# The Nuts and Bolts of Deploying Process-Level IDS in Industrial Control Systems

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## Industrial Control Systems (ICS)

- control industrial processes;
- typically operate on critical infrastructures.

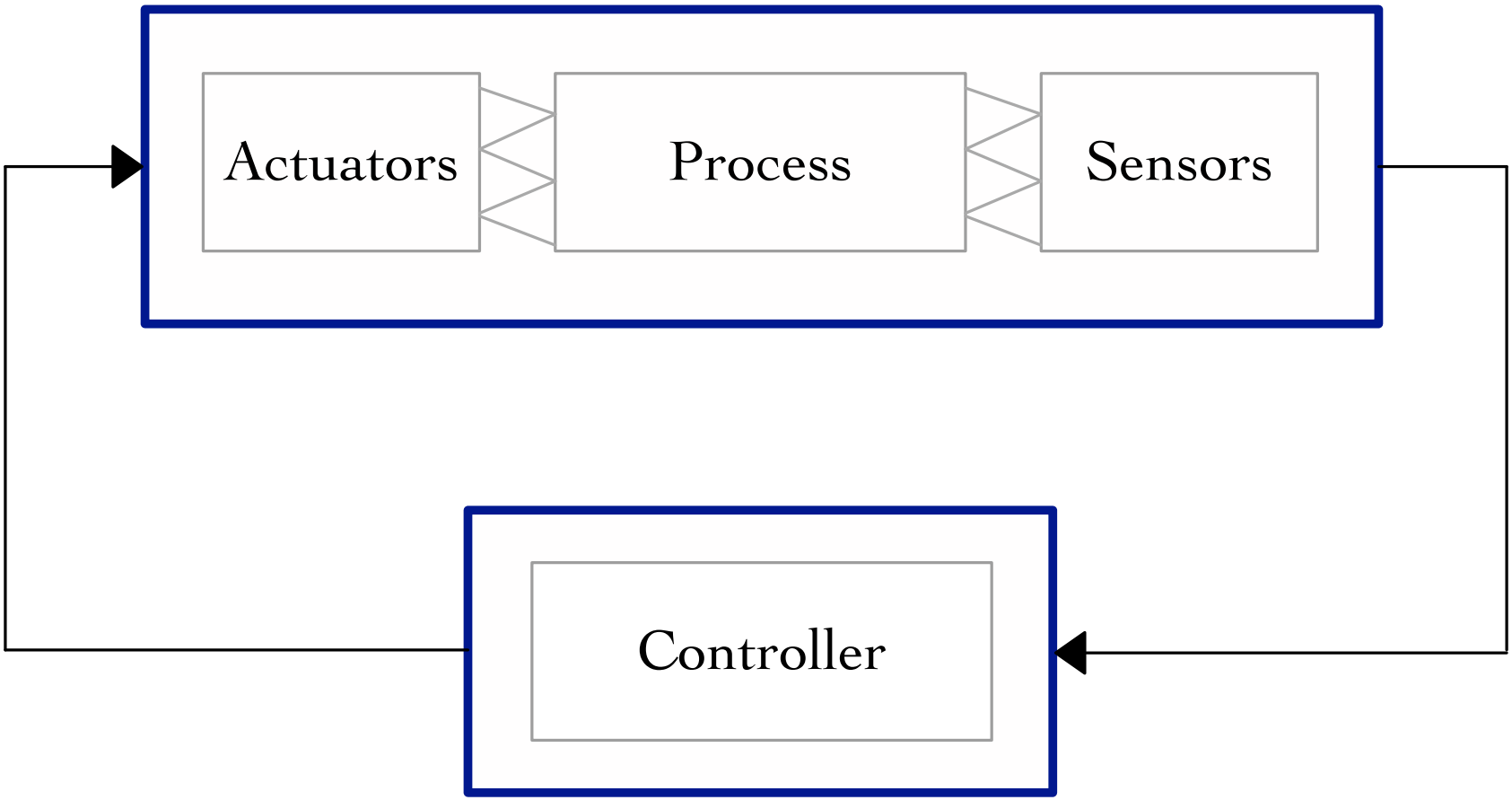
## The Problem

- Attacks on ICS are increasing.
- Successful attacks on ICS
  - can be highly rewarding for attackers;
  - may have far-reaching consequences on society at large.
- Classical IT-based security is not sufficient.

## Process-Level Attack Detection

| | |
|---|---|
| **Why?** | Because ICS combine both IT and OT technologies. |
| **What?** | Check if **physical process** deviates from **the norm**. |
| **How?** | By monitoring **process output** in real time. |

# Control Loop and Attacker Model



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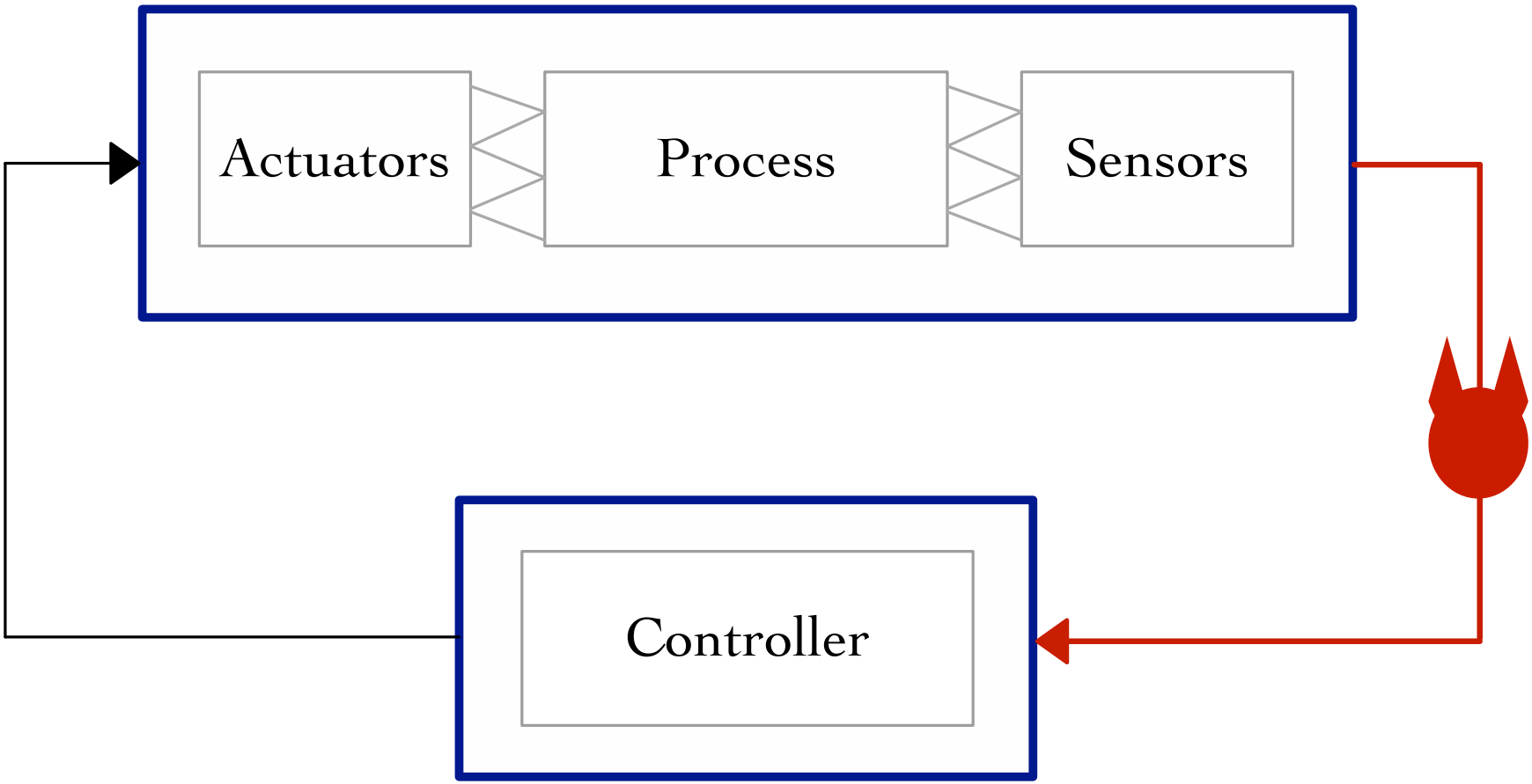

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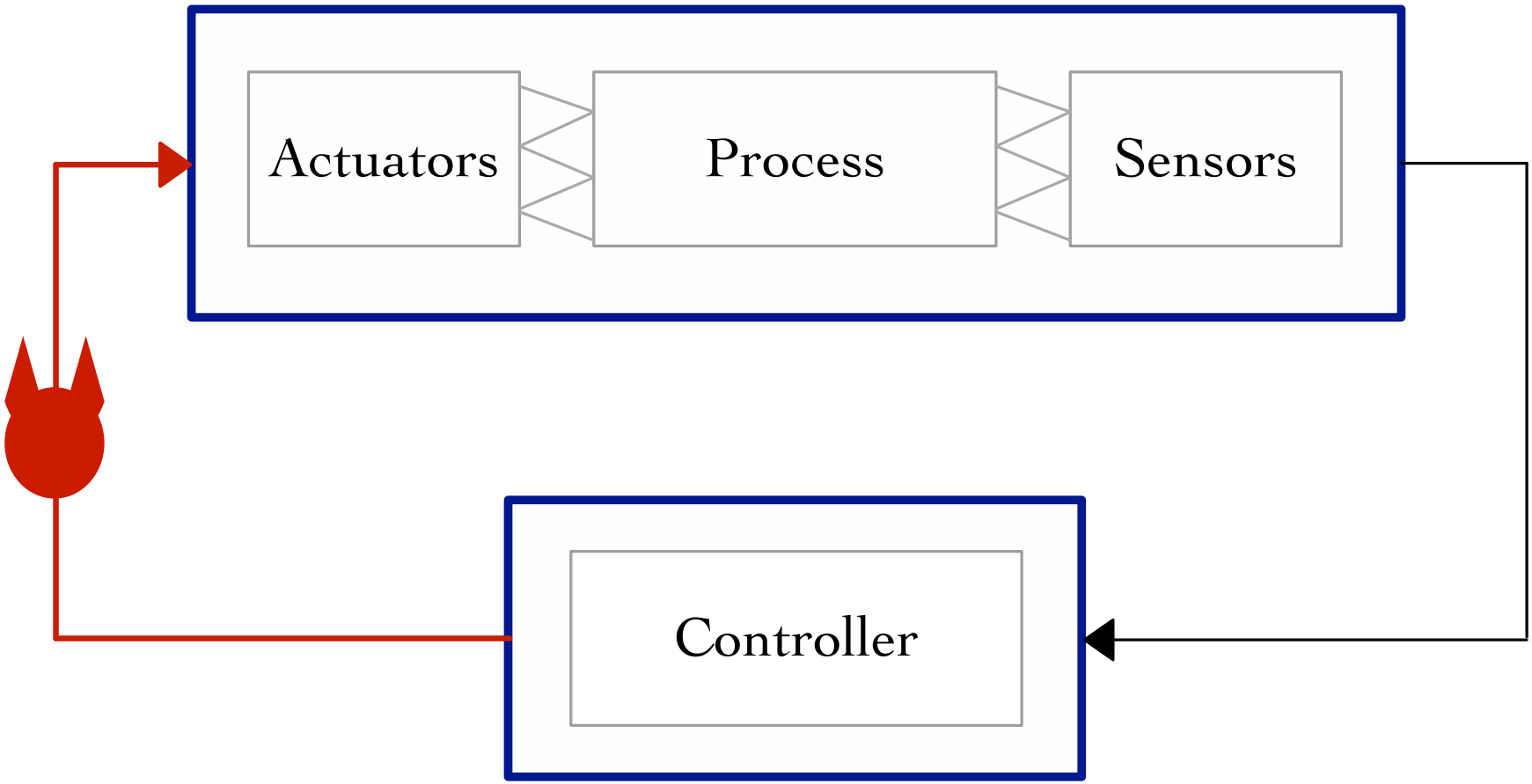

