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Spectroscopic Anomaly Detection and Isotope Identification using Non-Negative Matrix Factorization and Application to AWE SIGMA Challenge Data

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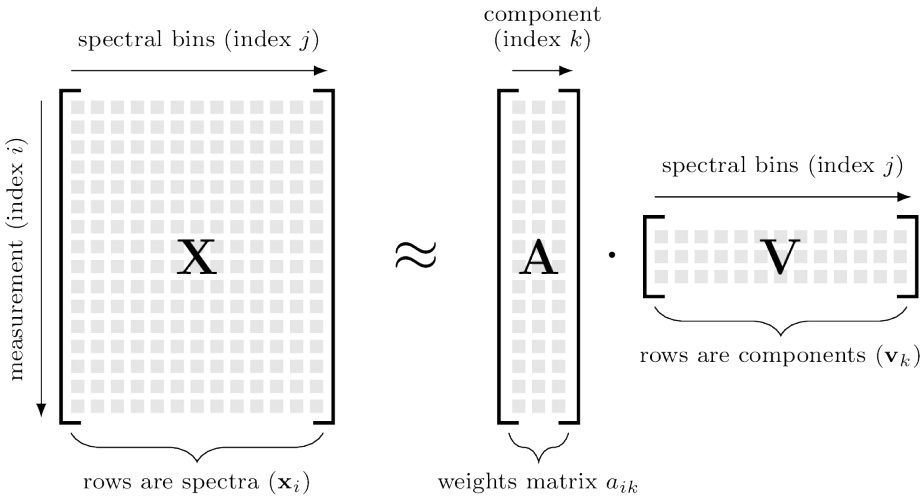
Outline

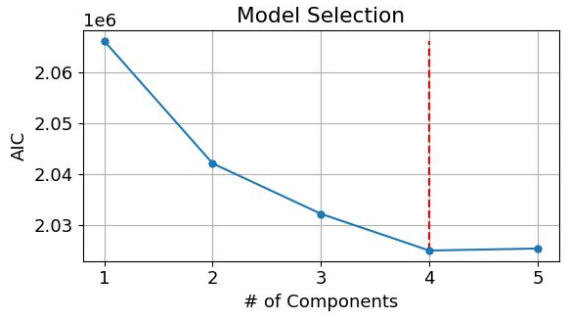
1. Non-negative matrix factorization (NMF)
   a. Overview
   b. Previous work
2. Analysis of AWE SIGMA Challenge Data
   a. Data Quality
   b. Background Models
   c. Interesting Medicals
   d. Broader Uses of Analysis
   e. Comments on Dataset

NMF

Non-negative matrix factorization (NMF) - Overview

- A background model **V** is a low-rank representation of a list of benign measurements **X**
  - Model selection with AIC
- Non-negativity constraint allows for a physically intuitive understanding [1]
- Detection: Difference between fit successes
  - Negative Log Likelihood loss between background, background + template
  - Threshold estimated Chi-Squared distribution
- Identification: Maximum loss statistic when alarm is triggered
  - Which template improved the fit the most?





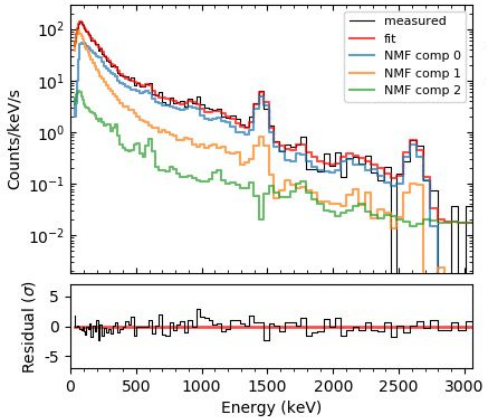
[1]: Lee, D., Seung, H. Nature (1999) DOI: https://doi.org/10.1038/44565

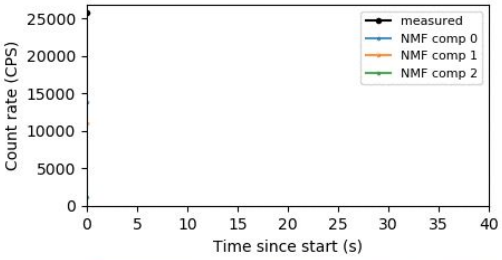
Previous Work- Background Models For Aerial Systems

- Mobile Detectors
  - Traverse several environments in single run
  - Complex and evolving backgrounds
  - Future work, RADAI, "Adaptive" NMF

- Static Detectors
  - Expect stable background environments, with some variability due to hardware gain shifts and atmospheric fluctuations
  - A few components, simple background and rain

NaI detector data from Aerial Measurement System (AMS) at Lake Mohave, NV





- "Distant terrestrial" decreases first
- "Nearby terrestrial" decreases later
- "Radon/cosmics/aircraft" remains approximately constant

M.S. Bandstra *et al.*, IEEE TNS (2020) DOI: 10.1109/TNS.2020.2978798

Mobile NaI (12 detectors)
Integration time = 1 s
FAR = 1/8 hours

Previous Work- Background Models For Static Systems

What does "rain" look like in these models?

- Characteristic gamma energies for "rain component"
- Characteristic count rate trend

Rn-226 Progeny Lines

Static NaI (Not AWE)
Integration Time = 5s

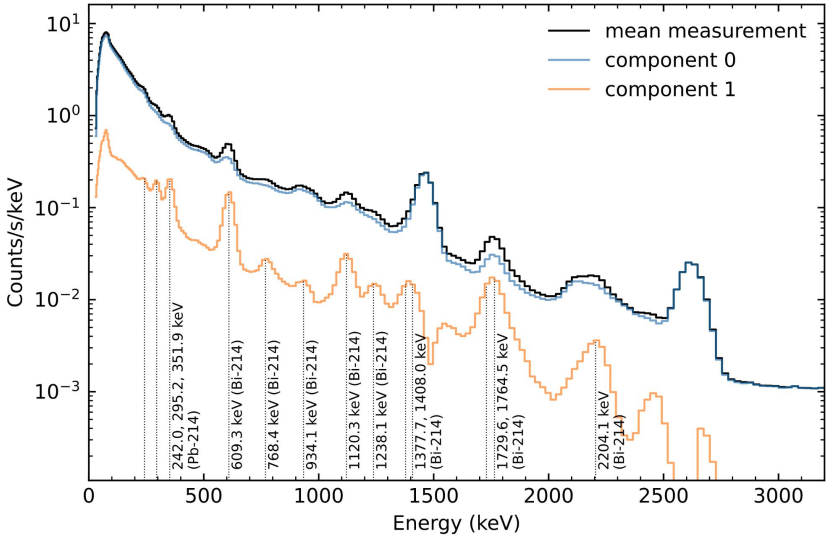
Pb-214:

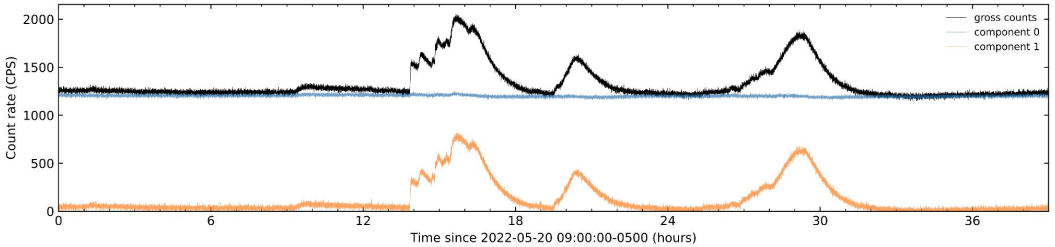
- 242.0keV
- 295.2keV
- 352keV

Bi-214

- 609keV — Bi-214
- 1120.3keV — Bi-214
- 1764keV — Bi-214

M.S. Bandstra *et al.* (2023) arXiv:2304.01336



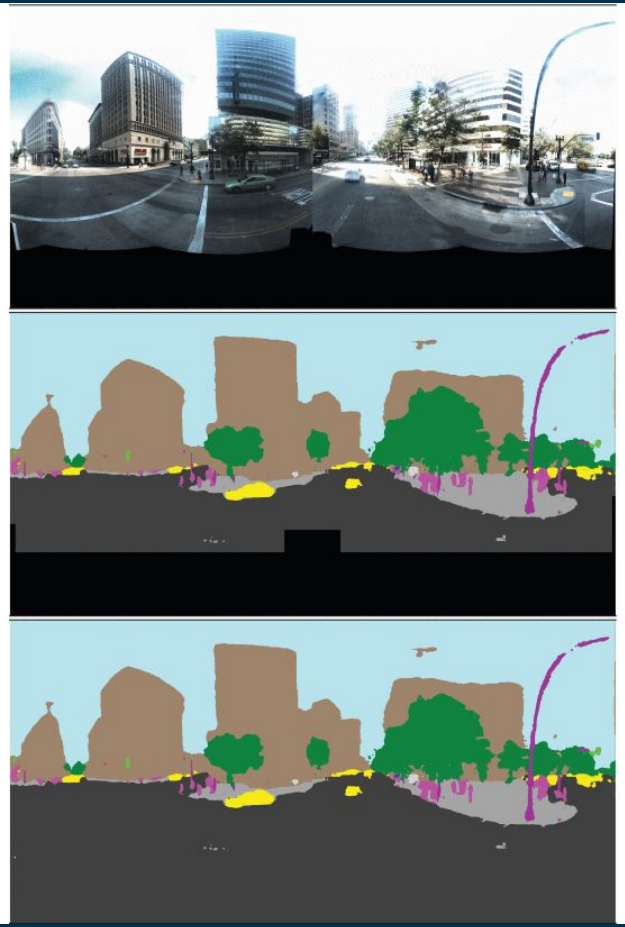


Previous Work- Multi-Sensor Correlations

Can other real-world features be captured by NMF?

- Work from 2019 demonstrated correlations between NMF components and semantic features from video

- Helps pave the way for multi-sensor contextual scene data fusion

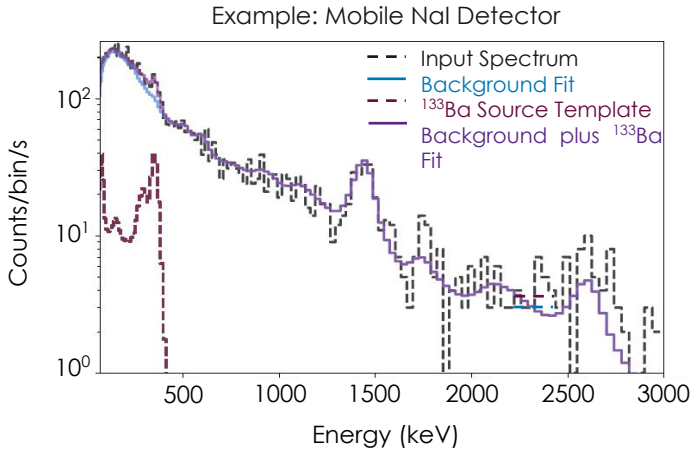


M. S. Bandstra et al., IEEE (NSS/MIC),]
DOI: 10.1109/NSS/MIC42101.2019.9059803.

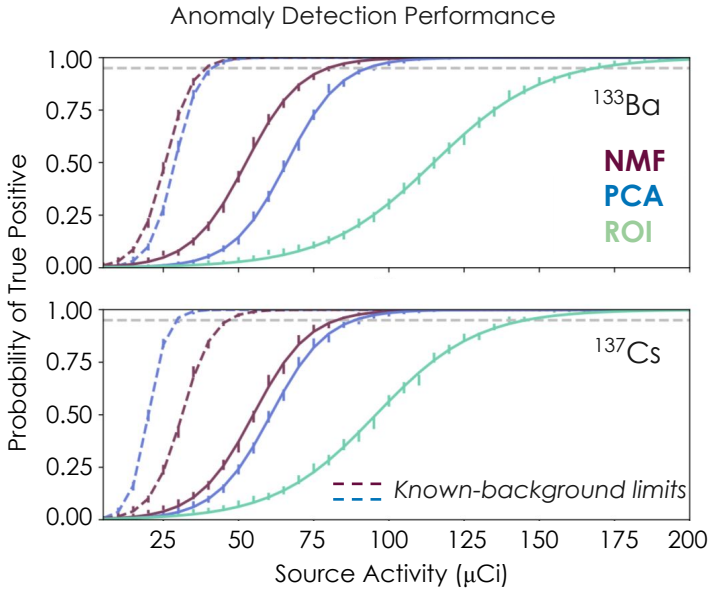
Previous Work- Improved Detection

- Work from 2019 demonstrating improved performance using NMF over PCA, ROI algorithms

