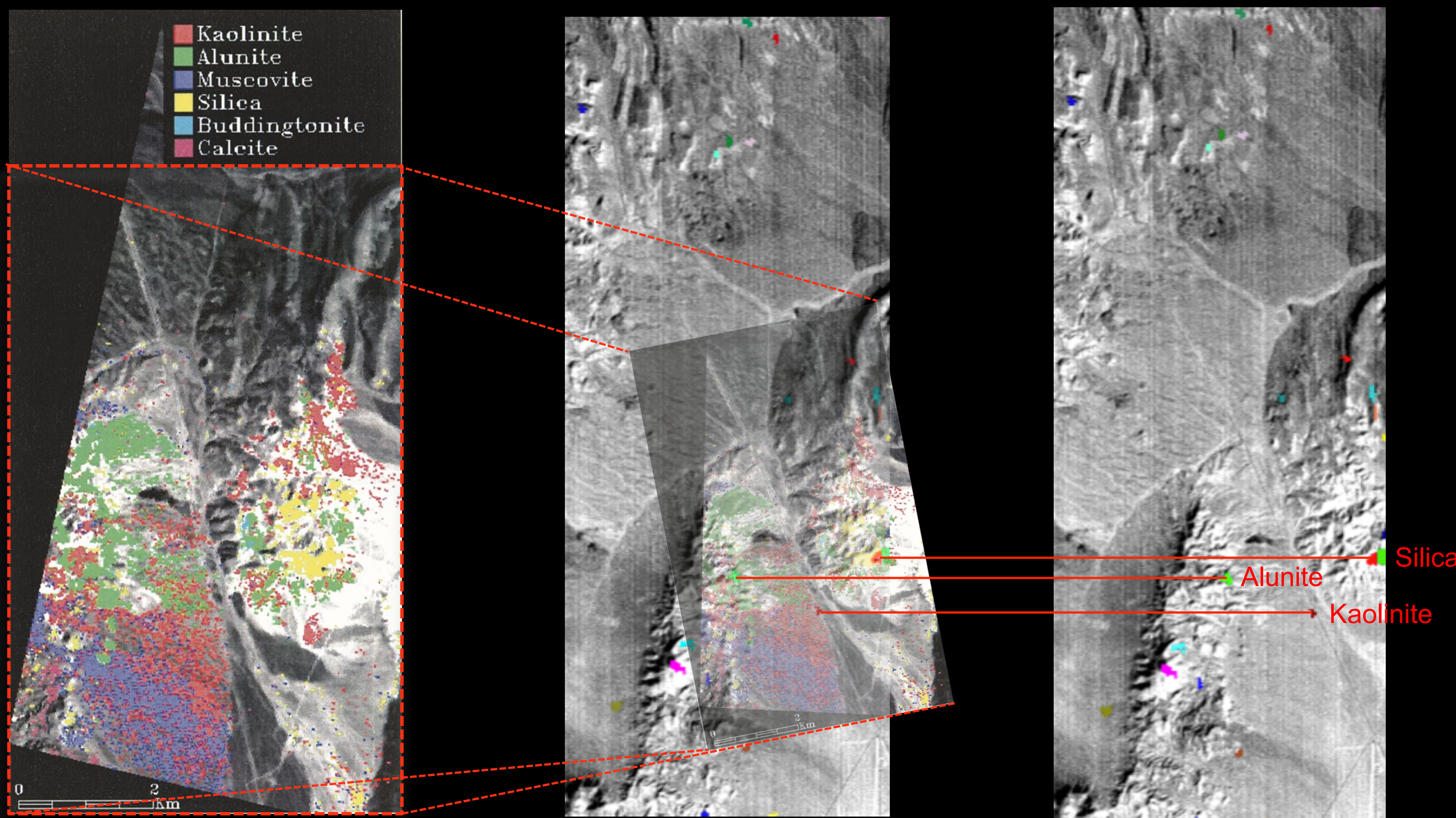



Top Detected Endmembers




[Kruse et al. 2003]