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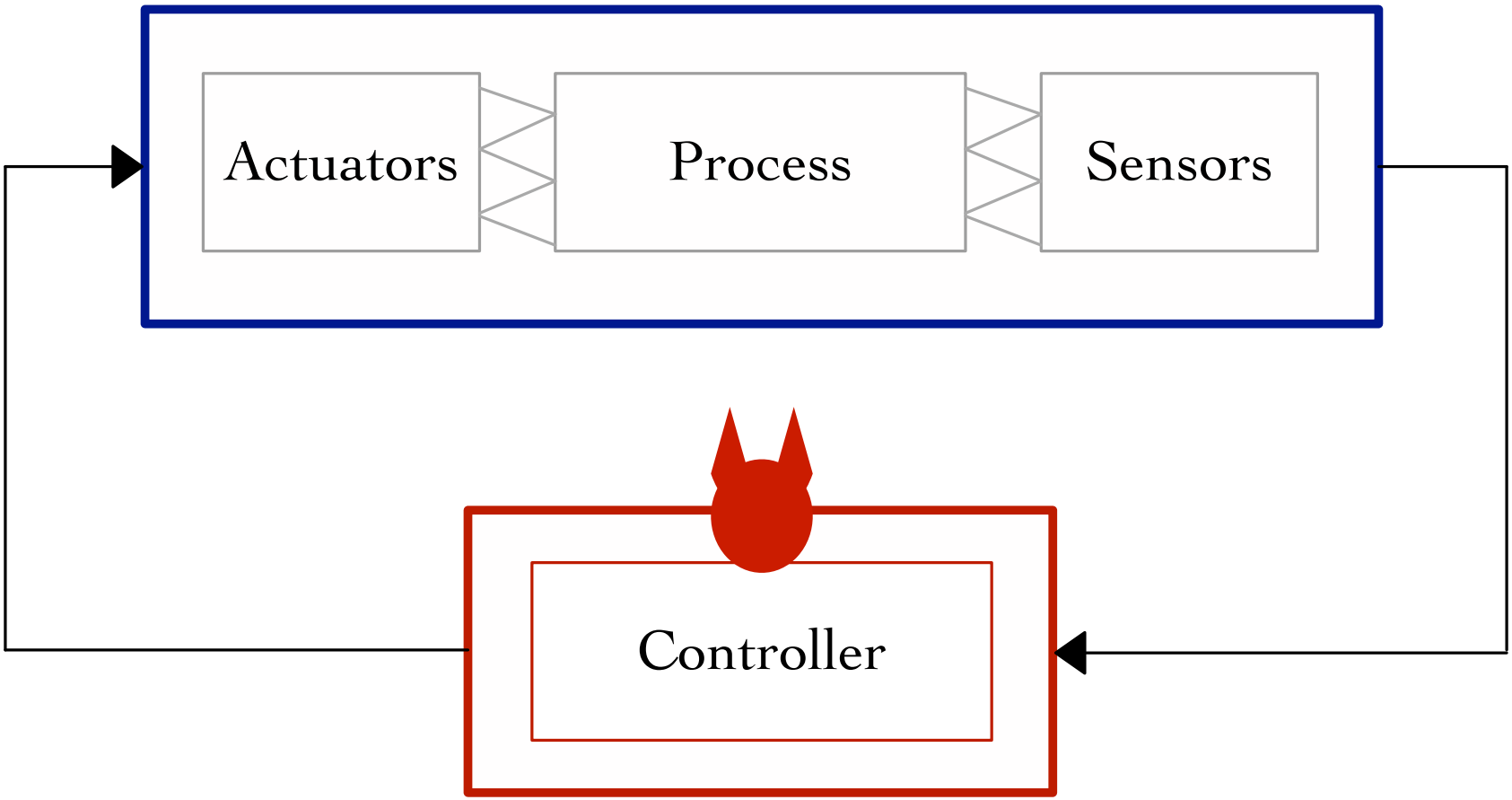

# ICS behavior is deterministic

## ICS-Specific Features

- Controllers (e.g., PLCs) operate in a **cyclic** manner.
- Signals repeat $\Rightarrow$ level of **determinism** is relatively high.
- Normal behavior can be **learned** or **modeled**.

# ICS behavior is deterministic

## ICS-Specific Features

- Controllers (e.g., PLCs) operate in a **cyclic** manner.
- **Regularity of ICS behavior enables data-driven approaches.**
- Normal behavior can be **learned** or **modeled**.

## Classical Approach

**Build** a model of the physical process

↓

Use the model to **predict** future system behavior

↓

Monitor residuals: Is $|$**observed** $-$ **predicted**$|$ too large?

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Urbina, David I., et al. "Limiting the Impact of Stealthy Attacks on Industrial Control Systems." 2016 ACM Conference on Computer and Communications Security.

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*Solving a more general problem as an intermediate step!*

↓

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## PASAD

1. solves an easier problem;
2. requires limited knowledge of system dynamics;
3. is capable of detecting subtle changes in system behavior.

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2. requires limited knowledge of system dynamics:

- It is entirely data-driven.
- Uses only **raw** sensor readings.
- It is model-free.

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# PASAD

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**PASAD is specification-agnostic.**
**Applicable to various systems.**

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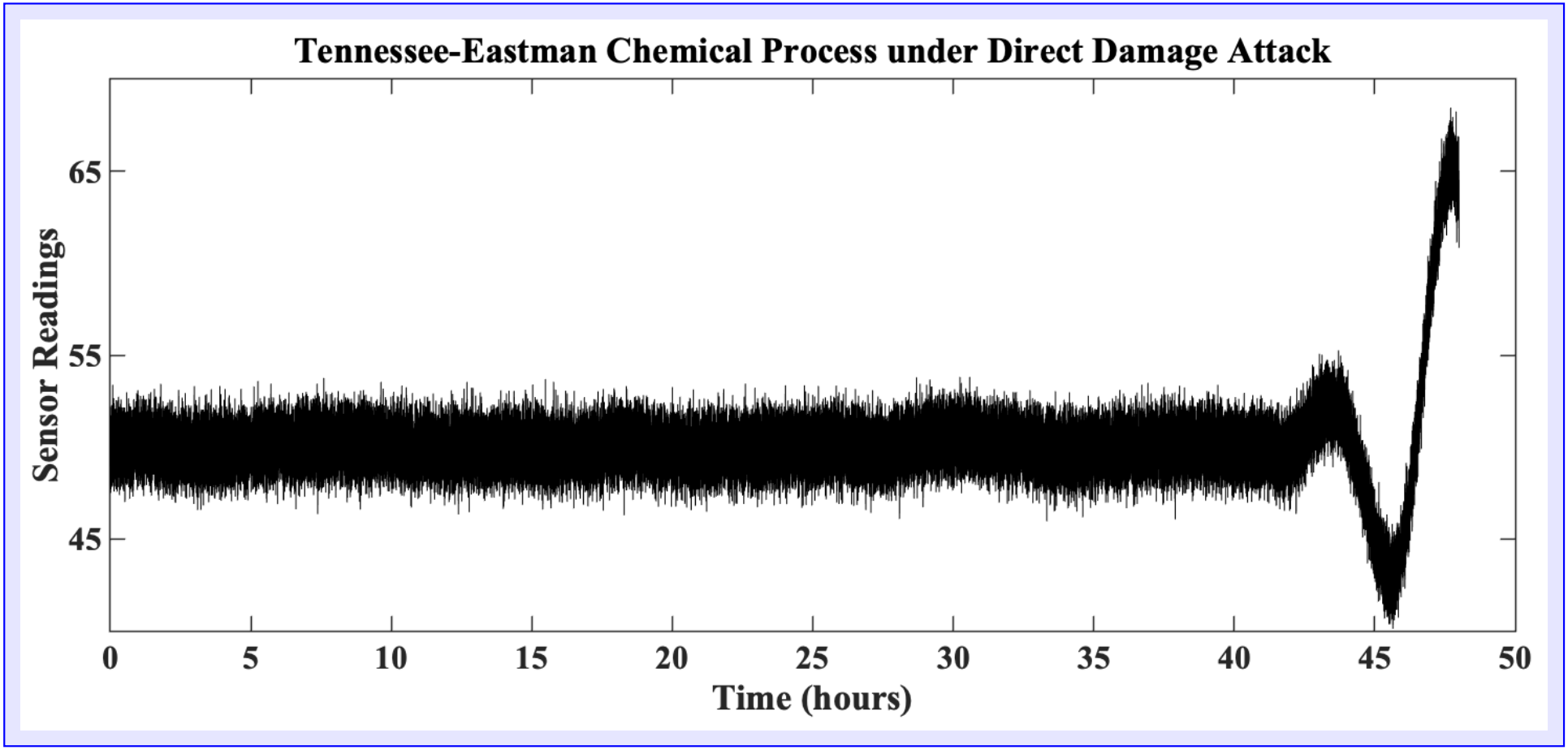