Mobile NaI
Standoff = 20 m
Integration time = 1 s
FAR = 1/8 hours

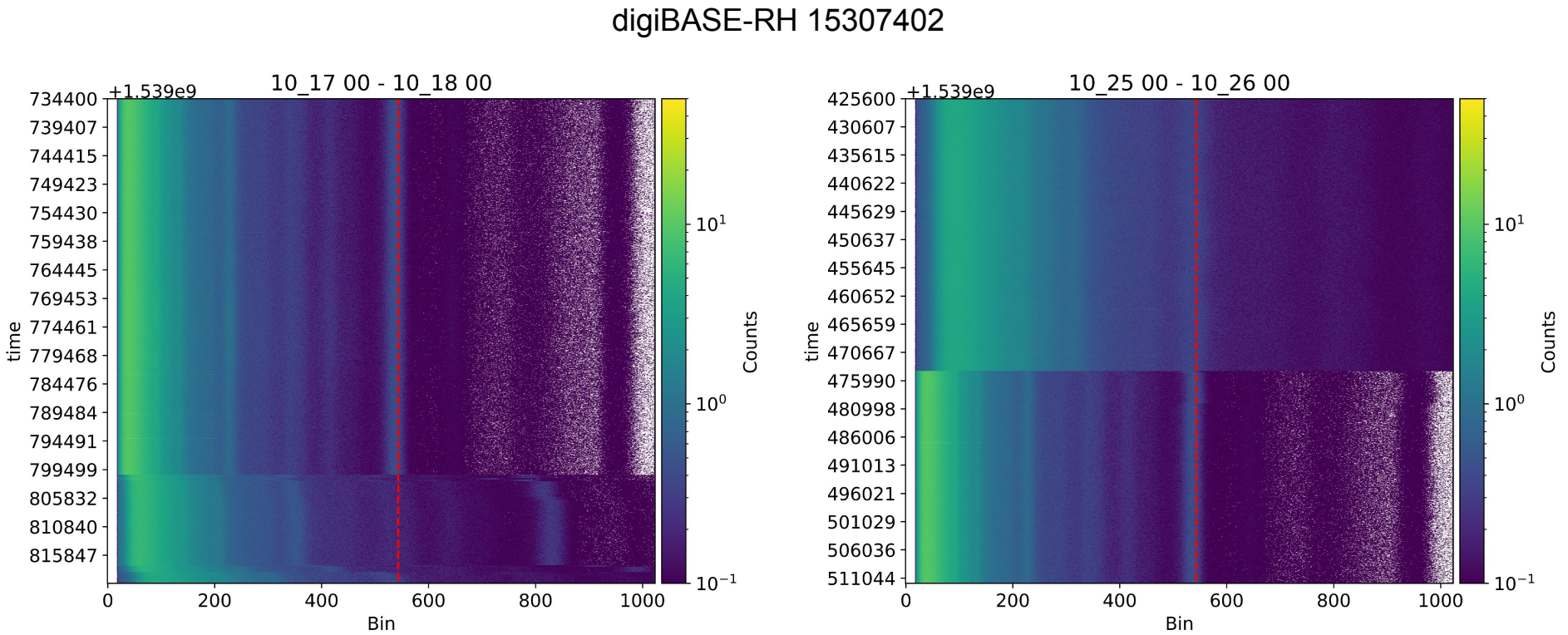


K.J. Bilton *et al.*, IEEE TNS (2019), DOI: 10.1109/TNS.2019.2907267



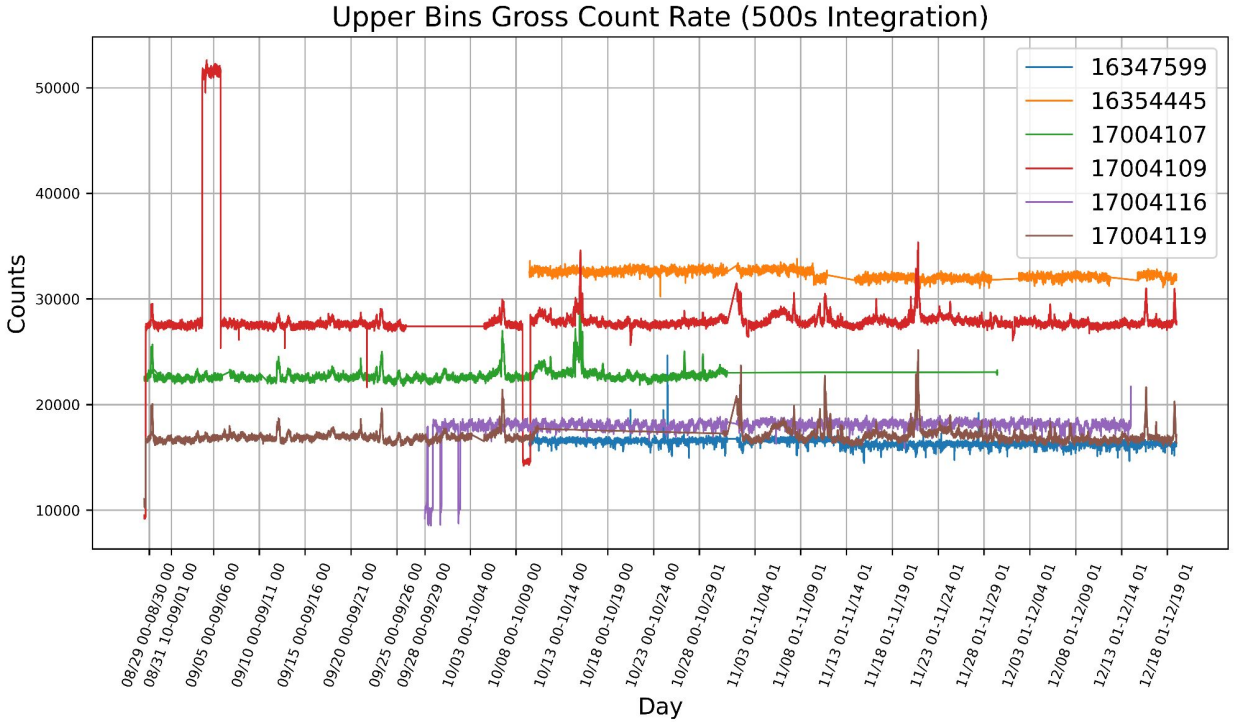
Analysis of AWE SIGMA Challenge Data

Data Quality



Data Quality

- Proxy calibration measurement:
  - look at gross counts in upper bins
- Some notable gain shifts
- Diurnal trends
- Data will need to be calibrated to use NMF

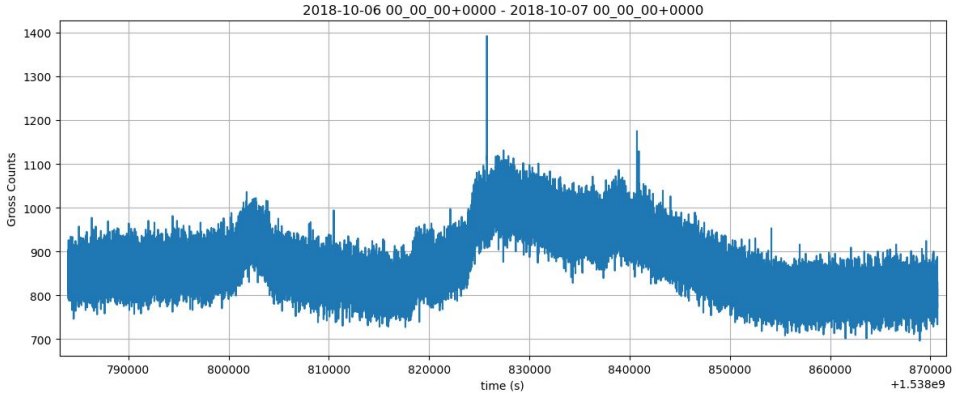


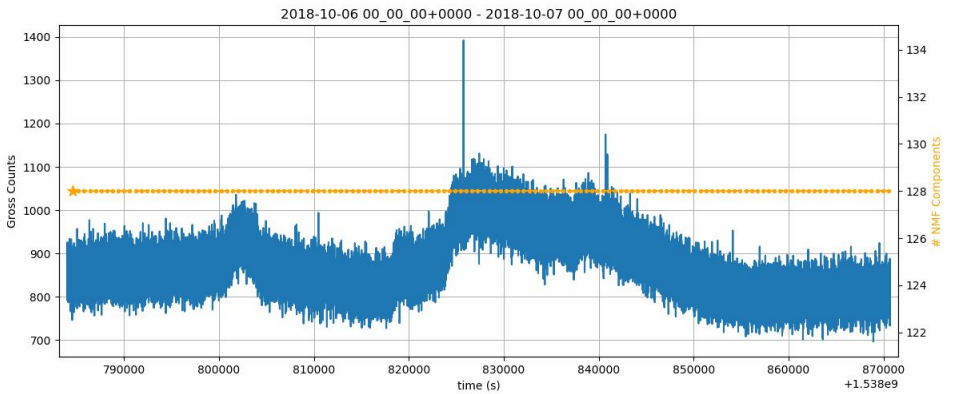
Conclusion:

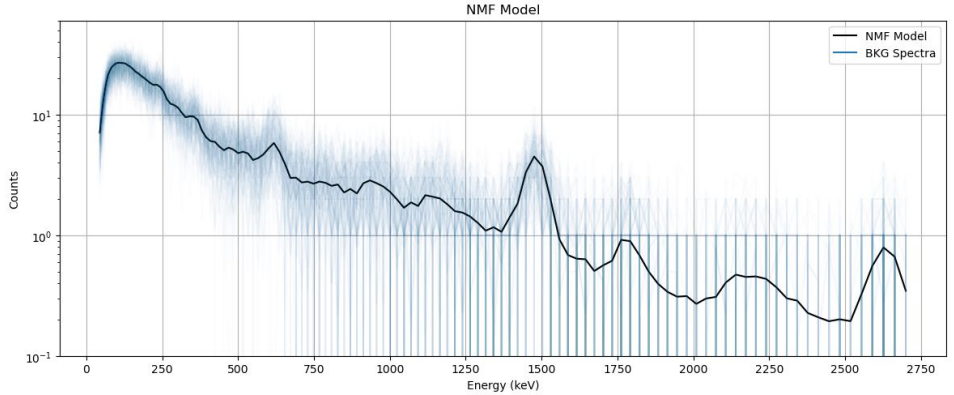
- NaI data is generally stable
- Will need further calibration to run NMF optimally

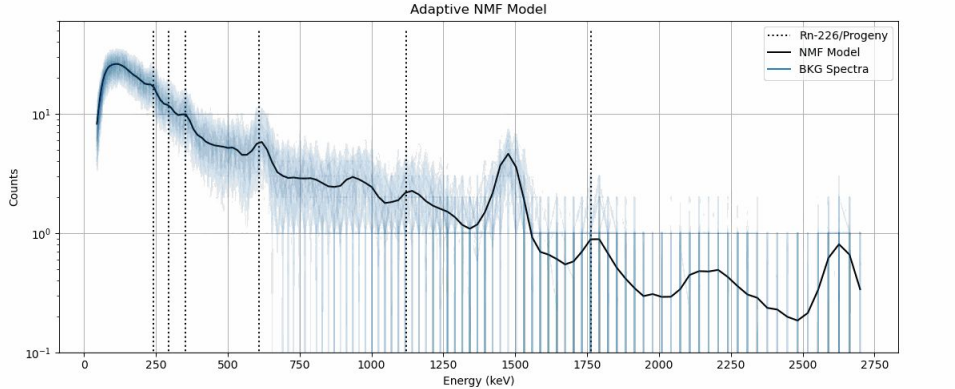
Background Models

digiBASE-RH 15307402









Background Models

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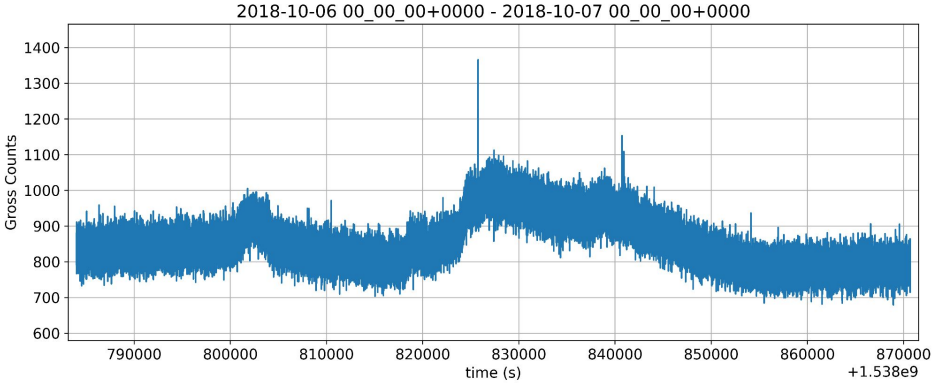
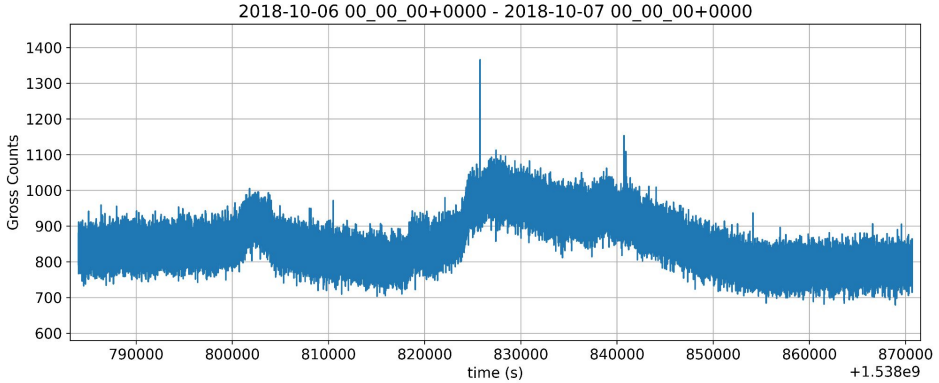
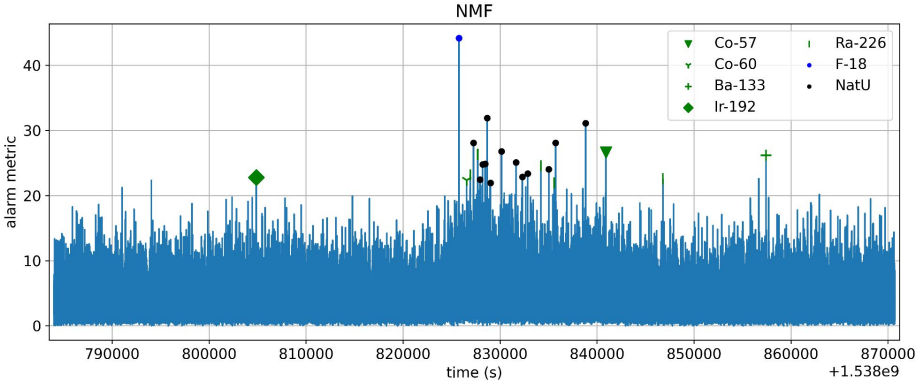
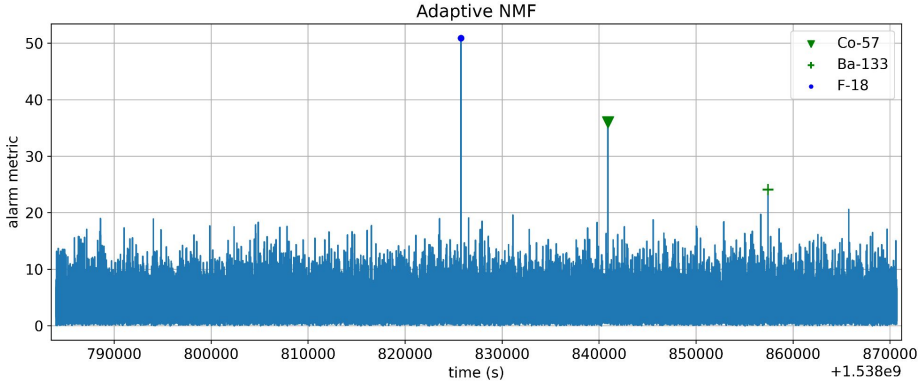






