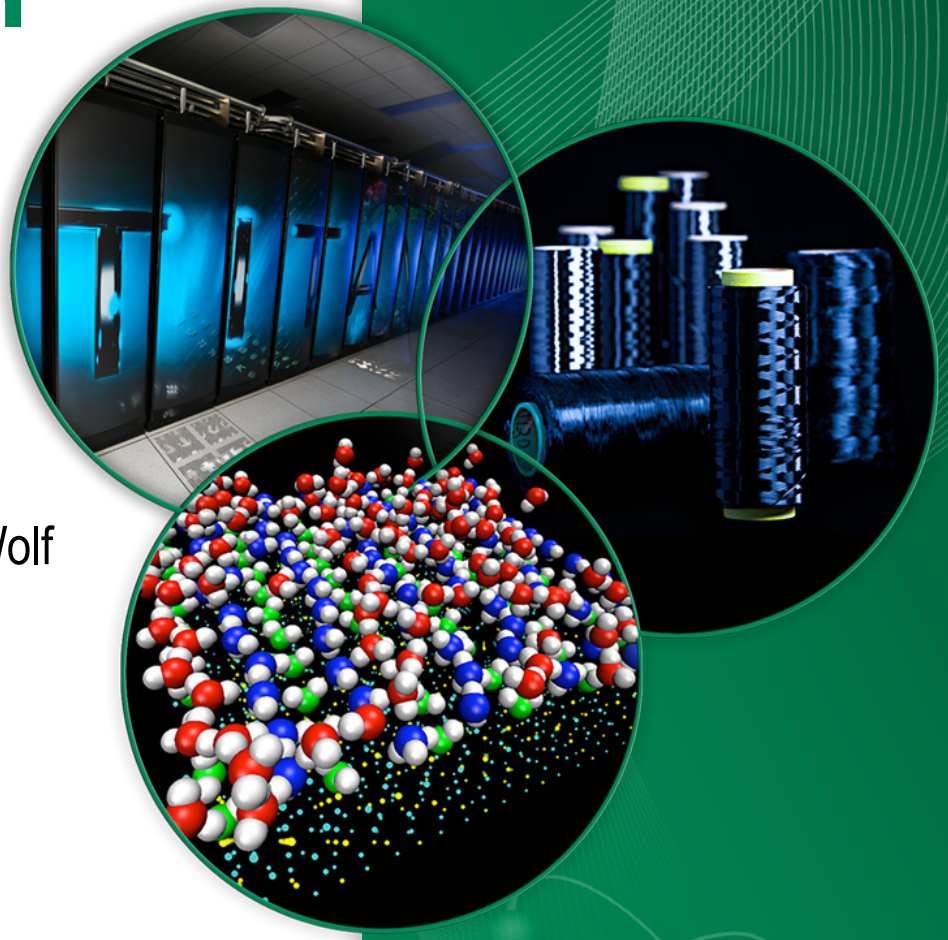
Smart Smoke Alarm



Principal Investigator: Bruce Warmack

Sensors & Controls Research Group

Co-Investigators: Shane Frank & Dennis Wolf

Sponsors:

U.S. Fire Administration

U.S. Consumer Product Safety Commission

ORNL Technology Transfer Division

Technology

- Smart Smoke Alarm detects fires sooner and with fewer false alarms than present home smoke alarms at comparable unit costs.
- Intelligently combines one or more sensors using an advanced mathematical algorithm to more accurately and rapidly recognize fire conditions.
- Linear discriminant analysis (LDA) is used to distill data from hundreds of residential fire and nuisance tests
- Give inexpensive microcontrollers a map to recognize real hazards from ordinary and nuisance conditions.

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Motivation

- Since 1975, the number of deaths due to home fires has been cut in half.
- Nevertheless, in 2012*
  - Residential Fires: 381,000
  - Lost lives: 2,405
  - Injuries: 12,875
  - Property Loss: $7.2B

Capt. Gary Watlington
ORNL Firefighter

- Residential construction methods and home furnishings have decreased safe egress times from an average of 17 minutes in 1975 to about 3 minutes in 2008
- Alerting occupants sometimes can be problematic

* M.J. Karter, Jr. *"Fire Loss in the U.S. During 2012"* Nat. Fire Protection Assoc., NFPA FLX10-01, September 2013.

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Advanced Discrimination

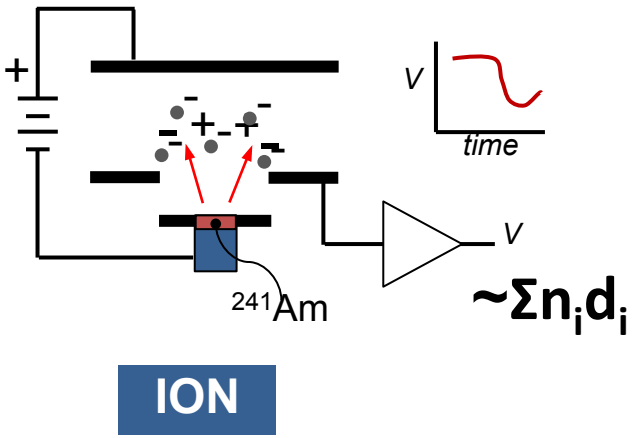
- Smart Smoke Alarm exploits ORNL leadership in advanced discrimination techniques
  - Chemical and Biological Mass Spectrometer (CBMS) to detect threats in Army fields of operation
  - SNIFFER for situational awareness of toxic industrial chemicals (TICs) for first responders
  - JUNO™ differential mobility spectrometer for chemical agents and TICs
- All make use of linear discriminant analysis (LDA) for classification using multiple data streams

