# Autonomous Characterization of Chloride and TPH in Contaminated Soils Using Ground-based Robotic Platforms

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# Impacted Site Assessment Today

- Impacted sites must be characterized
  - Determine extent of impact
  - Identify remedial alternatives
  - Monitor remediation progress
  - Collect high-quality data

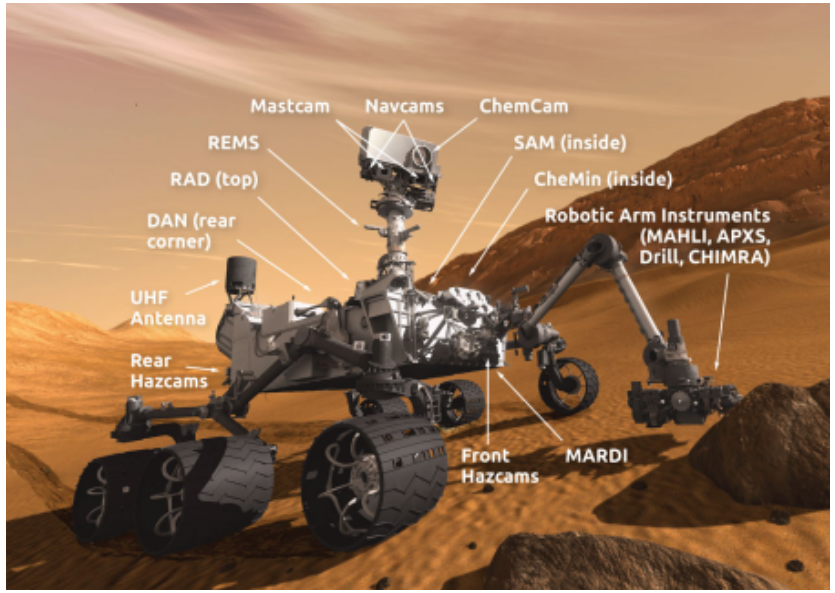
- Challenges
  - Requires people in the field
  - Harsh environments, difficult to access, and potentially dangerous
  - Expensive (shipping, lab analysis, personnel time, equipment)
  - Potentially long turn around times for laboratory analysis
  - Potential for mistakes (mislabeling, lack of time or location stamp)

# Opportunity for Robotics and Autonomy

- Robotic sampling can replace people in the field
- Can provide high data density and quality
- Can automatically label GPS location & time stamp to reduce errors
- Can lower cost compared to current practices

# Existing platforms are not necessarily designed for soil characterization

- Common platform features
  - Tracks, wheels, or legs
  - Operate in well-defined spaces
- Some limitations
  - Drones cannot collect samples easily
  - Built for specific purpose
  - Missing some environments of interest, e.g. mudflats

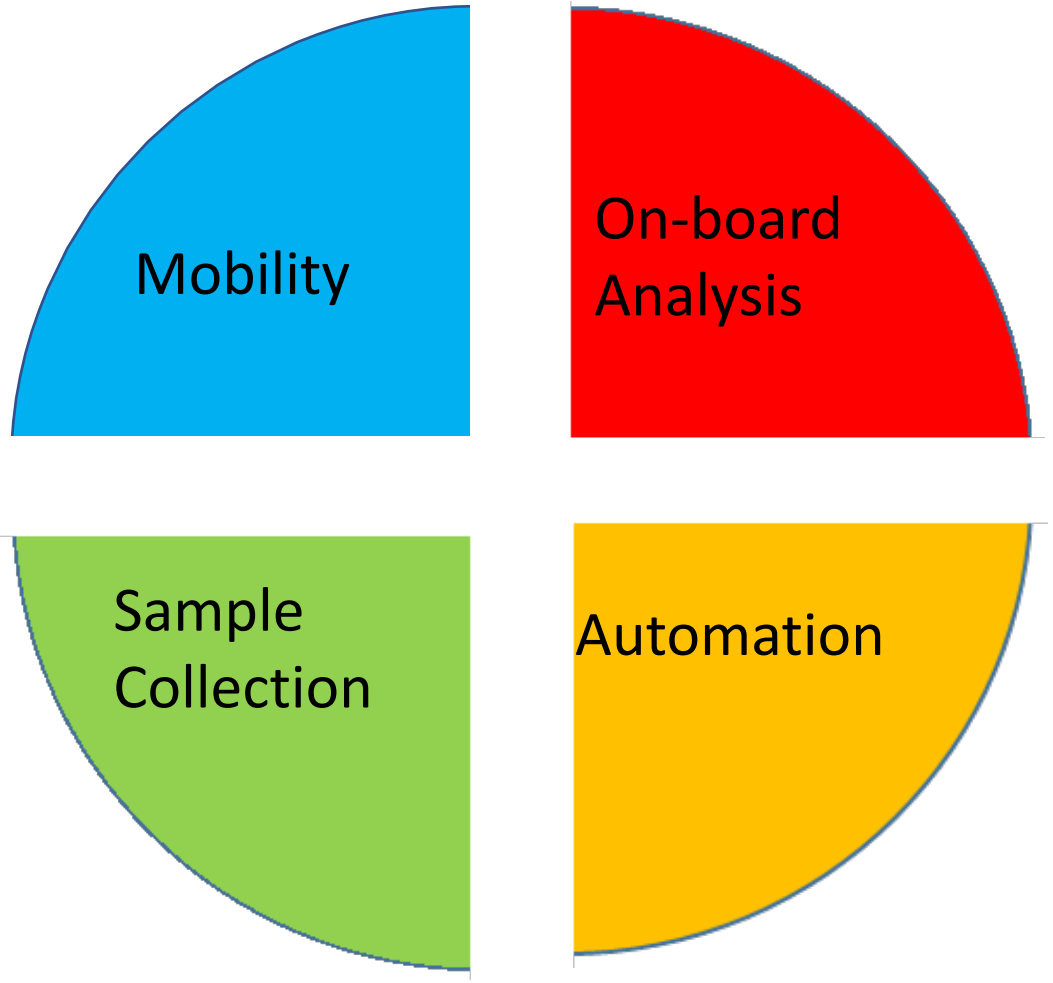



# Our Vision

- Provide light weight and inexpensive ground-based autonomous vehicles to:
  - Collect soils at and below the surface in a variety of terrains
  - Provide reliable on-board measurements of analyte concentration
  - Can log precise location and time
  - Can collect samples with highest value of information to accurately delineate the contamination
  - Can return physical samples
  - Varying levels of autonomy

# Key Considerations

Power
Ground Clearance
Center of Gravity
Size
Weight
Durability
Cost




Analyte
Interferences
QA/QC
Robustness
Durability
Calibration

Soil Properties
Sampling depth
Sample size
Sample handling

Path finding
Obstacle Avoidance
Contaminant mapping
Data logging
Data analysis and transmission