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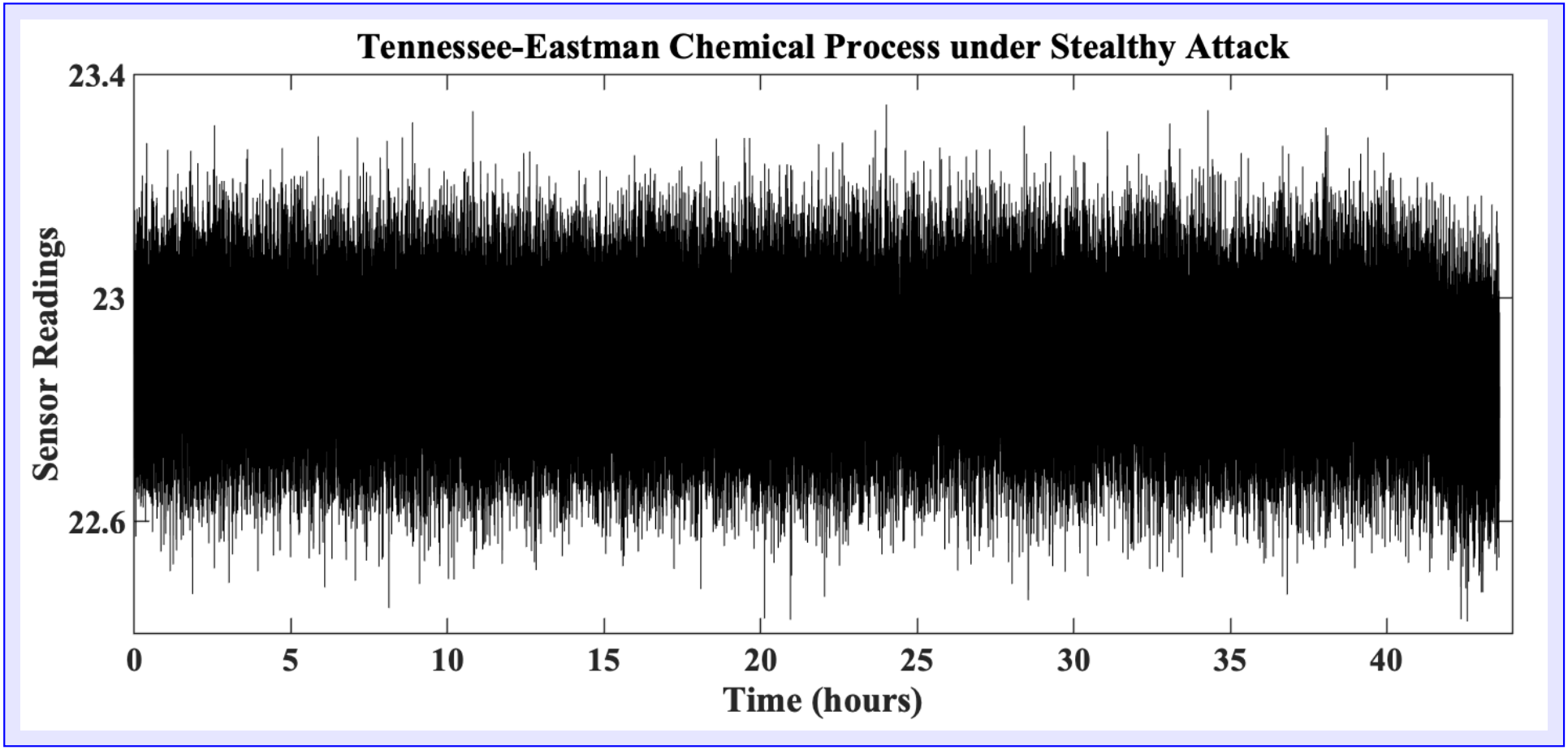

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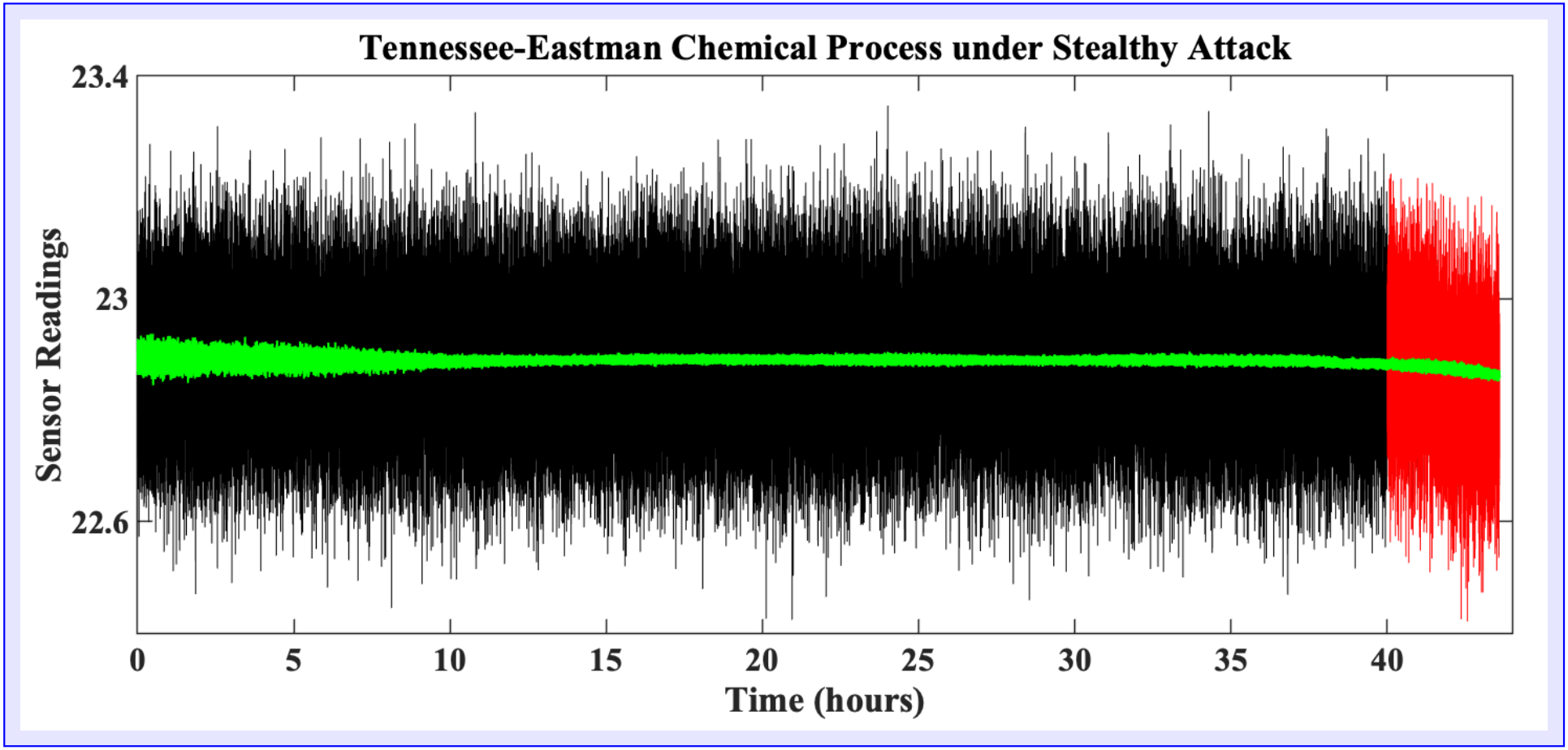

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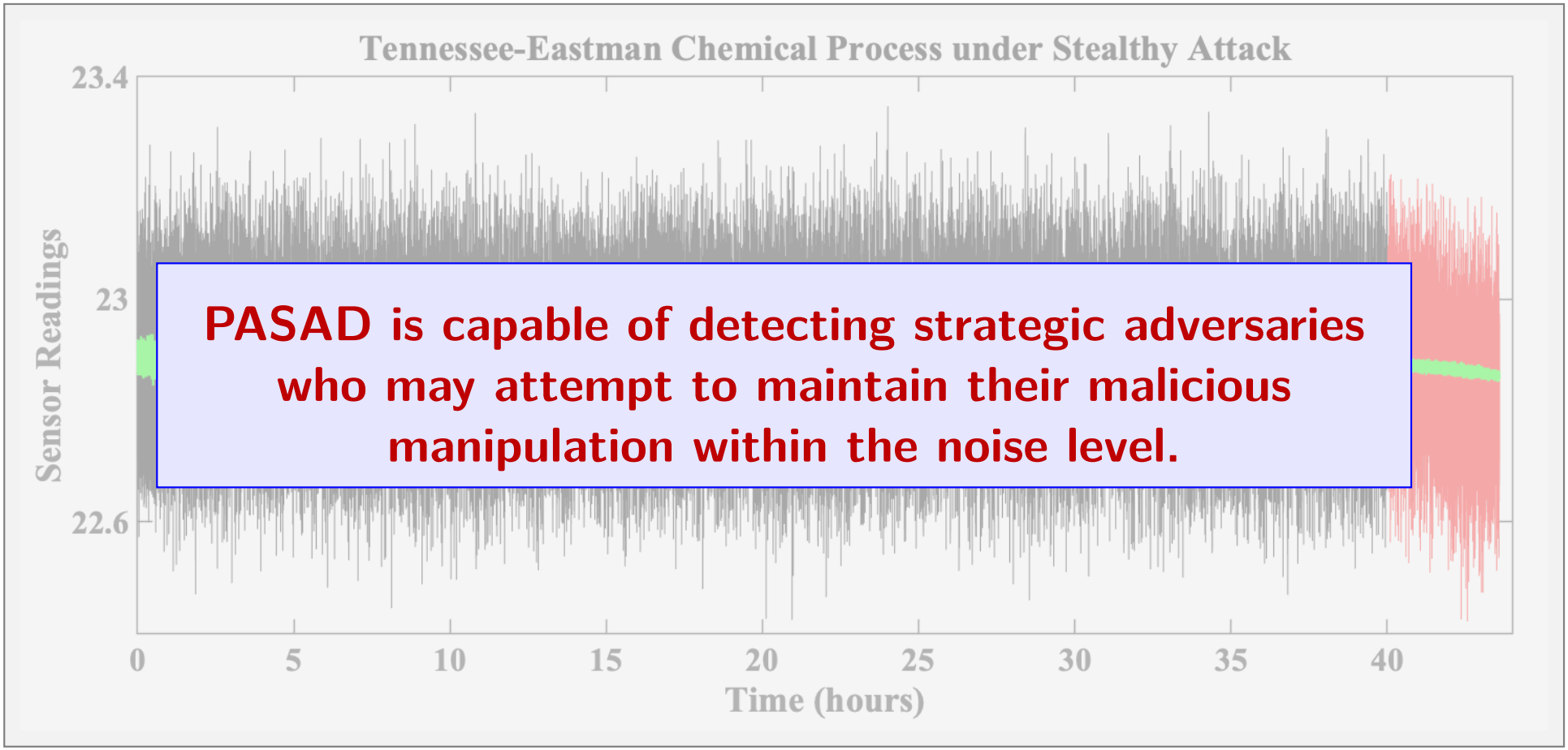