# Cuprite ground test

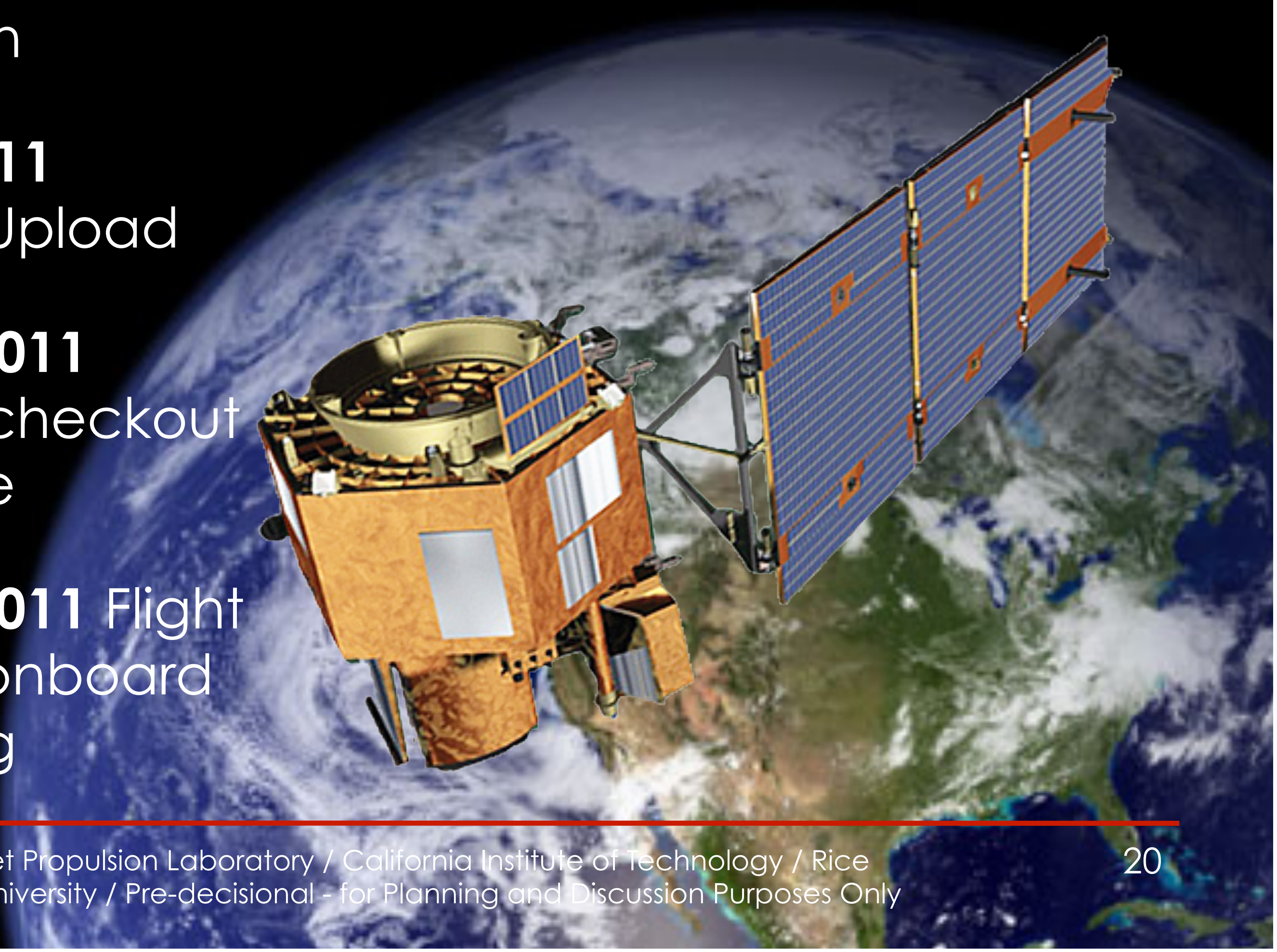



[Kruse et al. 2003]