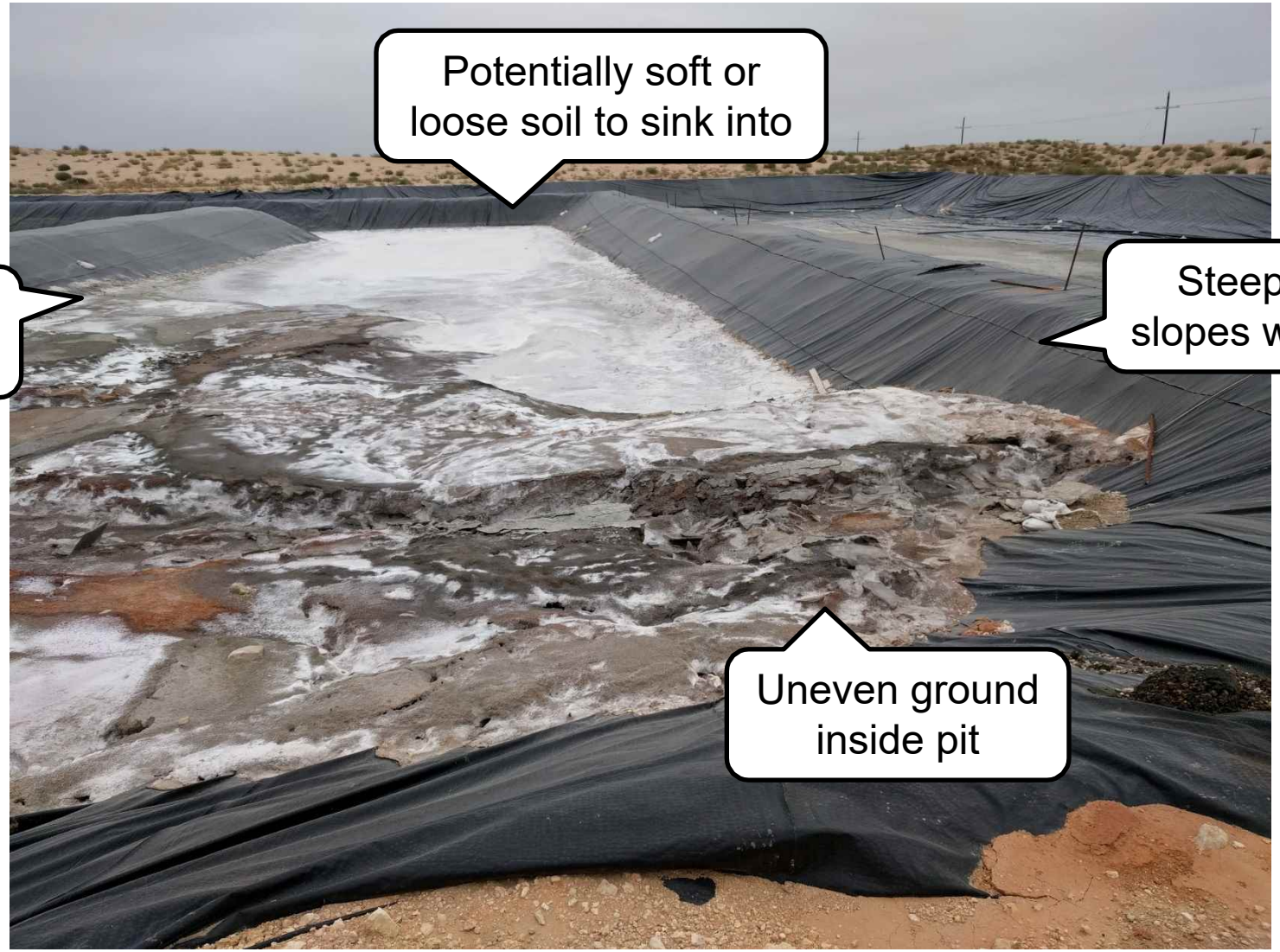
# Mobility options

- Tracks, Wheels, Legs
- Choices depend on
  - terrain and payload
  - Weight, cost, durability

First Prototype

Second Prototype

# Mobility Challenges



# Additional Mobility Challenges

- Need to be able to navigate over obstacles
- Need to “see” small vegetation
- Need to develop algorithms that can navigate to desired locations while avoiding obstacles

# Sample collection

- Physical sample collection
  - Surface removal
  - Collection
  - Storage
- In situ Measurements
  - Sample preparation, e.g. drying or homogenization
- Avoid Cross-contamination

# Rototiller to “rake and measure”

# Detectors: IR for TPH

Remscan

Neospectra

## Strengths

Robust

- Non-destructive
- Non-invasive

Sensitive

- Some commercial products will inform user of water content

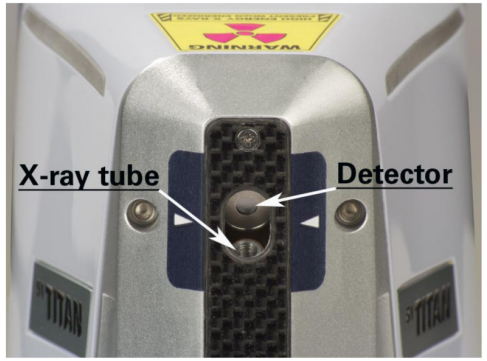
Easy operation

- Fast
  - RemScan claims 15-30 seconds for one scan

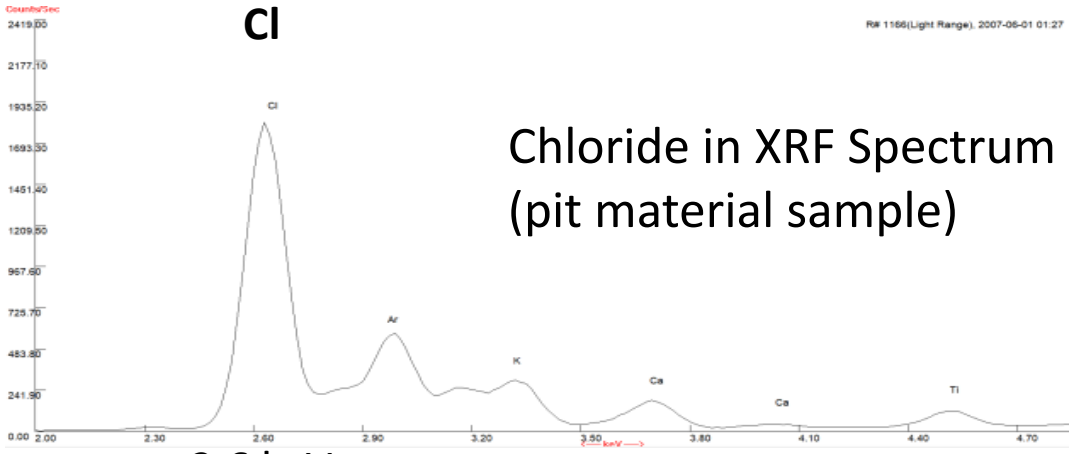
## Limitations

- Sensitivity of detection
  - Affected by moisture content
    - Water has a stronger effect in the MIR range
  - Affected by soil matrix
    - Particle size
    - Mineral composition
    - Presence of iron
    - Other organics
- Site specific calibration

