Passive Infrared Hyperspectral Imaging for Standoff Detection of Tetryl Explosive Residue on a Steel Surface

Neal B. Gallagher

Eigenvector Research, Inc.

James F. Kelly, Thomas A. Blake

Pacific Northwest National Laboratory

nealg@eigenvector.com

PASSIVE INFRARED HYPERSPECTRAL IMAGING FOR STANDOFF DETECTION OF TETRYL EXPLOSIVE RESIDUE ON A STEEL SURFACE

Neal B. Gallagher[1], James F. Kelly[2], Thomas A. Blake[2]

[1] Eigenvector Research, Inc., 160 Gobblers Knob Lane, Manson, WA 98831, USA
[2] Pacific Northwest National Laboratory, P.O. Box 999, Mail Stop K8-88, Richland, WA 99352, USA

Abstract: A commercial imaging FTIR spectrometer that operates between 850 and 1300 cm^{-1} was used to passively image a galvanized steel plate stained with a residue of the explosive tetryl (2,4,6,N-tetranitro-N-methylaniline). The tetryl was coated onto the plate in a 30 cm diameter spot with an areal dosage of 110 mg tetryl/cm^2. The stain on the plate was easily detected at standoff distances of 14 and 31 m by examining the hyperspectral data cubes using maximum autocorrelation factors and a slight modification to a generalized least squares target detection algorithm. End-member extraction showed good comparison in a few key bands between the target end-member and laboratory reflectance spectra; however, significant differences were also observed.

Passive Standoff Detection of RDX Residues on Metal Surfaces via Infrared Hyperspectral Imaging

Thomas A. Blake[1], James F. Kelly[1], Neal B. Gallagher[2*], Paul L. Gassman[1], Timothy J. Johnson[1]

[1]Pacific Northwest National Laboratory, P. O. Box 999, Mail Stop K8-88, Richland, Washington 99352; (509) 371-6131

[2]Eigenvector Research, Inc. 160 Gobblers Knob Lane, Manson, Washington, 9883; (509) 687-1039; nealg@eigenvector.com

* presenting author

Abstract: Hyperspectral images of galvanized steel plates, each containing a stain of an explosive RDX, were recorded using a commercial longwave infrared imaging spectrometer. RDX areal concentrations were between 16 and 90 μg / cm^2 and measurements were made at practical stand-off distances between 14 and 50 m. Anomaly detection clearly showed target RDX using principal components analysis (PCA), principal autocorrelation factors (PAF) and principal difference factors (PDF). PAF is analogous to maximum autocorrelation factors but retains properties of PCA while PDF is a novel multivariate edge detection methodology that can be used to augment traditional target and anomaly detection methodologies. Generalized least squares (GLS) was also used as a target detection method and allowed some classification capability. Results from PAF, PDF and GLS will be shown.

Objective

- Detection of explosive residues at standoff distances using multivariate images
  - Tetryl (2,4,6,N-tetranitro-N-methylaniline)
  - RDX (cyclotrimethylenetrinitramine)
  - Plates tilted back 45° (no active illumination)
  - Telops FIRST* imaging FTIR spectrometer
    - operating range was 850 and 1300 cm^{-1}
    - *field-portable imaging radiometric spectrometer technology
  - 3x3 pixel spatial median filter
    - remove bad pixels / channels
  - images were trimmed to ignore off-plate pixels (for Tetryl)