# PASAD — Process-Aware Stealth-Attack Detection

**Rationale:** Detect attacks on ICS by monitoring sensor measurements for unusual behavior.

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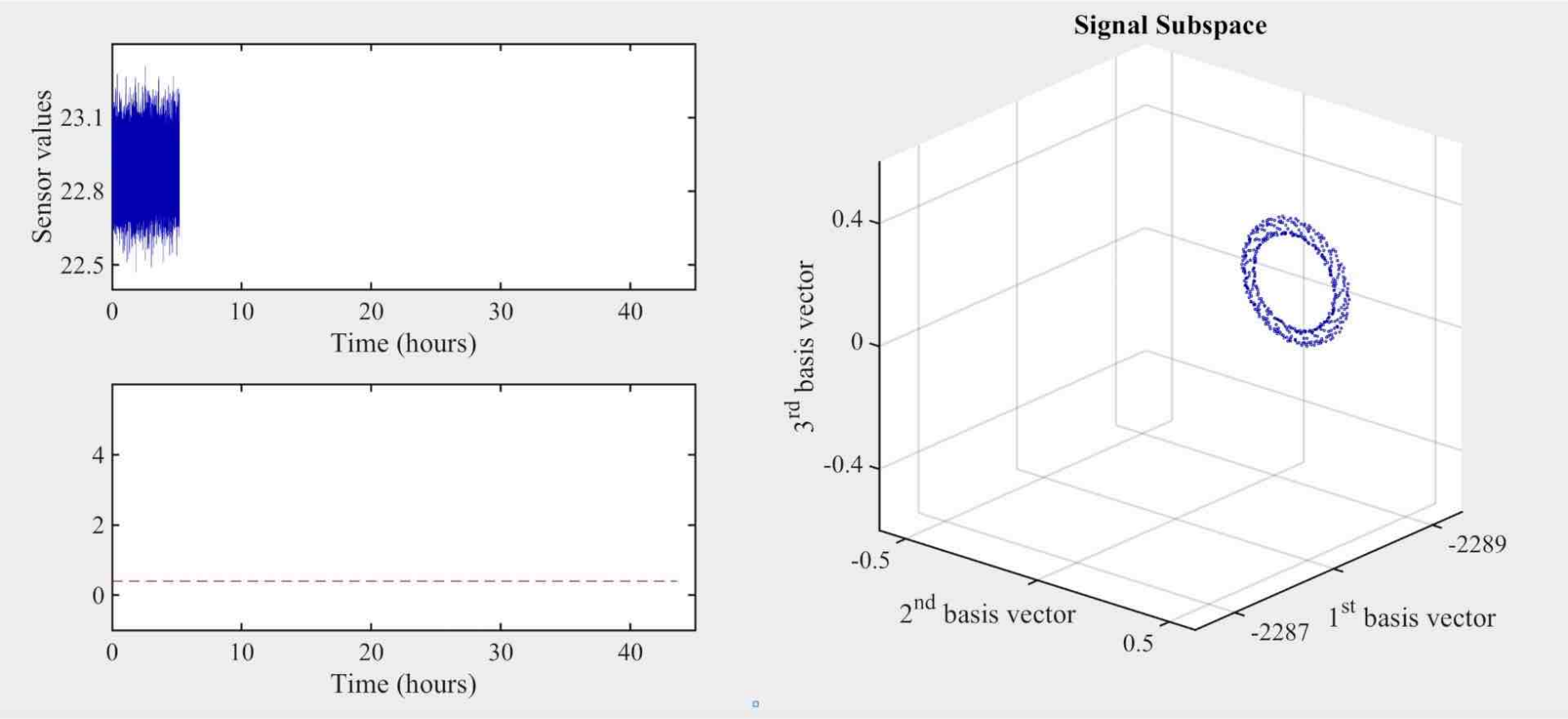
- Construct *Signal Subspace* and project training vectors.
- Compute centroid of the cluster formed by training vectors.

**Detection Phase:** **Track distance from the centroid**

- Project most recent measurement vector onto the subspace.
- Compute a *departure score*: distance from the centroid.
- Raise an alarm if a certain threshold is crossed.

# Validation — Visualizing the Departure

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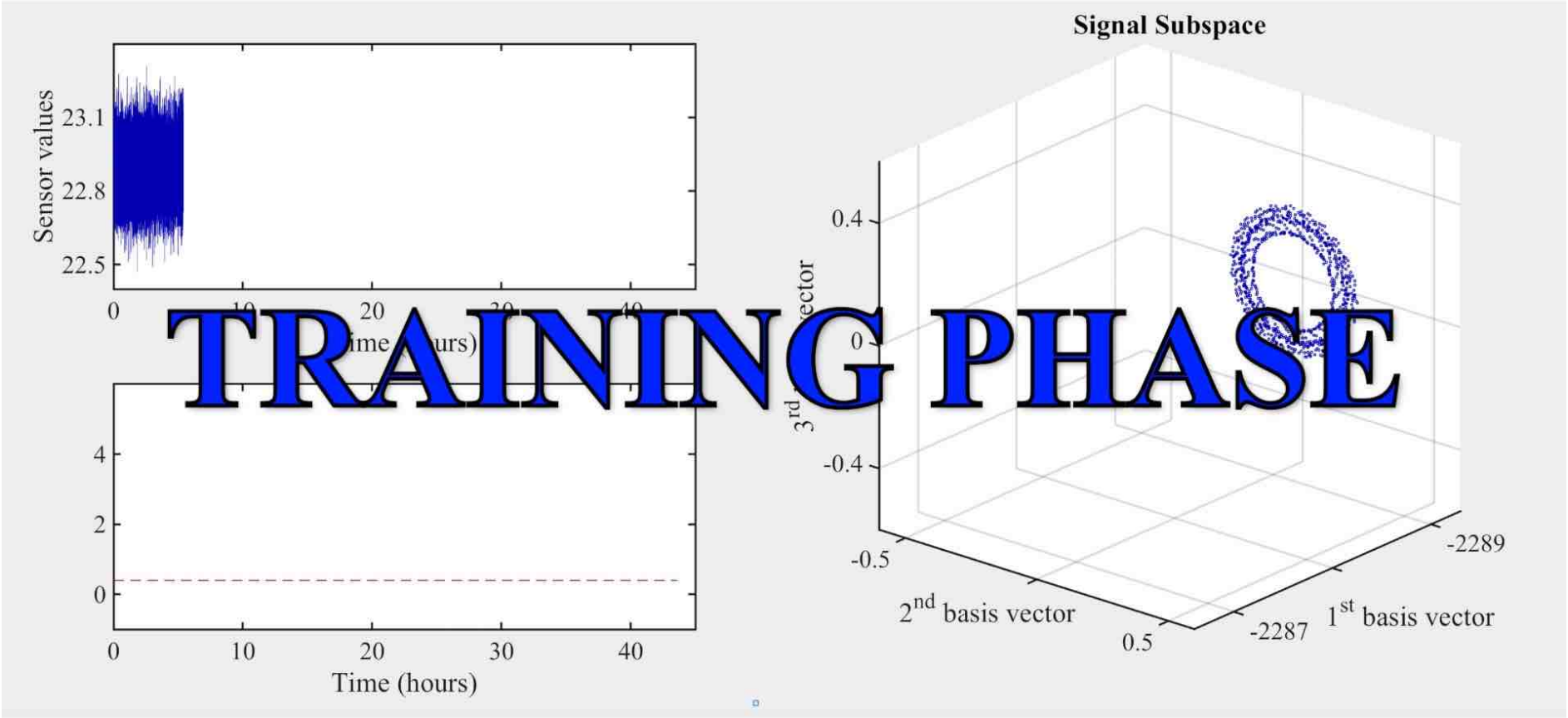


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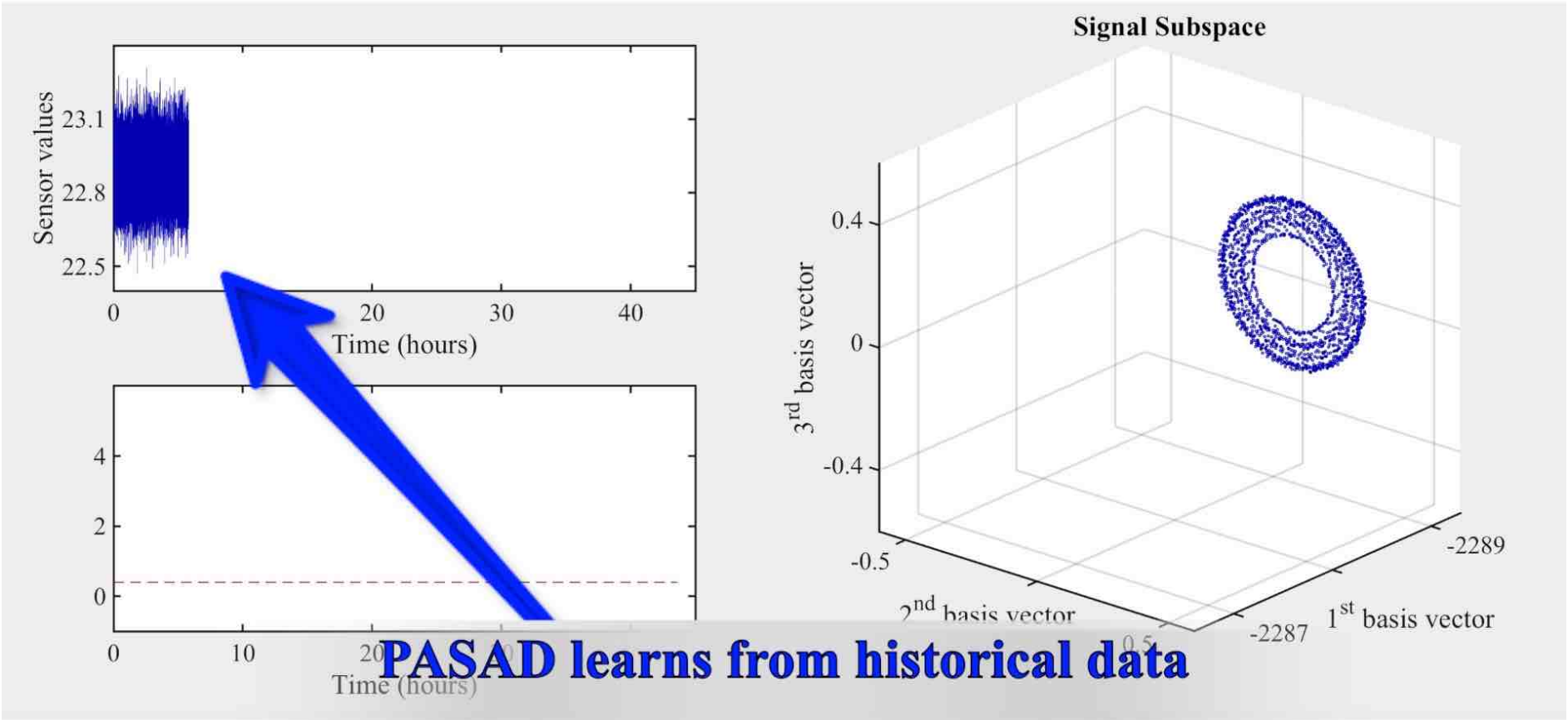