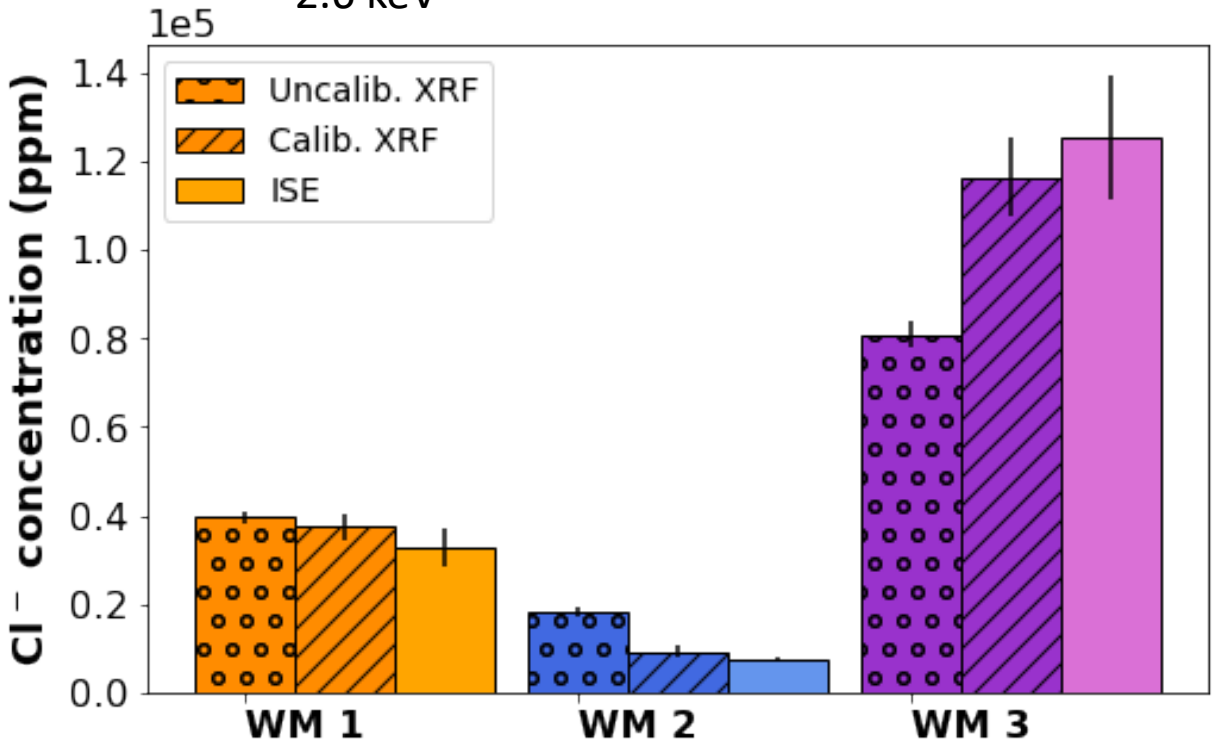
# Detectors: Portable XRF for Chloride







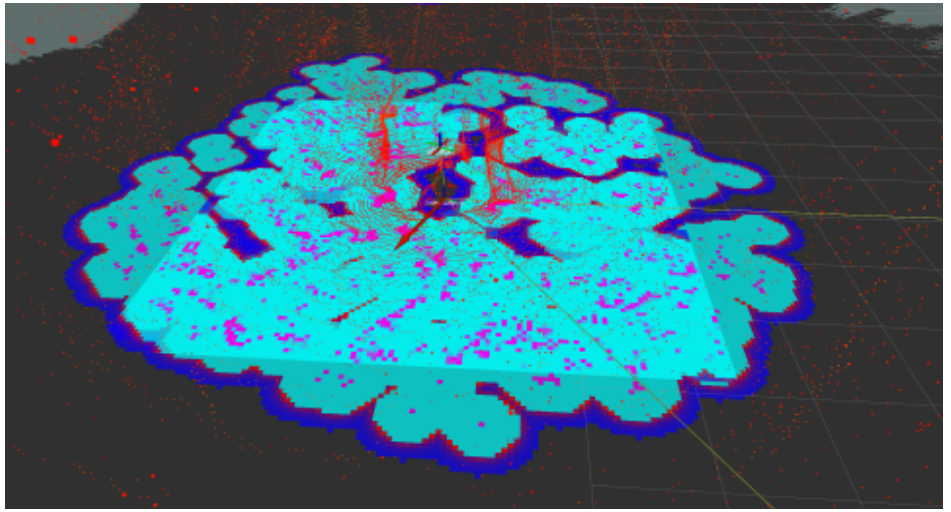

Chloride in XRF Spectrum (pit material sample)