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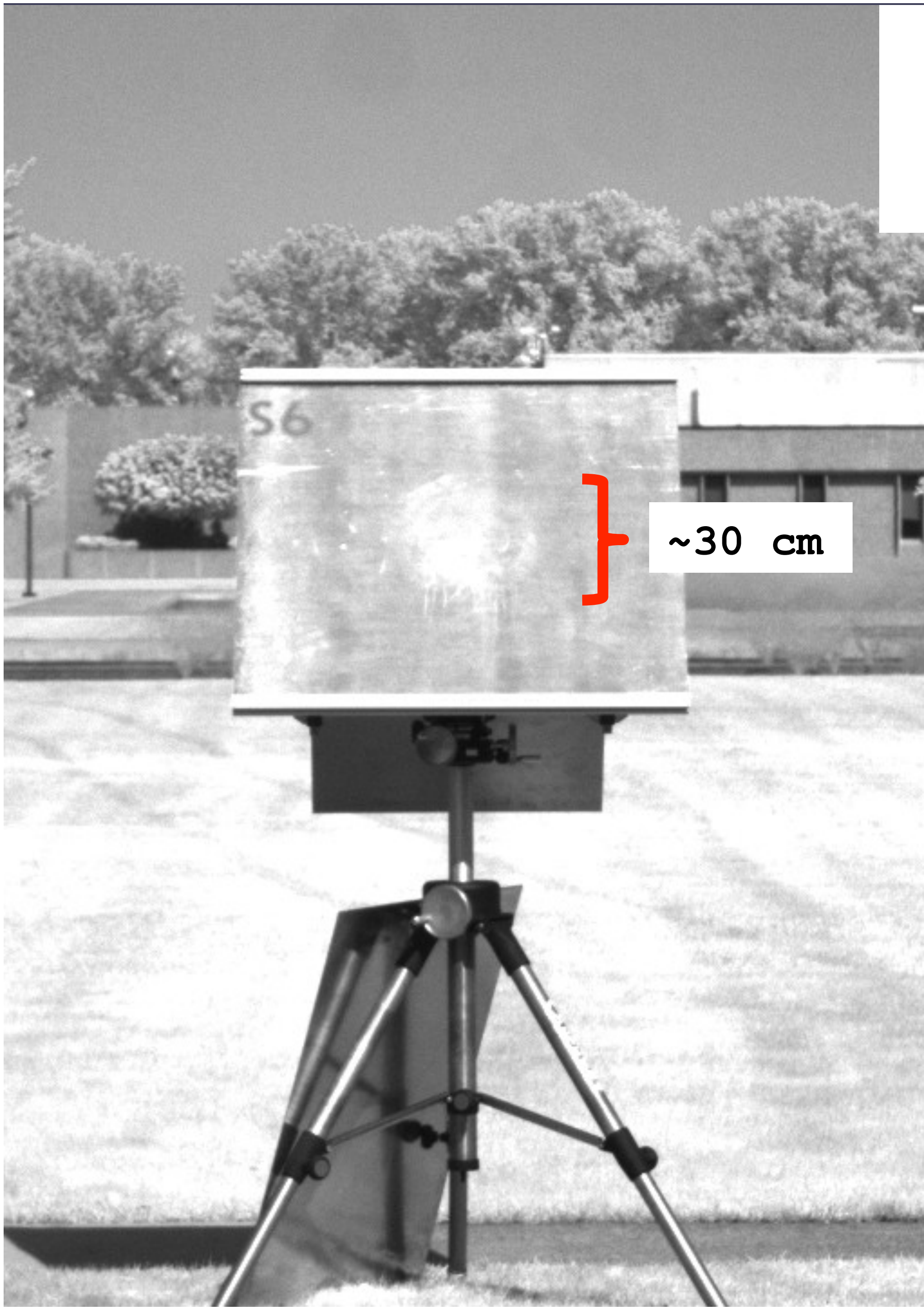
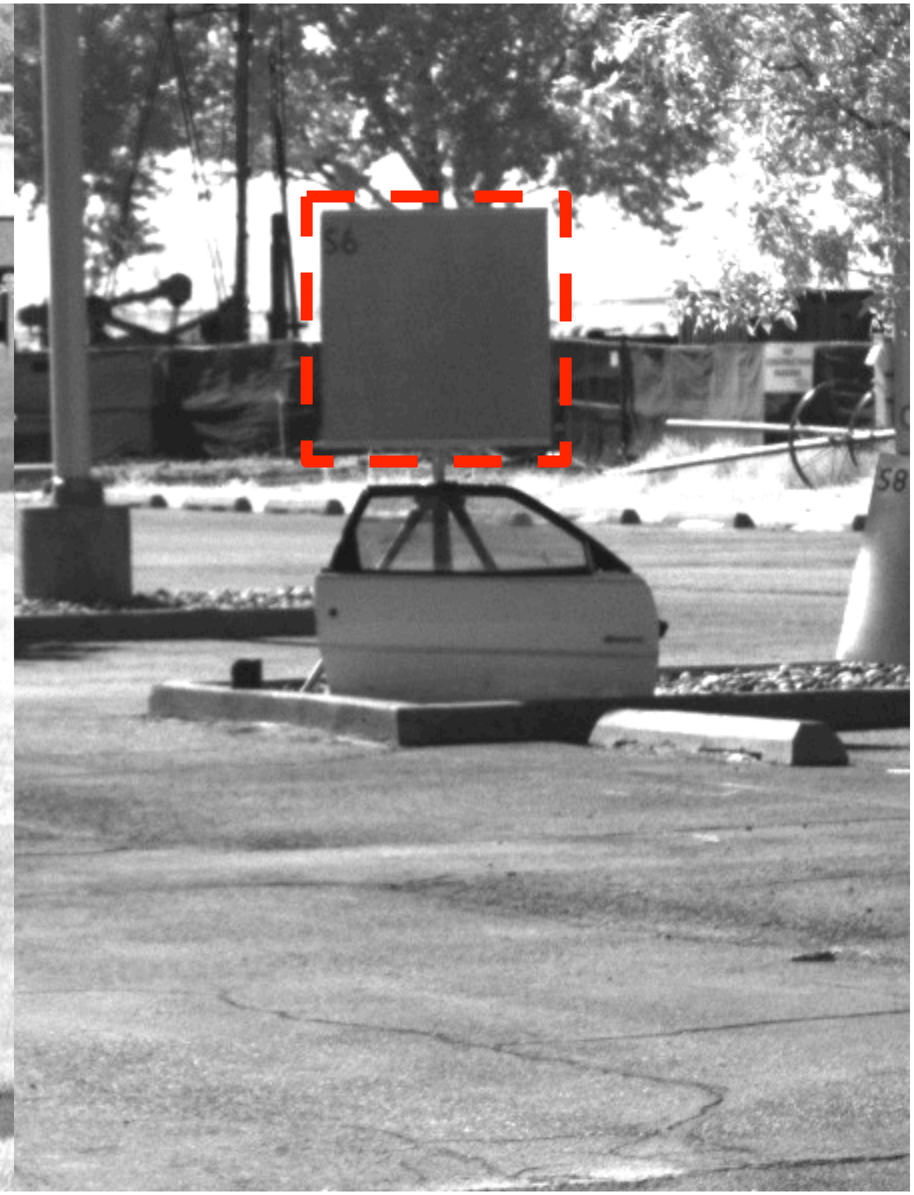
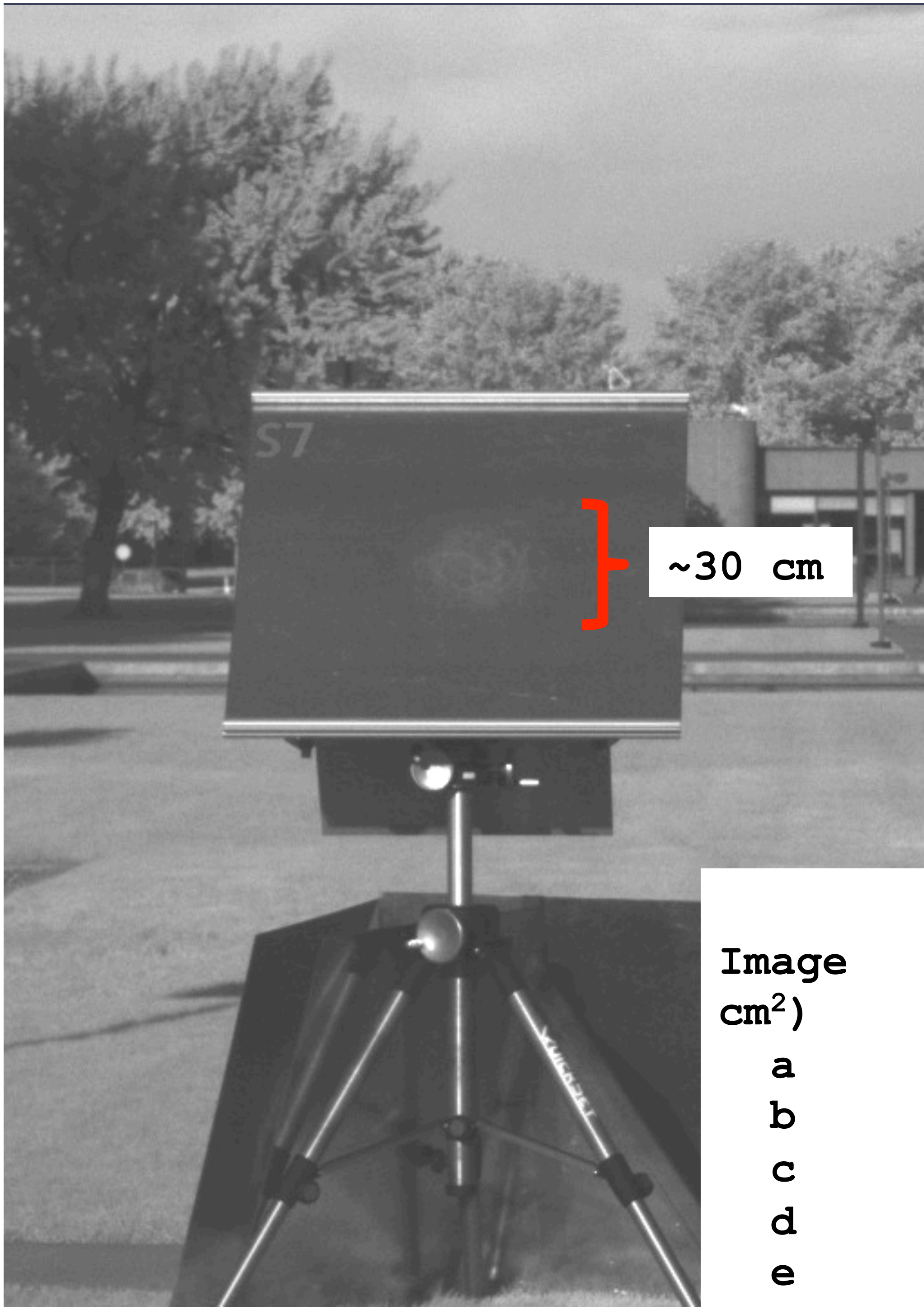
Image	Dist (m)	Temp. Amb. (K)	Tetryl ($\mu g/cm^2$)
a	14	307.2	110
b	31	312.1	110







