UXO Discrimination Using Vehicle Towed and Man Portable Sensor Data Collected at Camp Beale, California

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The University of British Columbia
Geophysical Inversion Facility

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14. ABSTRACT
Over the past few years there has been much research on the UXO discrimination problem whereby features derived from physics-based models fit to sensor data are used to determine the likelihood that a buried item is a UXO. Statistical and rule based classification techniques, when used with high quality EM data, have been found to be very effective at discrimination. Involvement in ESTCP Discrimination Demonstration studies have given us an opportunity to adapt and extend existing strategies for discrimination of Unexploded Ordnance (UXO) to emerging next-generation EMI sensors and to test discrimination performance at increasingly complex and cluttered sites. When participating in the ESTCP Discrimination Study, our technical objectives include (1) Developing robust inversion strategies to extract polarization tensor parameters from both production-type and ?next generation? EMI sensor data that are applicable when the spatial signature of adjacent anomalies overlap; (2) Further development and testing of a suite of discrimination strategies (e.g., statistical classification of polarization tensor parameters, library based matching, statistical classification of data-based features) at increasingly complex and cluttered sites for a wide-range of EMI sensors (production and next generation); (3) Develop tools and expertise to decide on the optimum discrimination strategy to apply at a newly encountered site; and (4) Develop tools and expertise to determine when to stop-digging. In this presentation we provide an overview of the methods and present results of applying them to data acquired as part of the ESTCP Discrimination Demonstration study at the Former Camp Beale, CA. Results from processing data from the Geonics EM61MK2 cart system, the Metal Mapper EMI system, the TEMTADS 2H2 system, the Berkeley UXO Discriminator (BUD) portable sensor, and Man Portable Vector (MPV) sensor are presented.

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UXO DISCRIMINATION USING VEHICLE TOWED AND MAN PORTABLE SENSOR DATA COLLECTED AT CAMP BEALE, CALIFORNIA

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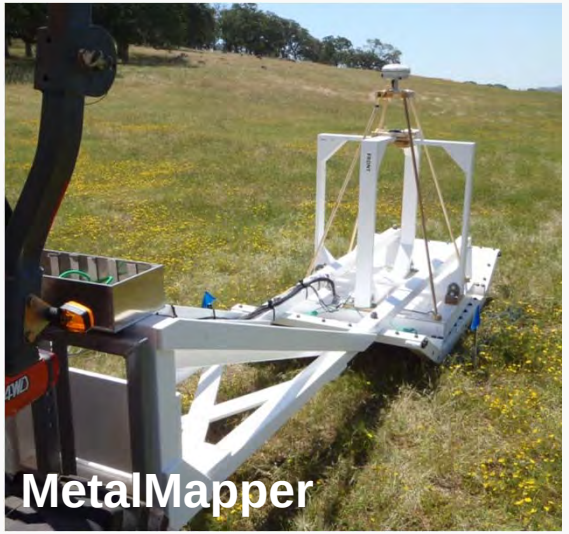
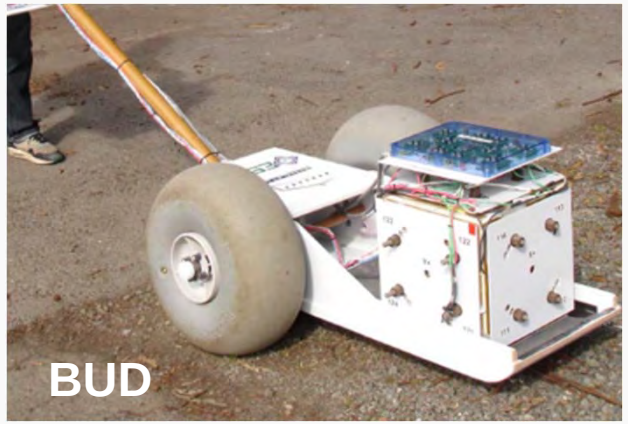
Over the past few years there has been much research on the UXO discrimination problem, whereby features derived from physics-based models fit to sensor data are used to determine the likelihood that a buried item is a UXO. Statistical and rule based classification techniques, when used with high quality EM data, have been found to be very effective at discrimination. Involvement in ESTCP Discrimination Demonstration studies have given us an opportunity to adapt and extend existing strategies for discrimination of Unexploded Ordnance (UXO) to emerging next-generation EMI sensors and to test discrimination performance at increasingly complex and cluttered sites. When participating in the ESTCP Discrimination Study, our technical objectives include (1) Developing robust inversion strategies to extract polarization tensor parameters from both production-type and "next generation" EMI sensor data that are applicable when the spatial signature of adjacent anomalies overlap; (2) Further development and testing of a suite of discrimination strategies (e.g., statistical classification of polarization tensor parameters, library based matching, statistical classification of data-based features) at increasingly complex and cluttered sites for a wide-range of EMI sensors (production and next generation); (3) Develop tools and expertise to decide on the optimum discrimination strategy to apply at a newly encountered site; and (4) Develop tools and expertise to determine when to stop-digging. In this presentation we provide an overview of the methods and present results of applying them to data acquired as part of the ESTCP Discrimination Demonstration study at the Former Camp Beale, CA. Results from processing data from the Geonics EM61MK2 cart system, the Metal Mapper EMI system, the TEMTADS 2×2 system, the Berkeley UXO Discriminator (BUD) portable sensor, and Man Portable Vector (MPV) sensor are presented.

UXO Discrimination at Camp Beale

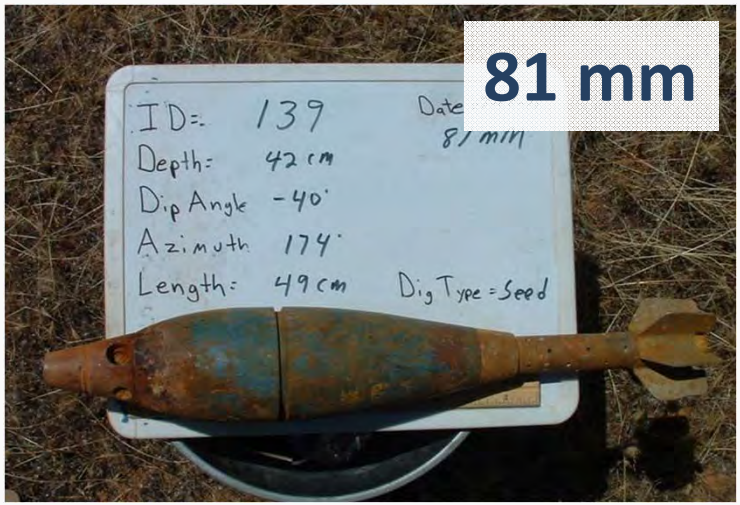
- Apply ***practical*** UXO discrimination techniques to all EMI data sets collected.
- Evaluate discrimination performance using portable EMI sensor data

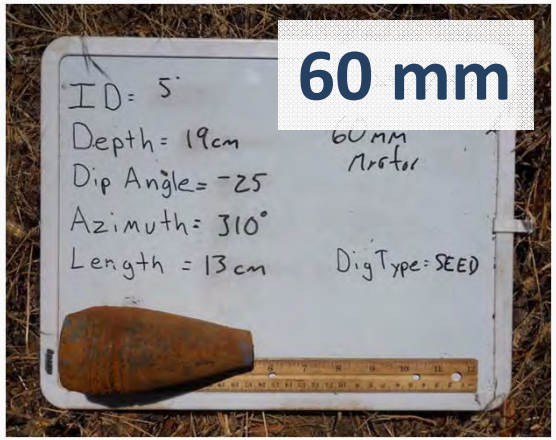


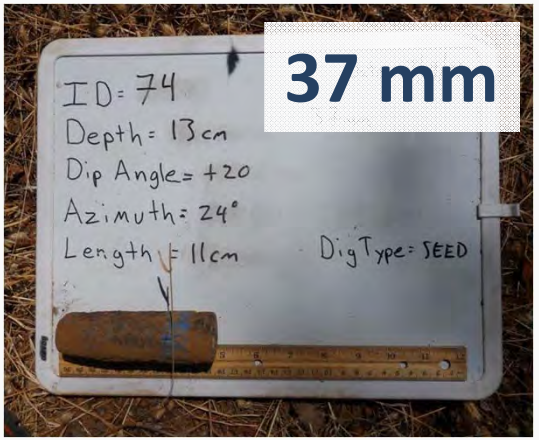


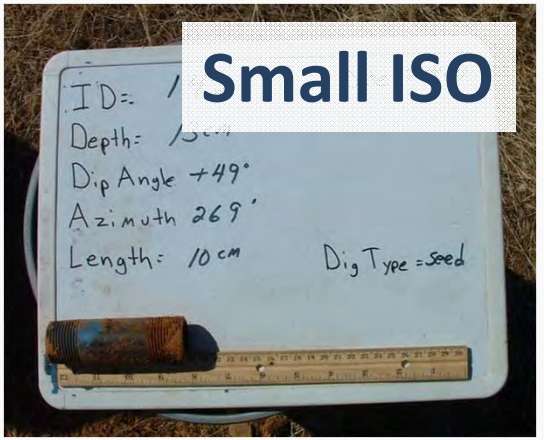
UXO discrimination at Camp Beale

- **UXO at site**



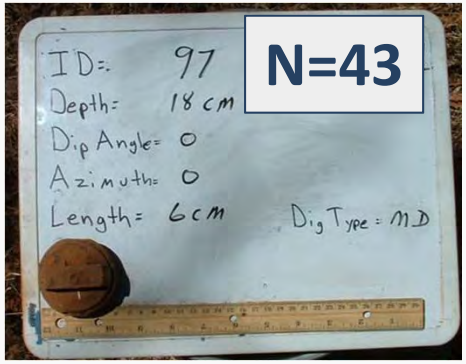




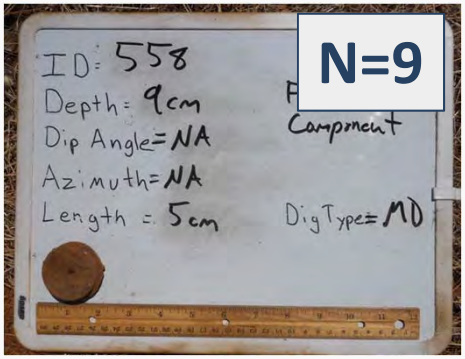


UXO discrimination at Camp Beale

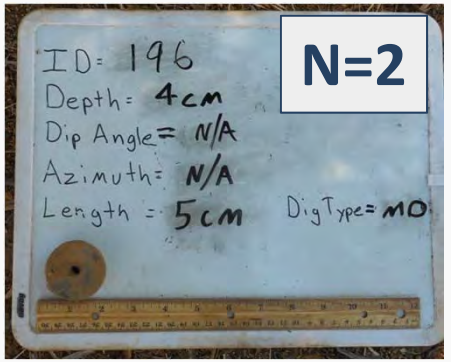
- **Fuze components**
  - Classified as non-harmful, non-UXO



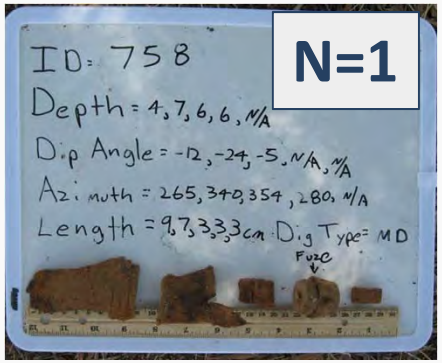
- 6cm



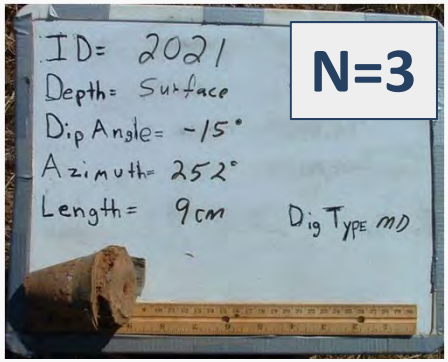
- 5cm



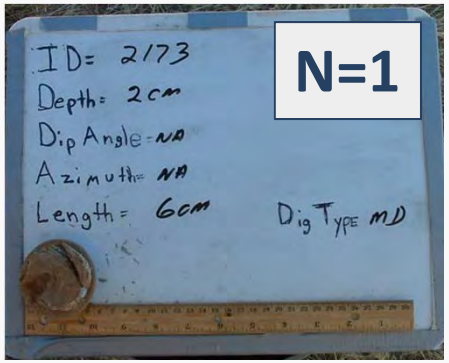
- Equal polarizabilties
- 5cm.



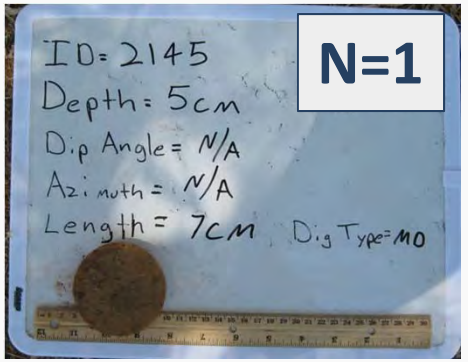
- 3cm



- Conical shield attached. 9cm.