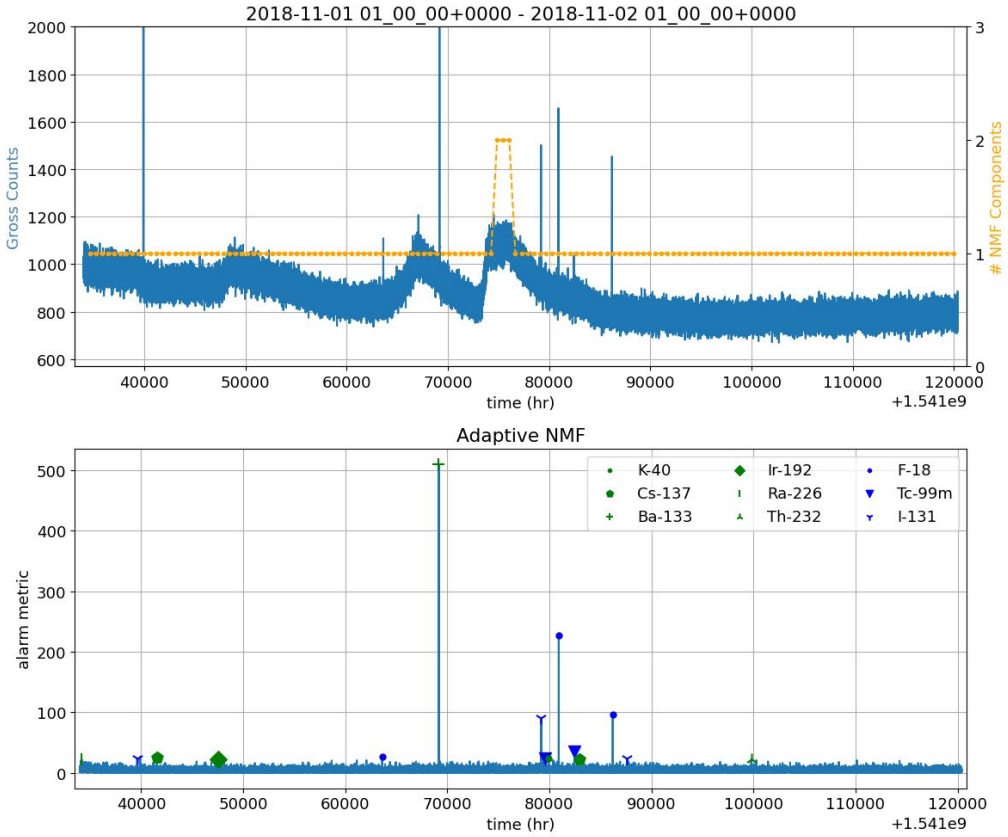


Background Models

- Sometimes rain produces enough spectral variability that a NMF model with two components is preferable according to our AIC

Does the new component show the expected characteristic lines?

digiBASE-RH15307402



Background Models

Rn-226 Progeny Lines

Pb-214:

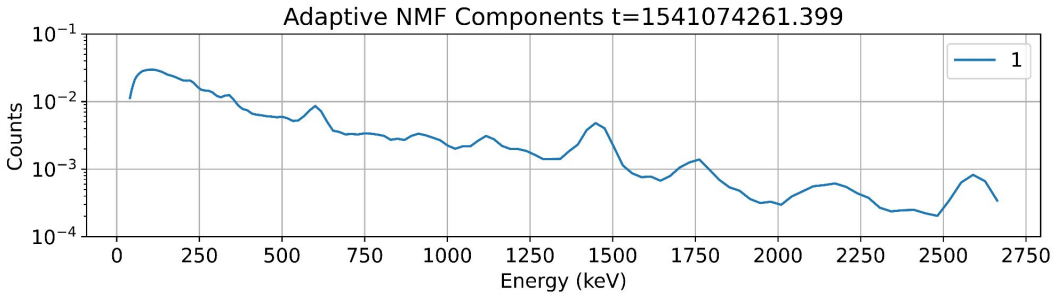
- 242.0keV
- 295.2keV
- 352keV

Bi-214

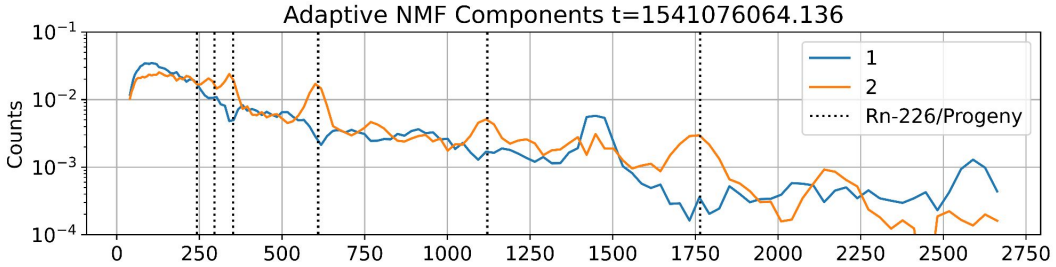
- 609keV — Bi-214
- 1120.3keV — Bi-214
- 1764keV — Bi-214

With this in mind, what do results look like?

Before



During



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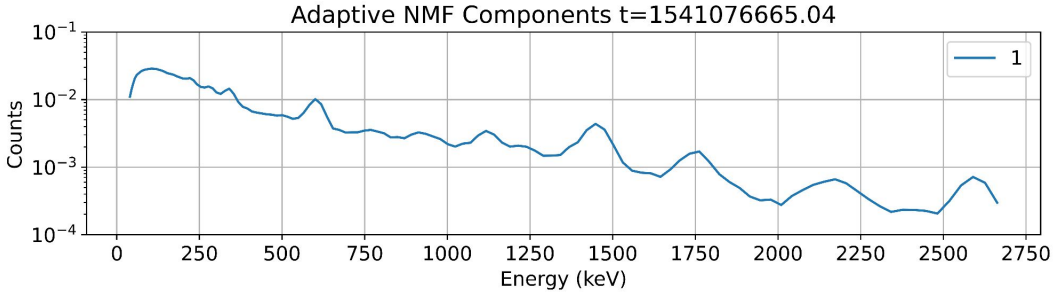
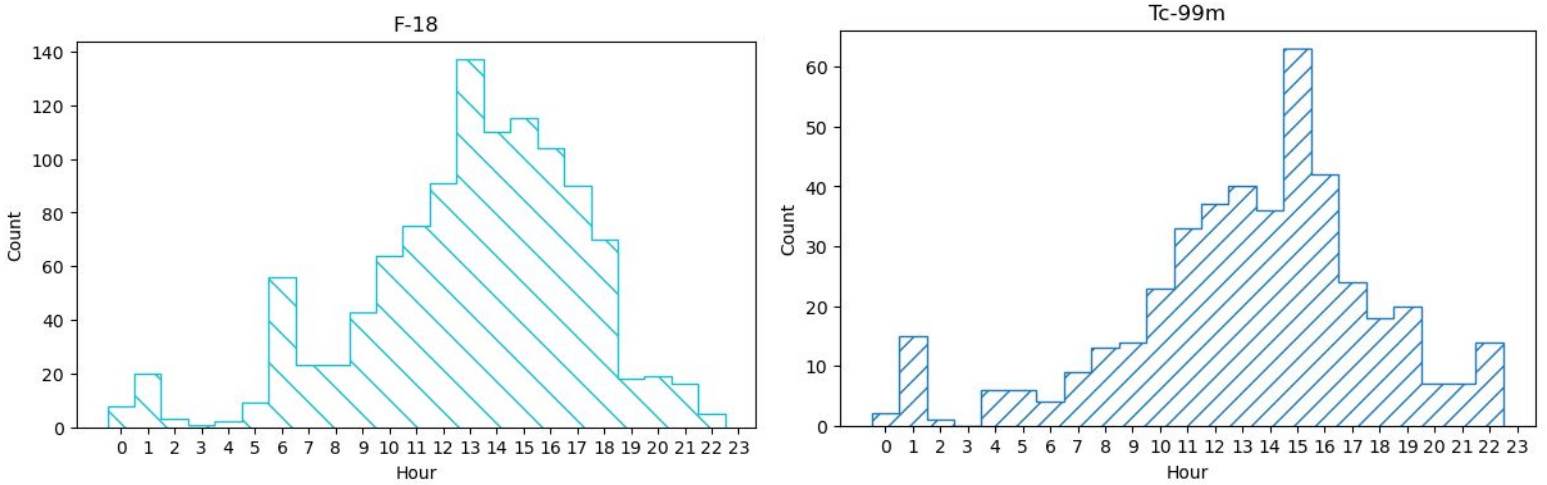