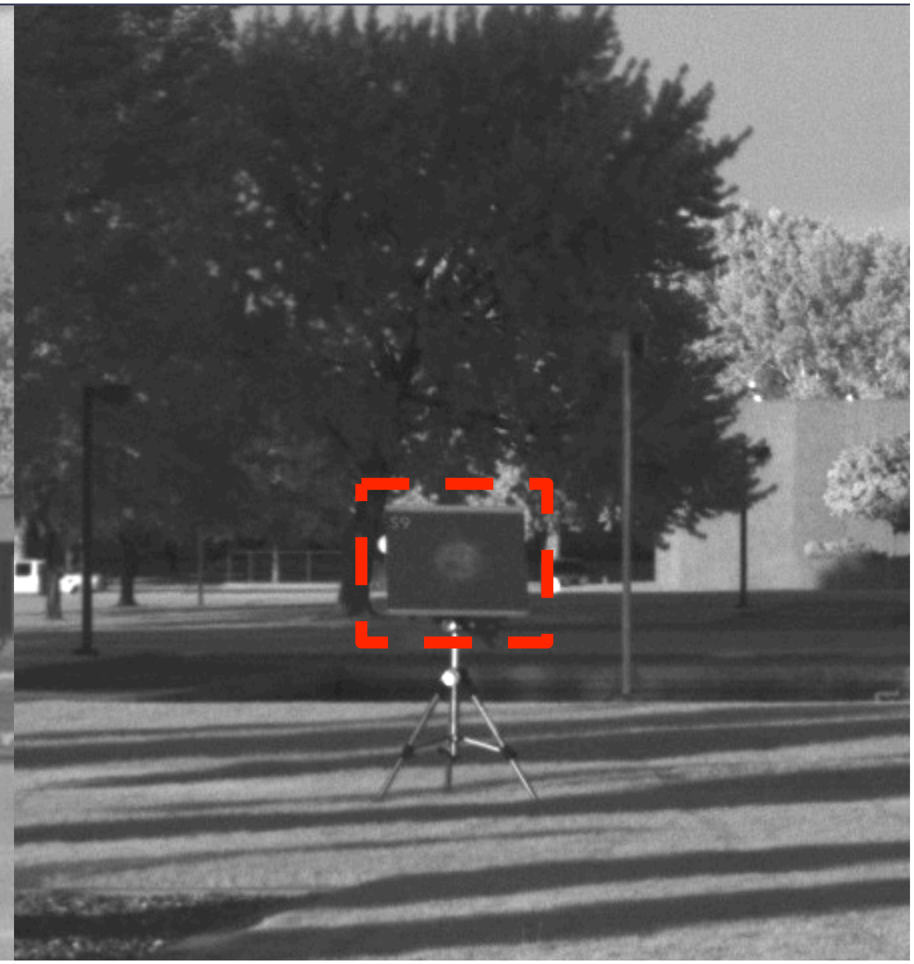


Image	Temp. Amb. (K)	Dist. (m)	Image Size	Target ($\mu g/cm^2$)
a	307.96	14.0	120x180	16
b	308.04	14.0	120x180	40
c	307.95	14.0	120x180	90
d	304.56	31.0	80x120	40
e	306.35	50.5	80x120	40
f	306.72	50.5	80x120	90

Detection Methods

- Anomaly Detection
  - Principal Components Analysis
  - Maximum Autocorrelation Factors (MAF), PAF
    - w/ and w/o smoothing
    - finds spatially correlated regions
  - Maximum Difference Factors (MDF), PDF
    - finds edges (multivariate edge detection)
- Target Detection
  - Generalized Least Squares
    - matched filter, Aitken estimator
    - centered to clutter (RDX), clutter used as a target (Tetryl)

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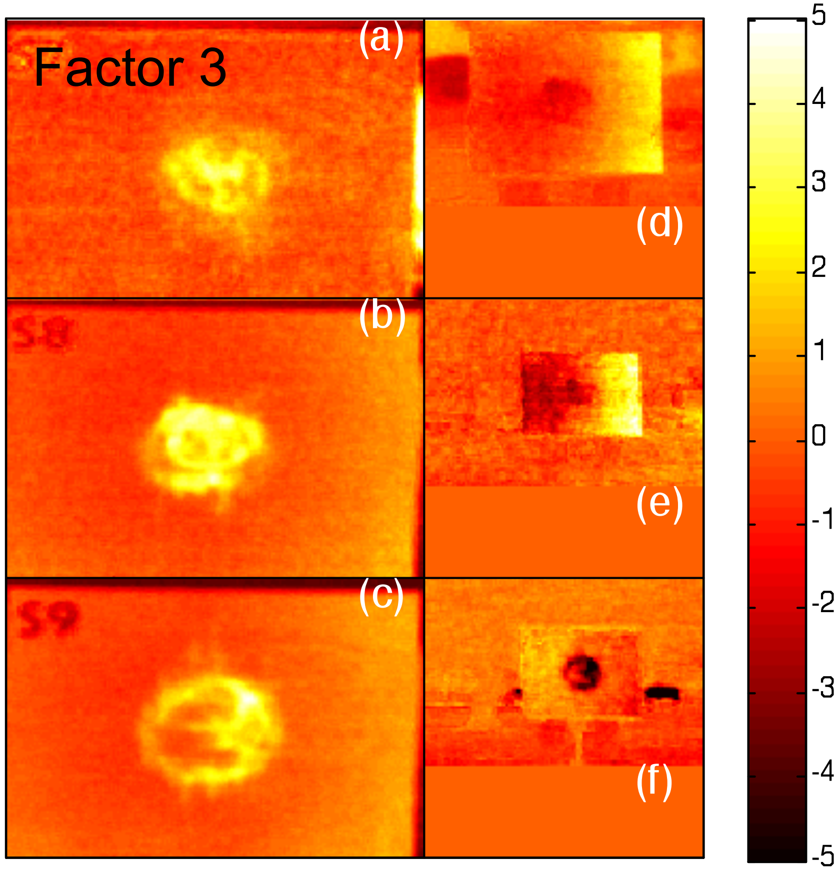
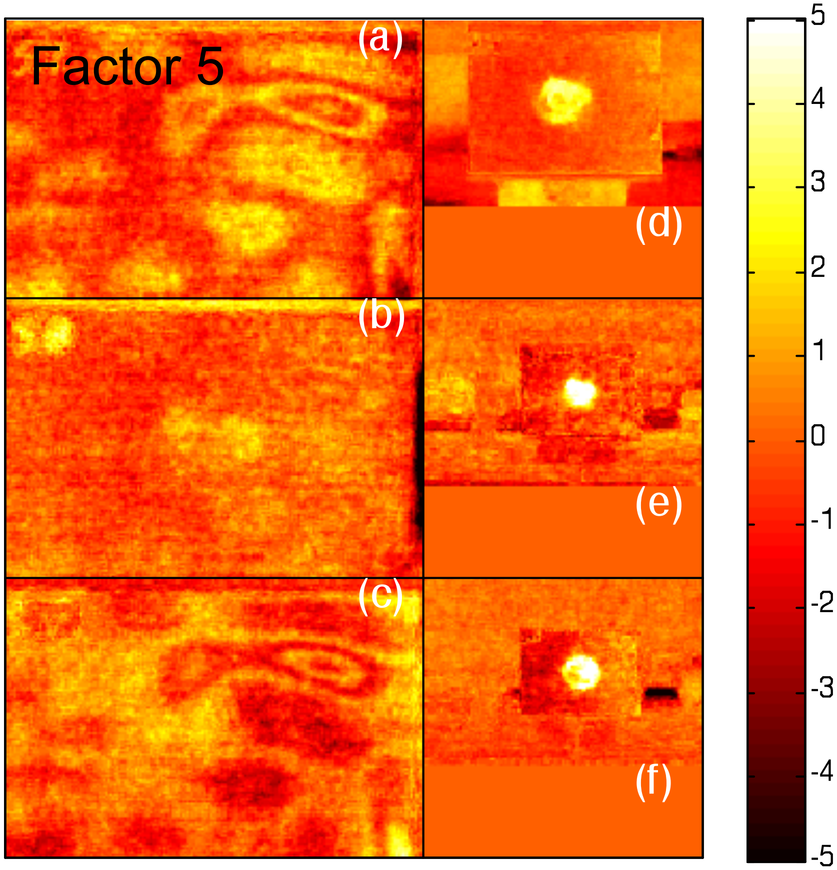
MAF for RDX Detection