- 6cm

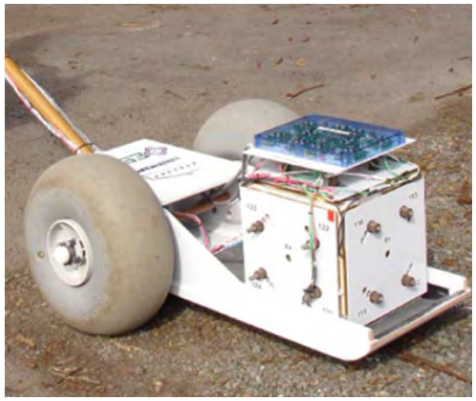


- Plate-like. 7 cm

Data Acquired at Camp Beale

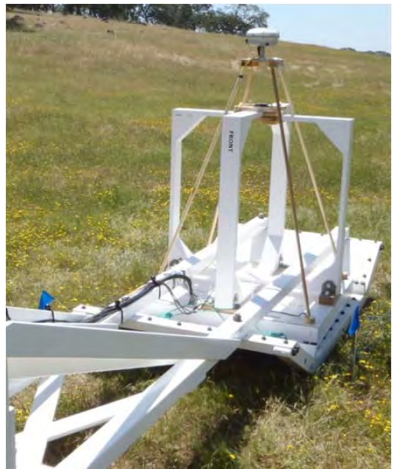
Treed Area

- EM61
- TEMTADS 2x2
- MPV
- BUD



Open Area

- EM61
- MetalMapper
  - o CH2M Hill
  - o Parsons

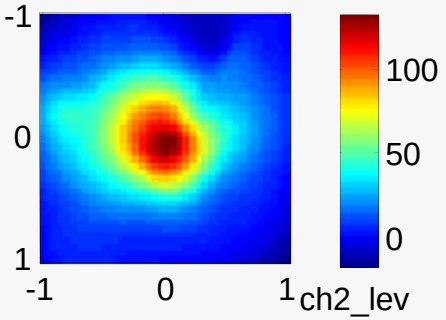


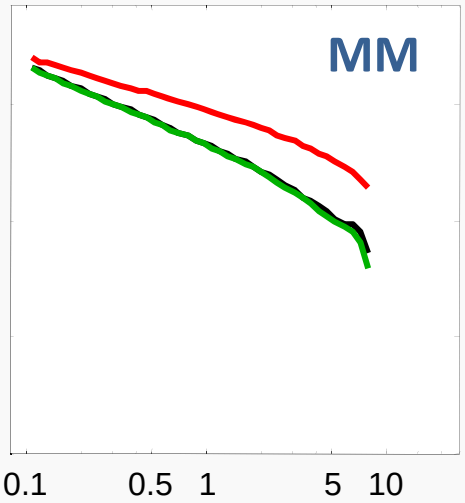
UXO discrimination at Camp Beale

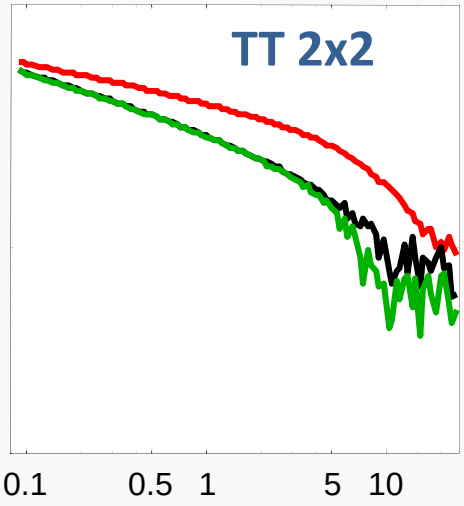
UXO: 81 mm

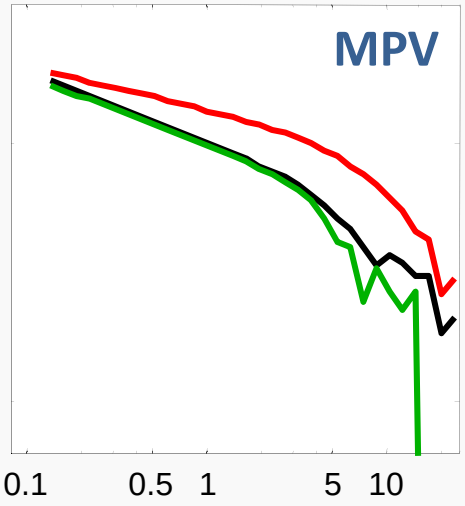
Depth = 35 cm

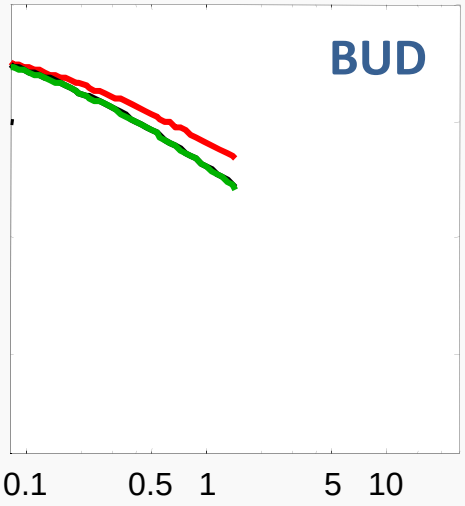
BE-205







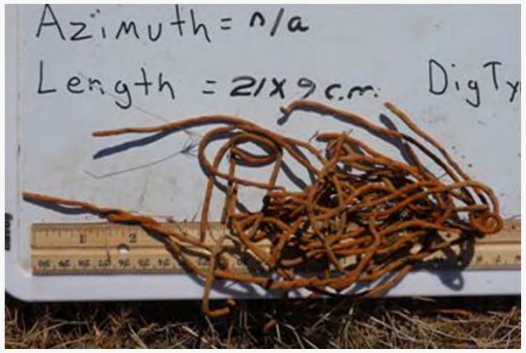




UXO discrimination at Camp Beale

Cultural Scrap. Wire

Depth = 4.5 cm



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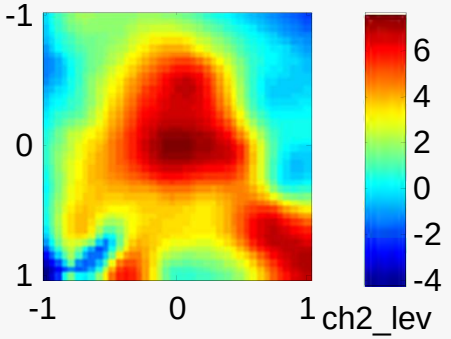
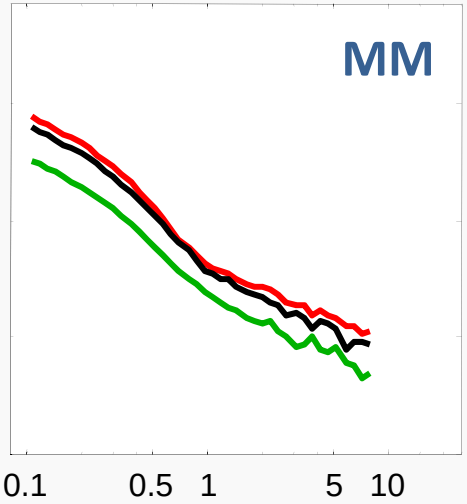
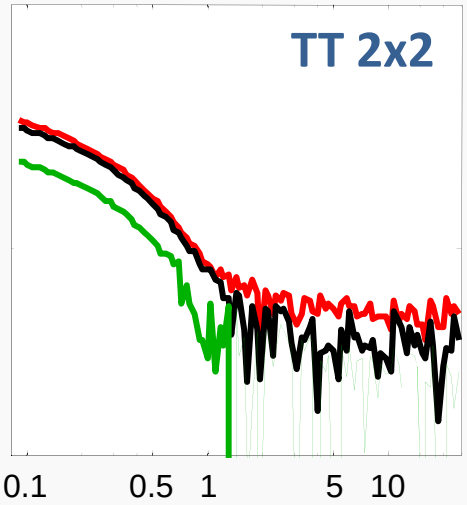
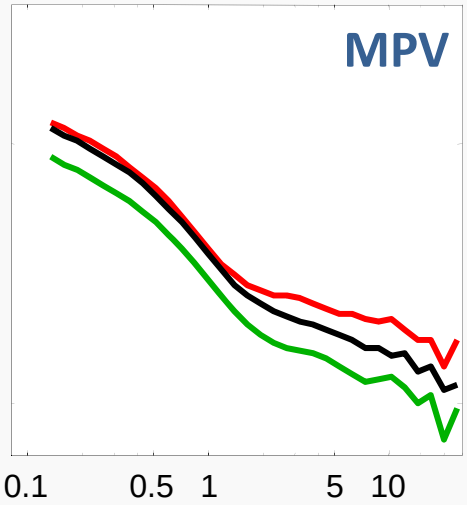
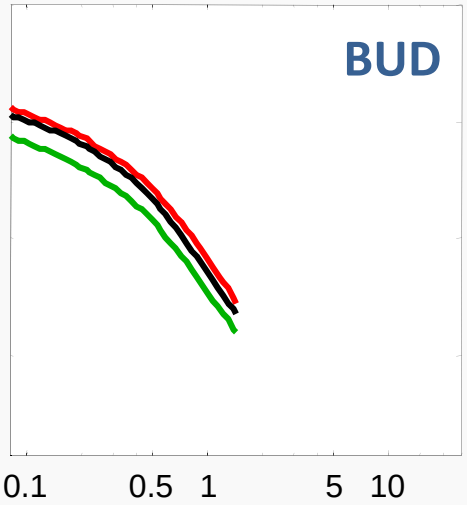