Top 30 Endmember ROIs

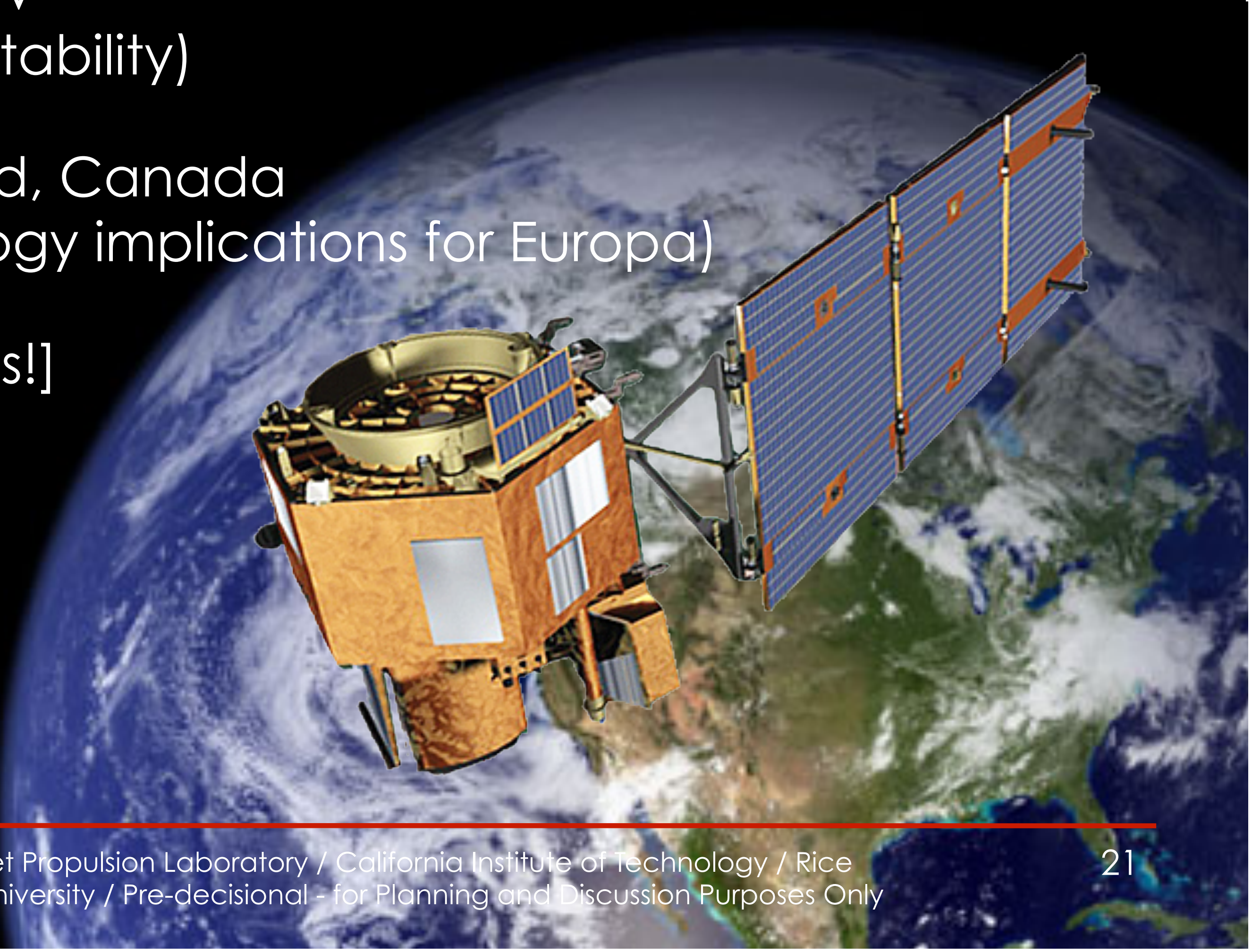
# Next steps

- **June-July 2011** Integration
- **August 2011** Software Upload
- **Summer 2011** Software checkout procedure
- **Summer 2011** Flight demo of onboard processing