RDX target apparent for a,b and c at 14 m and 40 and 90 μg/cm^2



RDX target apparent for d, e and f at 31 and 50 m and 40 and 90 μg/cm^2



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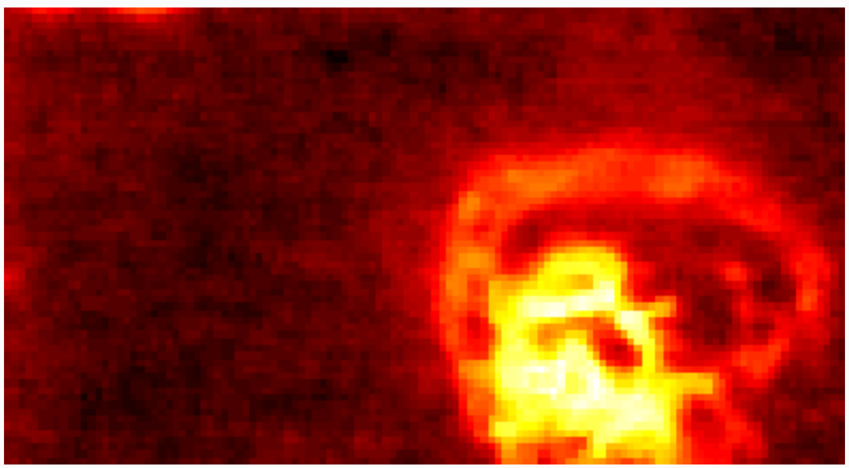
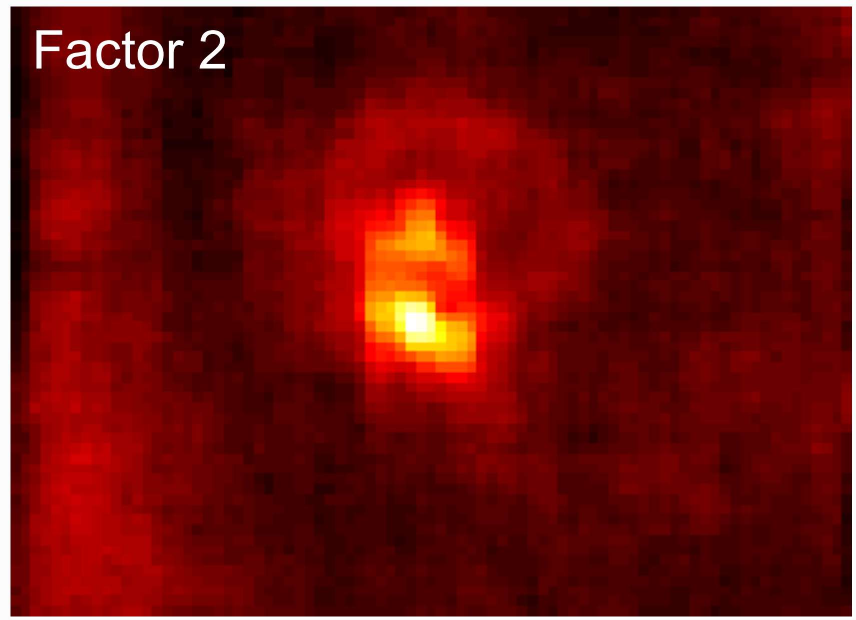
MAF for Tetryl Detection

Tetryl target apparent for *a* at 14 m and 110 µg/cm^2

Factor 1



Tetryl target apparent for *b* at 31 m and 110 µg/cm^2



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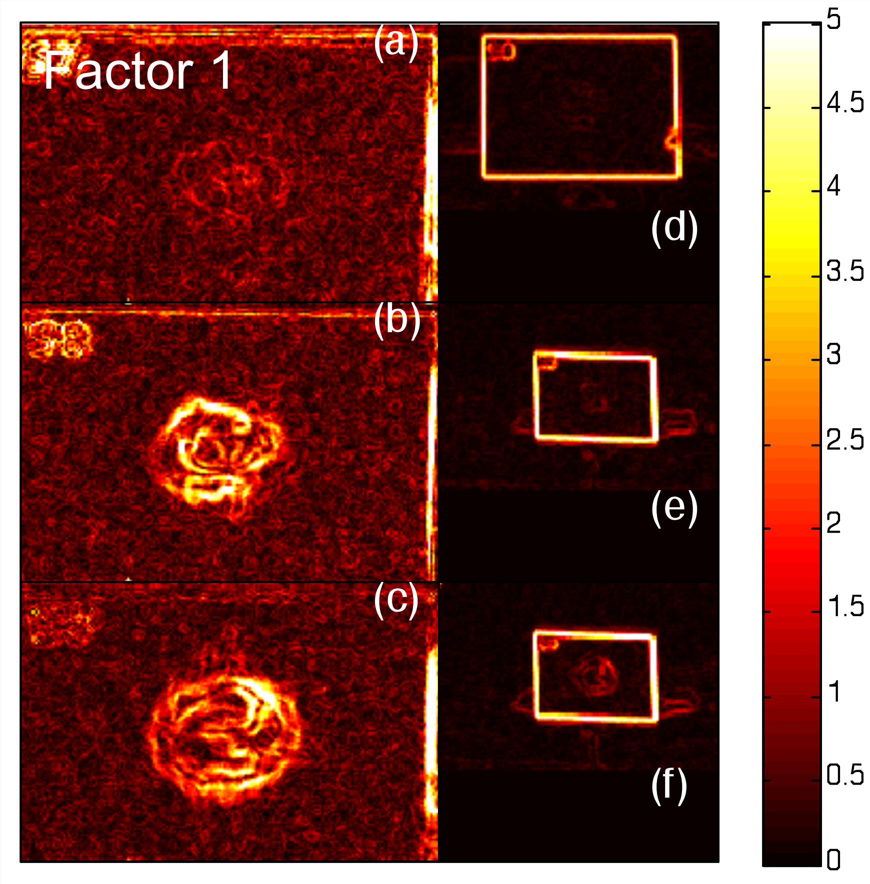
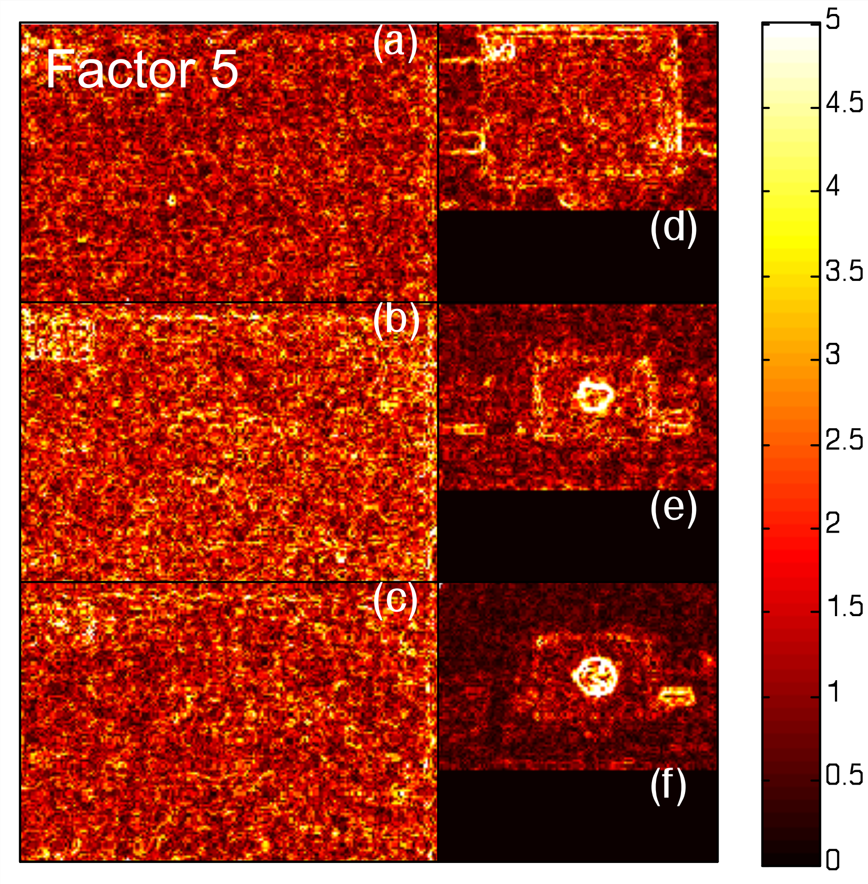
MDF for RDX Detection

RDX target apparent for b and c at 14 m and 40 and 90 μg/cm^2



RDX target apparent for e and f at 50 m and 40 and 90 μg/cm^2



edge magnitudes sqrt(dx^2+dy^2)