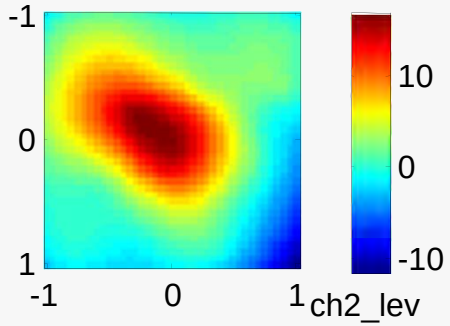


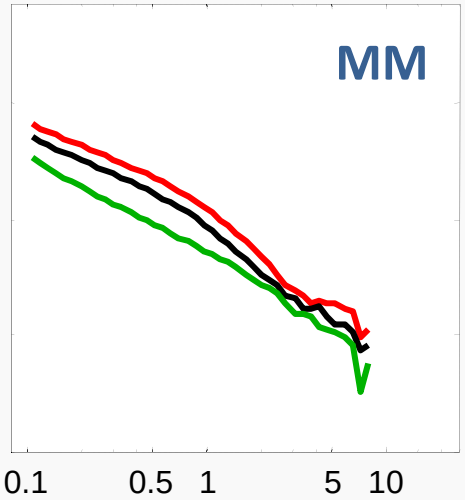
UXO discrimination at Camp Beale

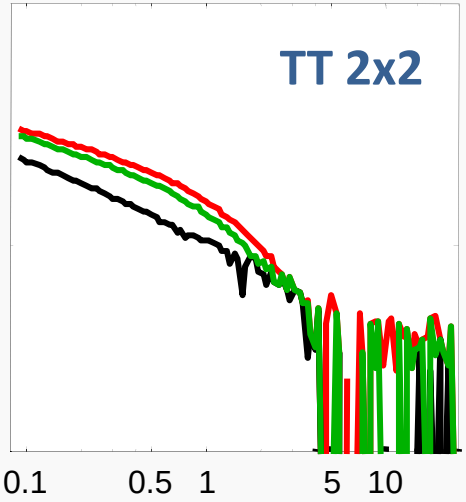
Frag

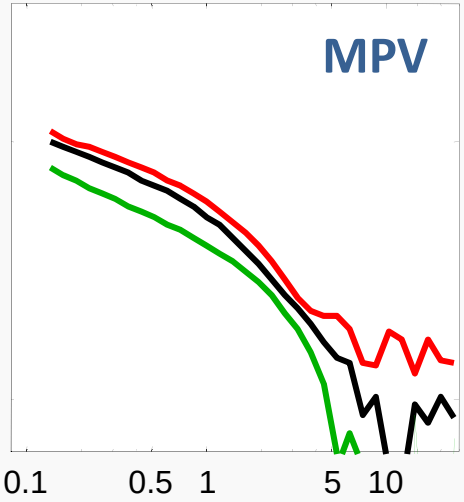
Depth = 3 cm

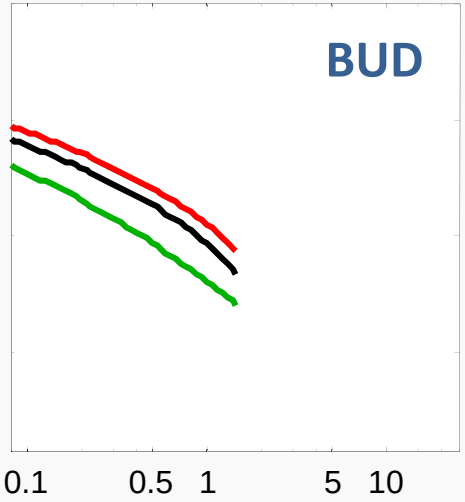
BE-469







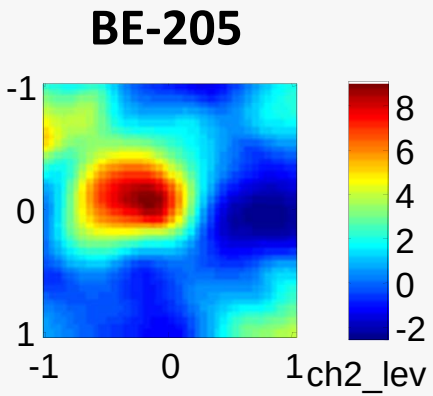


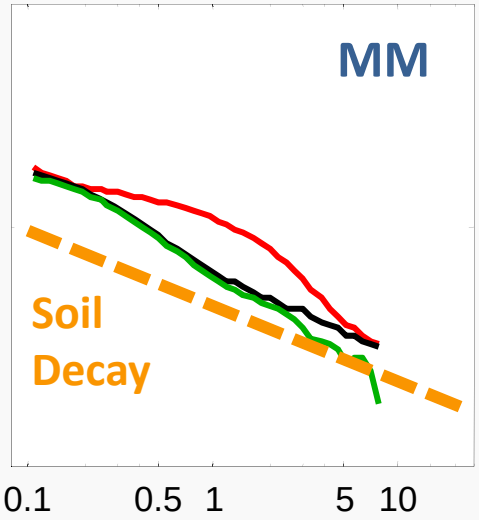


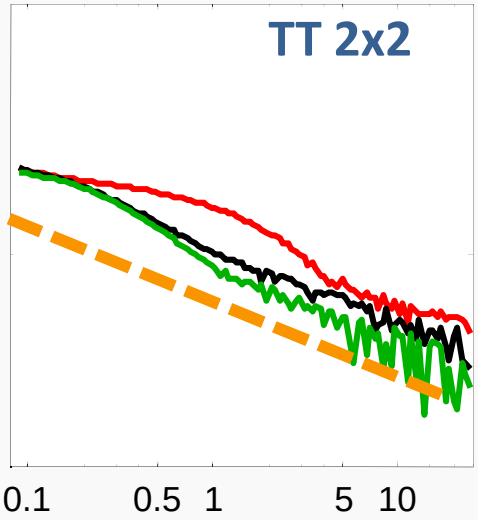
UXO discrimination at Camp Beale

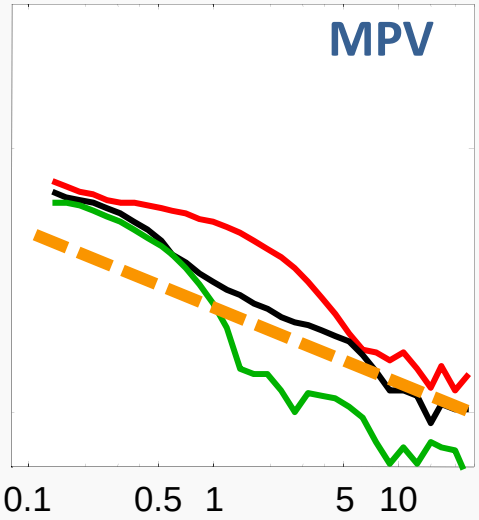
0.50 cal

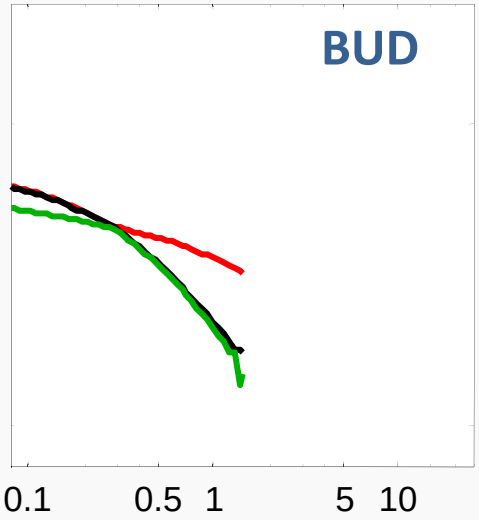
Depth = 1 cm





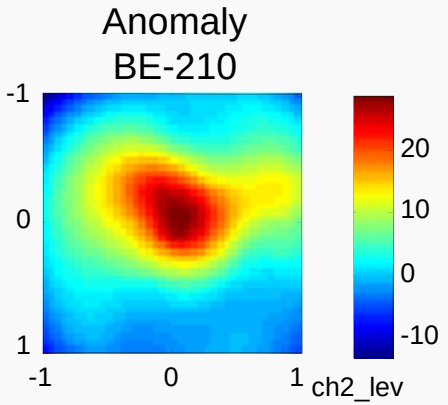


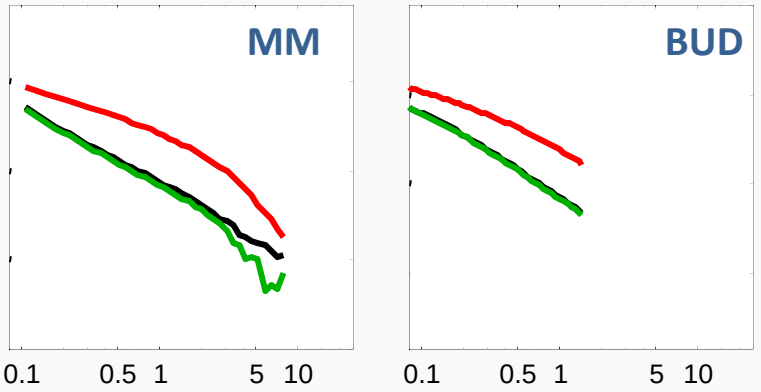


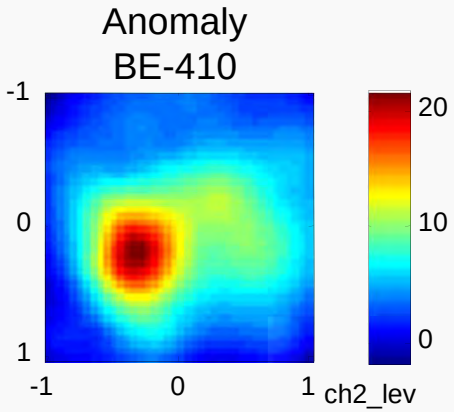


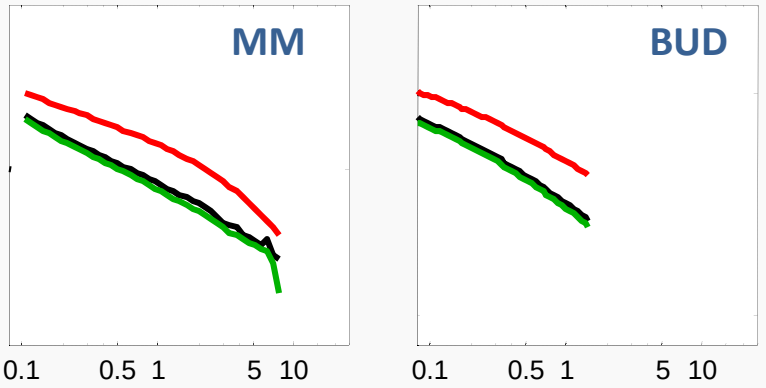
UXO Discrimination at Camp Beale

- Discrimination limited by similarity of UXO vs. scrap features



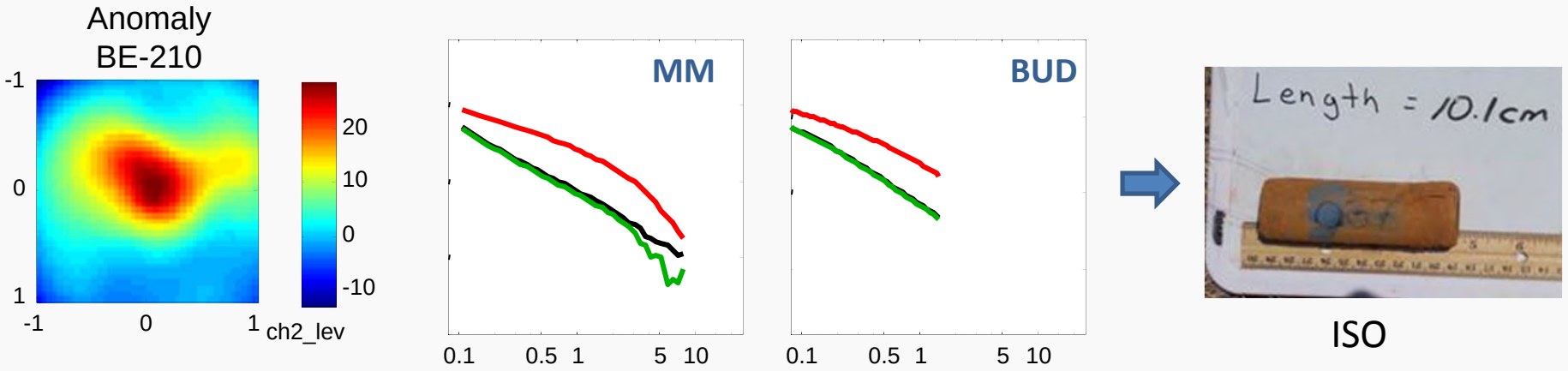






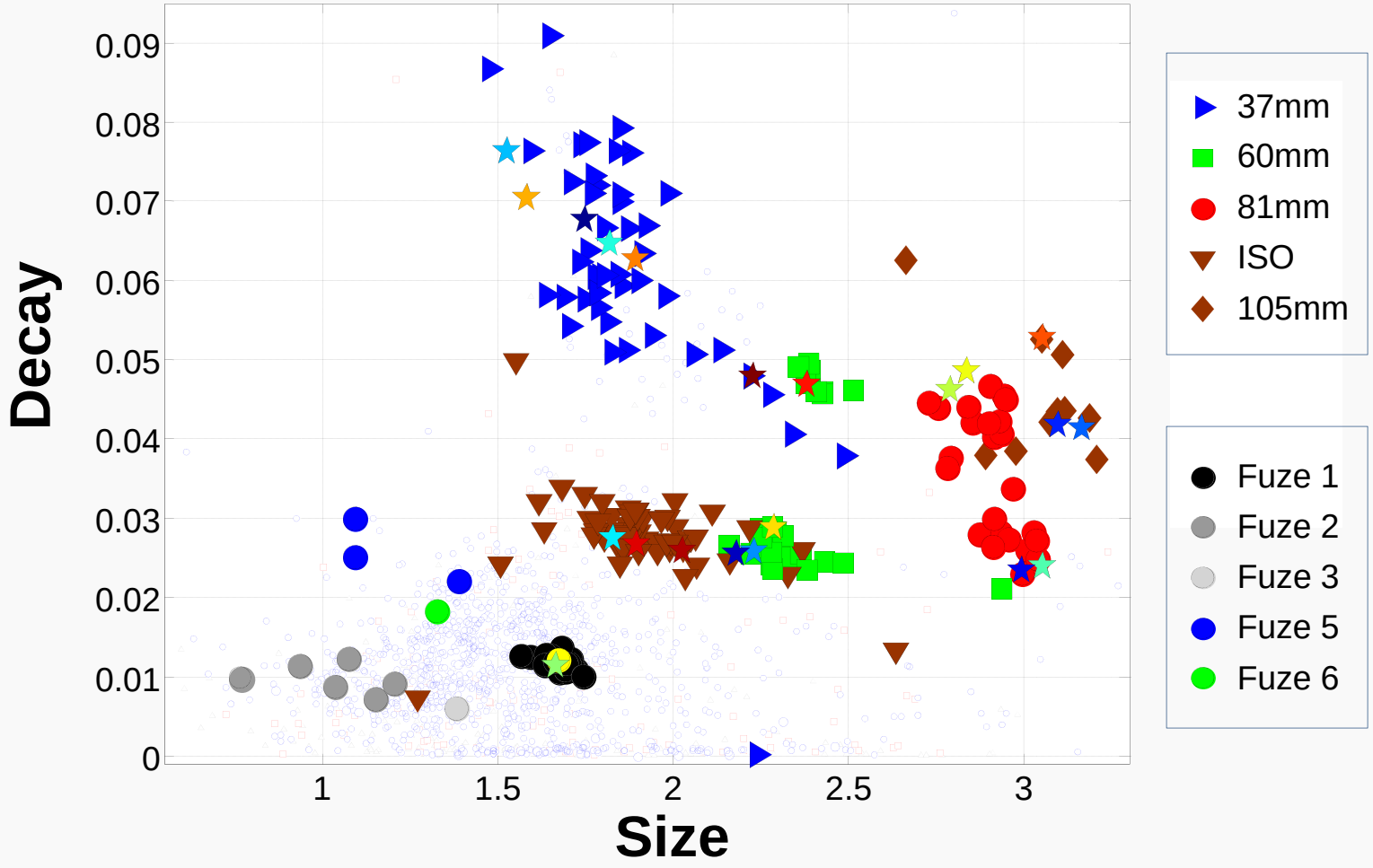
UXO Discrimination at Camp Beale

- Discrimination limited by similarity of UXO vs. scrap features



UXO Discrimination at Camp Beale

- MetalMapper (Parsons): Size vs. Decay Feature space



UXO Discrimination at Camp Beale

1. FEATURE EXTRACTION

- Derive parameters from the data that tell us something about the buried target

2. CLASSIFICATION

- Features are used to decide how likely that a particular anomaly is due to a UXO