Interesting Medicals

- Anomaly encounters aggregated from 5 detectors over ~3 months

  Observations likely associated with individuals in receipt of nuclear medical procedures
- Distributions are generally consistent with previous analysis of static detectors in (US) urban environments
- Individual detector distributions may reveal finer ‘pattern-of-life’ information



Broader Uses of Analysis

- Can serve as a performance baseline to judge other detection/identification algorithms if adjudications are made available

- Example of performance in unrestricted urban environment

- NMF framework allows operators to visually assess alarms and background variability

Comments on Dataset

Main Takeaways:

- Large and interesting real-world data set!
- NaI data is fairly stable, though improved calibration required for optimal performance of NMF techniques
- Variety of relevant detector locations such as hospitals and high-density tourist /cultural sites provide rich avenues for investigation
- Potential for network science methods with simultaneous nodes
- Weather events provide engaging spectroscopic challenges

Future Avenues for Development

- Labeled source encounters
- Calibrated data
- Scrubbed data
- Injectable source encounters for range of isotopes

Acknowledgement

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Berkeley National Laboratory (LBNL) under Contract DE-AC02-05CH11231. The project was funded by the U.S. Department of Energy, National Nuclear Security Administration, Office of Defense Nuclear Nonproliferation Research and Development.

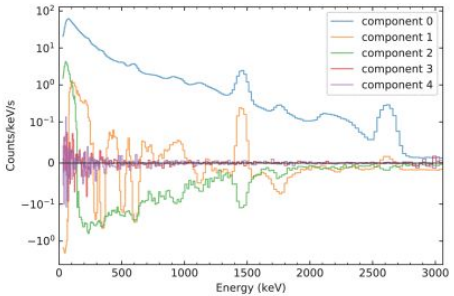
Extra Slides!

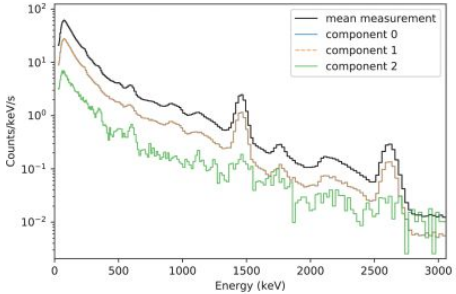
Previous Work- Improved Interpretability

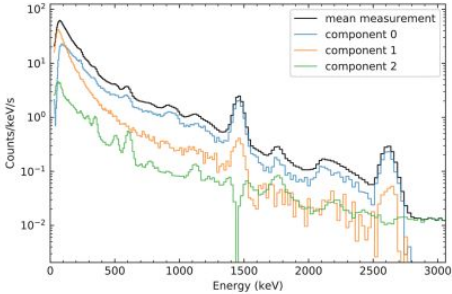
- Work from 2020 highlights improved physical interpretation of NMF over NASVD
  - Data taken from 12 NaI detectors

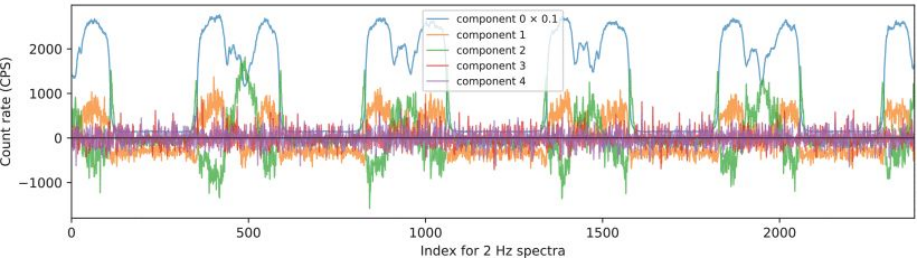
Mobile NaI (12 detectors)
Integration time = 1 s
FAR = 1/8 hours

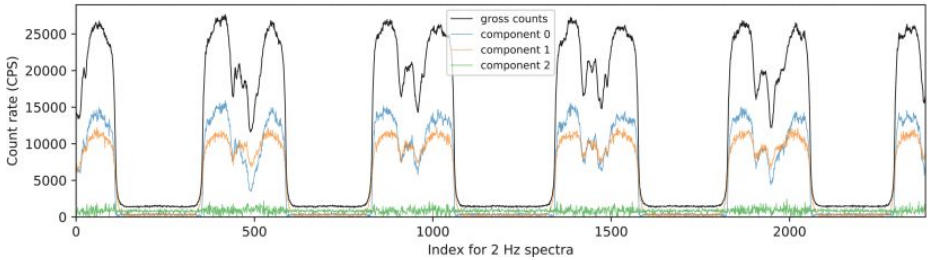
M.S. Bandstra *et al.*, IEEE TNS (2020) DOI: 10.1109/TNS.2020.2978798











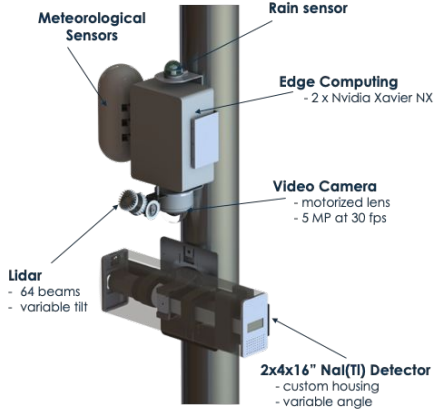
Previous Work- Networked Detector Systems

- Developing static sensor network in urban Chicago, US to test intelligent networked contextual detector systems

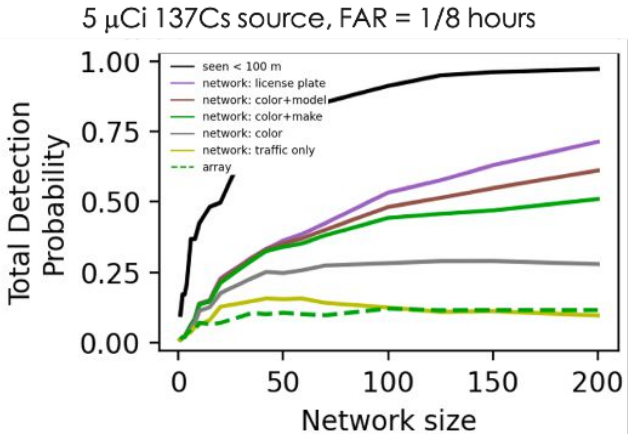
  - Hardware:
    - 2”x4”x16” NaI detectors with temperature-correction hardware
    - 5MP 30hz Video, 64-beam LIDAR with 90° vertical FOV, microphone, rain/humidity/pressure sensors, two Nvidia edge computers