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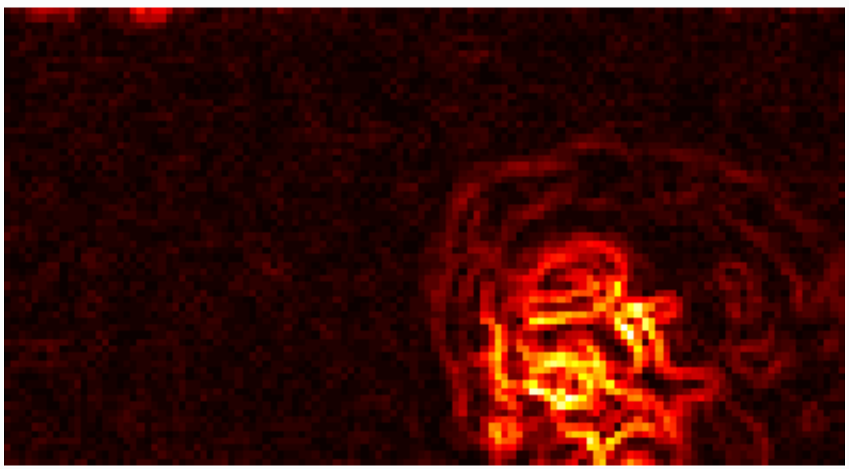
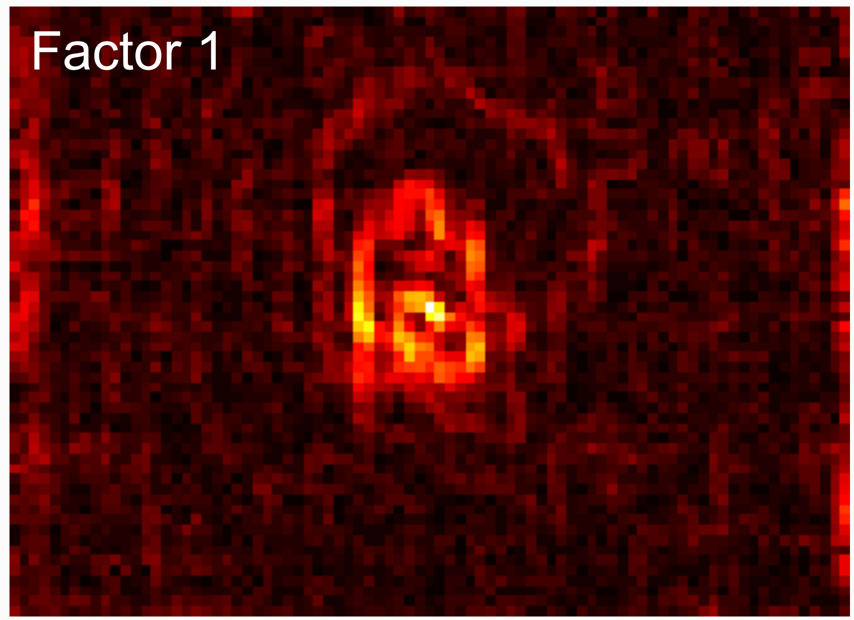
MDF for Tetryl Detection

Tetryl target apparent for *a* at 14 m and 110 μg/cm^2

Factor 1



Tetryl target apparent for *b* at 31 m and 110 μg/cm^2



edge magnitudes sqrt(dx^2+dy^2)

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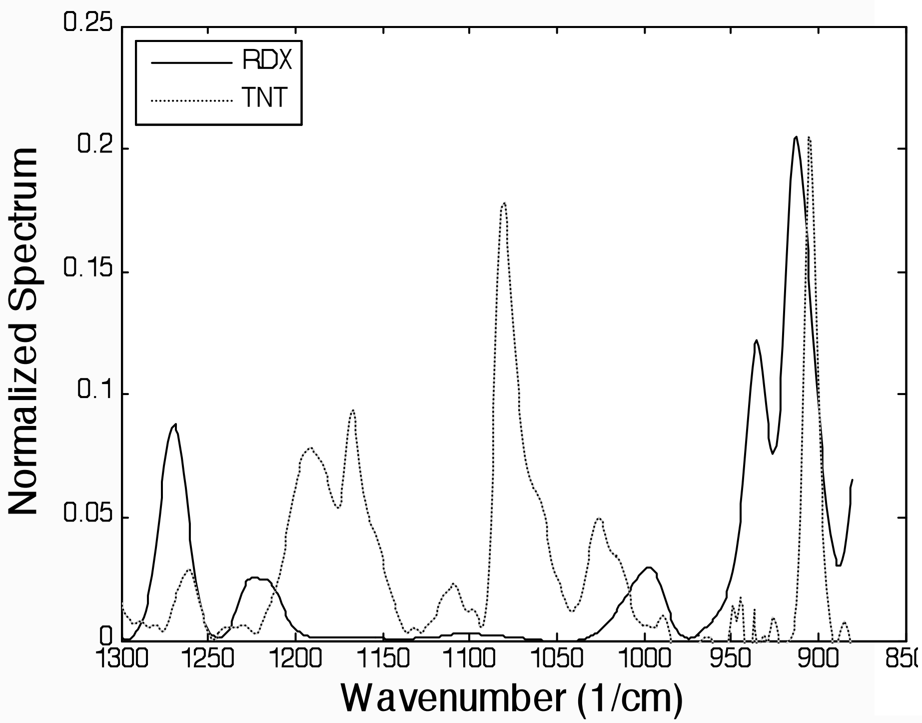
Target Detection

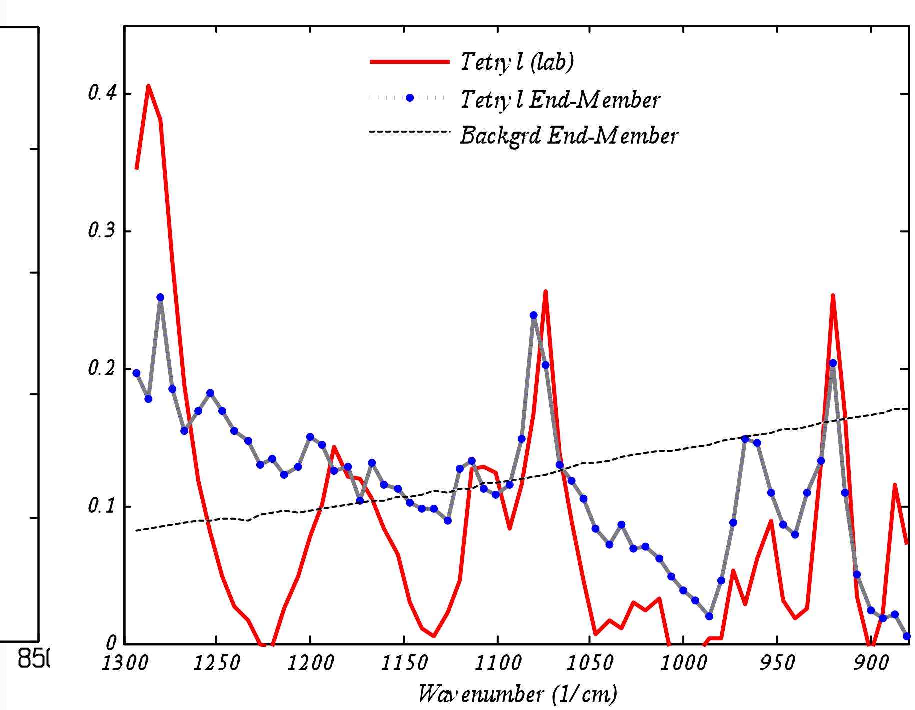
Use only a single target 1) RDX or 2) TNT and display contributions images **c**/δc.

$$\hat{c} = \left(\mathbf{x}-\mathbf{x}_{bkg}\right)^T \mathbf{W}_c^{-1}\mathbf{s}\left(\mathbf{s}^T\mathbf{W}_c^{-1}\mathbf{s}\right)$$