Feature Extraction

1. **Estimate target parameters**
   - Single source and two source inversions
   - Location, orientation, polarizabilities

2. **Data /Inversion QC**
   - Look for poor fits to the data
   - Determine if any anomalies are “Can’t Analyze”

3. **Model Selection**
   - Determine which of the models should be used in the classifier

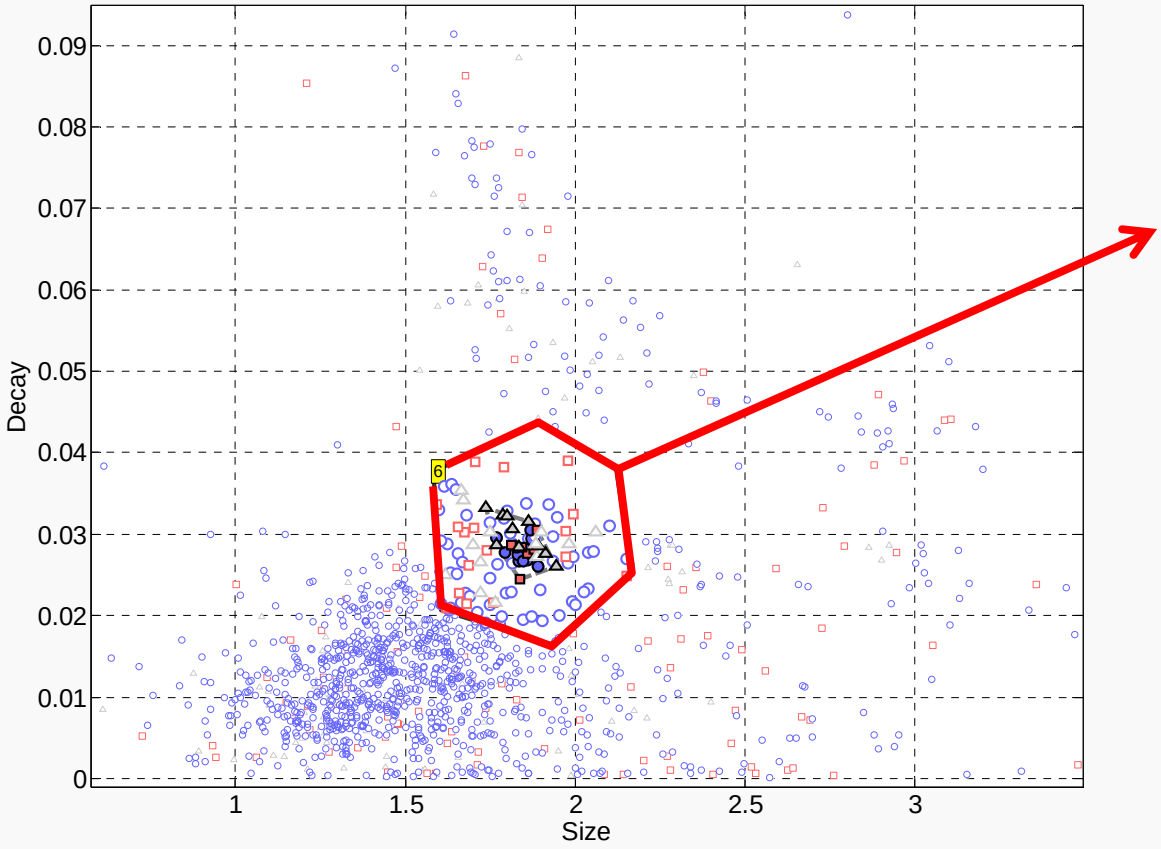
Classification

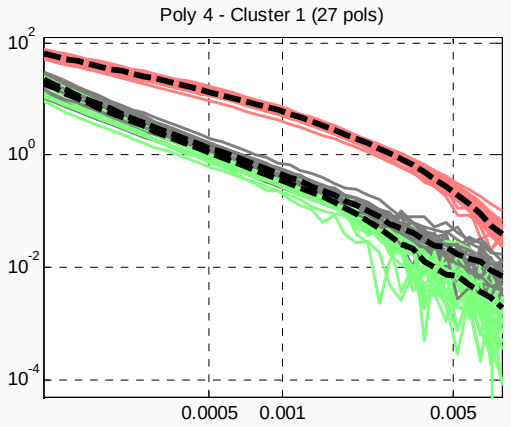
4. **Request training data**
   - Semi-supervised approach
5. **Create Ranked Anomaly List**
   - Library Matching Method
   - Support Vector Machine Classifier
6. **Determine a Stop Digging Point**
   - Manual: Visual inspection of list
   - Automated: Modeling the partial ROC curve

Classification

4. Request training data

- Establish clusters of UXO
- Determine extent of UXO clusters and boundaries with clutter classes.



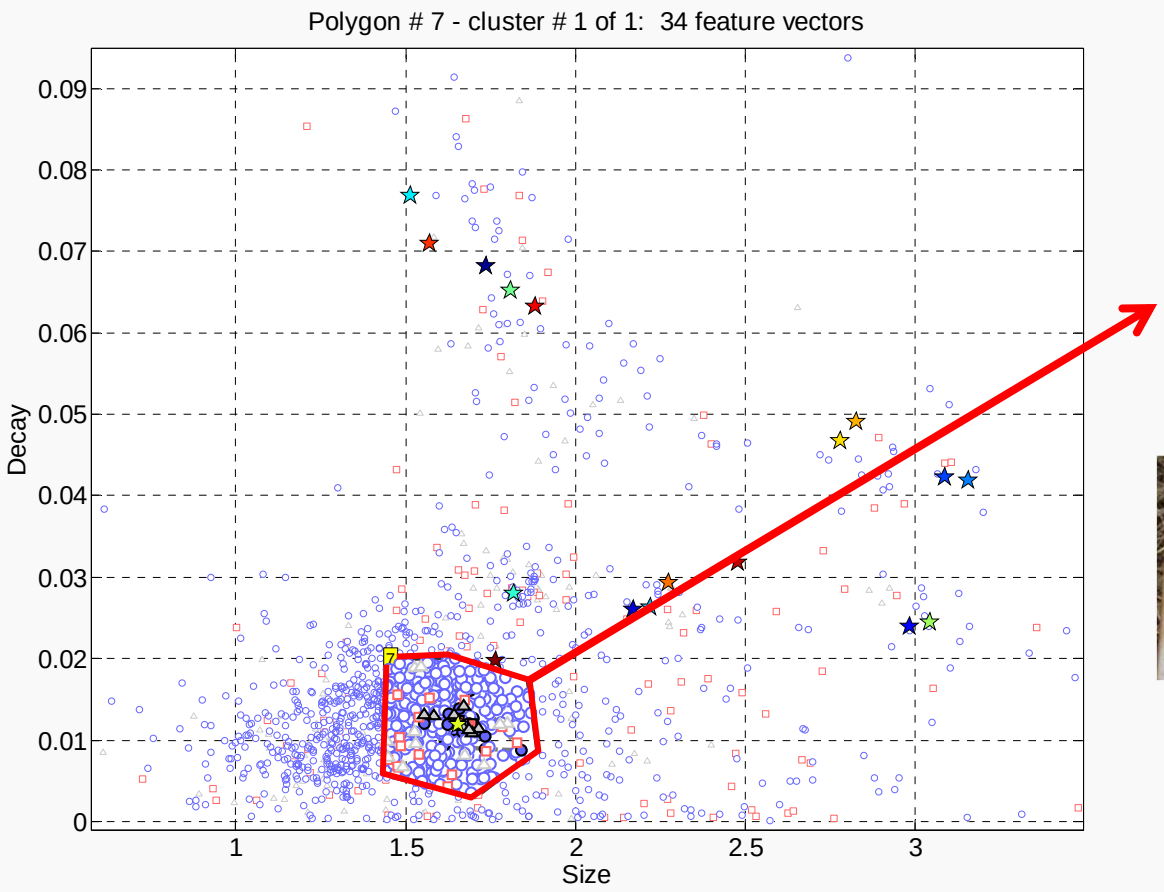


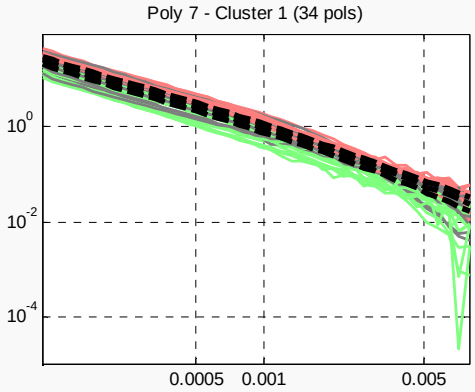
SMALL ISO

Classification

4. Request training data

- Establish clusters of UXO
- Determine extent of UXO clusters and boundaries with clutter classes.





6 cm Fuse

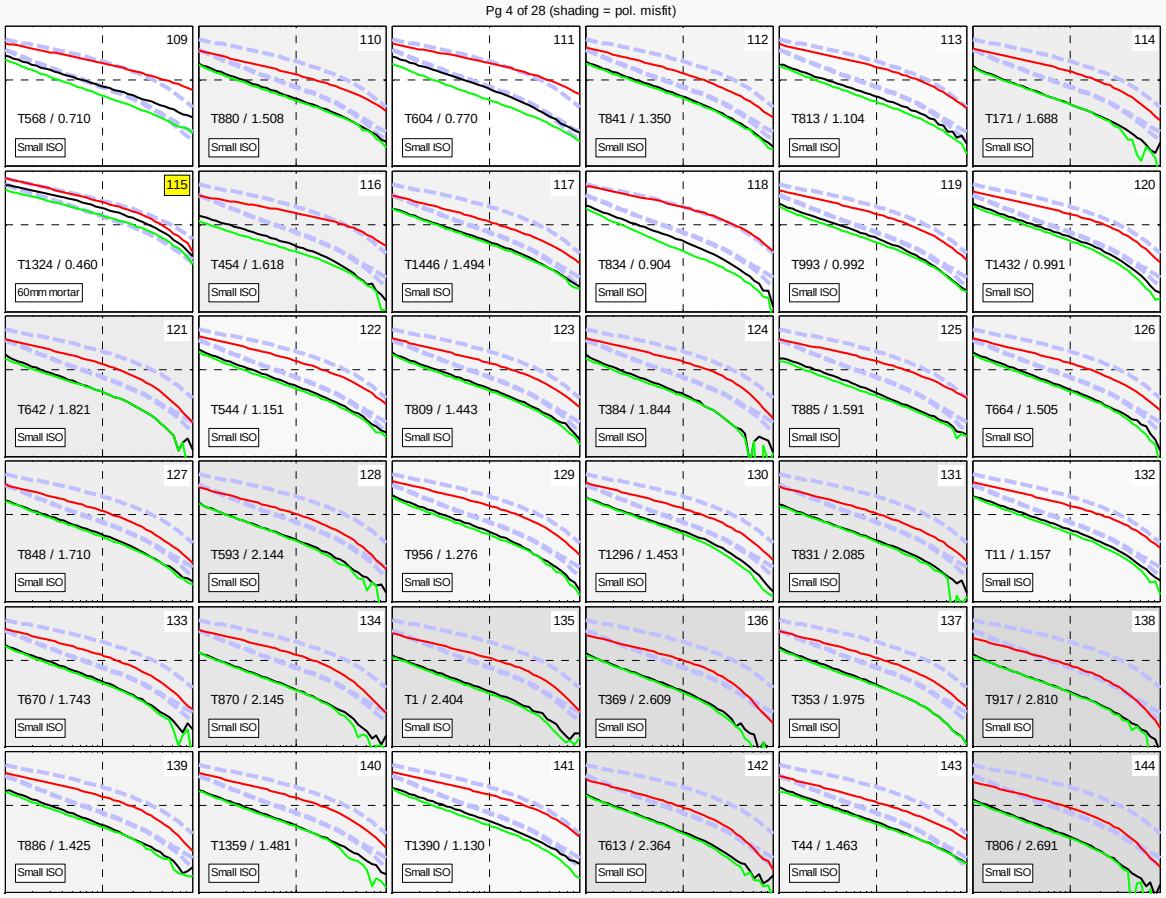
Classification

4. **Request training data**
   - Semi-supervised approach
5. **Create Ranked Anomaly List**
   - Library Matching Method
   - Support Vector Machine Classifier
6. **Determine a Stop Digging Point**
   1. Manual: Visual inspection of list
   2. Assigning a confidence: Modeling the partial ROC curve