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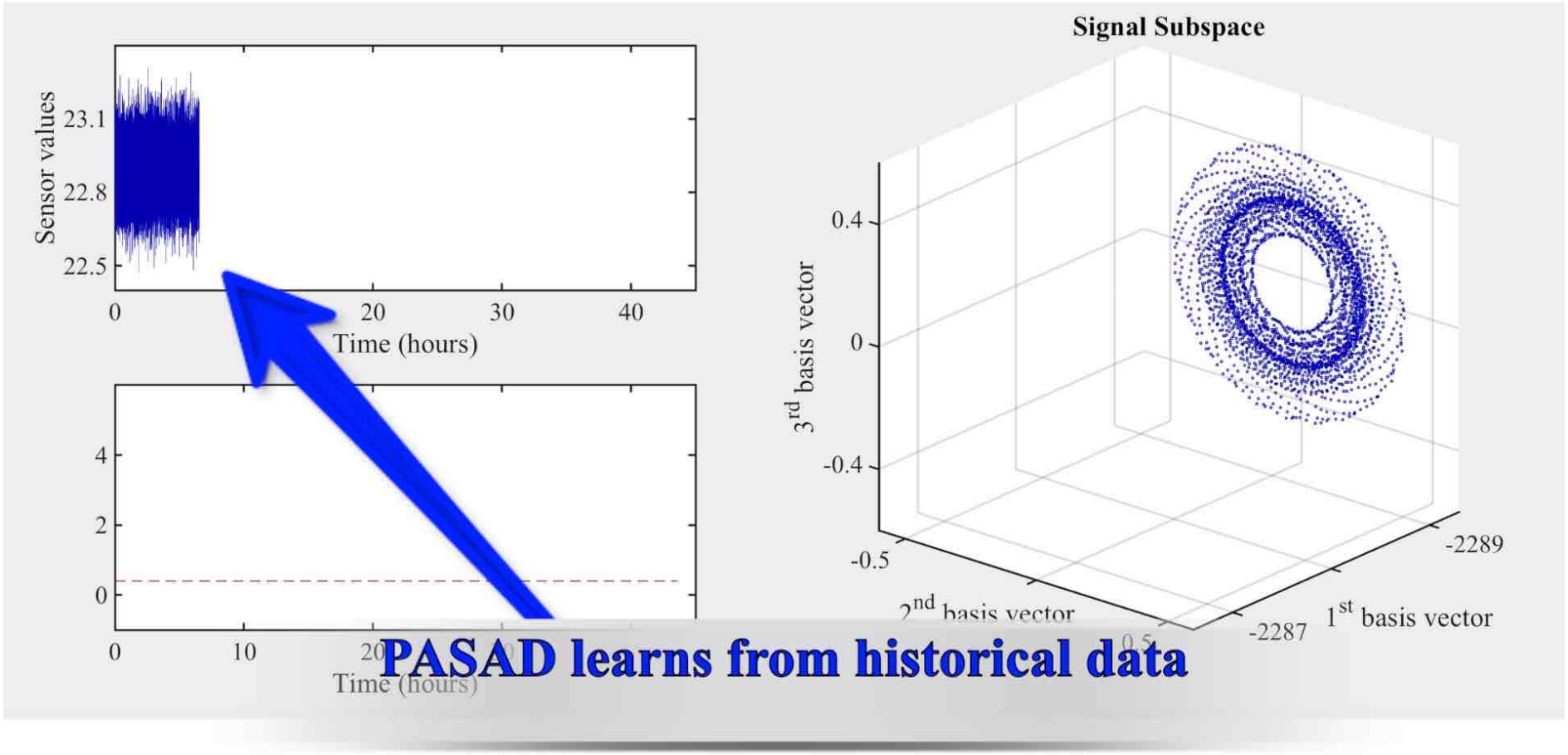


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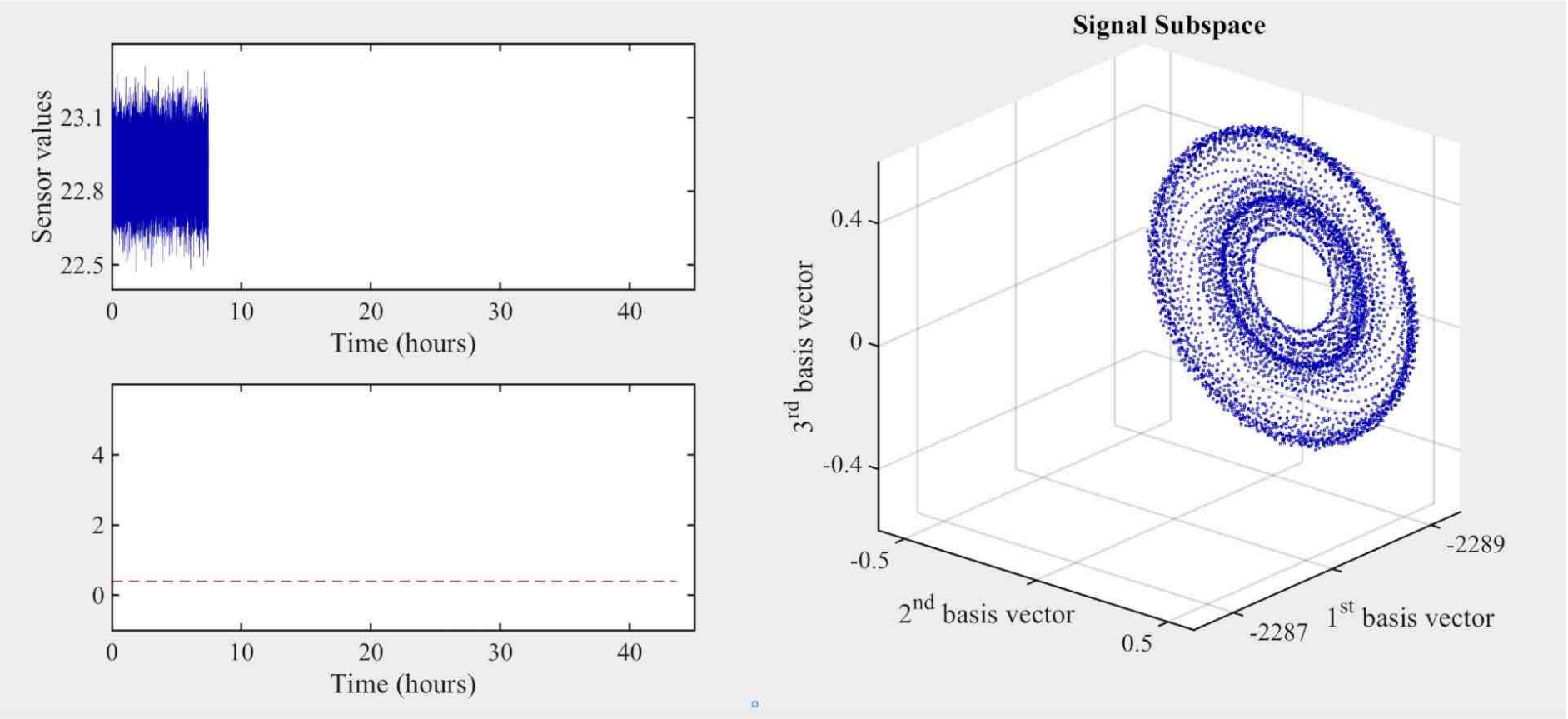


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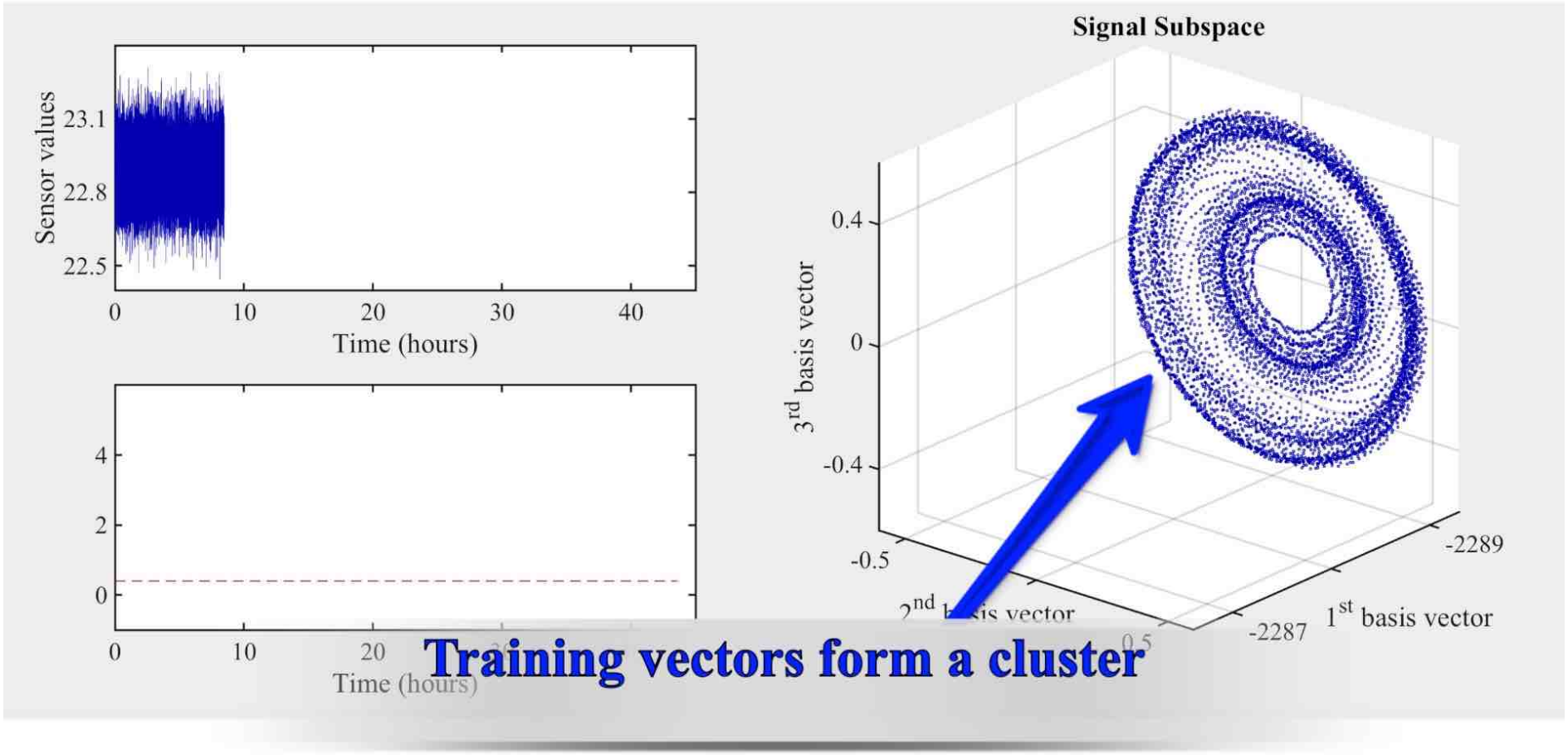