For tetryl, use two targets 1) tetryl and 2) background [off-target pixels]

$$\hat{\mathbf{c}} = \mathbf{x}^T\mathbf{W}_c^{-1}\mathbf{S}\left(\mathbf{S}^T\mathbf{W}_c^{-1}\mathbf{S}\right)$$





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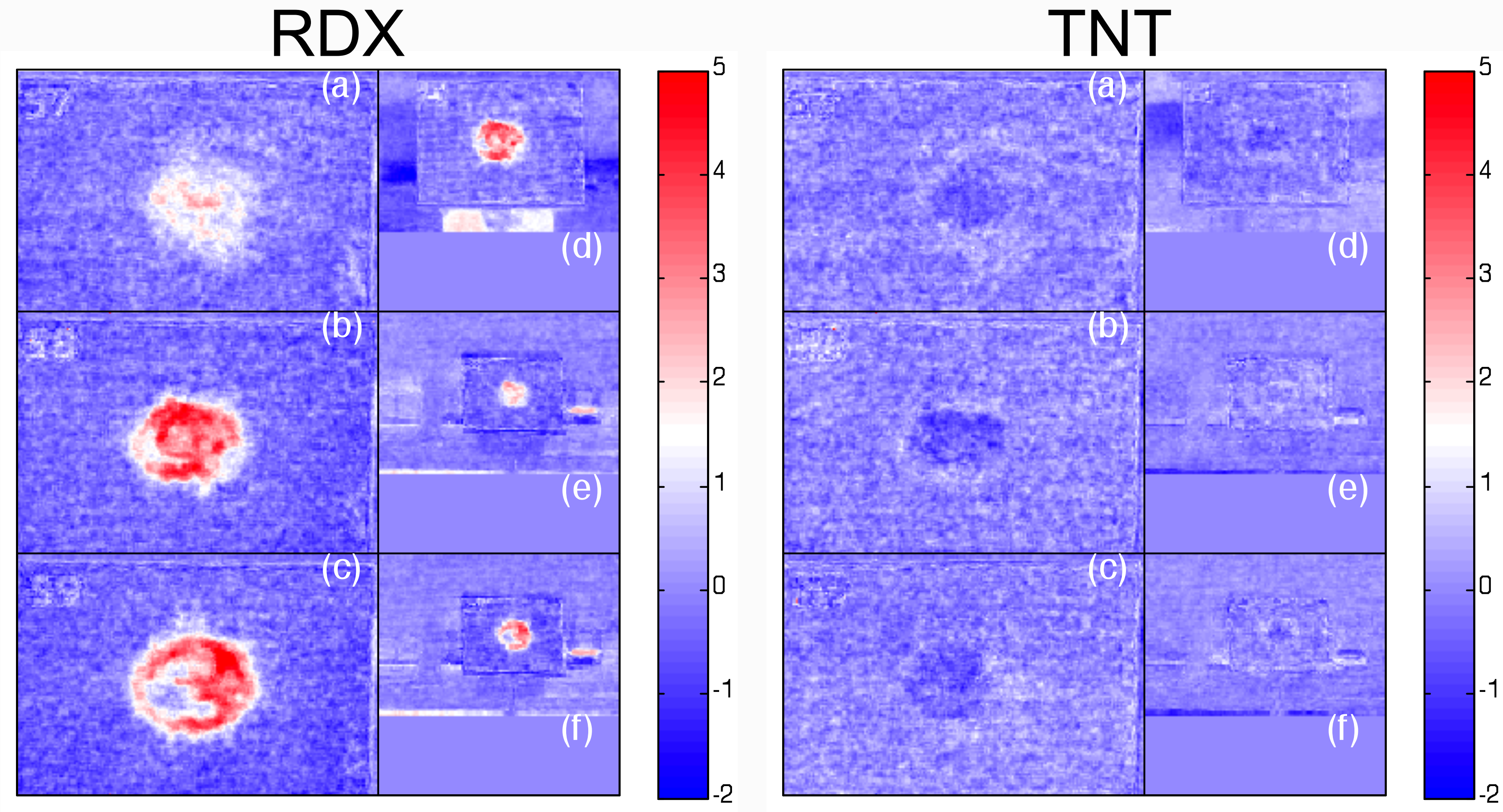
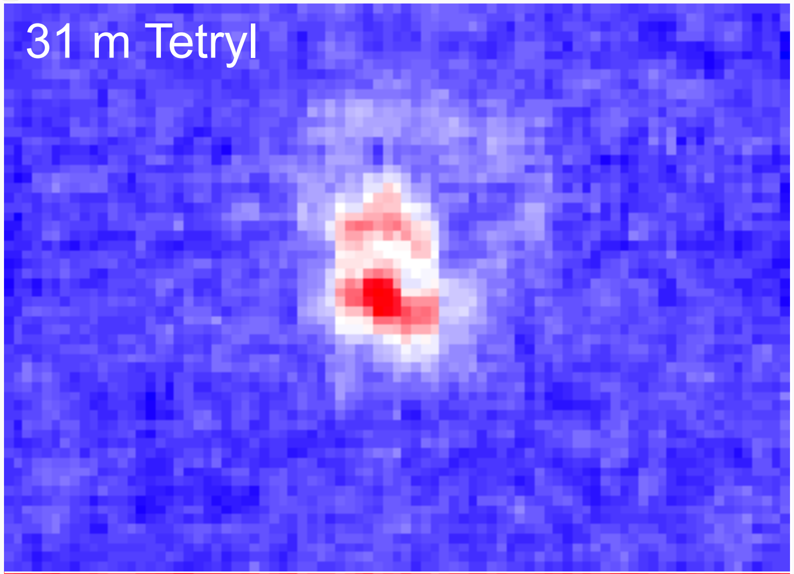
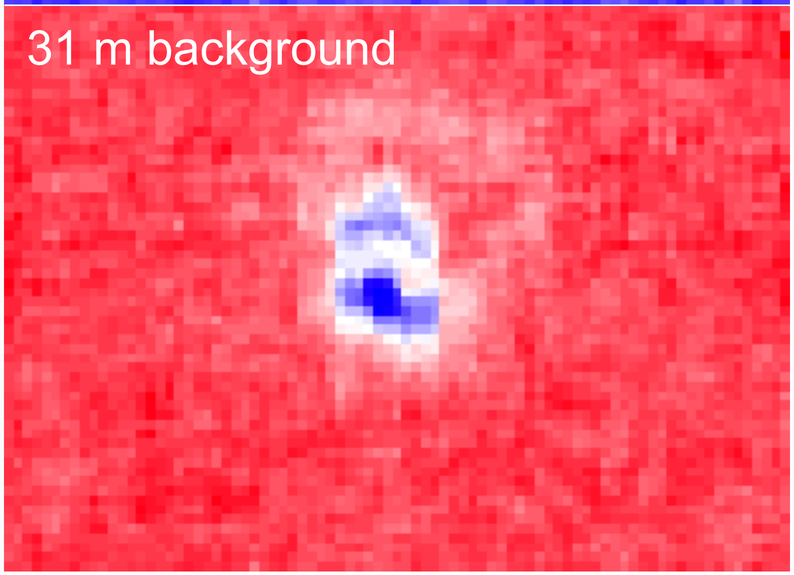
GLS Contributions: RDX