Classification

6. Determine a Stop Digging Point 1: Manual

- Visual inspection of list

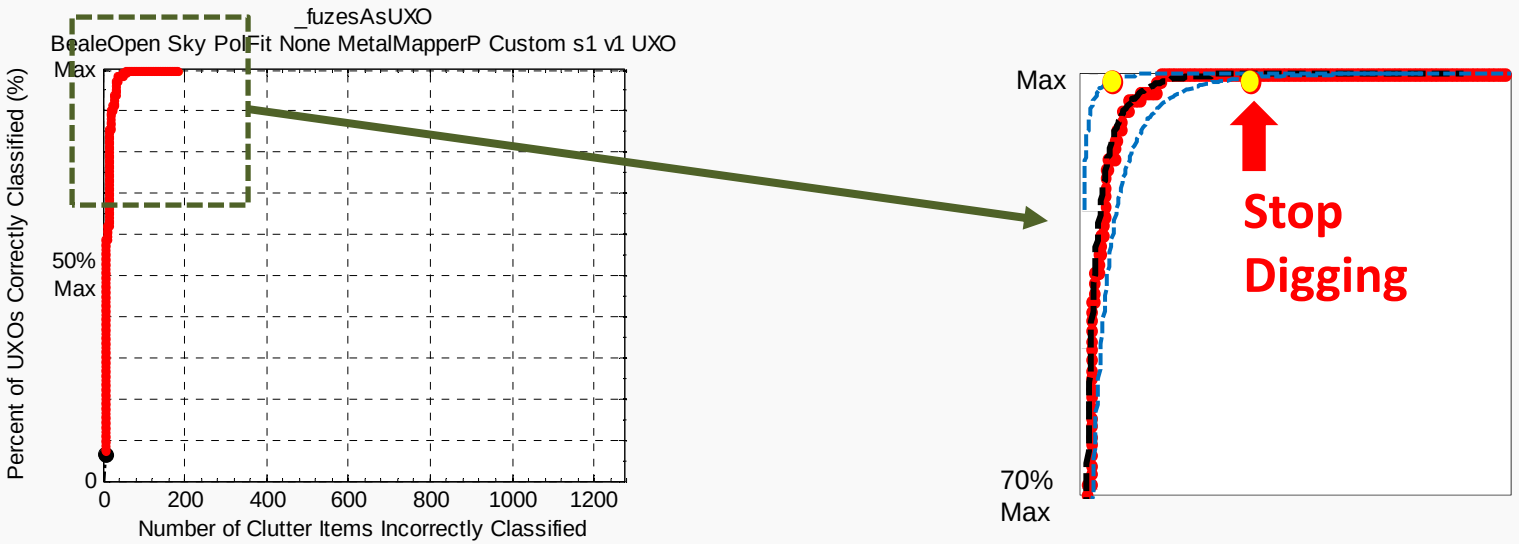


Classification

6. Determine a Stop Dig Point 2: Assigning a Confidence

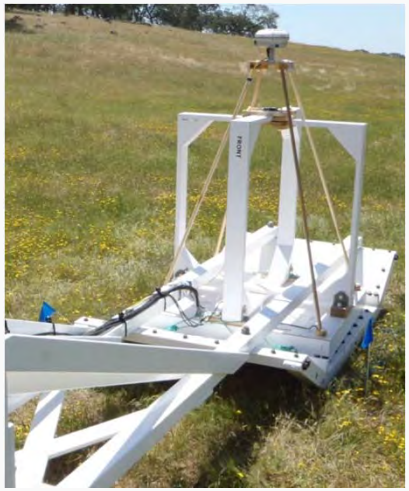
Generate objective numerical confidence that all the UXO are found:

- Test hypothesis that all UXO are found
- Fit a binormal model to the observed partial ROC curve
- There is an 99% expectation that the FAR falls within the interval



Beale Open Area: MetalMapper Processing

- MetalMapper data collected by Parsons and CH2M HILL
- Two classification methods to each dataset:
  1. Library based
  2. Two-stage Support Vector Machine
- A different analyst for each method and instrument

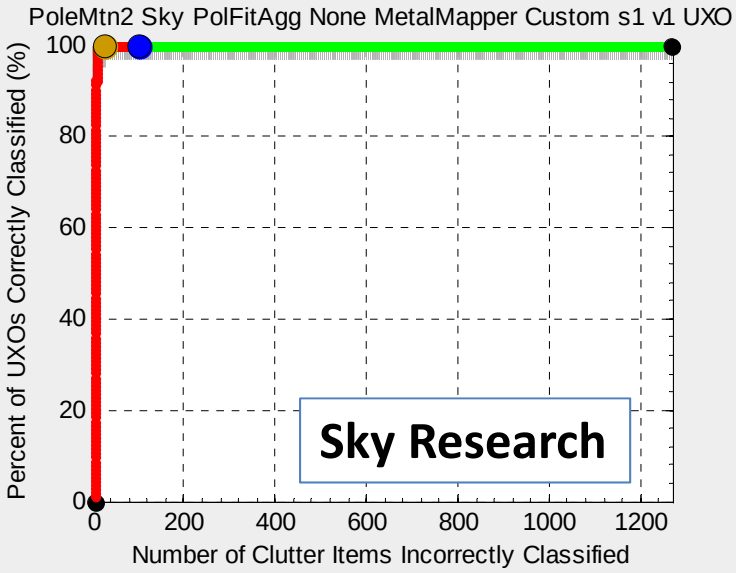


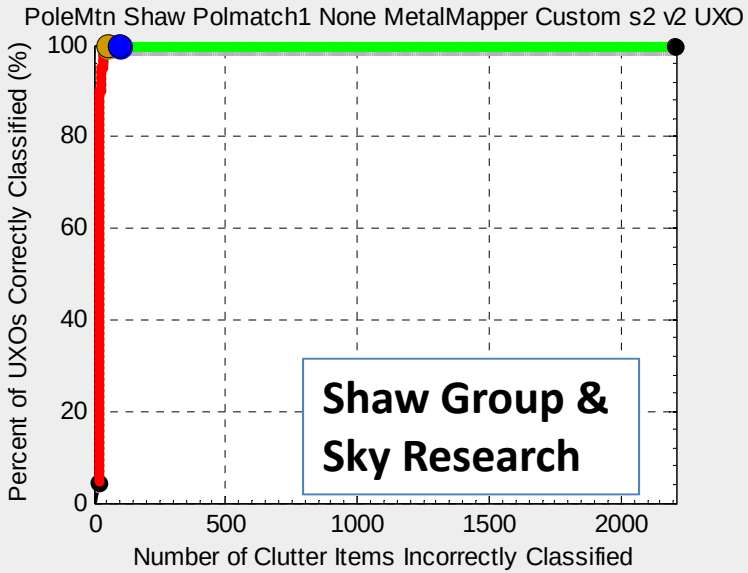
MetalMapper Processing 1: Library Matching

Anomaly rank based on:

- Library polarizability fit (3)
- Axial symmetry
- Misfit to non-UXO (e.g., horseshoe)

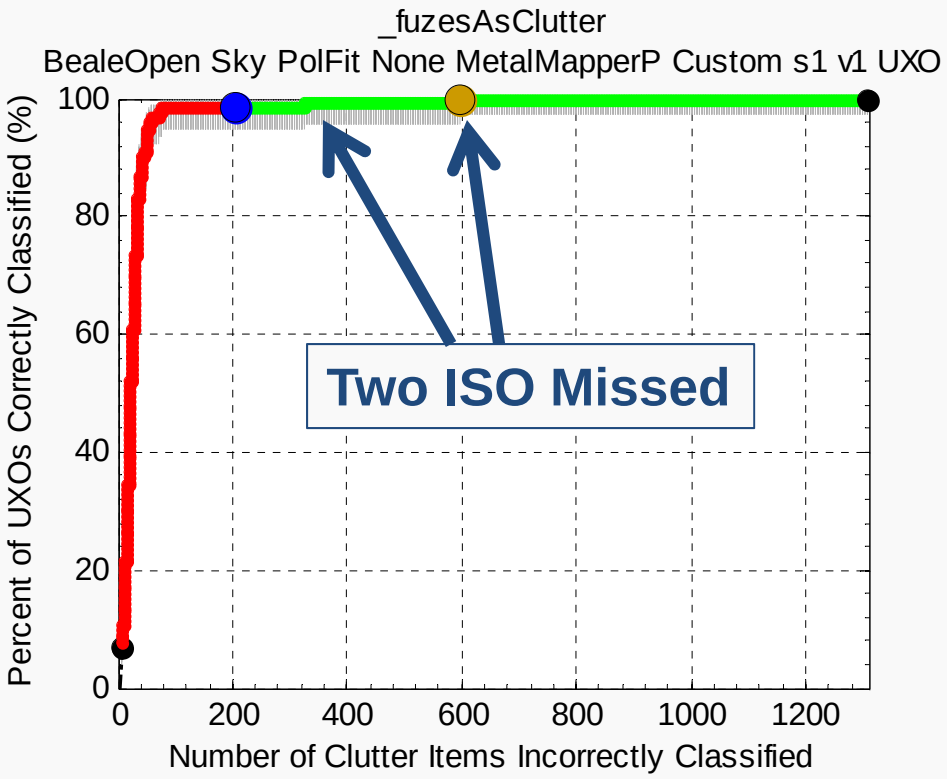
Example: Pole Mountain MetalMapper (ESTCP 201159)