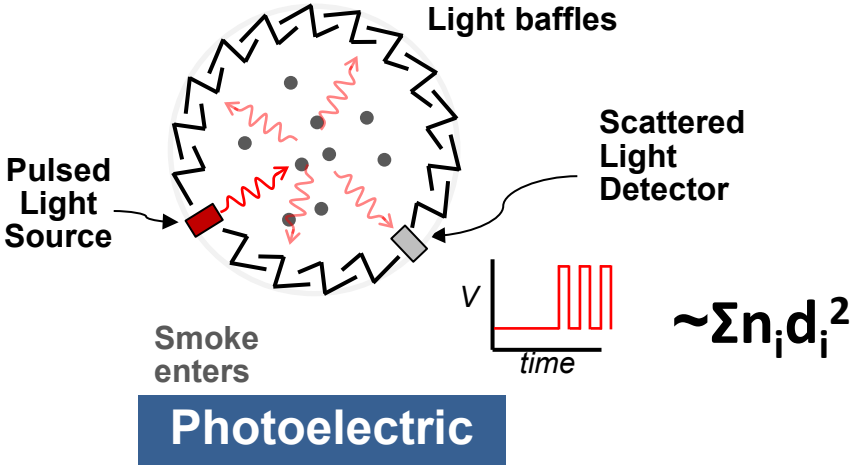
Block II CBMS

DHS SNIFFER

Chemring JUNO™

Smoke Detectors





- Ion detectors are sensitive to smaller aerosols generally associated with fast flaming fires
- Photoelectric detectors are sensitive to larger aerosols generally associated with slow smoldering
  - Smaller particles (< λ/3) – invisible
  - Larger particles (> λ/3) scatter light – visible

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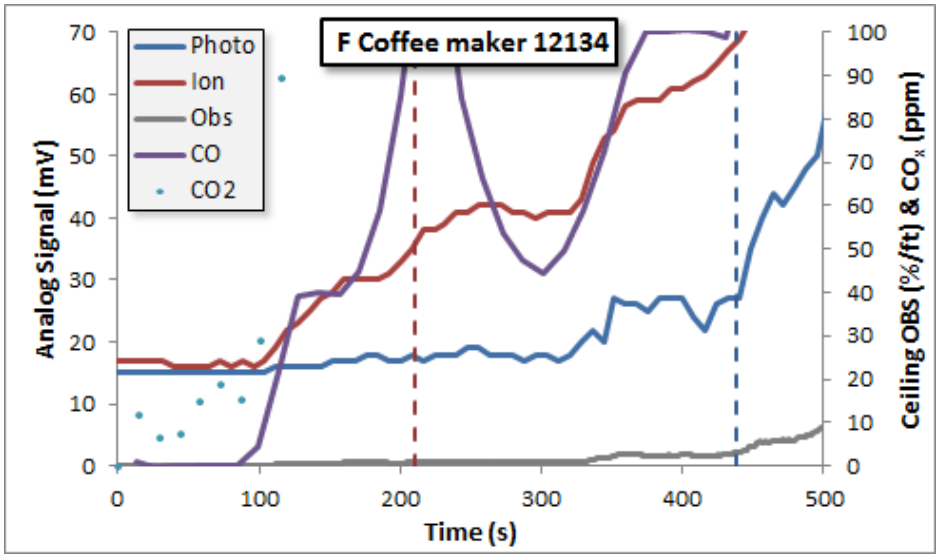
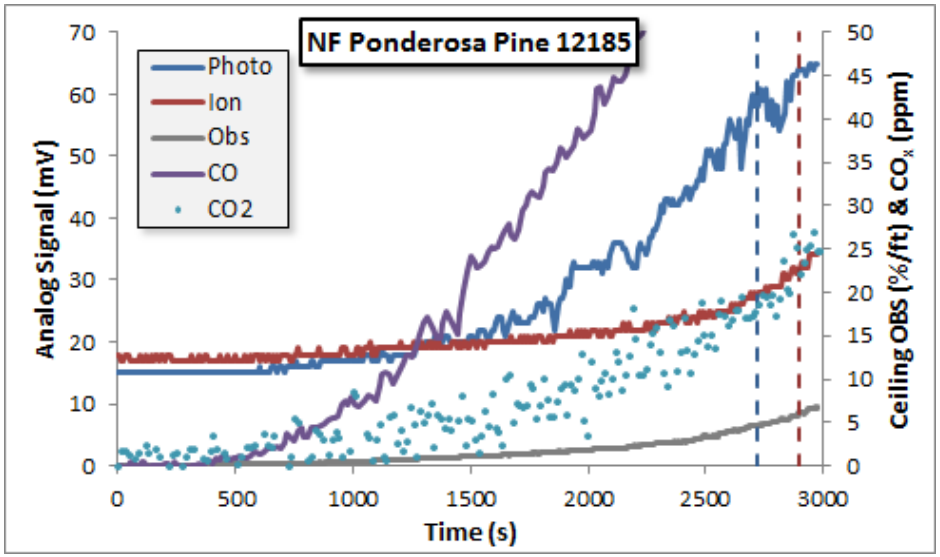
Fire Test Data

- UL data[1] from 18 fire tests in the UL217/UL268 Fire Test Room
- NIST data[2] from 21 fires each with multiple sensor locations (67 total) in a manufactured and a two-story home plus 25 nuisance tests
- Ceiling sensors common to both: ion, photo, temperature and CO
- Baseline – subtract average of previous n measurements (n is large)
- Rate – subtract average of previous n' measurements (n' is small)





[1]Fabian, T.Z. and Gandhi, P.D. 2007. "Smoke Characterization Project." Northbrook, IL: Underwriters Laboratory Inc.

[2]Bukowski, R.W. et al. 2008. "Performance of Home Smoke Alarms." NIST TN-1455-1 (Rev. 2008)

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Mathematical Analyses

- **Principal Components Analysis:**
  - PCA condenses multiple channels of correlated (redundant or interdependent) data into a series of variables or principal components that are independent (not redundant)
  - Can manage a large number of signal channels
  - The goal of PCA is to capture information about data variation but not necessarily to classify
- **Linear Discriminant Analysis:**
  - LDA is supervised pattern recognition in which training data is used to formulate rules to sort new observations as belonging to specified groups.
  - Useful for a small number of signal channels
  - The goal of LDA is to classify or discriminate
- **Both involve transforming data into virtual space**
- **Previous study of various algorithms including PCA in 2005**

Cestari, L.A., C. Worrell & J.A. Milke, *Advanced fire detection algorithms using data from the home smoke detector project*. Fire Safety Journal 40 (2005) 1–28