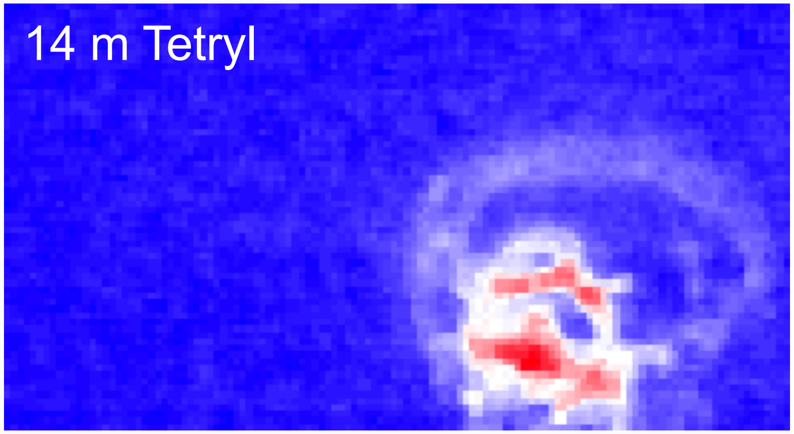


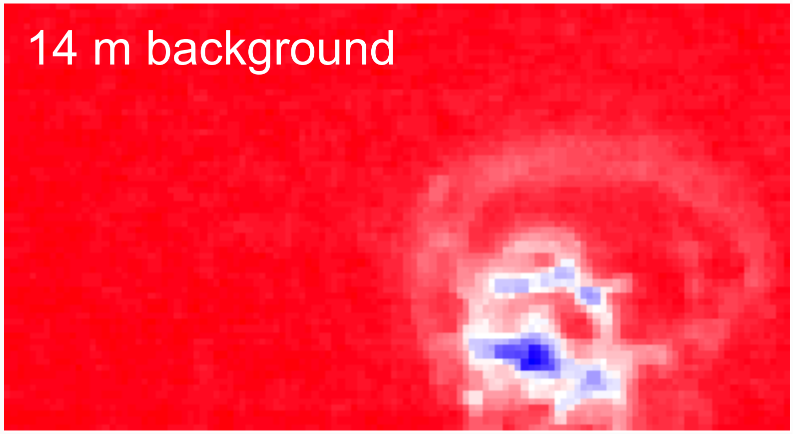
RDX target is detected at in all images while TNT is not.
False alarms suggested in images d-f.
Clutter is based on LH 52 and 48 pixels.

GLS Contributions: Tetryl









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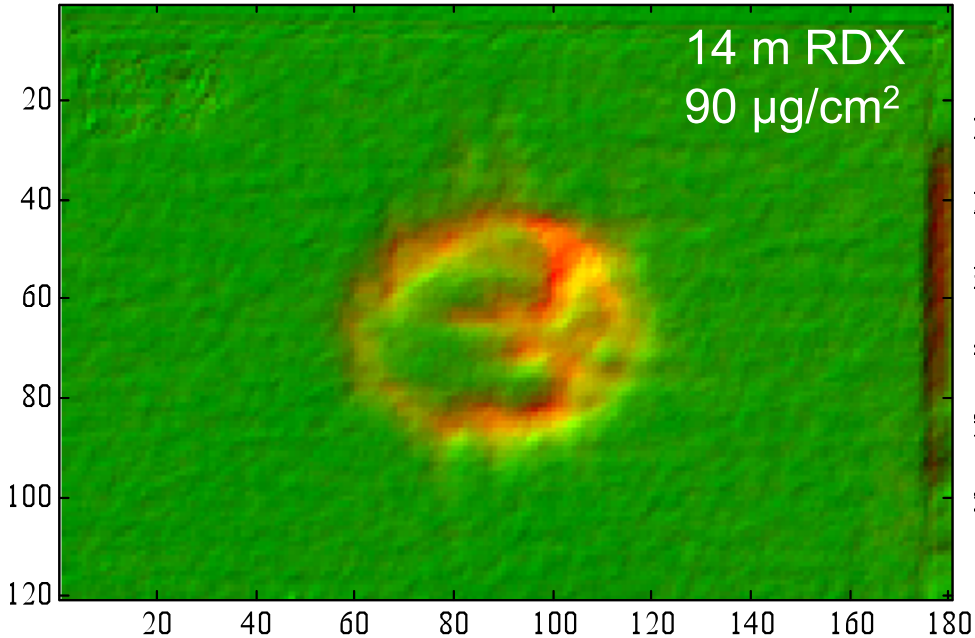
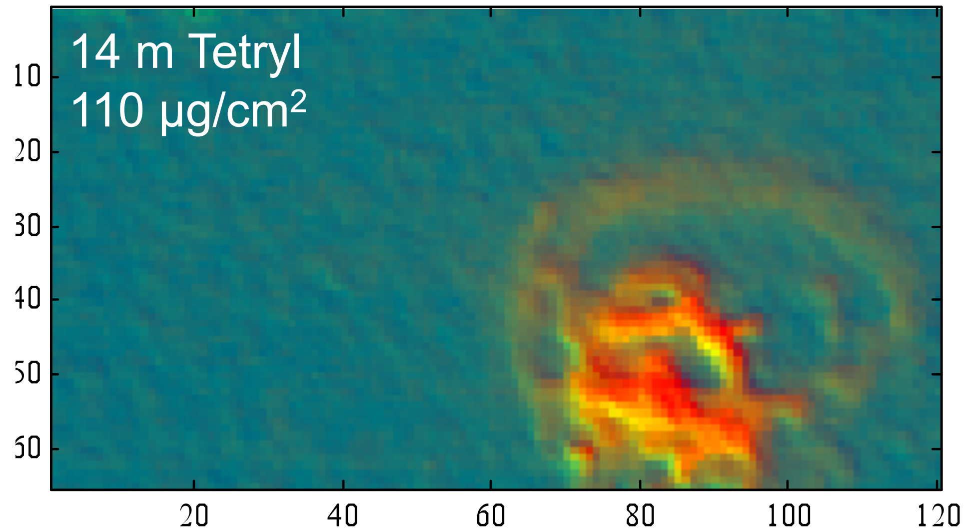
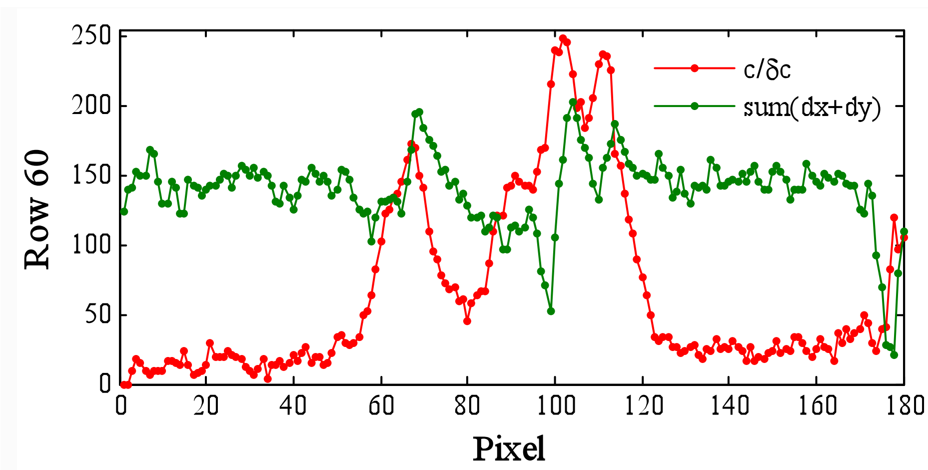
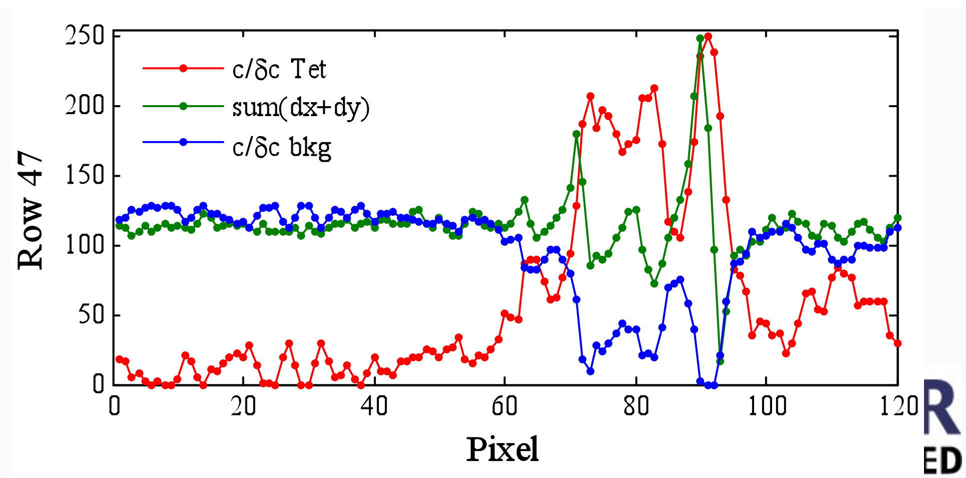
Red-Green for RDX and Red-Green-Blue for Tetryl