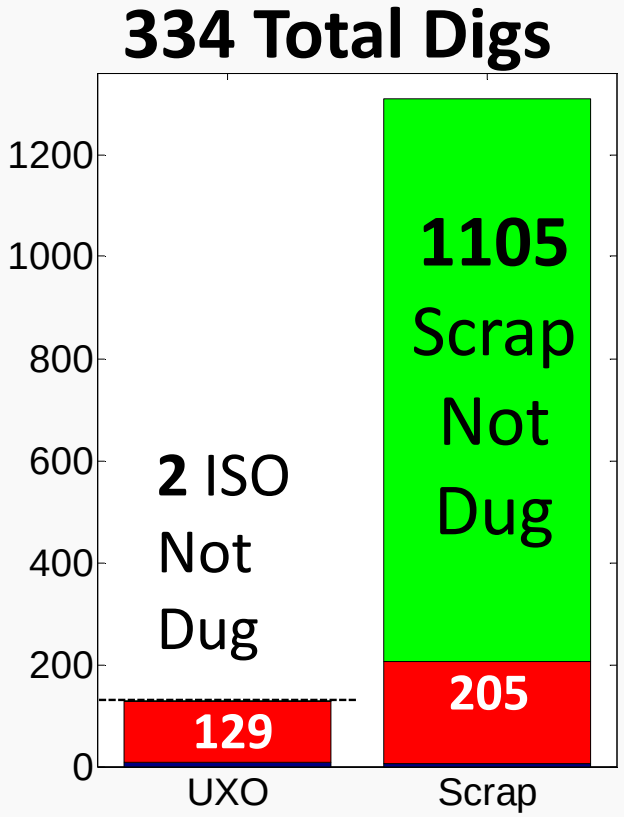




MetalMapper Processing 1: Library Matching

- Aggressive method
- Two ISO Missed

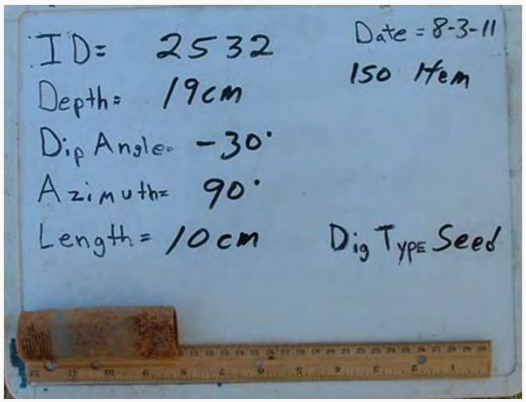


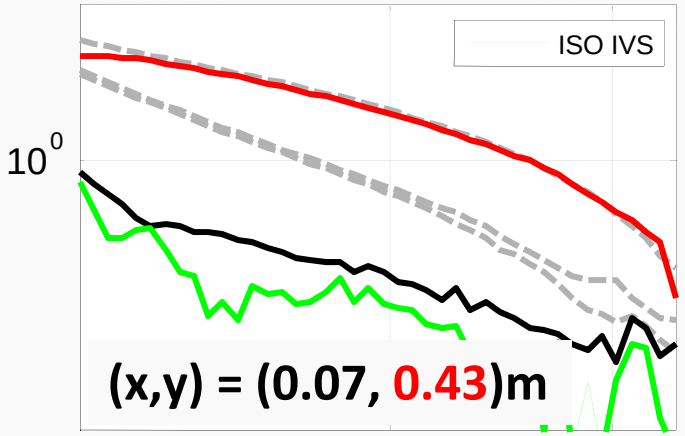


MetalMapper Processing 1: Library Matching

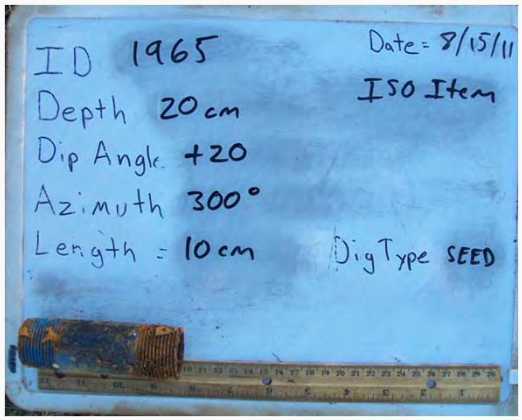
- Two ISO stats Seed missed

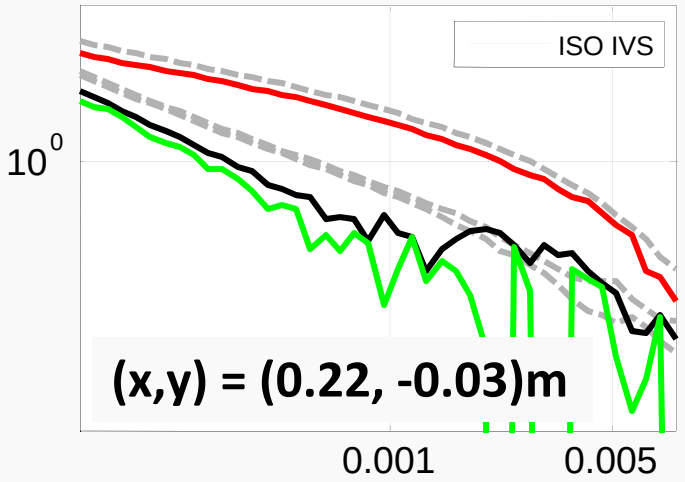
BE-2532





BE-1965

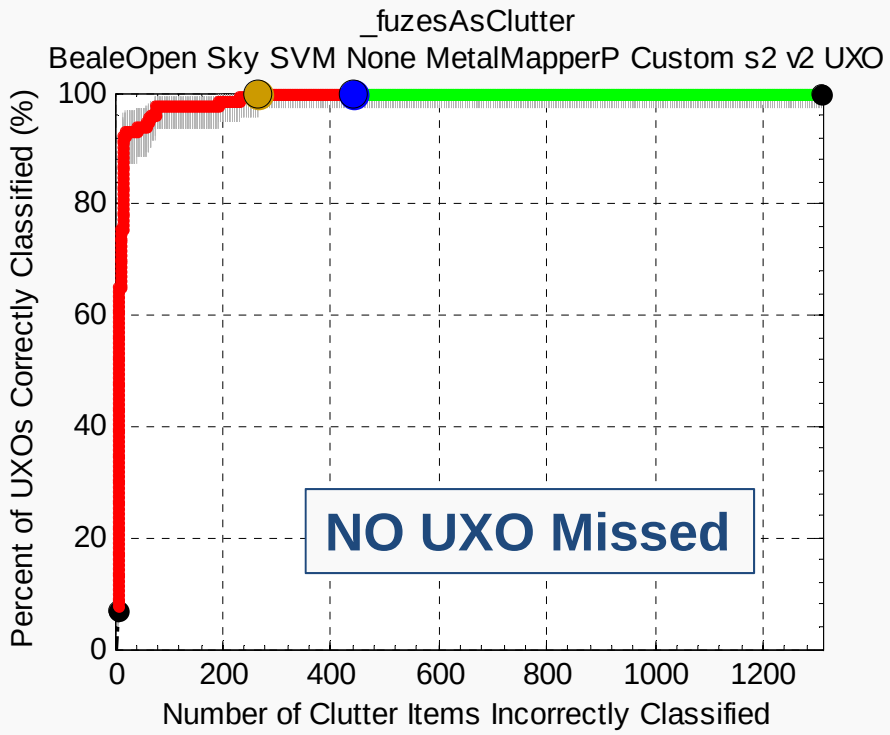


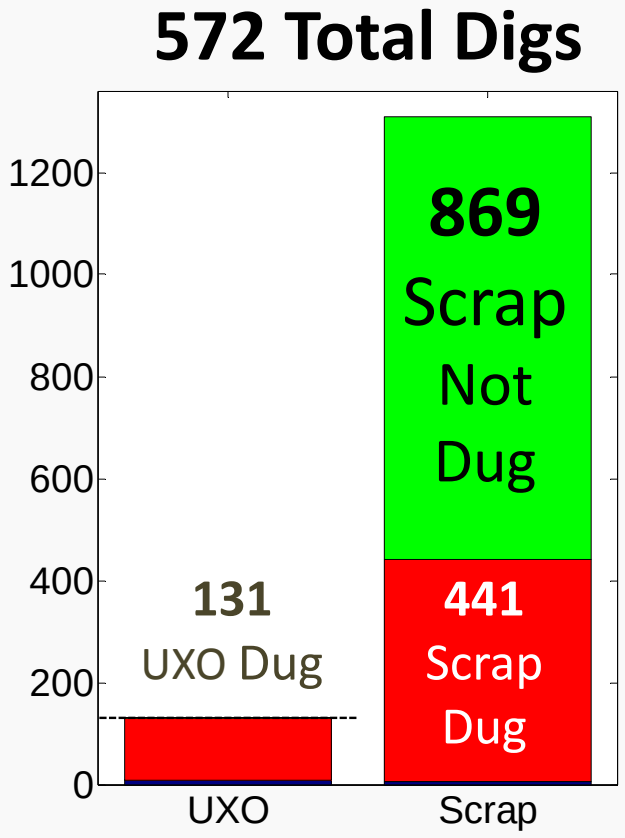


- ***All 3 polarizabilities sometimes not well constrained – should also use primary polarizability only fit for ISOs***

MetalMapper Processing 2

- More conservative approach
- Two-stage Support Vector Machine classifier

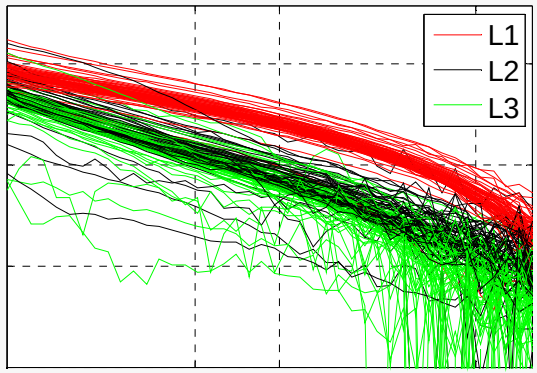




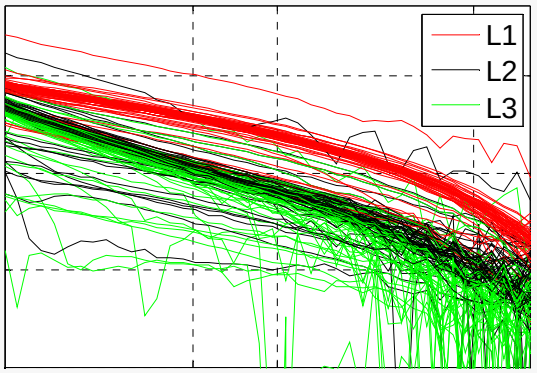
Camp Beale and Pole Mountain MetalMapper Performance Comparison

- Performance and data metrics calculated at both sites *(SERDP 1637 poster)*
- Sensor positioning slightly better at Pole Mtn. than Beale (Δr_{pole} = 0.08 m vs. Δr_{beale} = 0.20 m for UXO)
- Additional noise due to magnetic soil

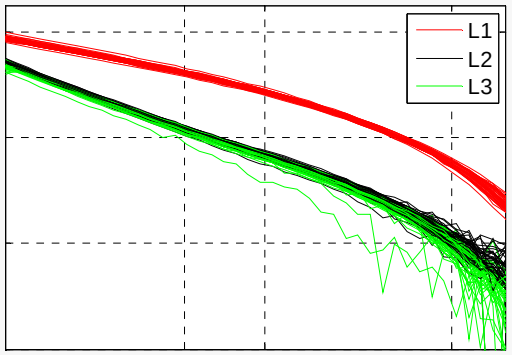
Recovered ISO Polarizabilities



Beale – Parsons



Beale – CH2M HILL



Pole Mountain

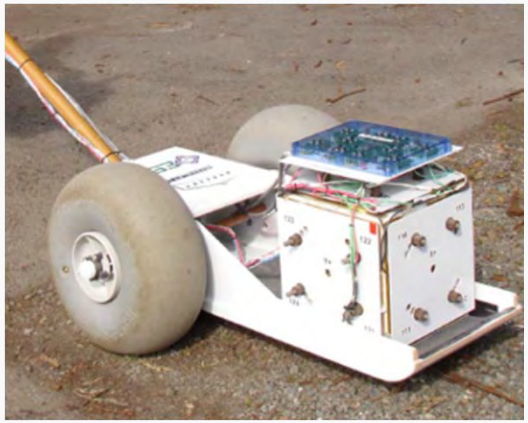
Beale Treed Area: Man Portable Instruments

- TEMTADS 2x2 and BUD data sets processed using the same method as was used for the MetalMapper
  - MPV results provided to us by Nicolas Lhomme (ESTCP 201158)
- A different analyst for each method and instrument