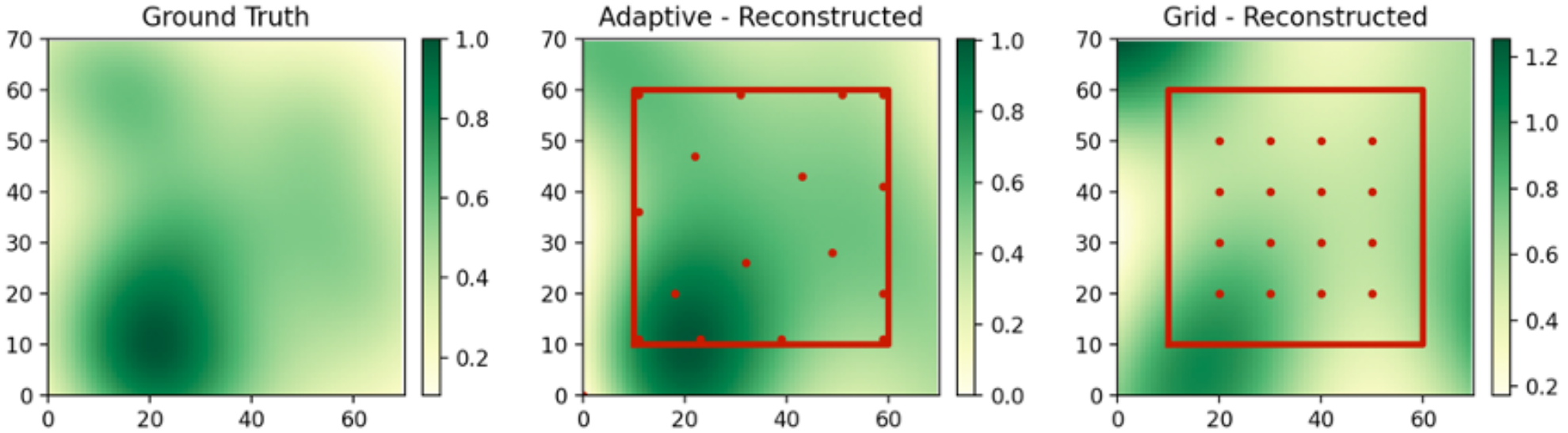



**Poster #88**

Nava et al., 2023 *Env. Pollut*. 316 120558

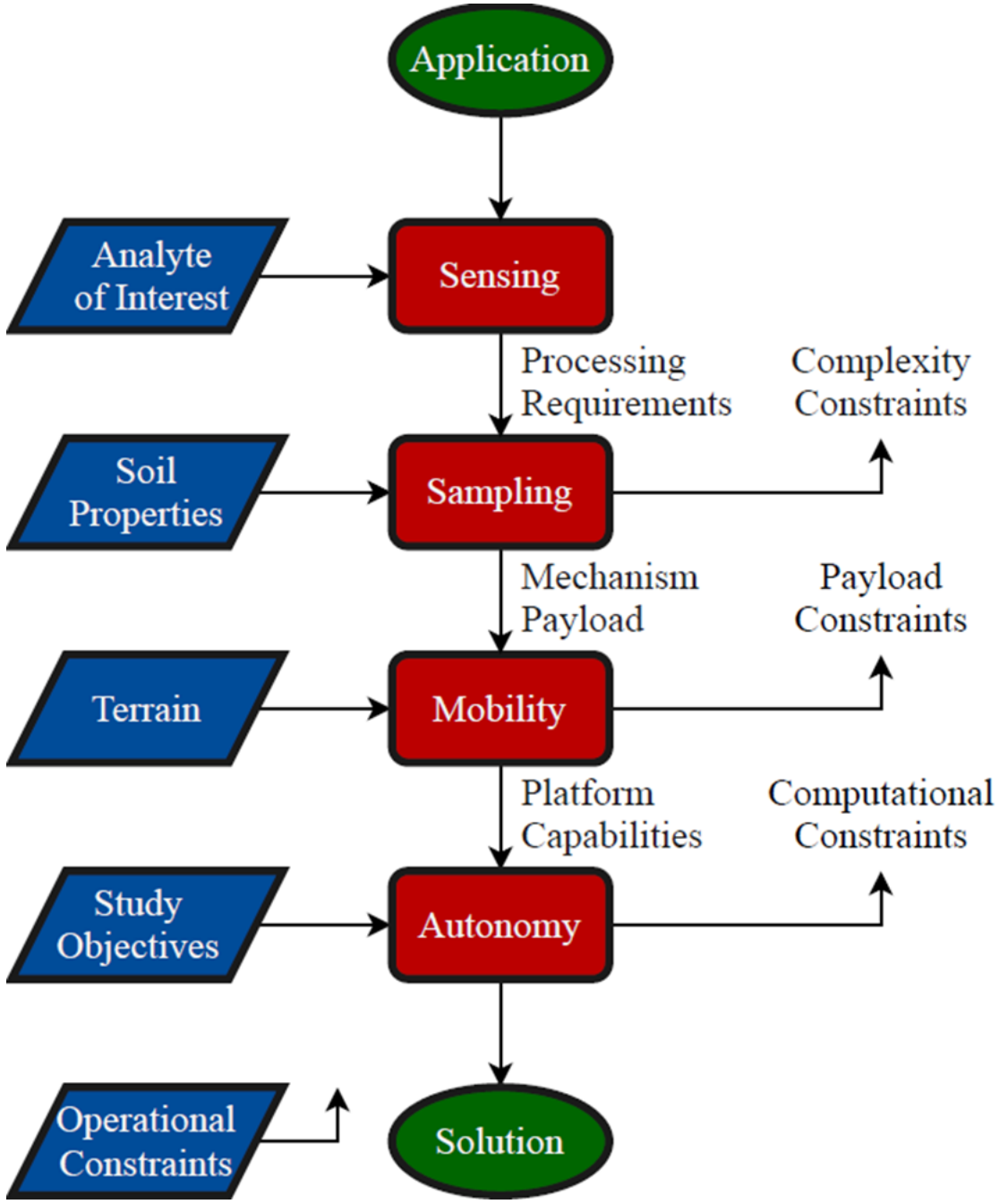
# Obstacle Avoidance (Vision) and Adaptive Sampling