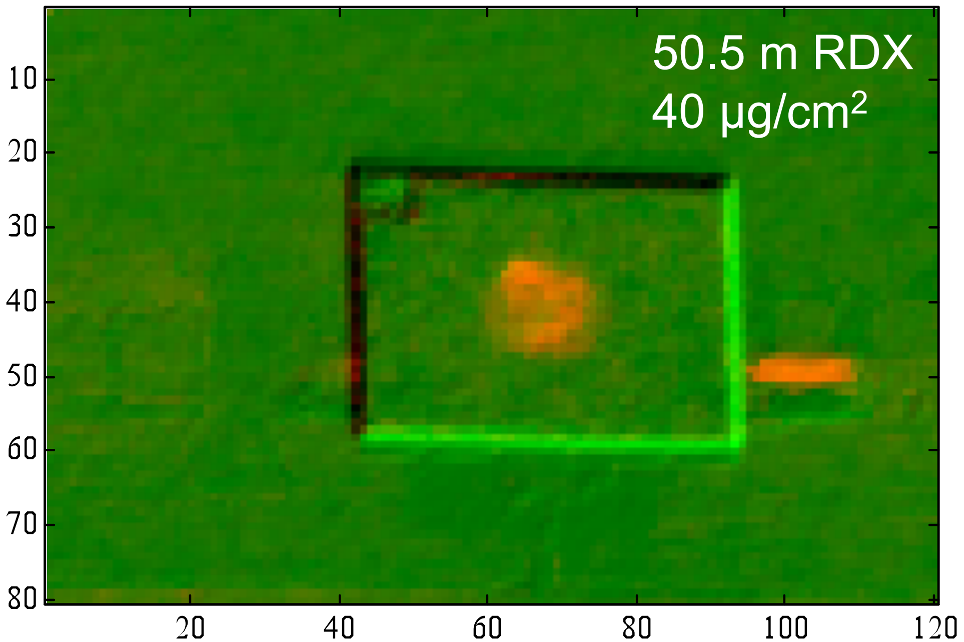


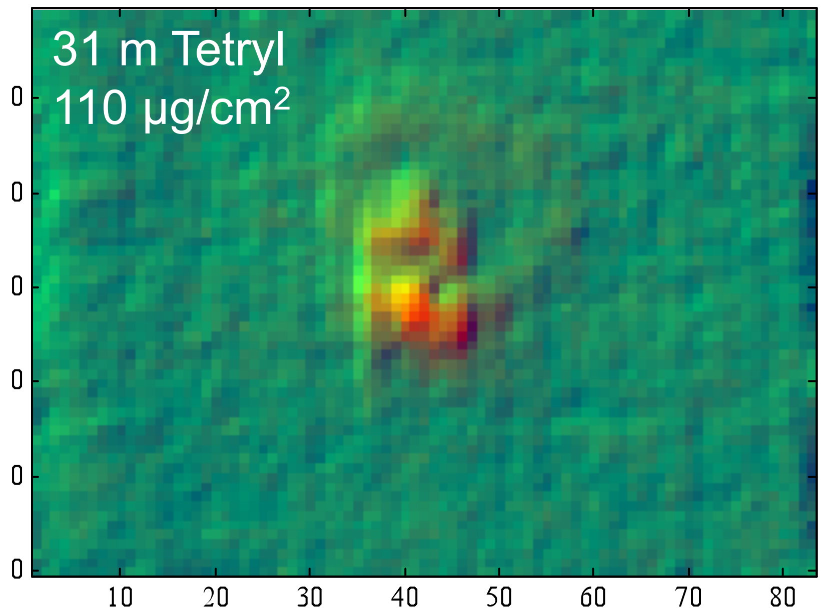


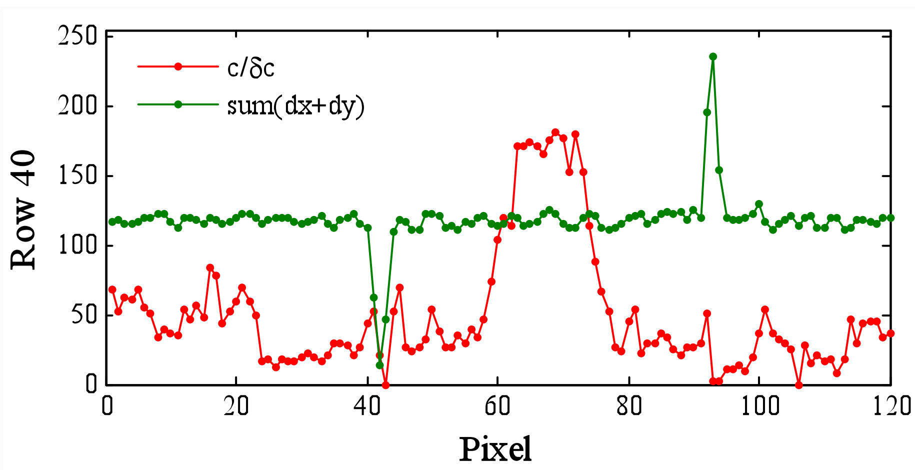


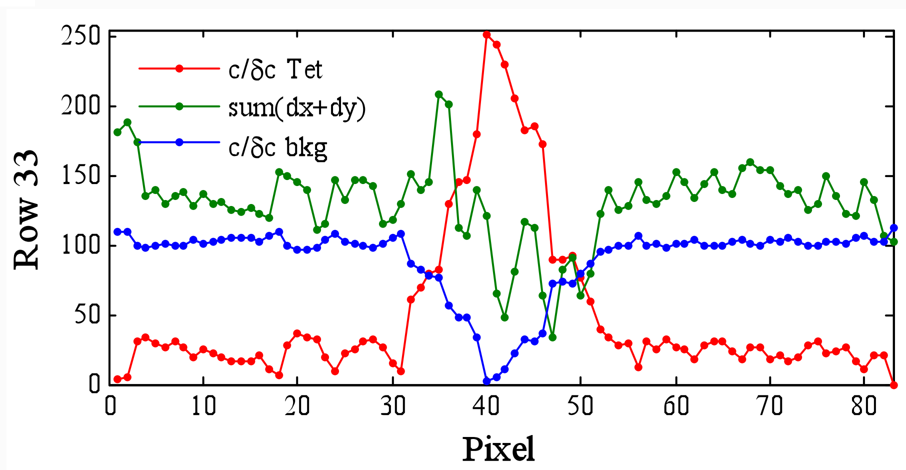


Red-Green for RDX and Red-Green-Blue for Tetryl









Conclusions

- Tetryl was detected at 14 and 31 m at 110 $\mu g/cm^2$
- RDX was detected at all distances (14 to 50 m) and areal concentrations (16 to 90 $\mu g/cm^2$)
  - using both anomaly and target detection methods
- As expected, detection was better for shorter distances and higher concentrations
- Results from both anomaly and target detection methods are useful for image exploration
- Tetryl GLS results suggest approximate closure may be useful in aiding in detection

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- Blake, T.A., Kelly, J.F., Gallagher, N.B, Gassman, P.L., Johnson, T.J., "Passive Detection of Solid Explosives in Mid-IR Hyperspectral Images" *Anal. Bioanal. Chem.* (2009). DOI 10.1007/s00216-009-2907-5

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