TEMTADS 2x2

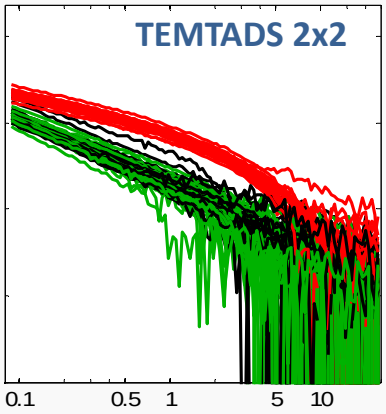
MPV

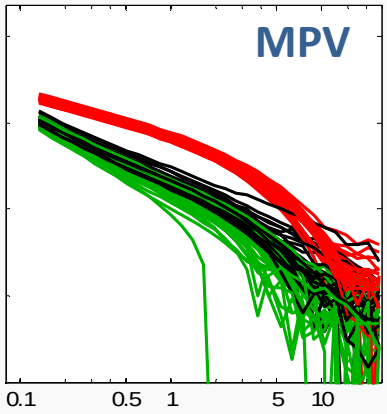
BUD

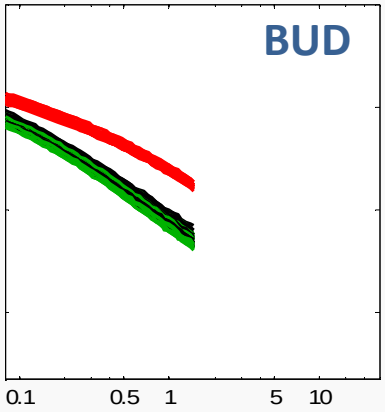


Beale Treed Area: Man Portable Instruments

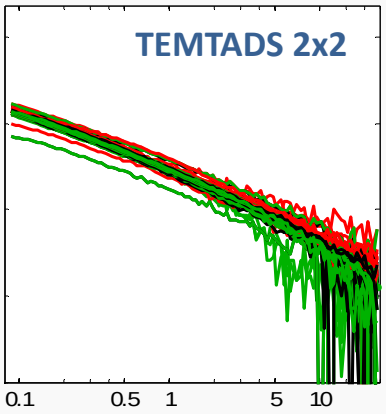
SMALL ISO

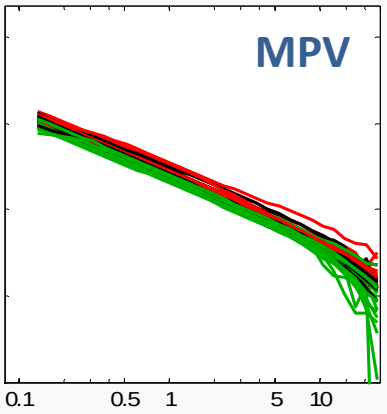


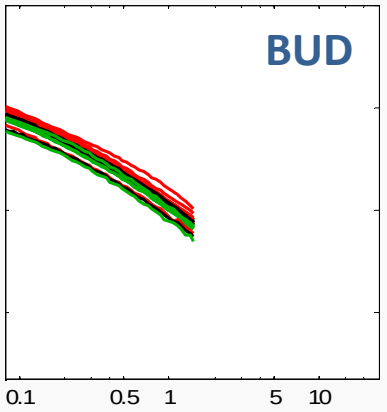




6 cm Fuse

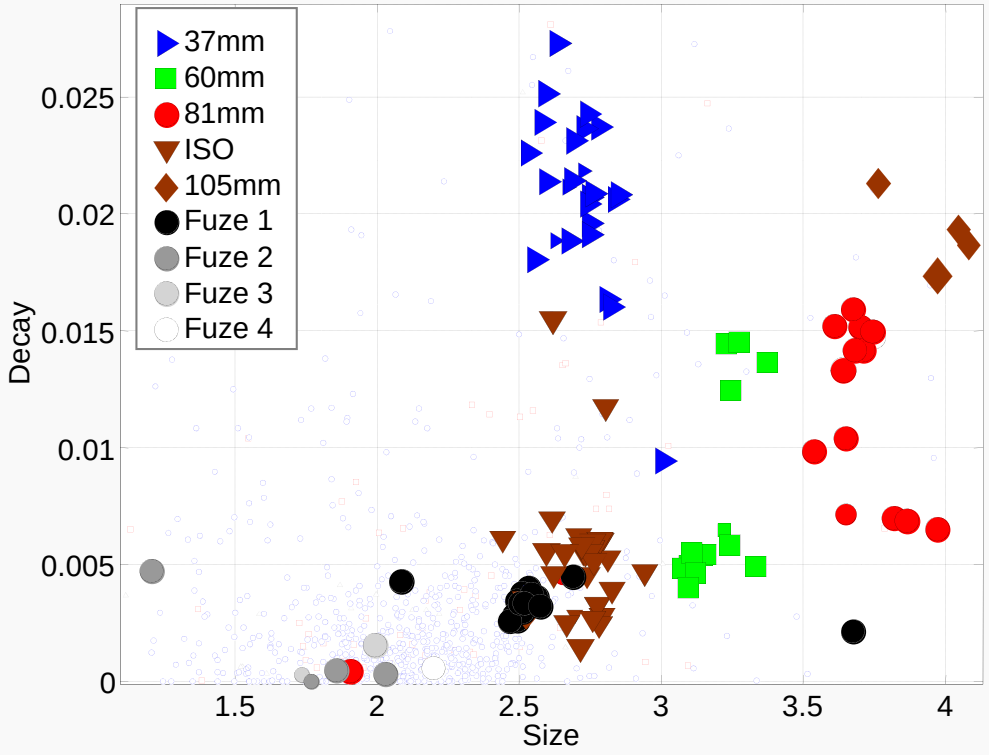




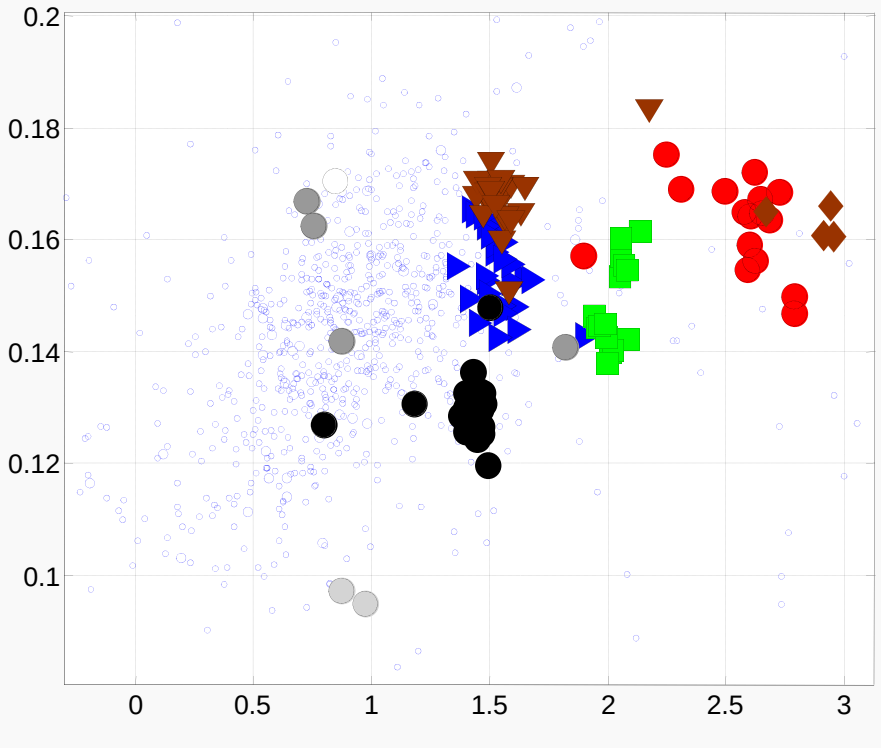


Beale Treed Area: Man Portable Instruments

TEMTADS 2x2

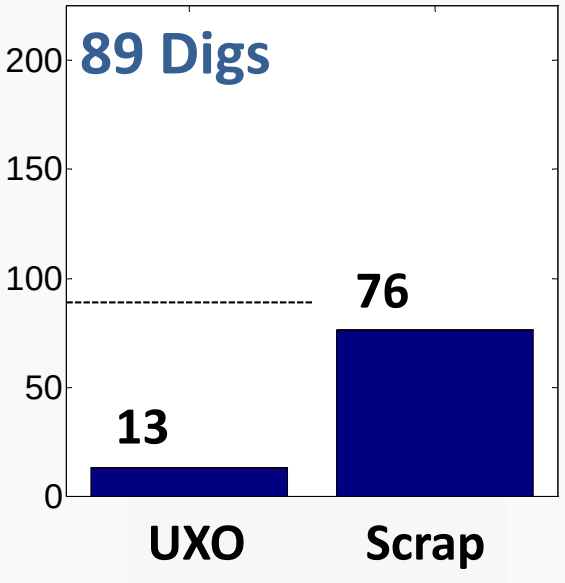


BUD HH

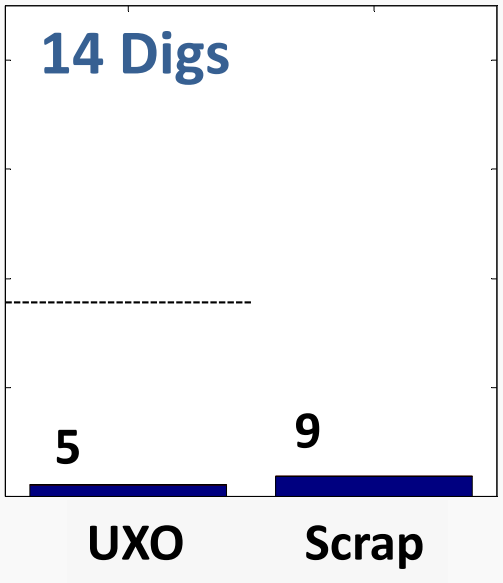


Diglist Progress: Training Data Requests/Can't Analyze

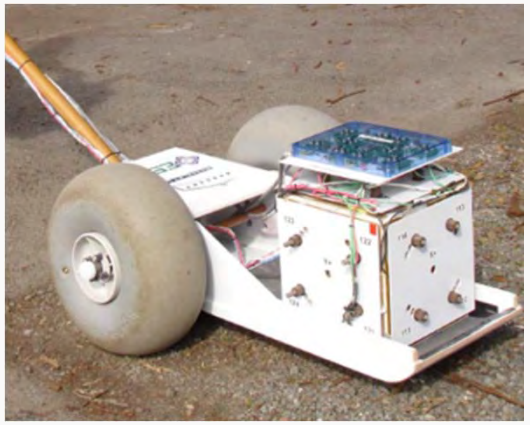
TEMTADS 2x2

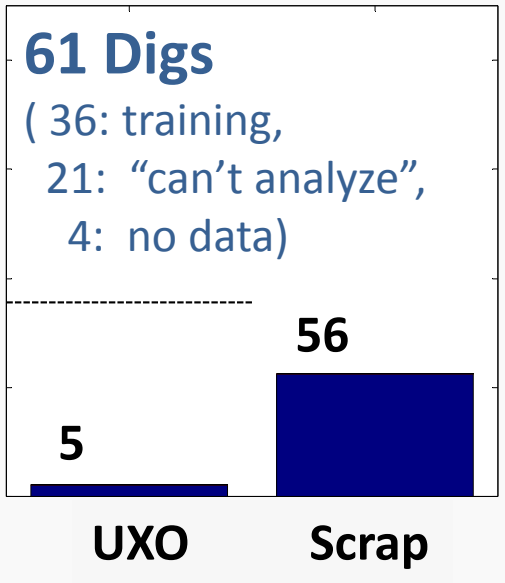


MPV



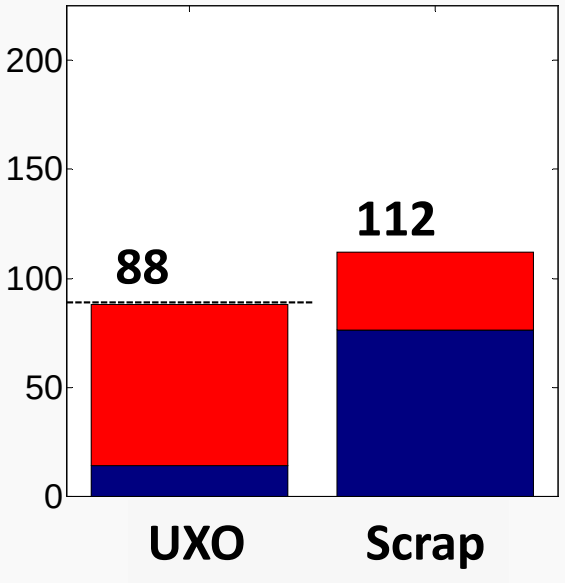
BUD



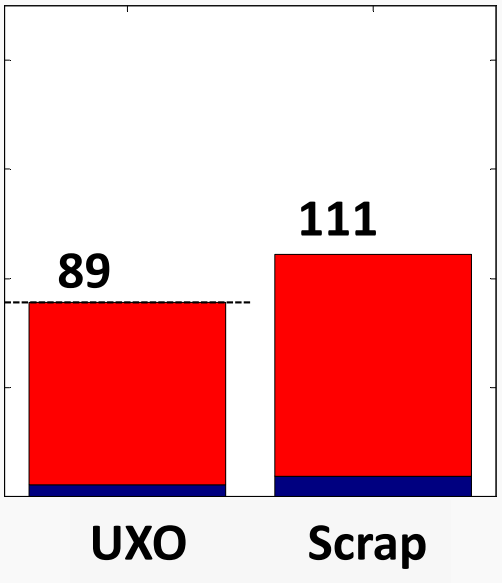


Diglist Progress: 200 digs

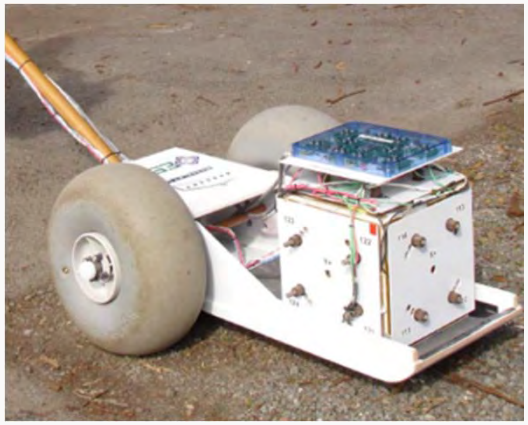
TEMTADS 2x2

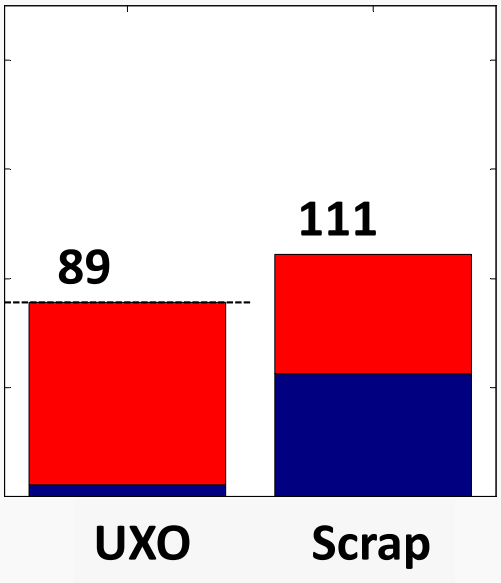


MPV



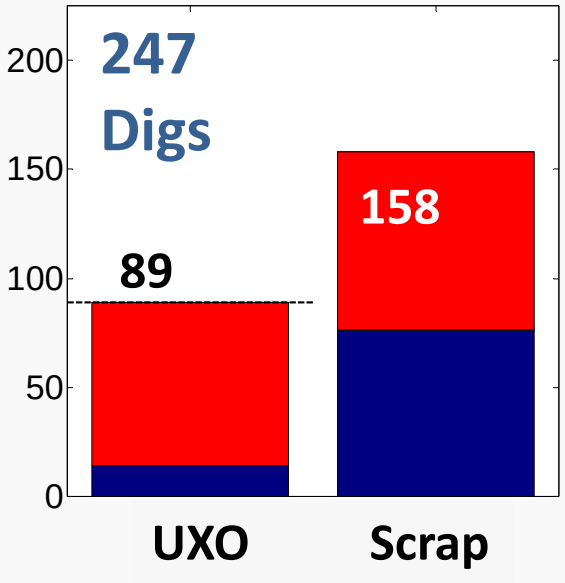
BUD



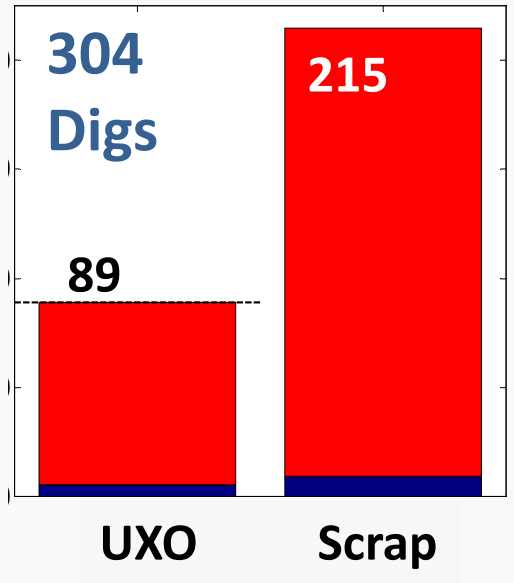


Diglist Progress: Final Dig Summary