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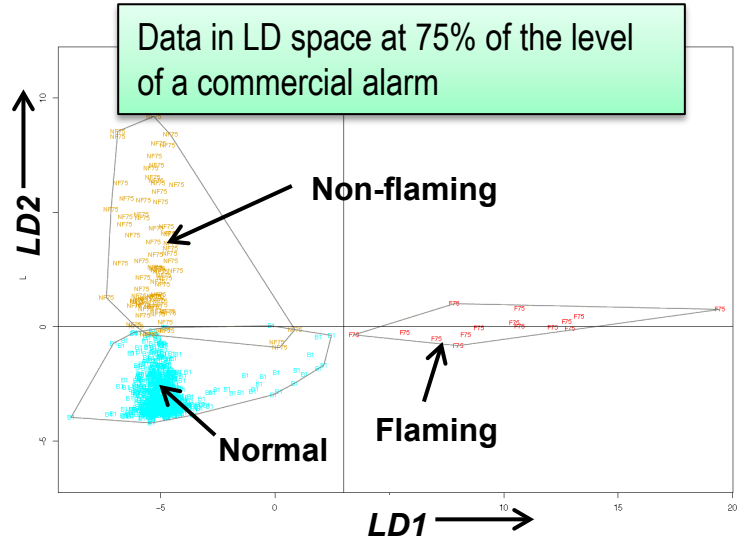
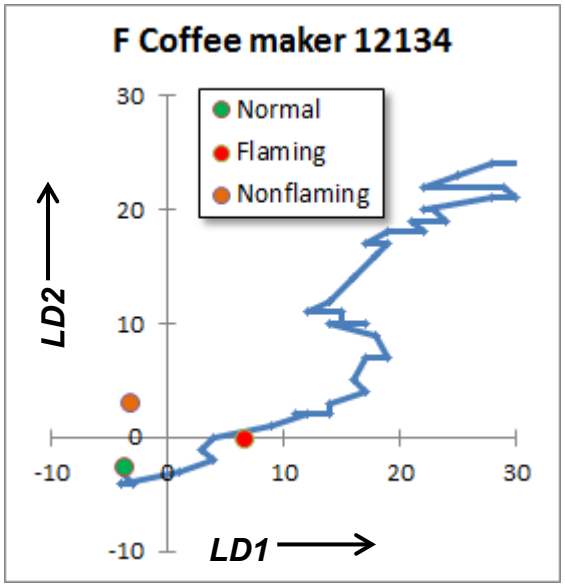
Simple LDA

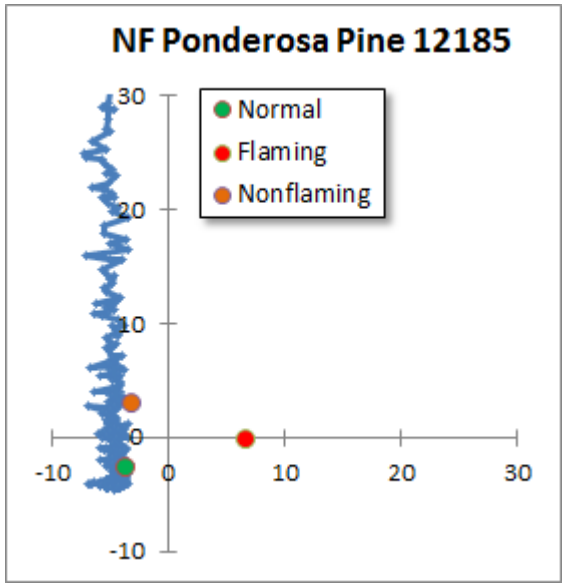
- Training data from UL (18 room fires)
- Signals: ion, Δion and ΔT
- Groups: normal, flaming and non-flaming
- Progression in LDA space shows the character of the fire type



Alarm Times

Test:	12134	12185
Ion/PE	3.5/7.3min	45/48min
LDA	2.2min	34min





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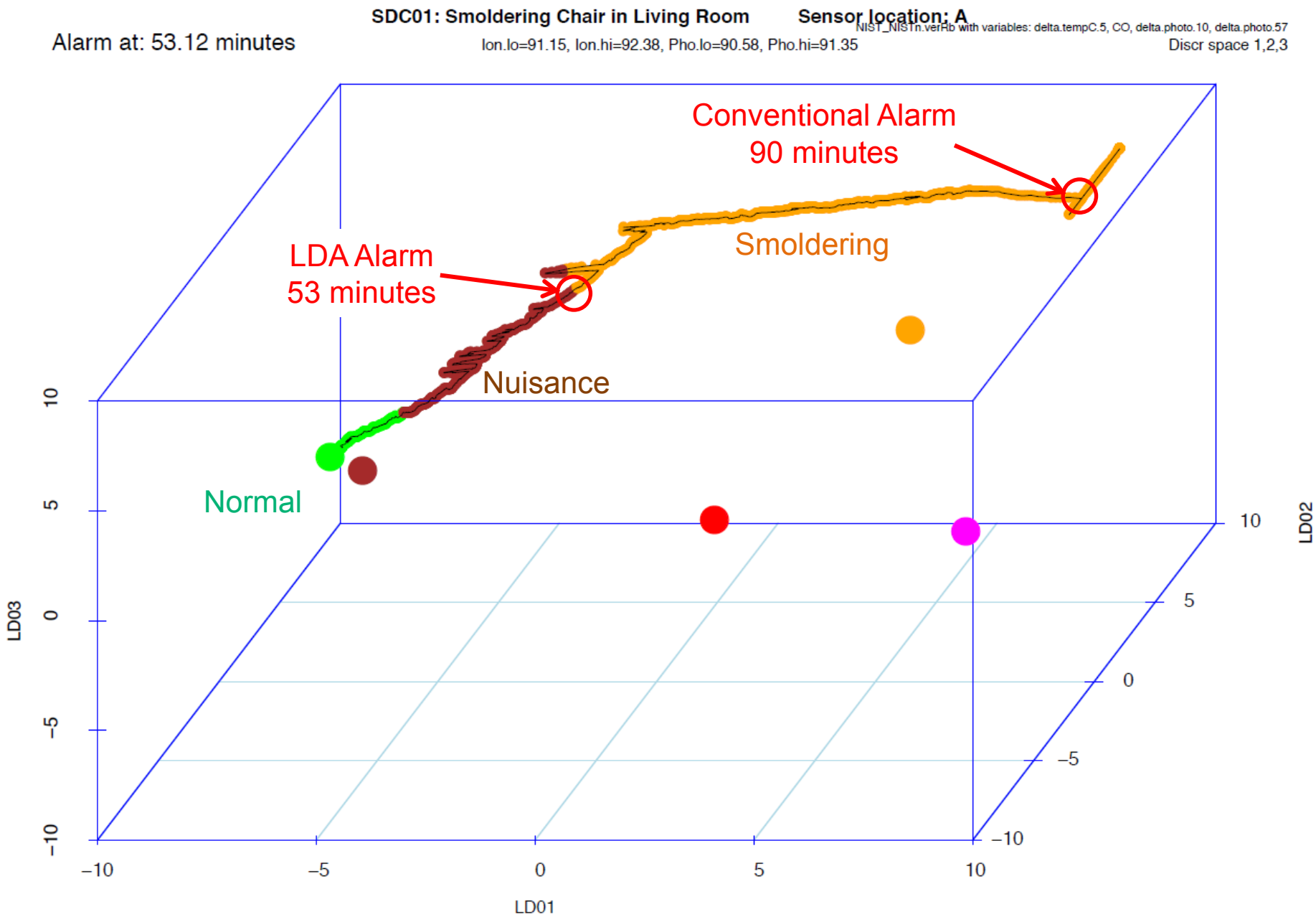