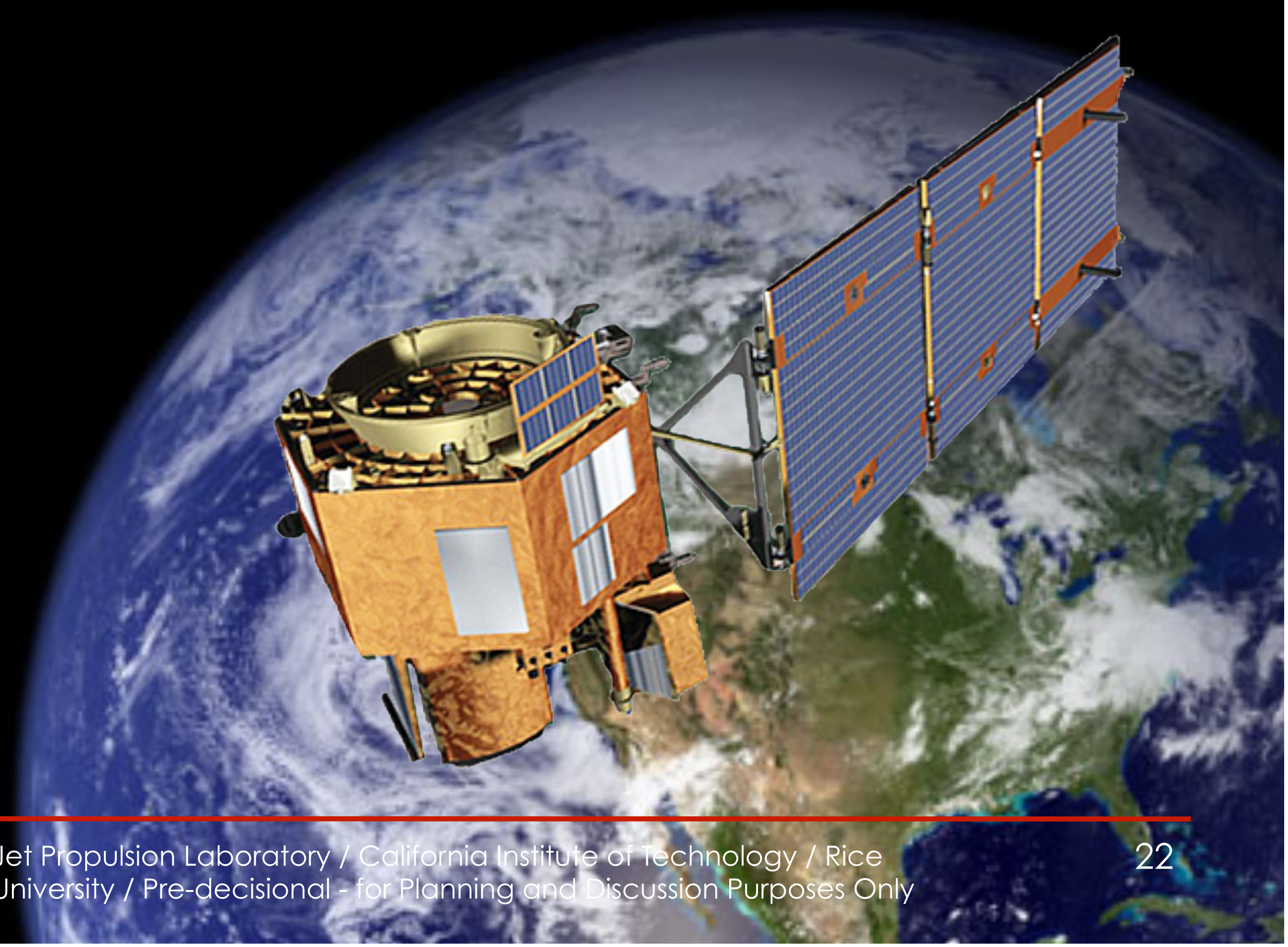


# Possible targets

- Cuprite, NV
  (for repeatability)
- Borup Fiord, Canada
  (astrobiology implications for Europa)
- [Your ideas!]



# Thanks!



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# Selected Bands