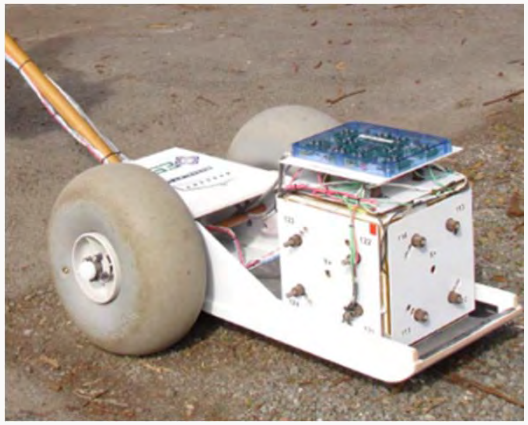
TEMTADS 2x2

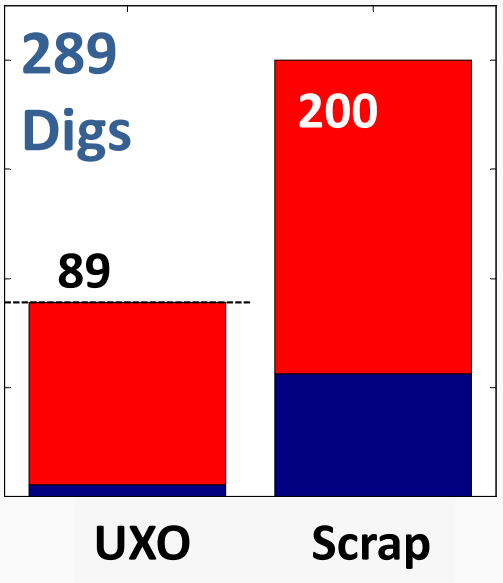


MPV



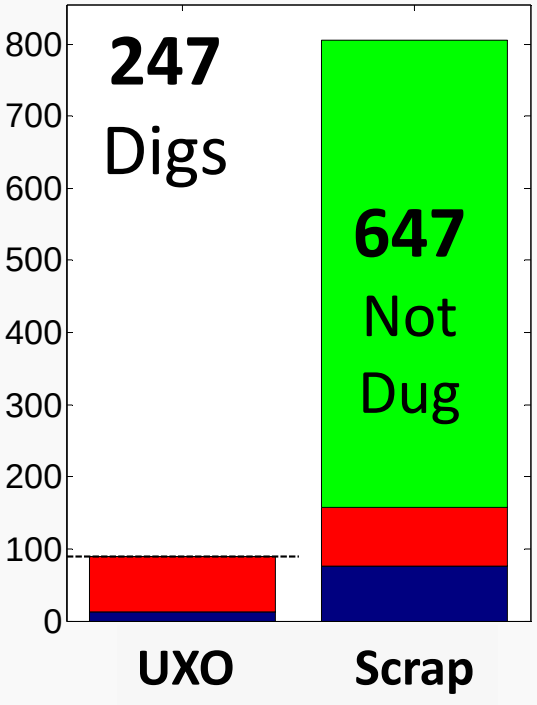
BUD



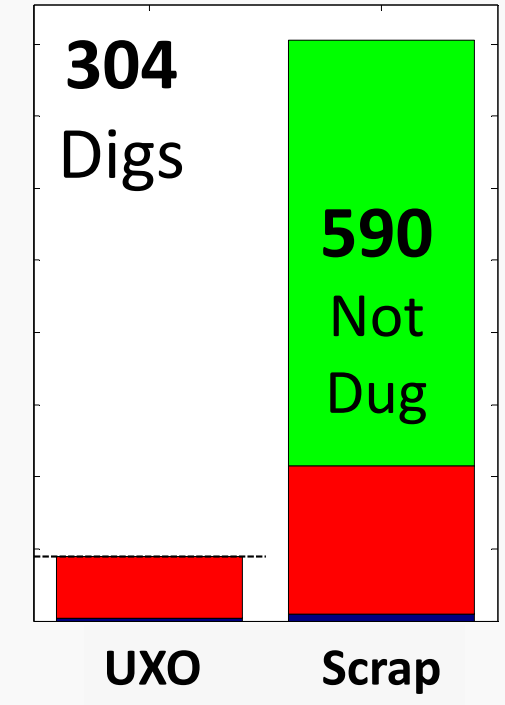


Discrimination Summary

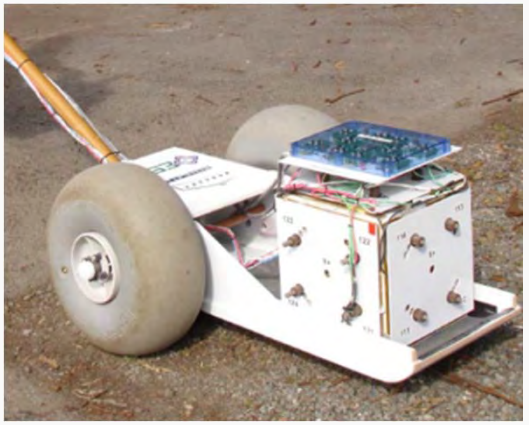
TEMTADS 2x2

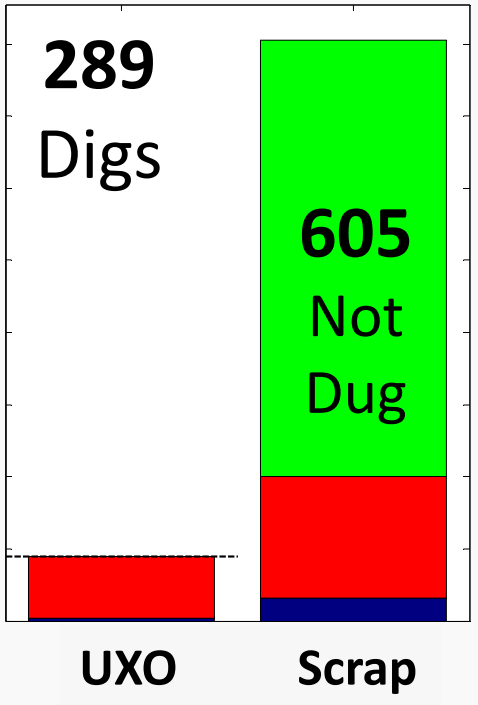


MPV



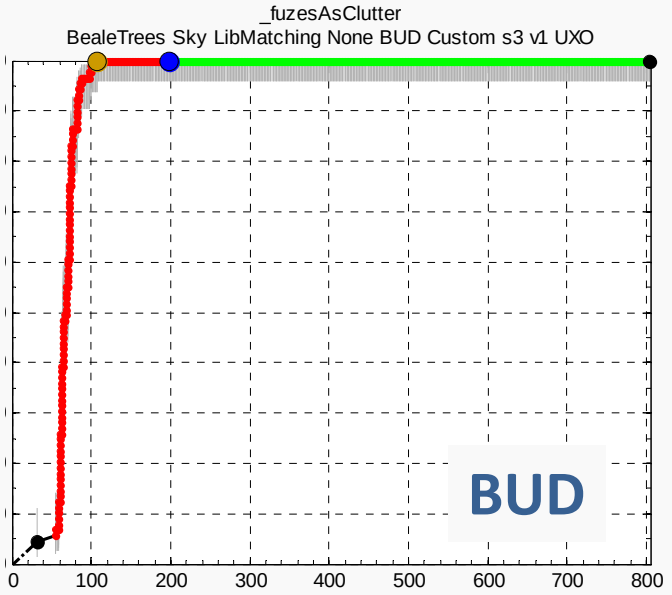
BUD

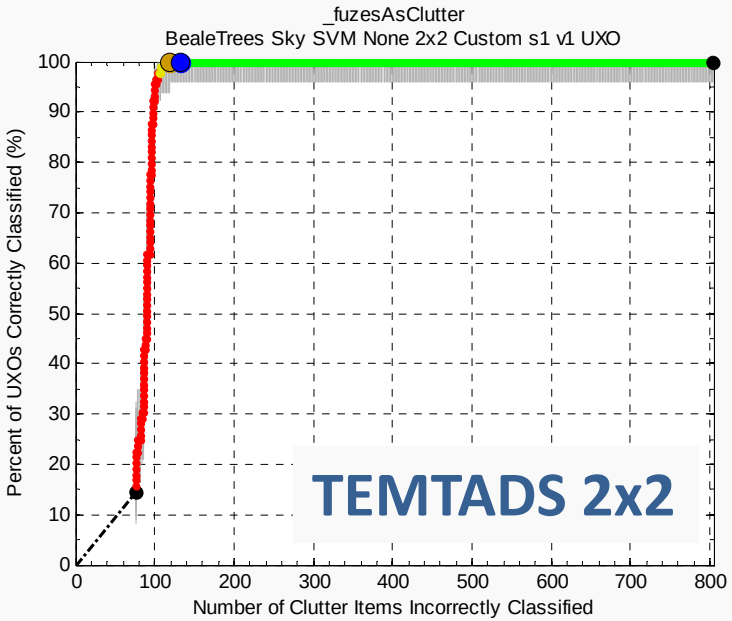


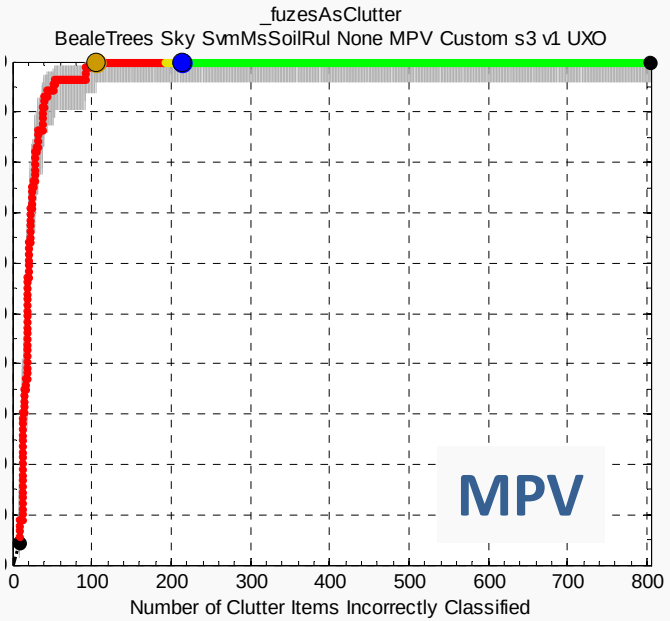


Beale Treed Area: Man Portable Instruments

- Similar performance for each instrument
- 100% of UXO found







Conclusions

- Effective discrimination could be achieved at the Camp Beale demonstration site using both MetalMapper data and data from Man Portable systems
- Man Portable systems performed very well. Each of the three Man Portable Systems had similar discrimination performance

Future Work

- Retrospective analysis to identify potential areas of improvement
- Develop more efficient QC and model selection methods
- Continued evaluation of novel discrimination techniques being developed in on-going research projects
- Continued tech transfer and training