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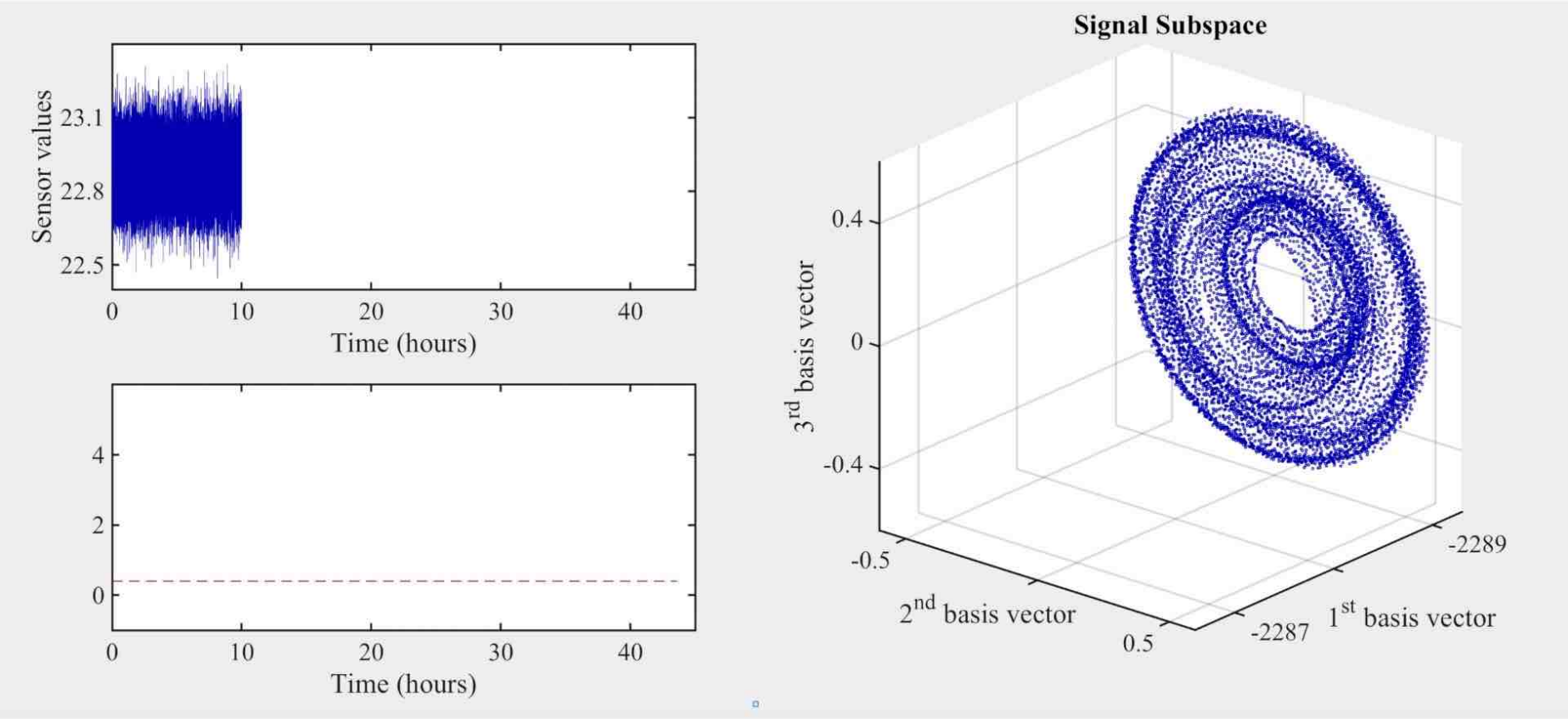


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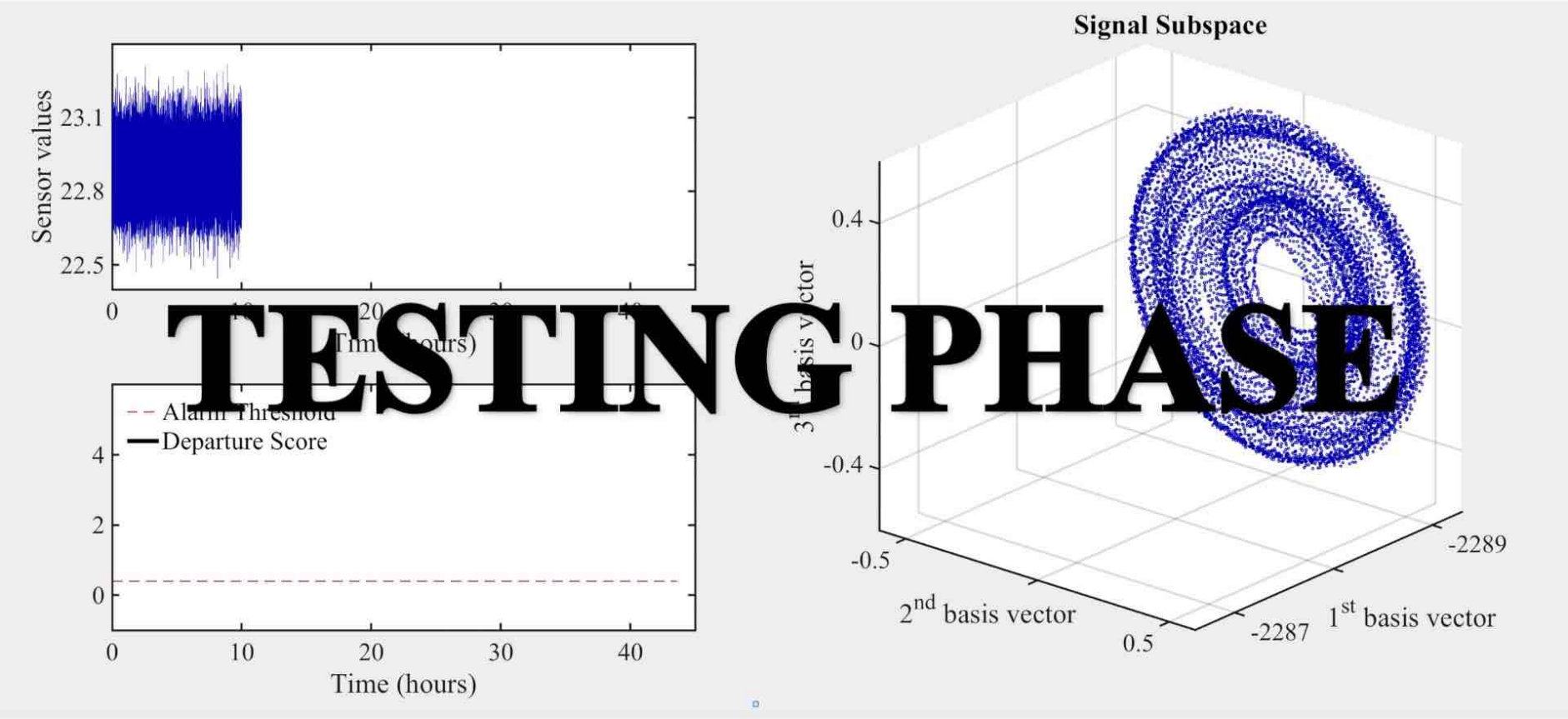


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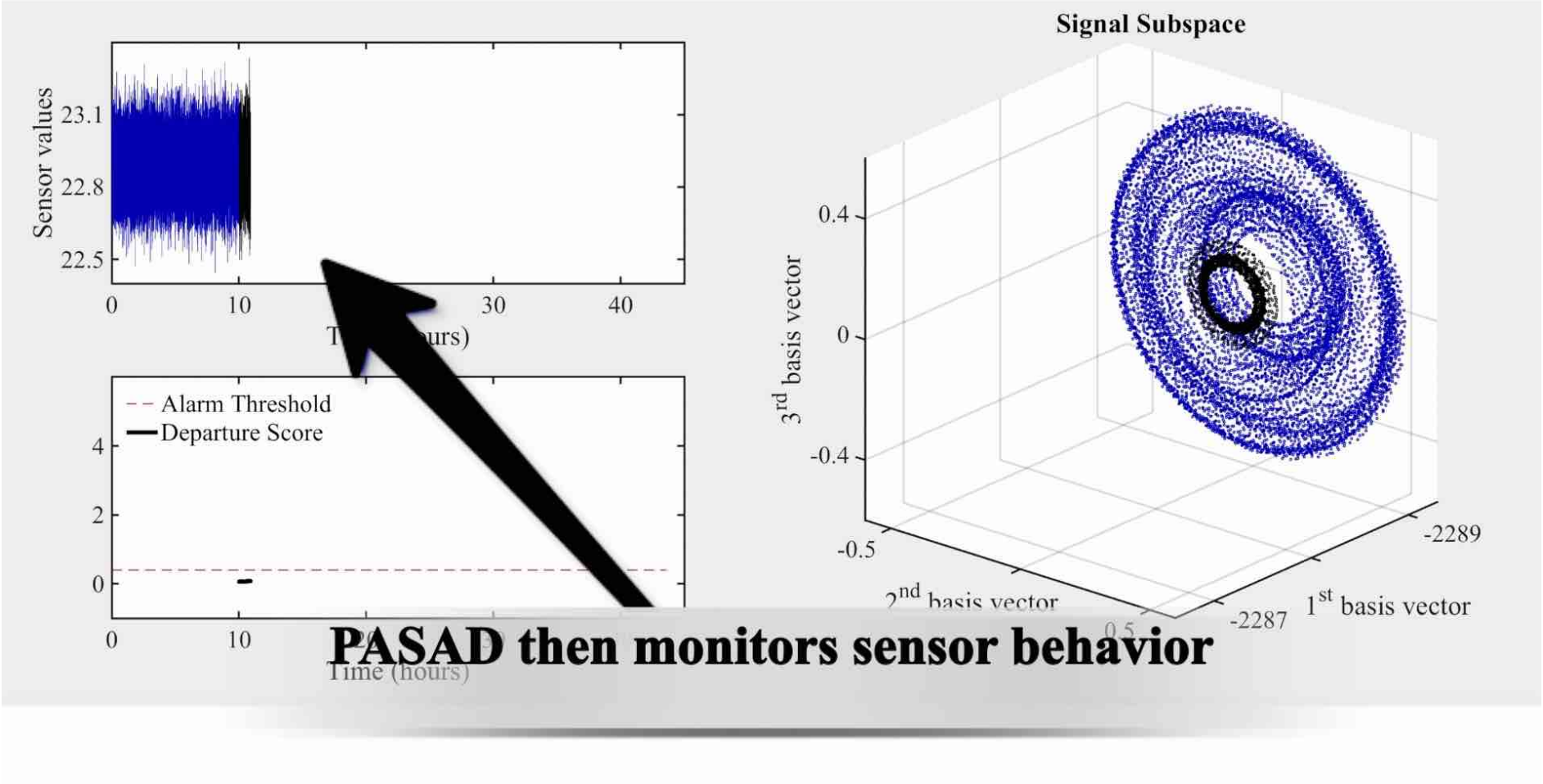