  - Node Level:
    - Spectral data continuously calibrated with a set of templates for single isotopes, series, cosmics
    - Detection and Identification performed with modified NMF

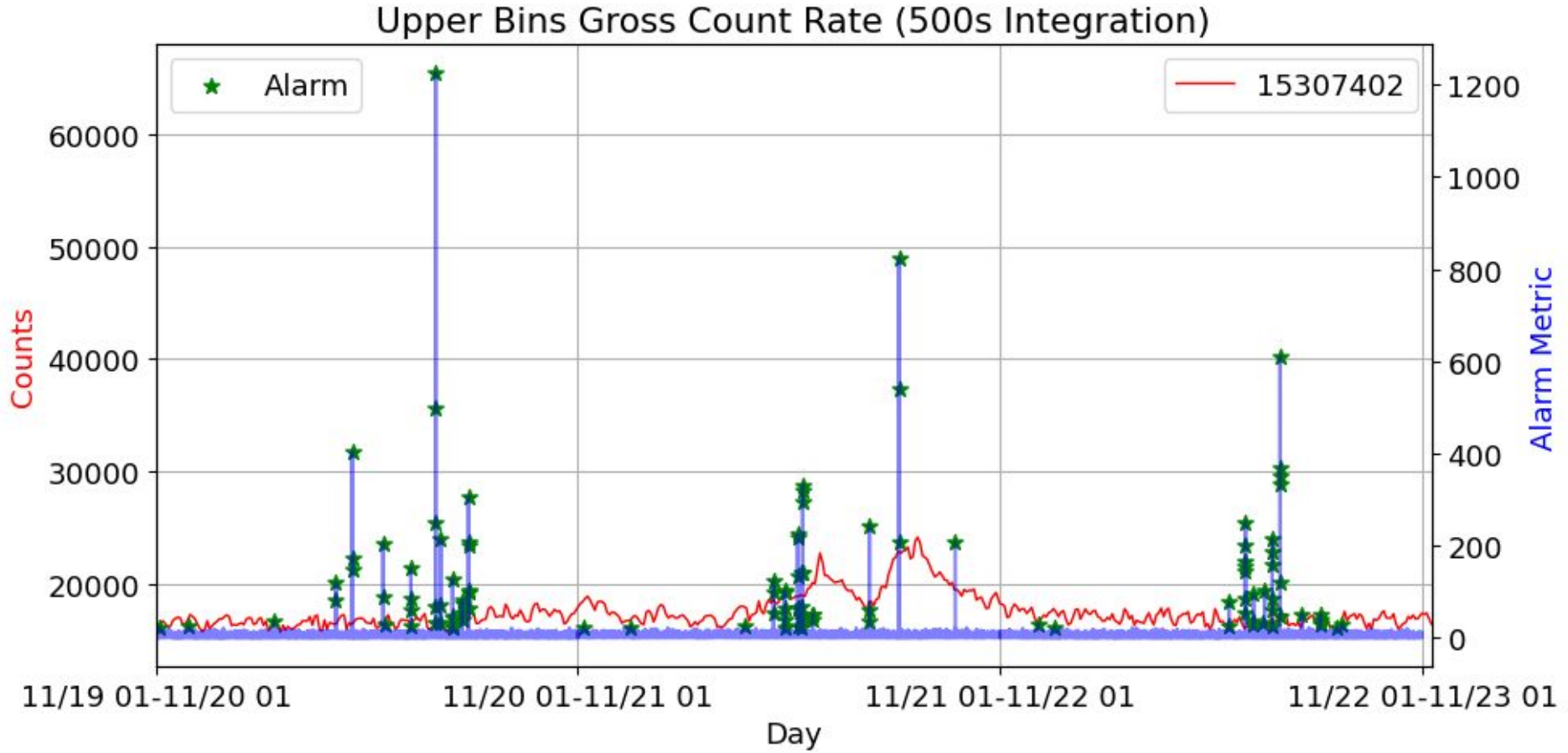
  - Cloud Level (in development):
    - NMF refitting, contextual data fusion, object *re*-detection, statistically informed source tracking



R.J. Cooper et al 2023 J. Phys.: Conf. Ser. 2586 012125



Data Quality- Non-Plateau Spikes

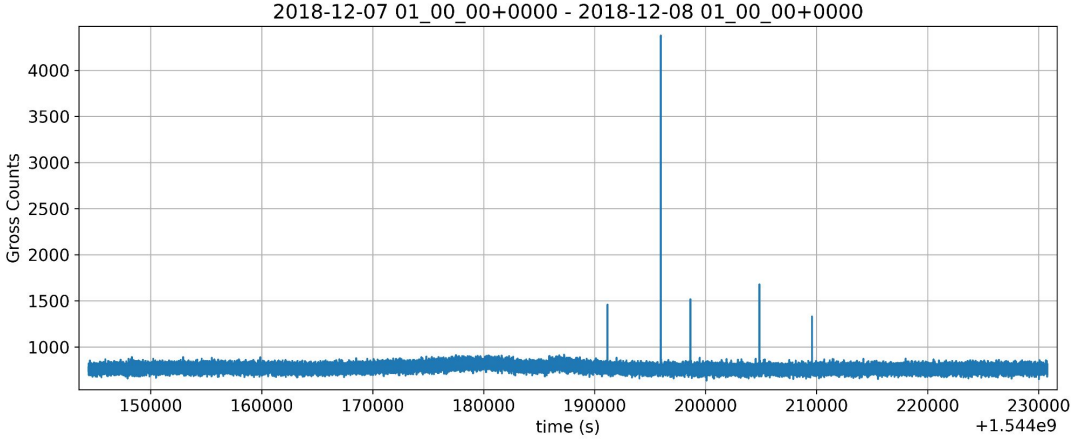


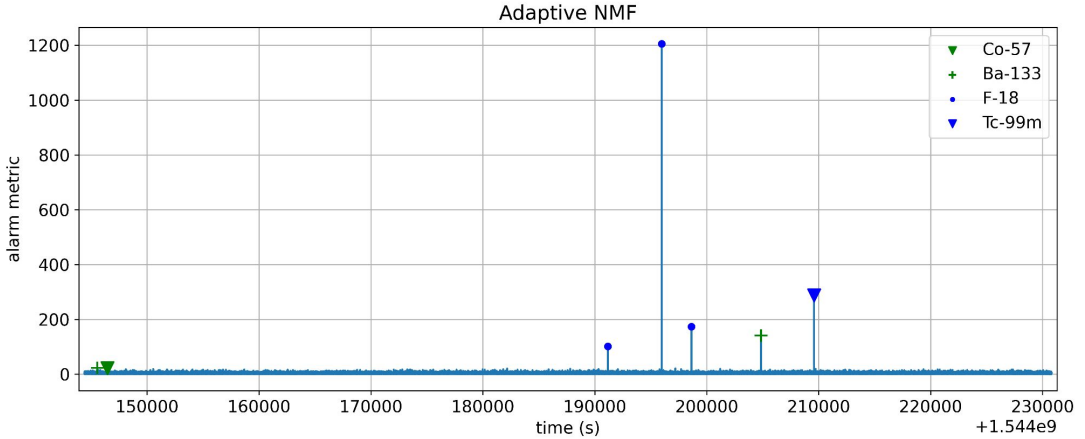
Example Analysis of AWE SIGMA Challenge Data

- NMF is trained on subset of apparently background data from second or third day
- FAR set at 1/8hrs
- Adaptive NMF refit every 600 spectra (10mins, at collection rate 1Hz)