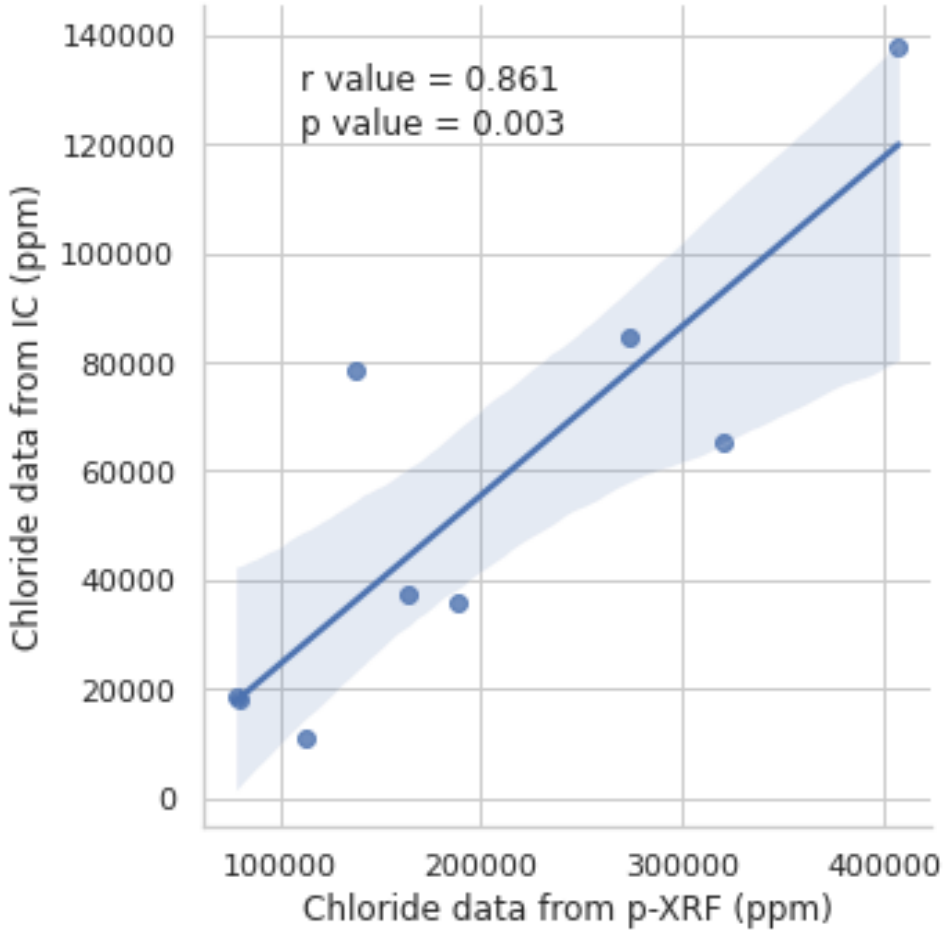

**Poster #89**

# Autonomous Robot Project Decision Tree



# Application of that diagram for sampling from reserve pits using PXRF

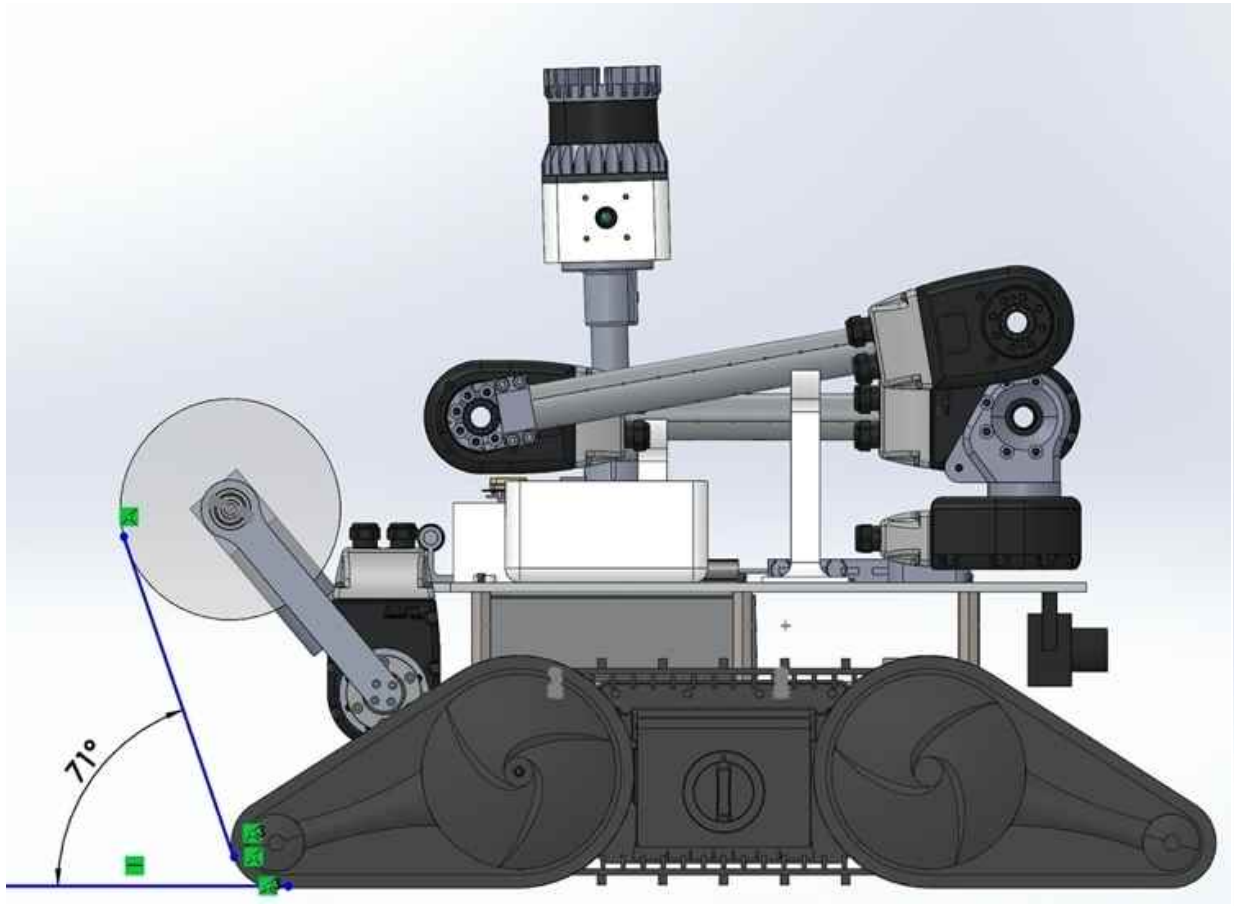
- Analyte
  - Chloride
  - pXRF based on trials showing pXRF correlates well with chloride by ISE
- Sampling
  - Measuring in situ to provide many measurements
  - Removal of top layer using “rake”
- Mobility
  - Tracks or wheels worked in this environment
- Autonomy
  - GPS waypoint algorithm (preset grid)
  - Automated “rake and measure” at each waypoint