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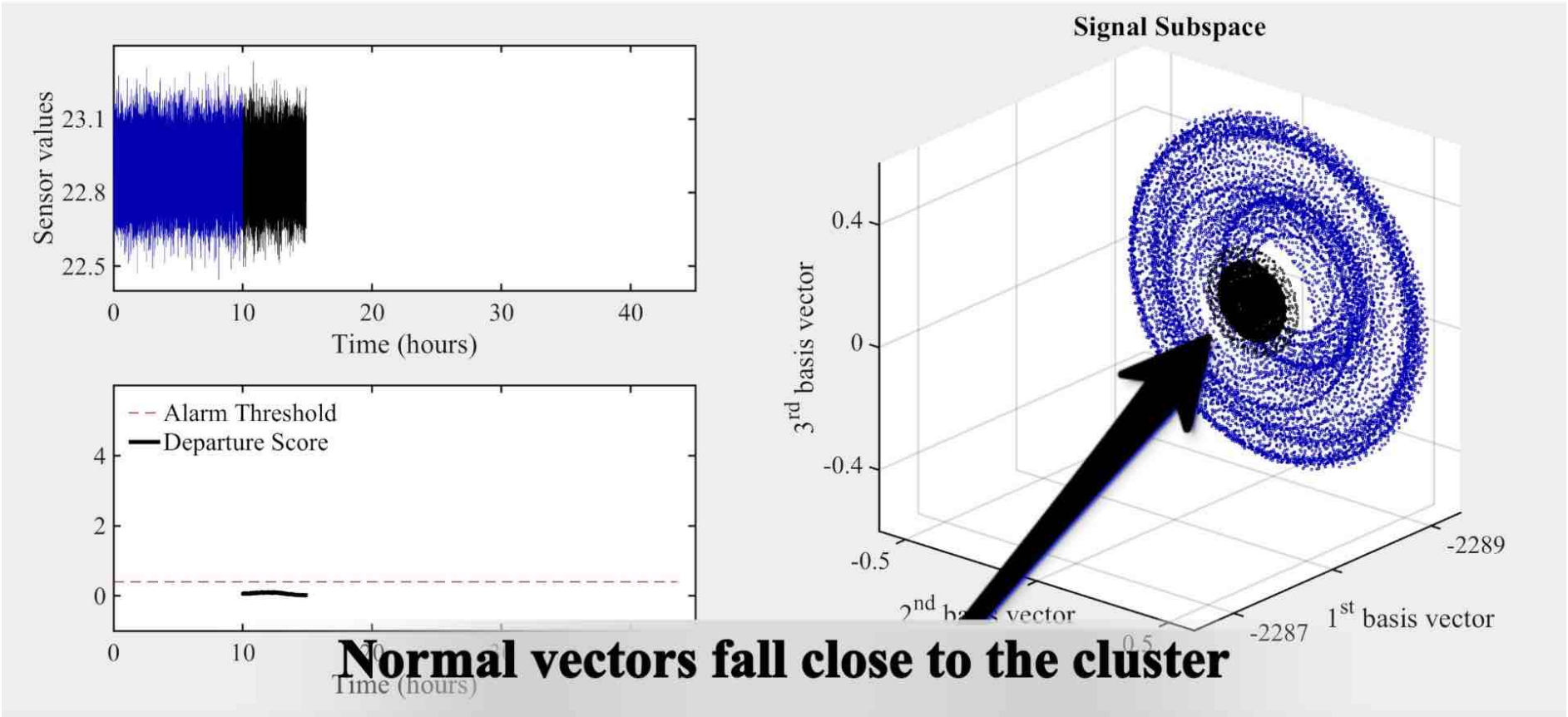


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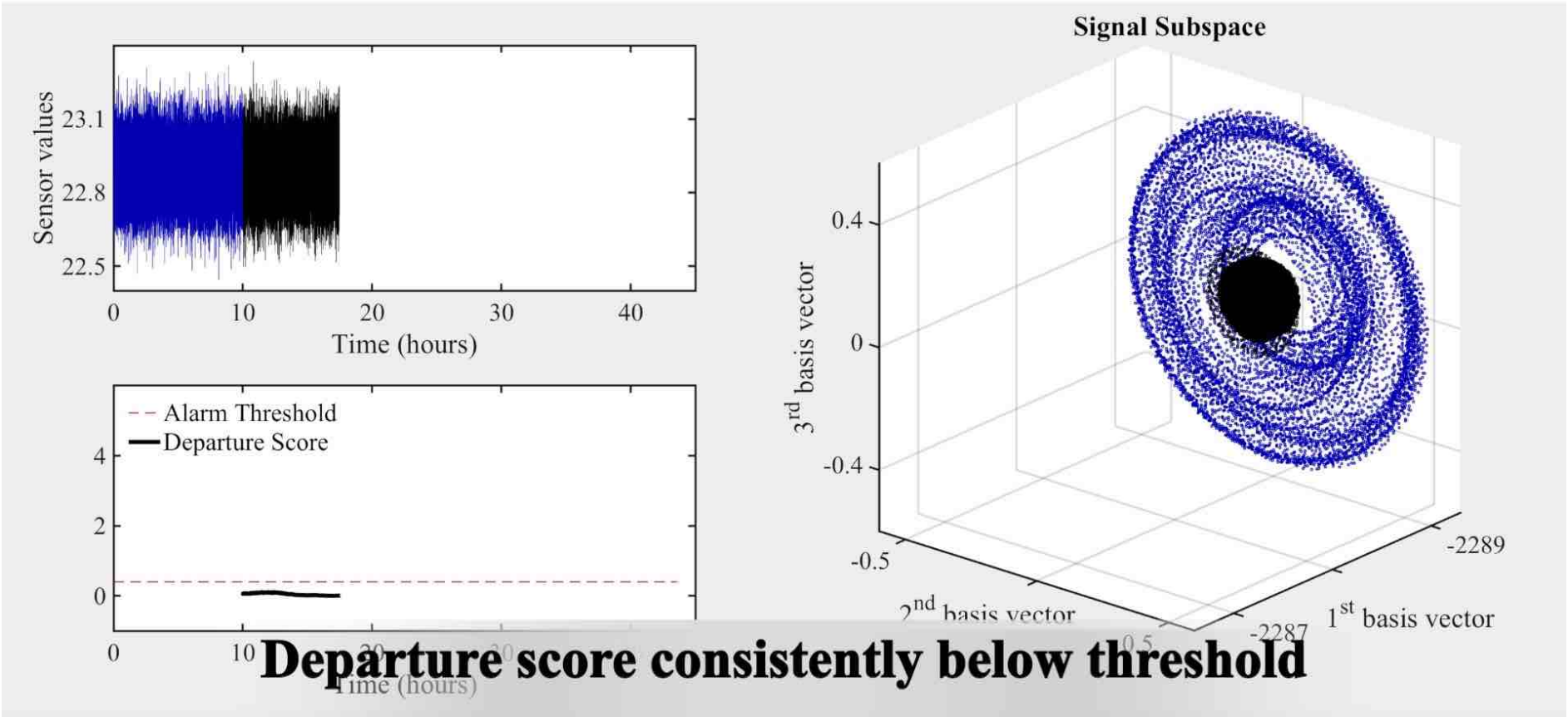


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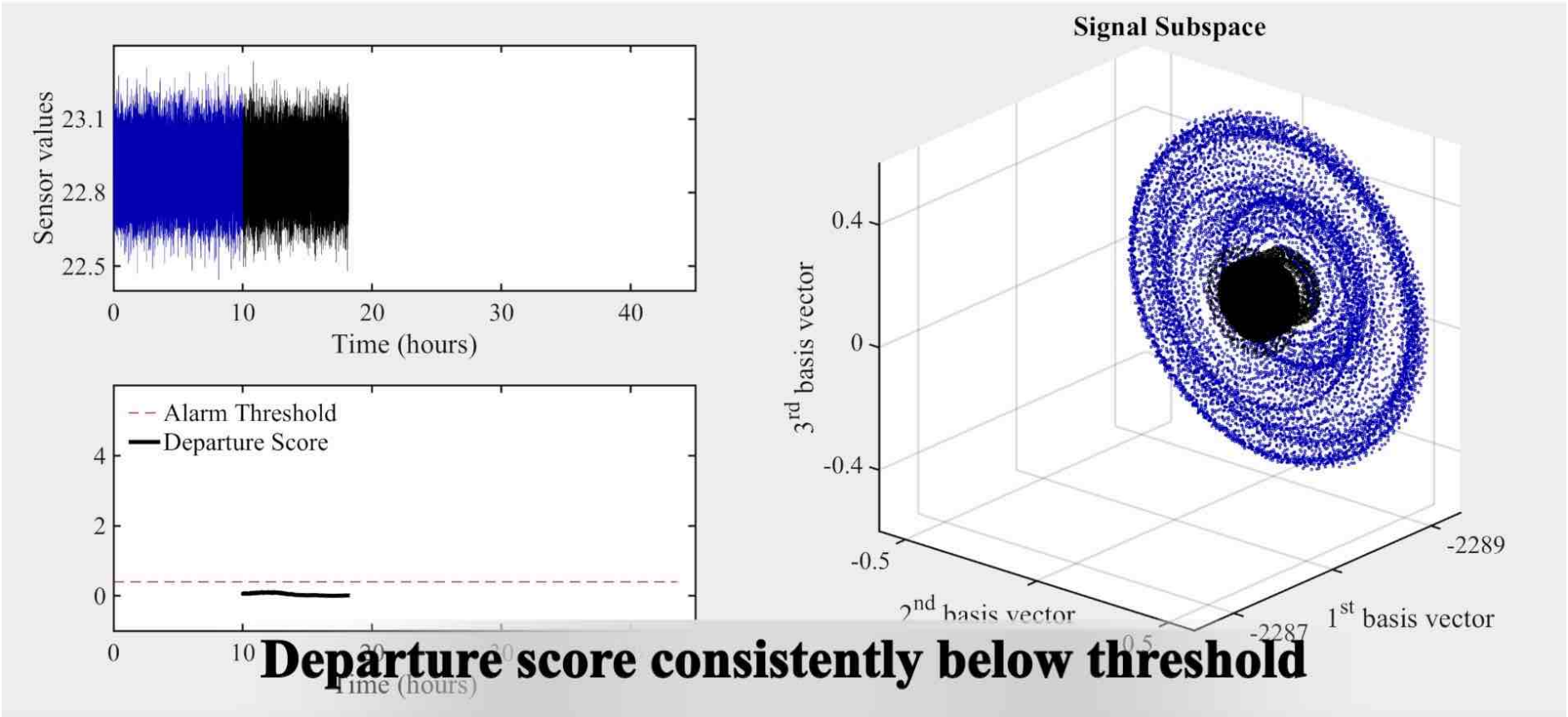