Primarily basic (Ba-133, Ir-192) and medical isotopes observed (Co-57, F-18, Tc-99m)

Example: Detector 15307402





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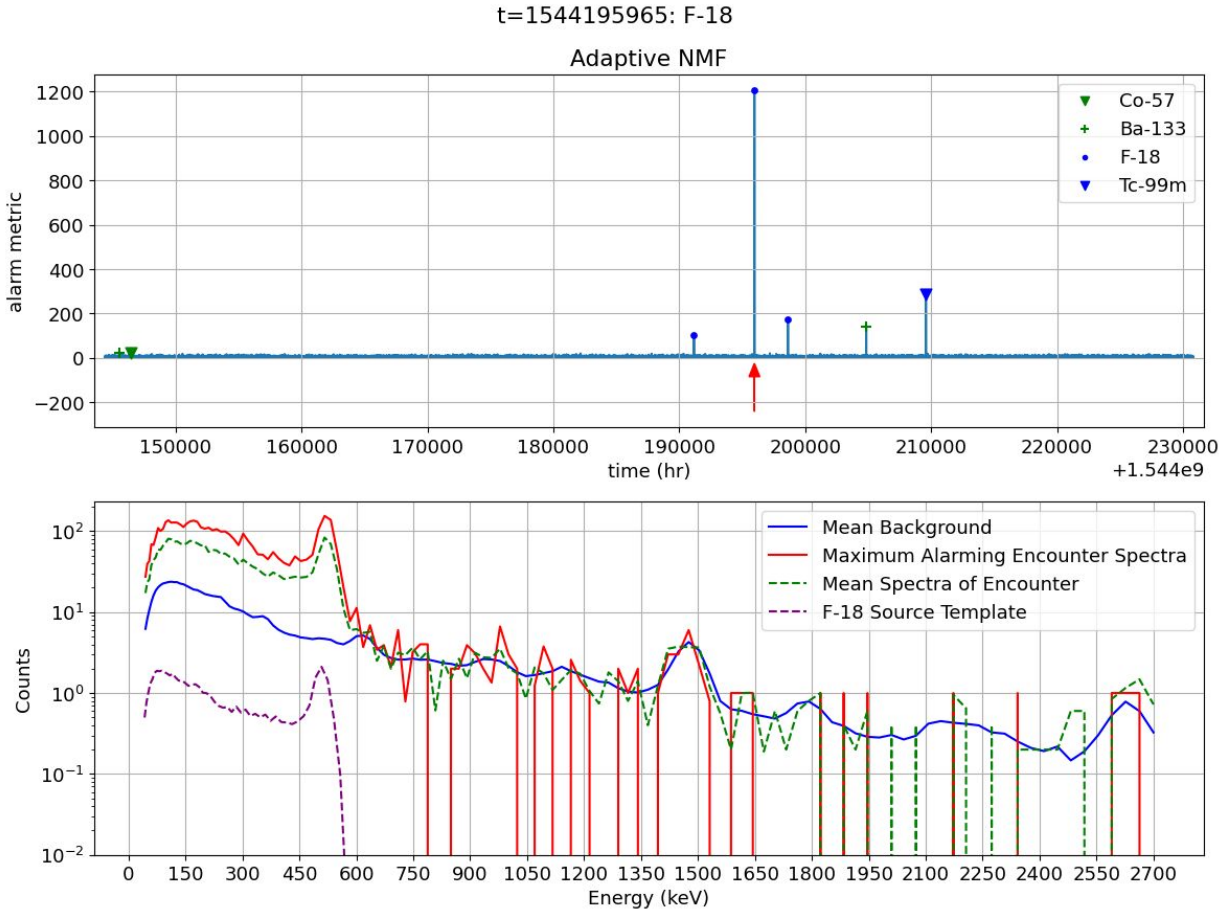

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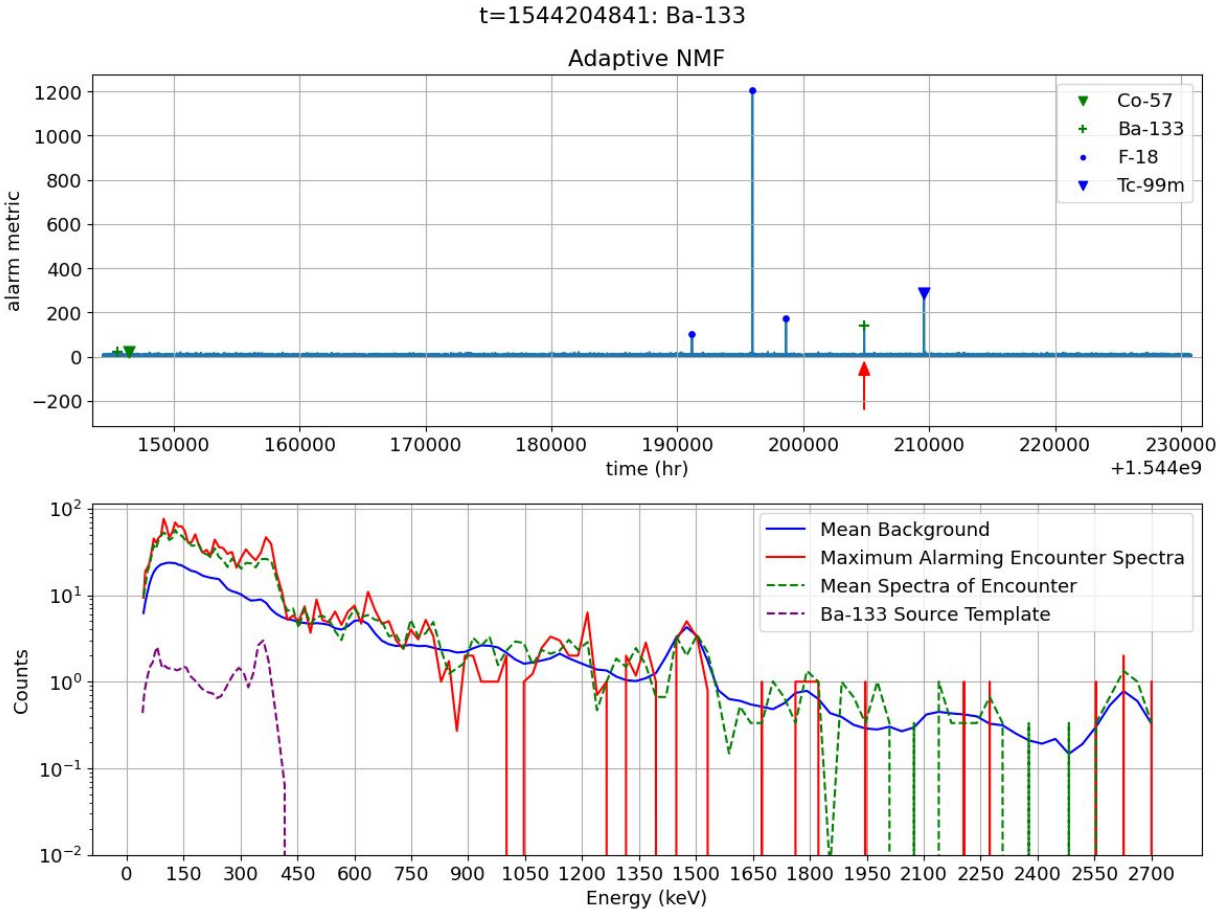

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