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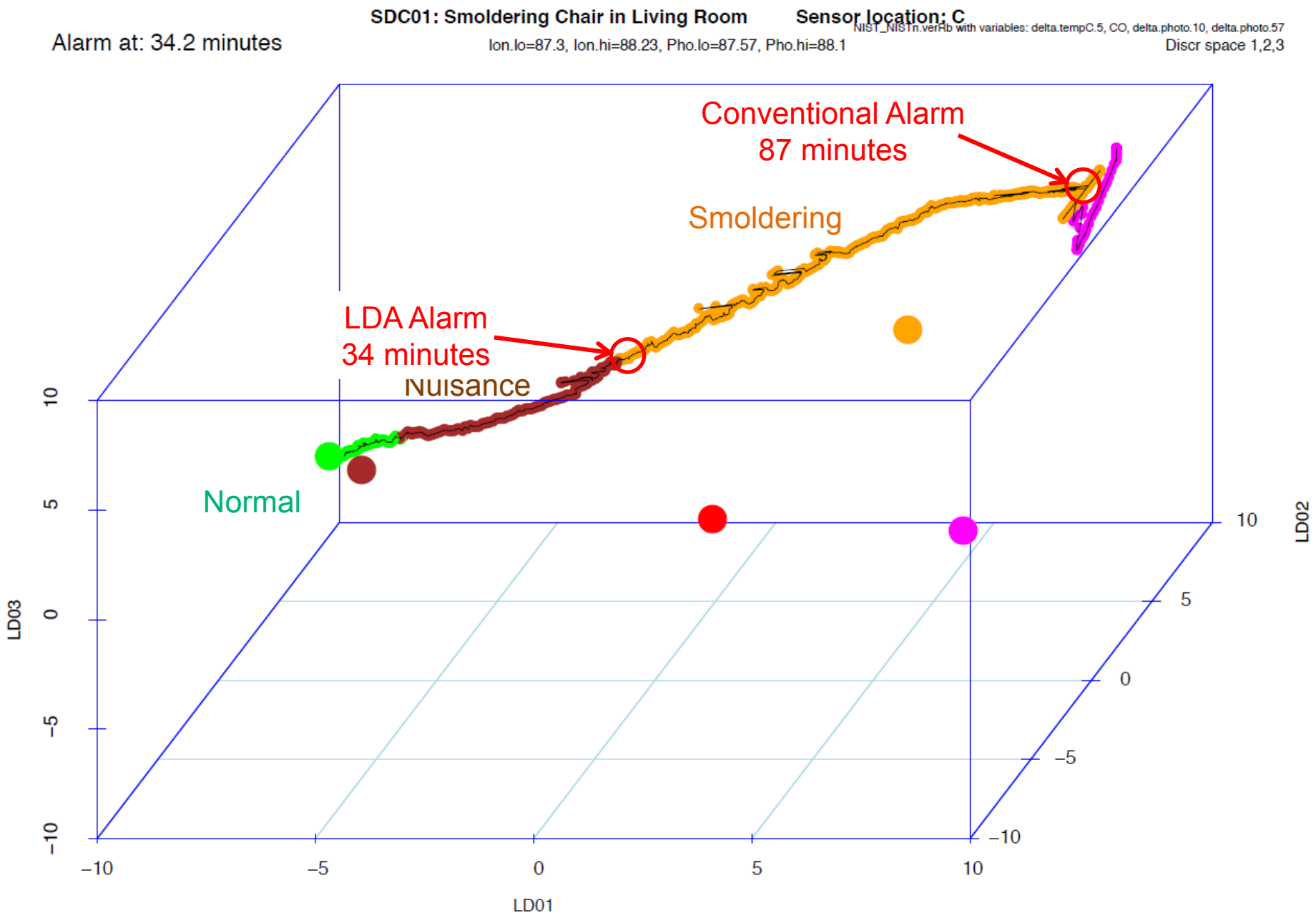