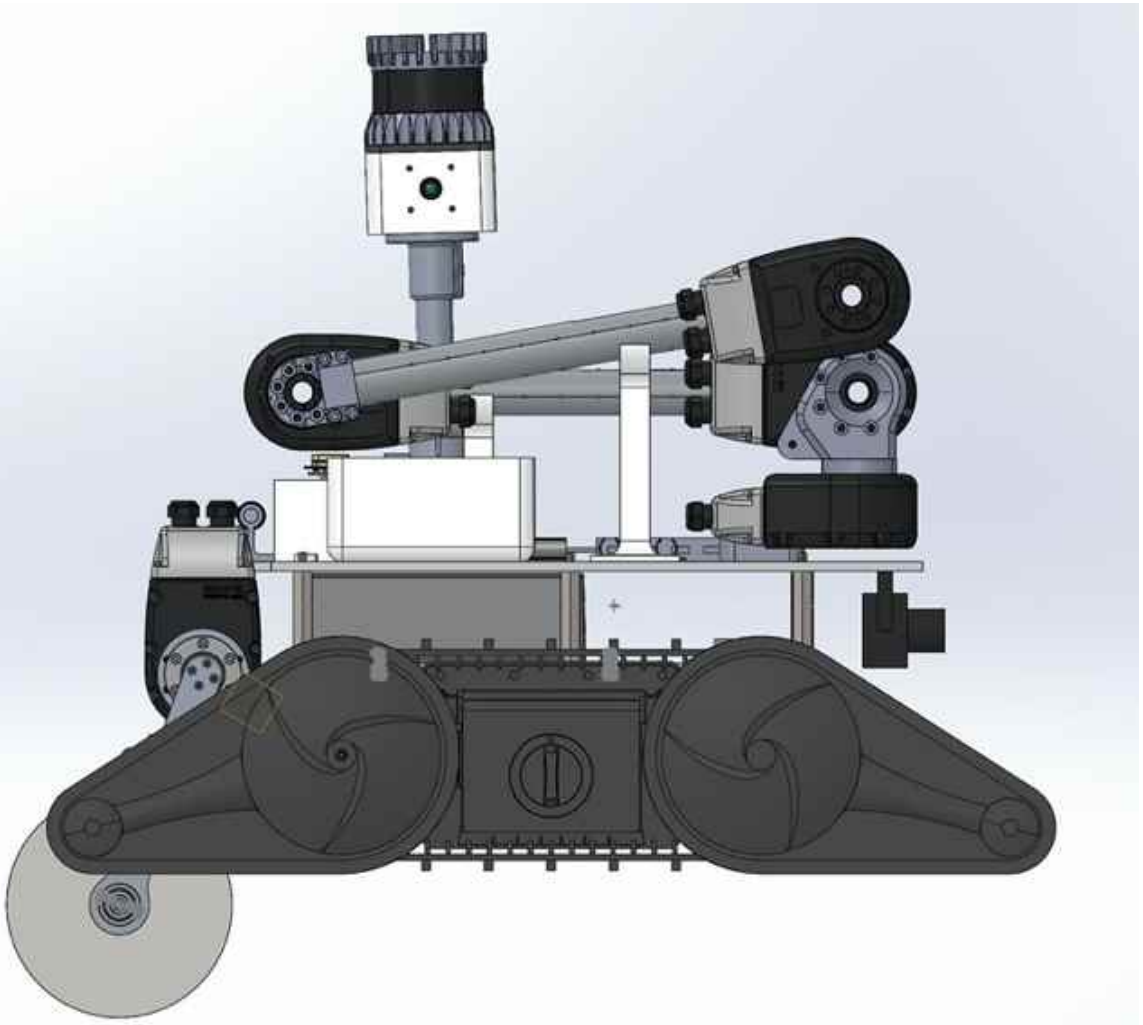


# Remaining Challenges and Future Directions

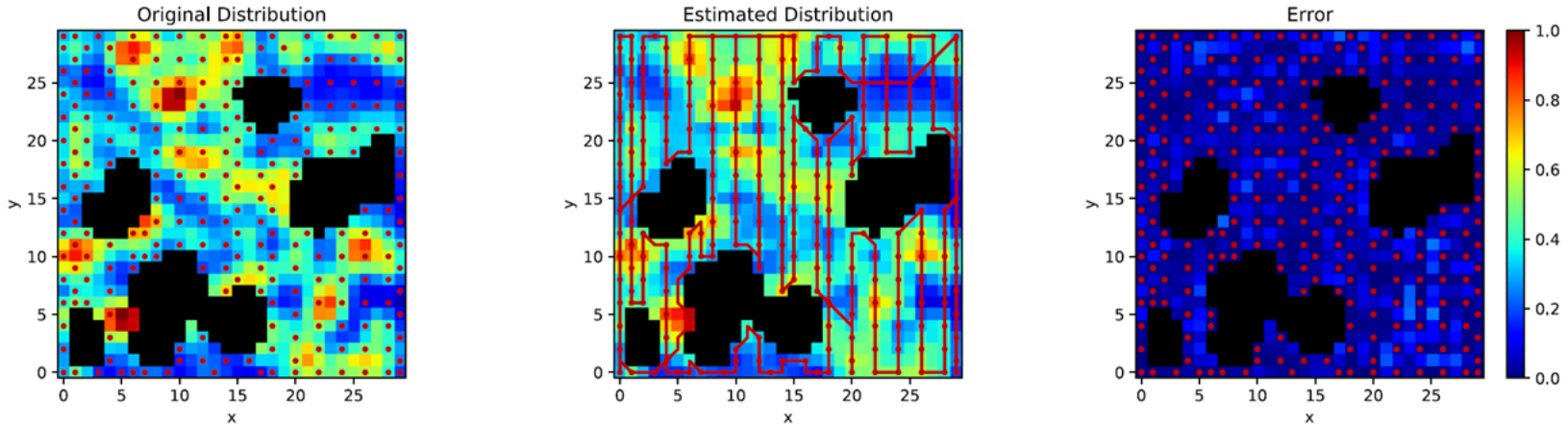
- Challenges
  - Automation of tasks for unknown environments
  - Sampling at depth and sample homogenization
  - Sensors for new analytes of interest
- Future directions
  - Working with Hebi to make robots rugged and robust
  - Assessing mobility platform for vegetated environments
  - Grow “Environmental Robotics” industry, offer a “technology selection tool”, and train personnel on their use