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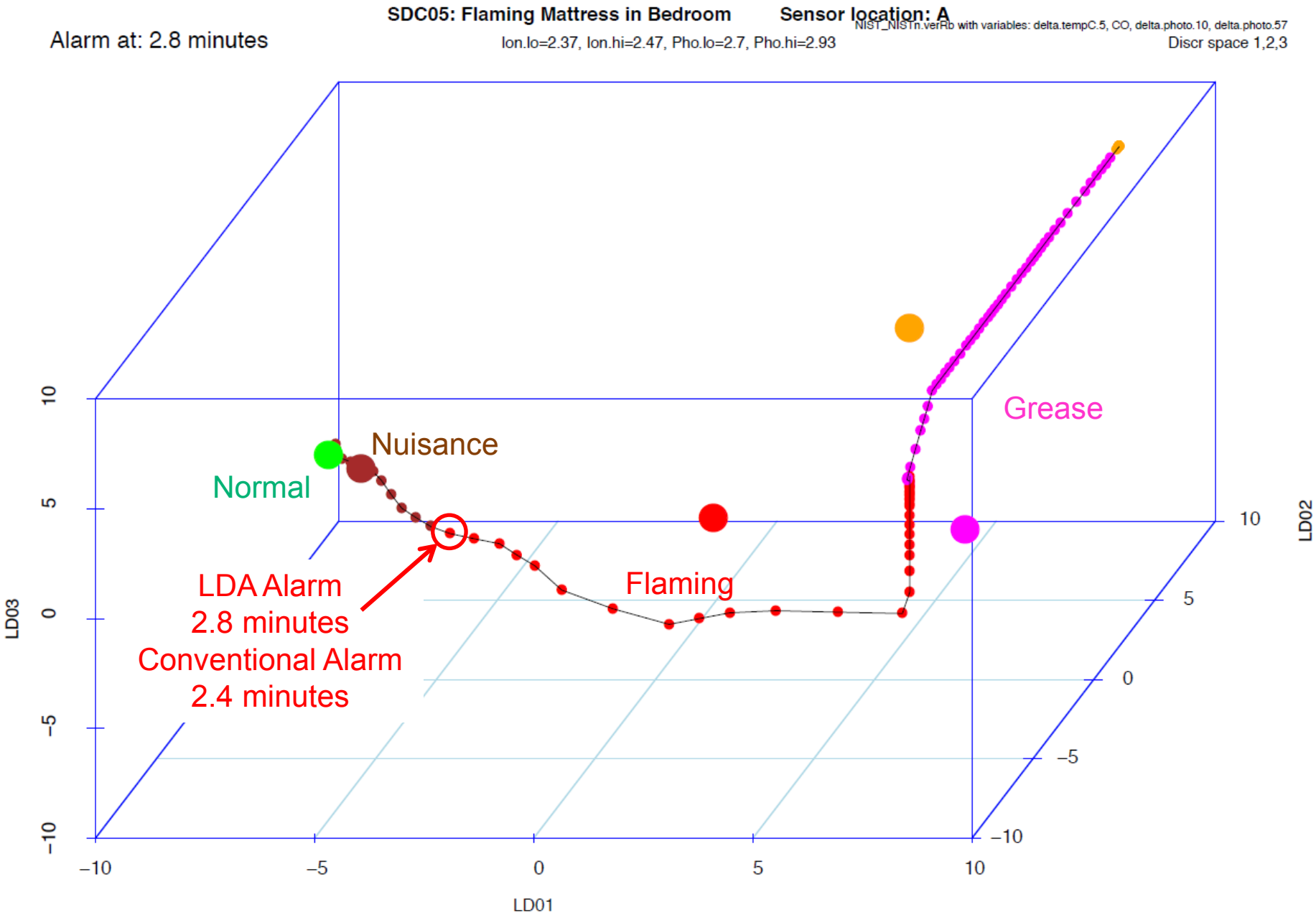
Alarm at: 2.8 minutes



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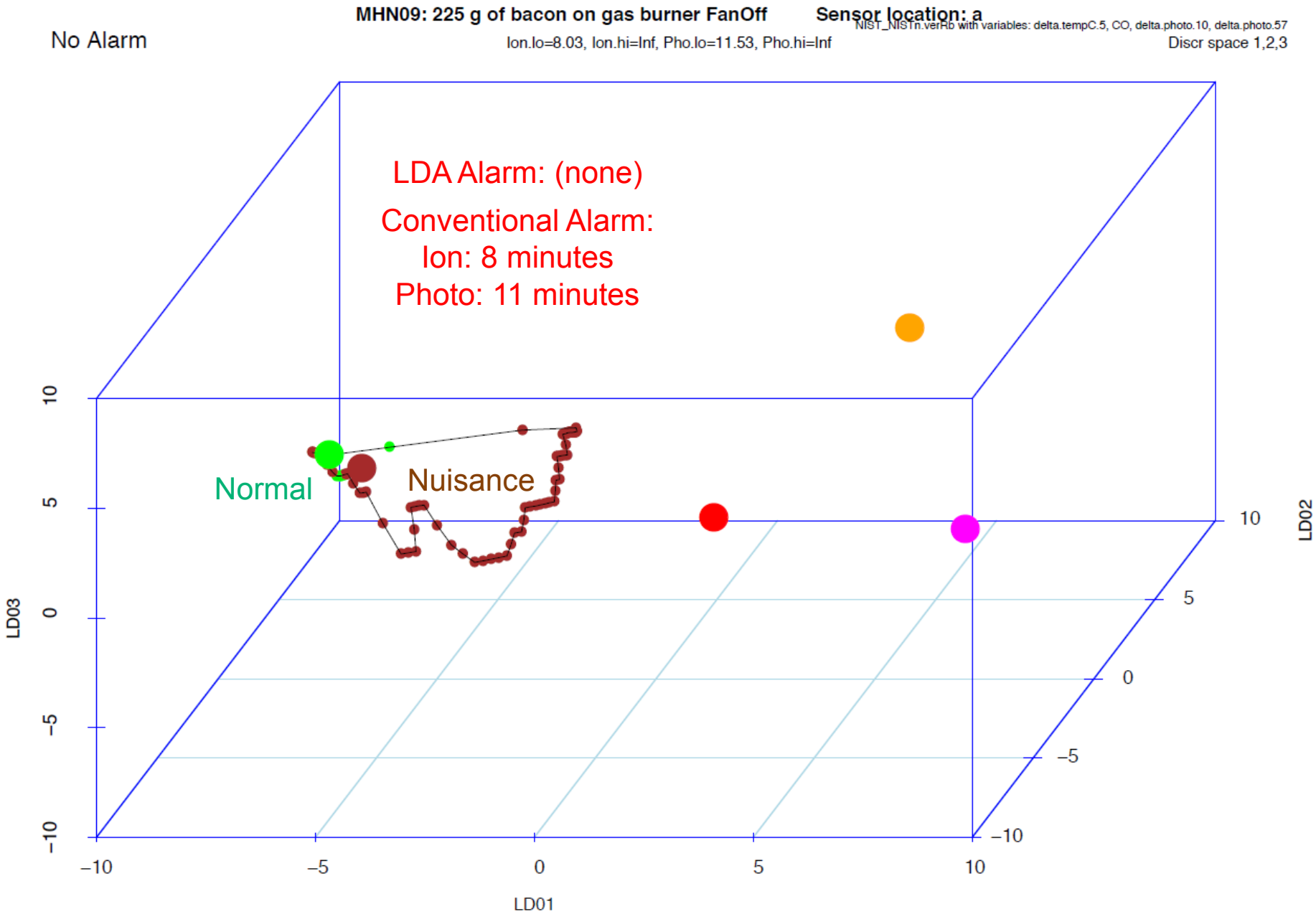

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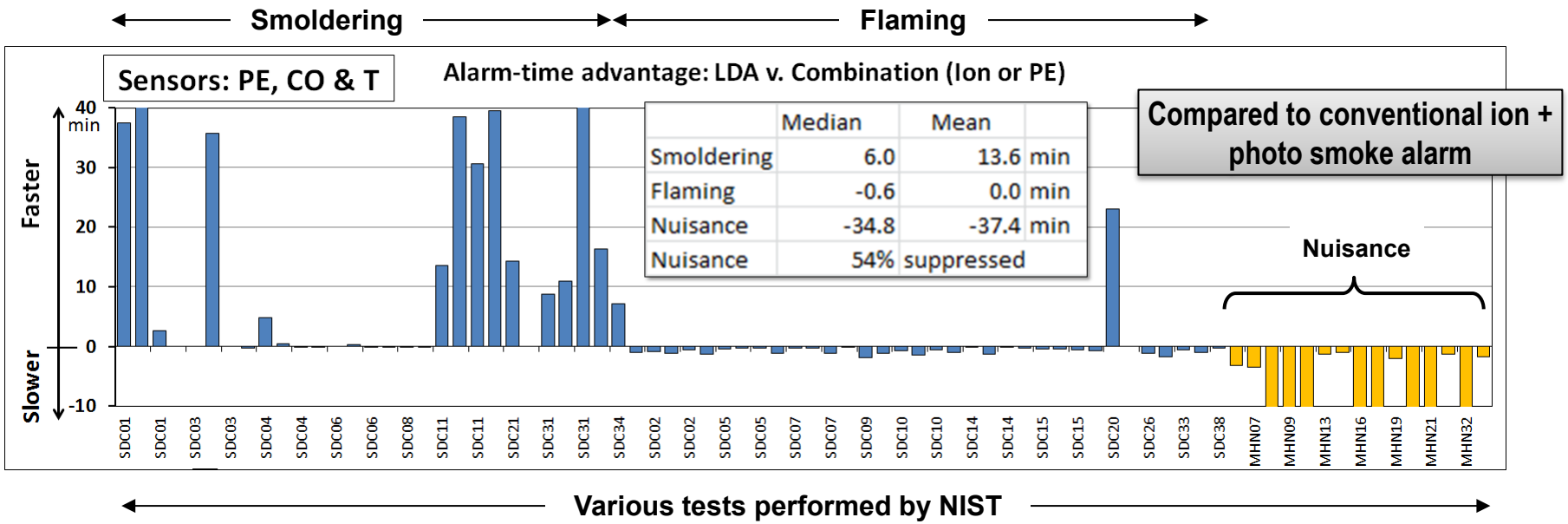
Performance

- Commercial smoke alarms still use threshold levels for alarming – Most alarms are *false* alarms
- Smart Smoke Alarm: faster detection and <u>complete elimination</u> of false alarms in more than half of cases



	Median	Mean	
Smoldering	6.0	13.6	min
Flaming	-0.6	0.0	min
Nuisance	-34.8	-37.4	min
Nuisance	54%	suppressed	

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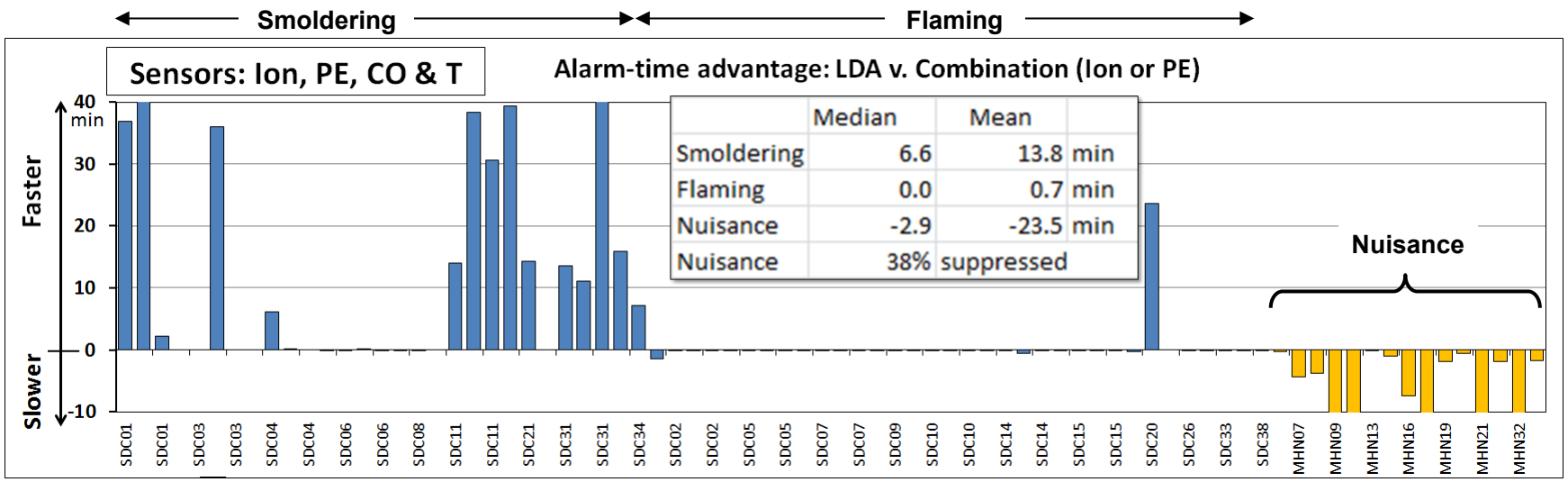
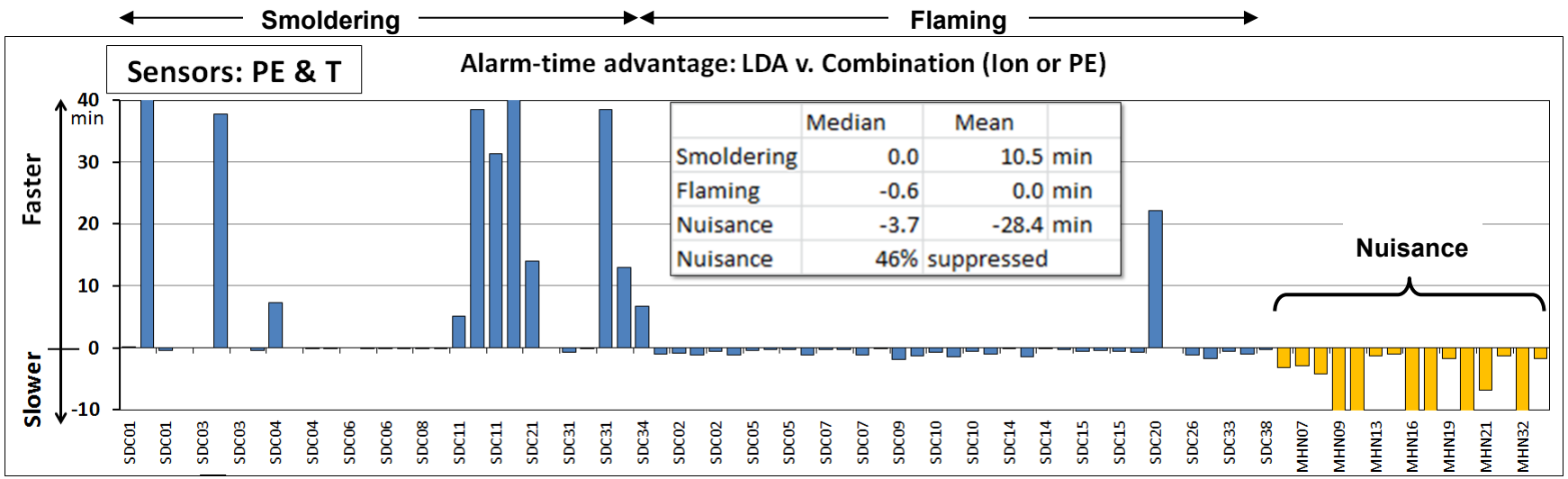
Performance for other combinations