# Deployable Rototiller

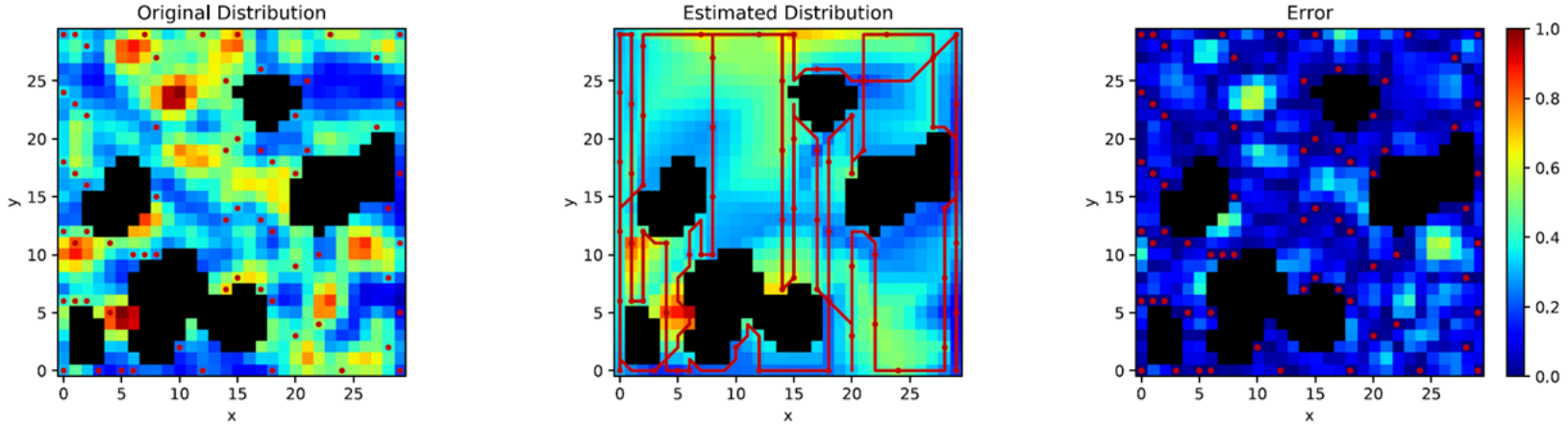


# Autonomy-Smart Sampling: Adaptive Sampling Algorithm Evaluation



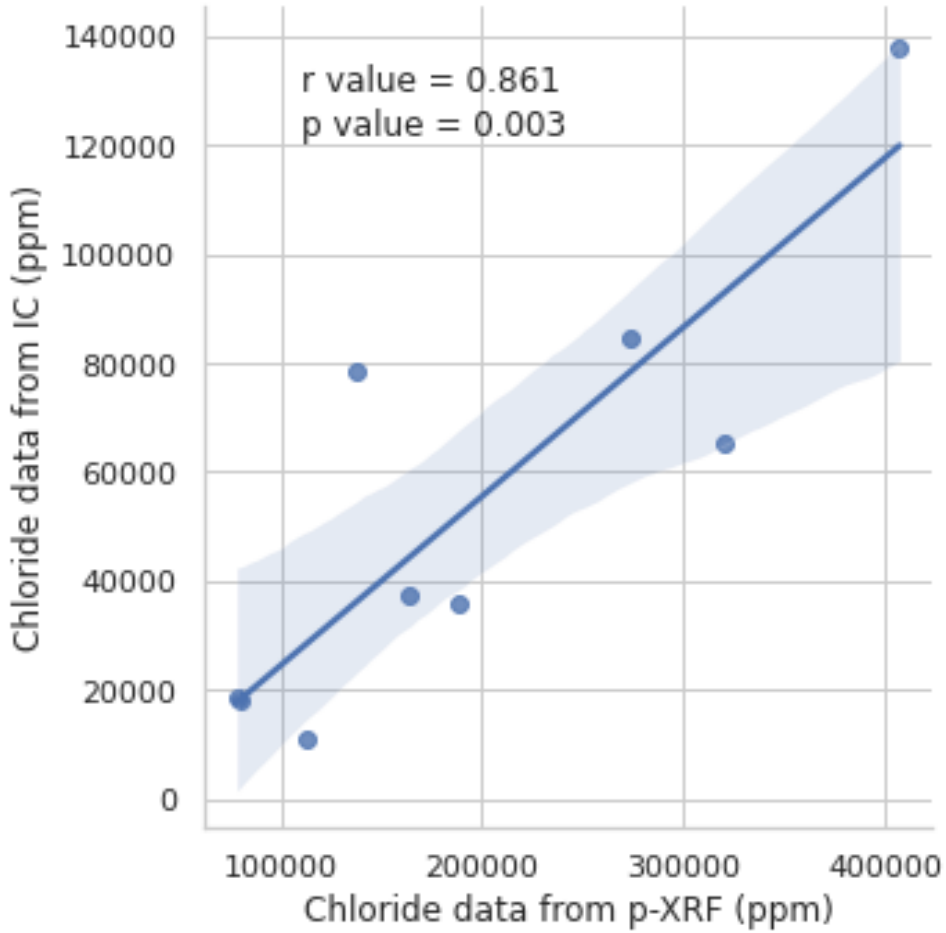

(a) Small sample spacing




(b) Large sample spacing

# Chloride measurements vs. Lab measurements

Will also have a map showing the “grid” in the pit that was sampled

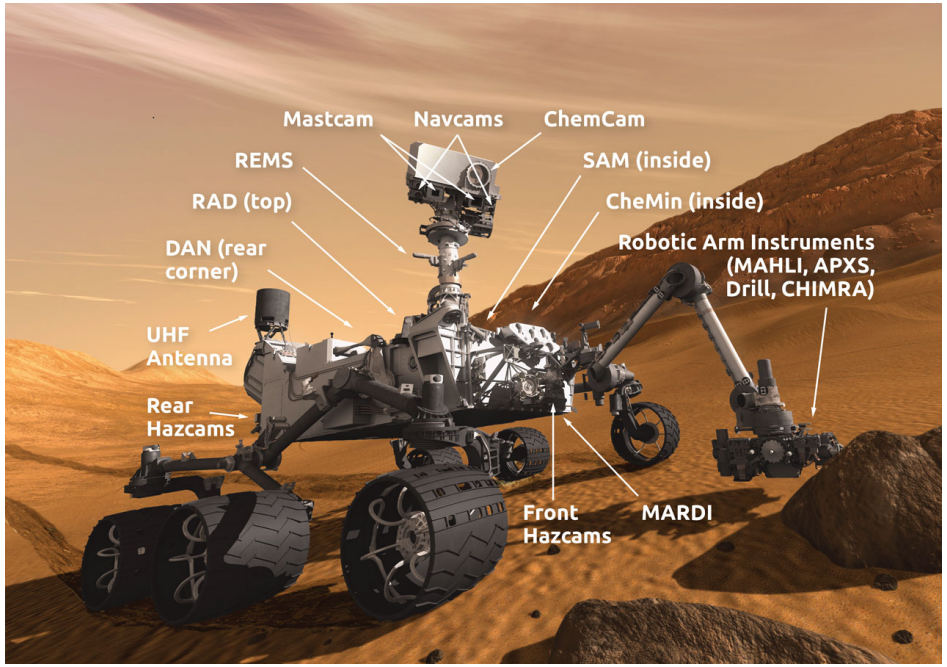


# Autonomy challenges

- Terrain Obstacles
- Robust sample collection and analysis procedures
- Adaptive sampling algorithms to determine the best sampling locations

# Commercial Robotic Platforms are Becoming Available

- Robots are currently built for a specific purpose
  - Highly mobile, varied levels of autonomy
  - Highly instrumented for **specific goals**



# Augering Design Considerations

**Objectives**

- Ability to exert required force (15 N)/torque (1 N-m)
- Ability to fold over robot base to shift center of gravity
- Water and dust proof electronic components

**Constraints**

- Weight of robot base must balance torque from augering
- Mass and space requirements

Could add a picture of Hebi bot with auger if you have one

# TPH: handheld Infrared Reflectance Spectroscopy (IR)

- Images retrieved from Ziltek (https://ziltek.com/remscan//)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# Wheels vs Tracks

**Tracks**

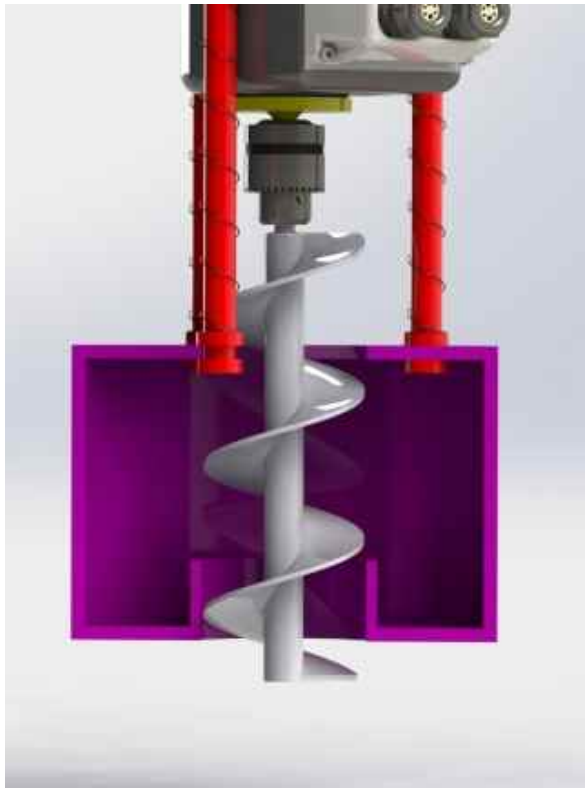
- Larger contact area
  - Lower contact pressure
  - Lower sinkage
  - Lower external motion resistance
  - Higher drawbar pull
- Longer contact length
  - Lower slip
  - Higher thrust

**Wheels**

- Higher road speeds
- Less wear on ground surface
- Other practical reasons

# Auger Testing

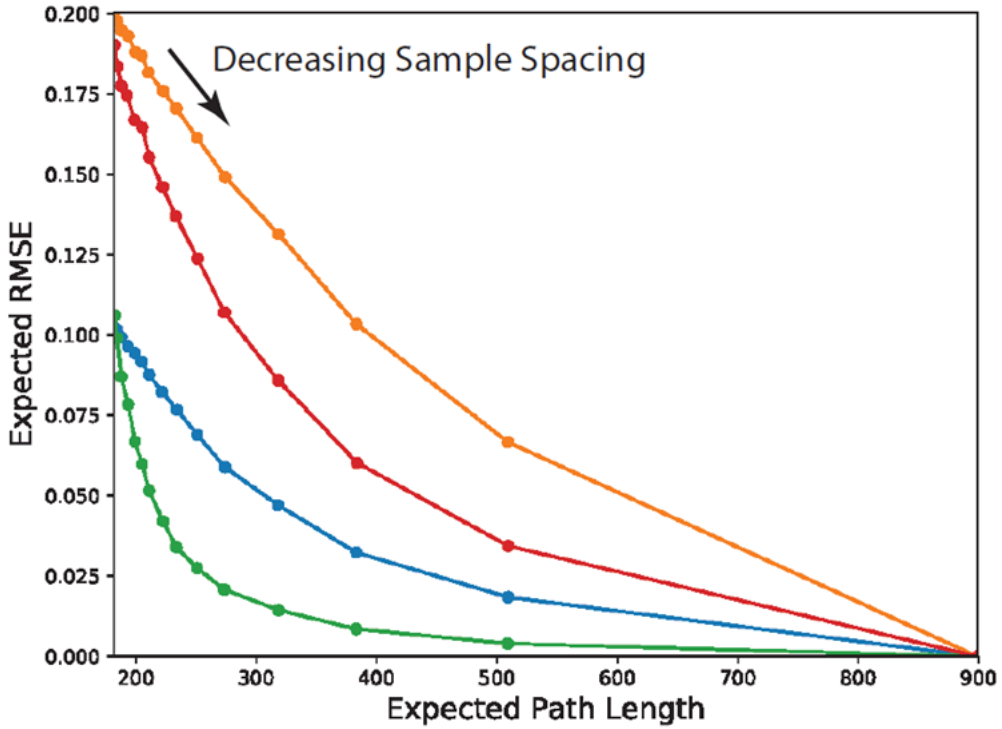
- Works to bring up soil from depth for field analysis
- Could be used to bring back physical samples
  - requires a collection device or auger plus scoop



# Challenges for Developing Automated Sampling and Real-time Measurements

- Must work in a variety of terrains
  - Mobility challenges (steep slopes), water, obstacles, unpredictable
- Full autonomy for sample collection and analysis
  - Sample preparation, cross-contamination, robust on-board detectors, calibration
- Effective algorithms to determine the ideal locations for follow-up sampling
- Ideally light weight, not too expensive, easy to operate, robust

# Exploration Algorithm Results



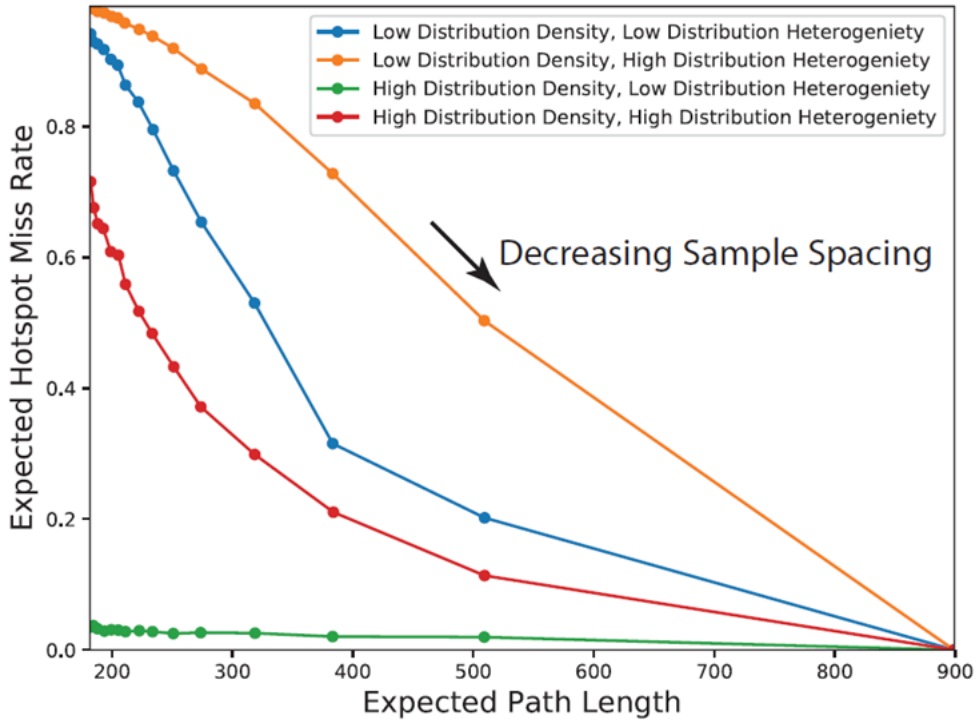




Figure 9: The expected distribution estimation error plotted against the expected path length of the robot for varying sample spacings. Decreasing sample spacing results in lower estimation error, but longer robot paths.