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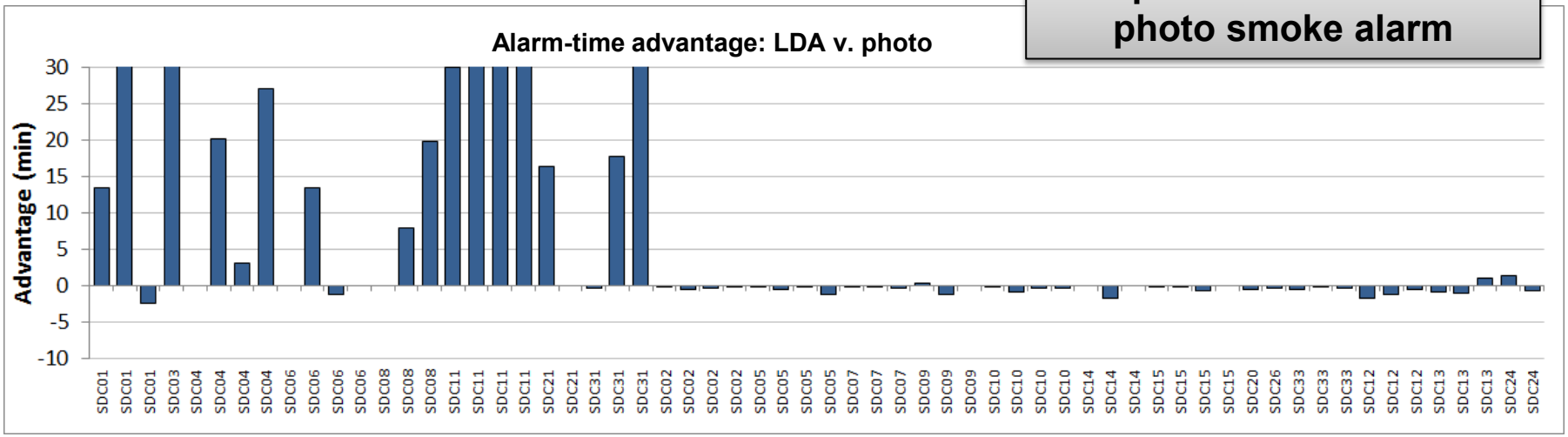
Photoelectric Only

- **LDA with only photoelectric sensor**
  - **Better than conventional photoelectric for smoldering alarms**
  - **Similar performance to conventional for other fires and nuisances**

	Median	Mean	
Smoldering	16.4	20.4	min
Flaming	-0.2	-0.4	min
Nuisance	0.0	1.4	min
Nuisance	0%	suppressed	

— Processing alone improves alarm —

Compared to conventional photo smoke alarm



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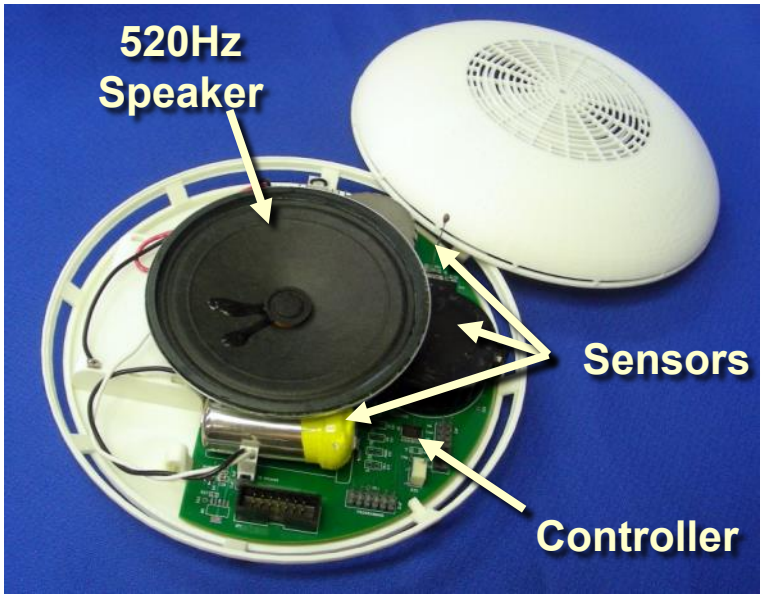
Present Prototype



- **Smart Smoke Alarm prototype**
  - **Uses conventional sensors**
  - **Looks conventional**
  - **Alerts more quickly for real hazards while suppressing or eliminating false alarms**
- **Prototypes have been built using custom PC board and 3D printer**
- Algorithms are embedded in a low cost microcontroller to provide optimal discrimination for various sets of commercial sensors
- Presently up to 6 sensor signals and 3 dimensions are easily programmed
- Low frequency alerting

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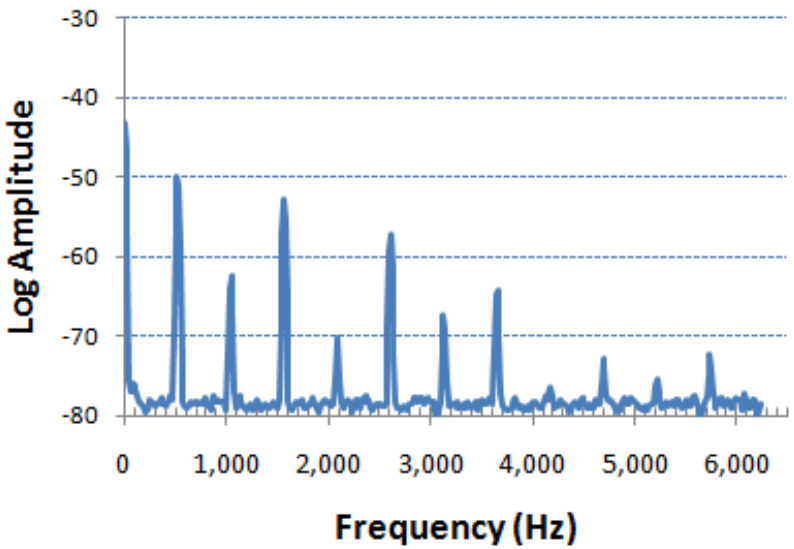
Alerting

- 37% of fire deaths occur while people are sleeping in homes with working alarms (*CPSC 2004*)
- Arousal is limited with sleep deprivation, alcohol/drugs, children, old age, hearing impaired



- Standard 3100Hz T-3 alerting tone is substantially less effective than low frequency or female voice
- 520Hz square wave much more effective than 3100Hz for all at-risk groups

E.g.: Thomas & Bruck 2010. Fire Technol. 46, 743

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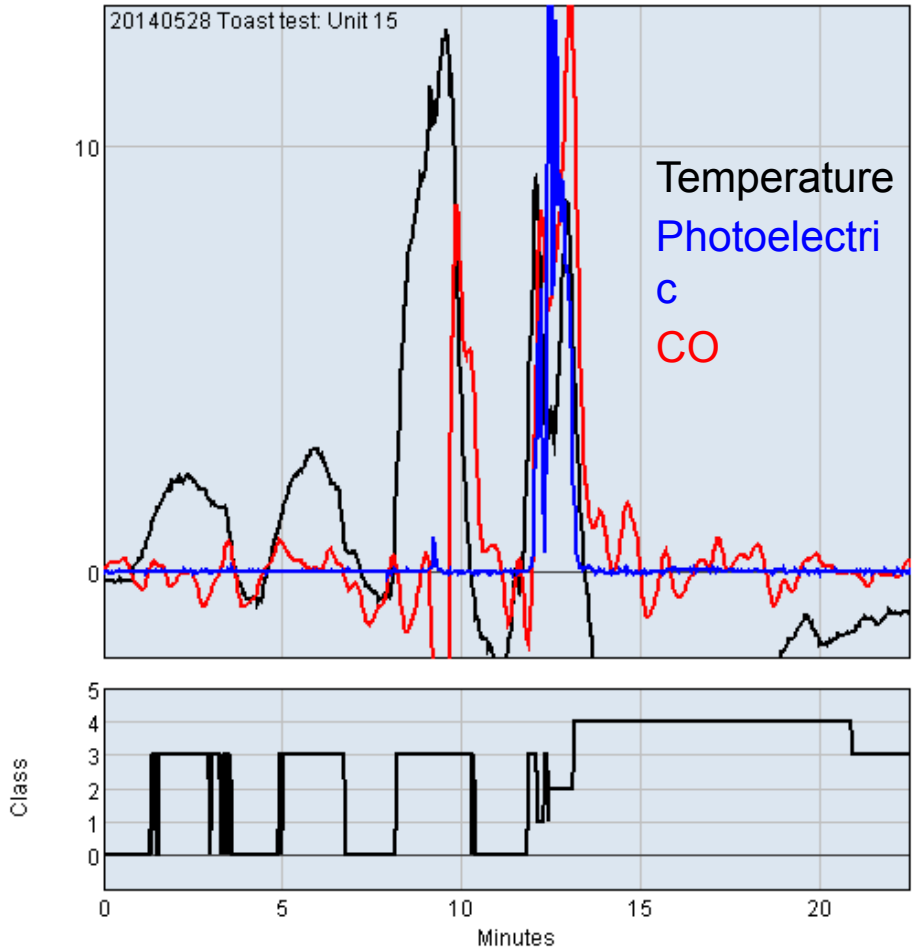
Toast tests

- Prototype with photoelectric, CO, and T sensors setup about 4 feet from toaster
- Successive cycles toasted from light to charred
- Prototype sensed nuisance until charred toast produced CO and heavy smoke
- Conventional photoelectric about 20 feet away alarmed twice during testing



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Market Opportunity

- Market is estimated at 20 million units annually or roughly $500 million
- Since the technology is adaptable for even single-sensor units at little incremental cost, none of the market is excluded
- Introduction of higher performance models are likely initially, followed by a progression of lower priced units to replace outdated designs
- Single-sensor alarms are unlikely to pass future standards
- Awareness of CO risks will help drive models that have high performance for fires and toxic hazards

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