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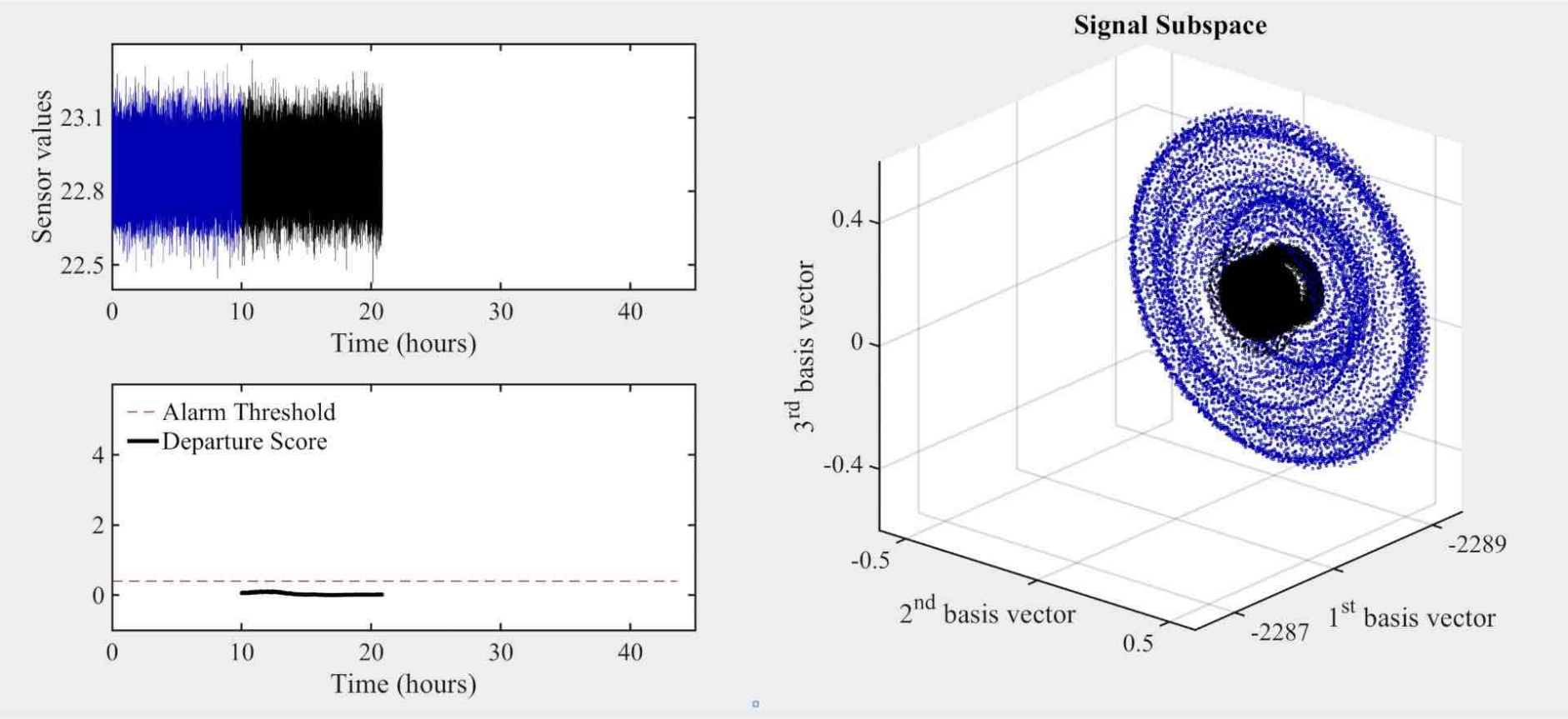


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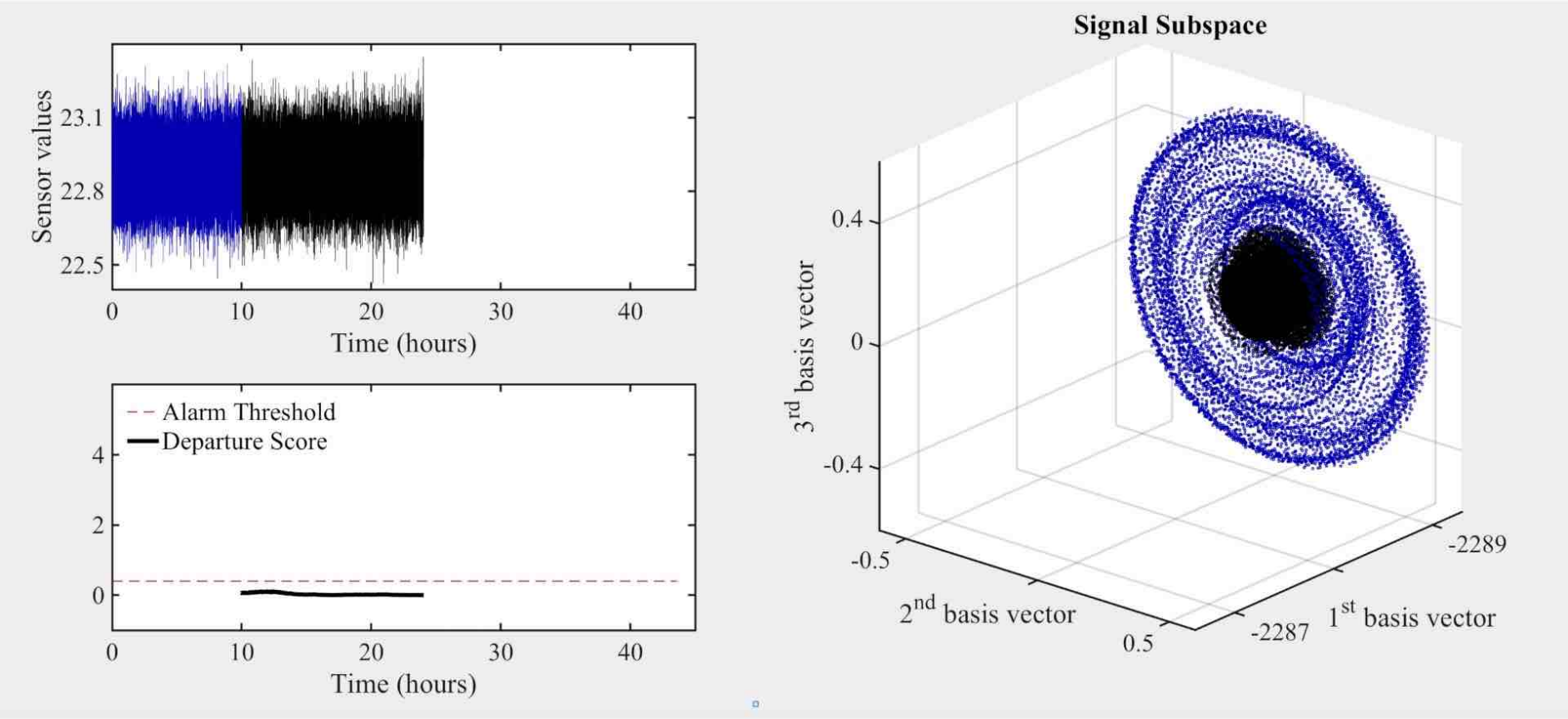


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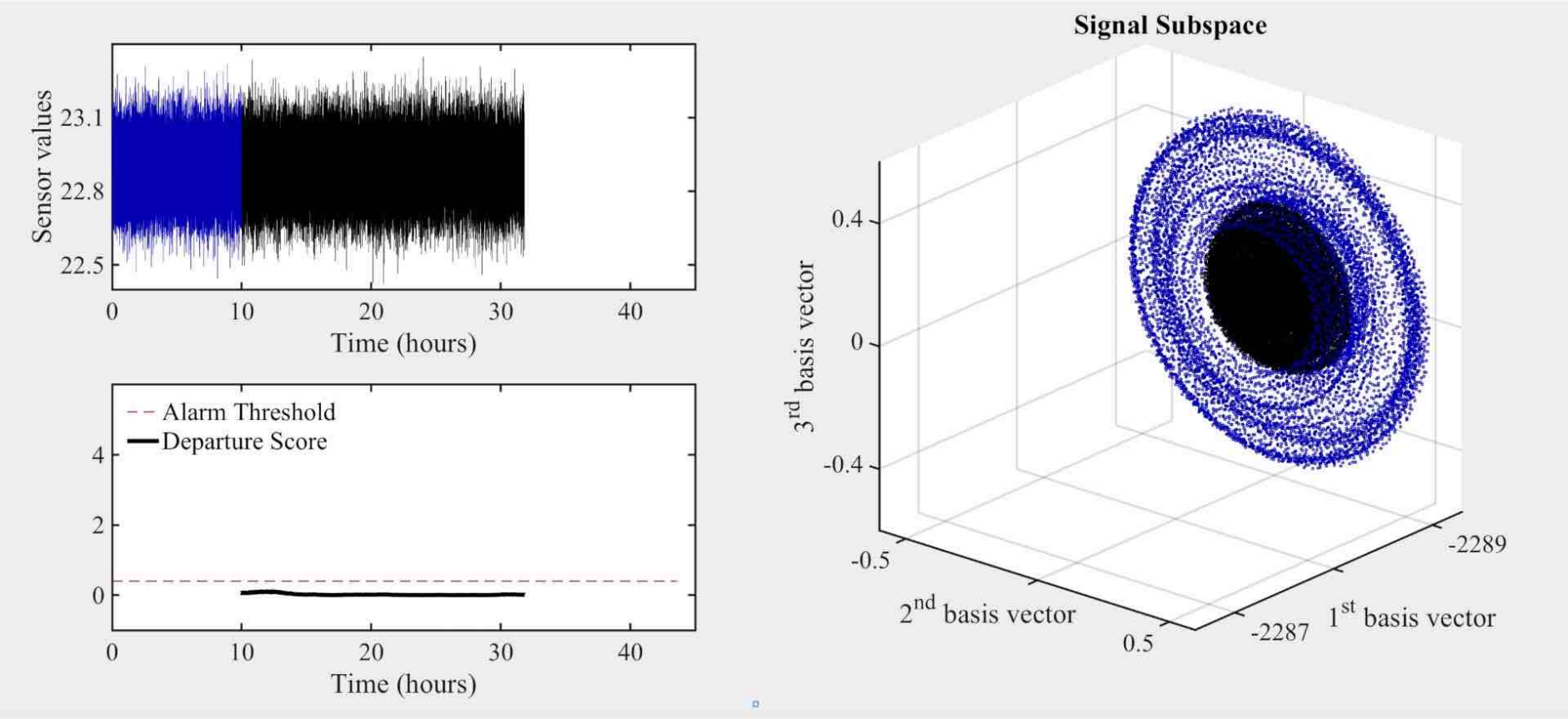


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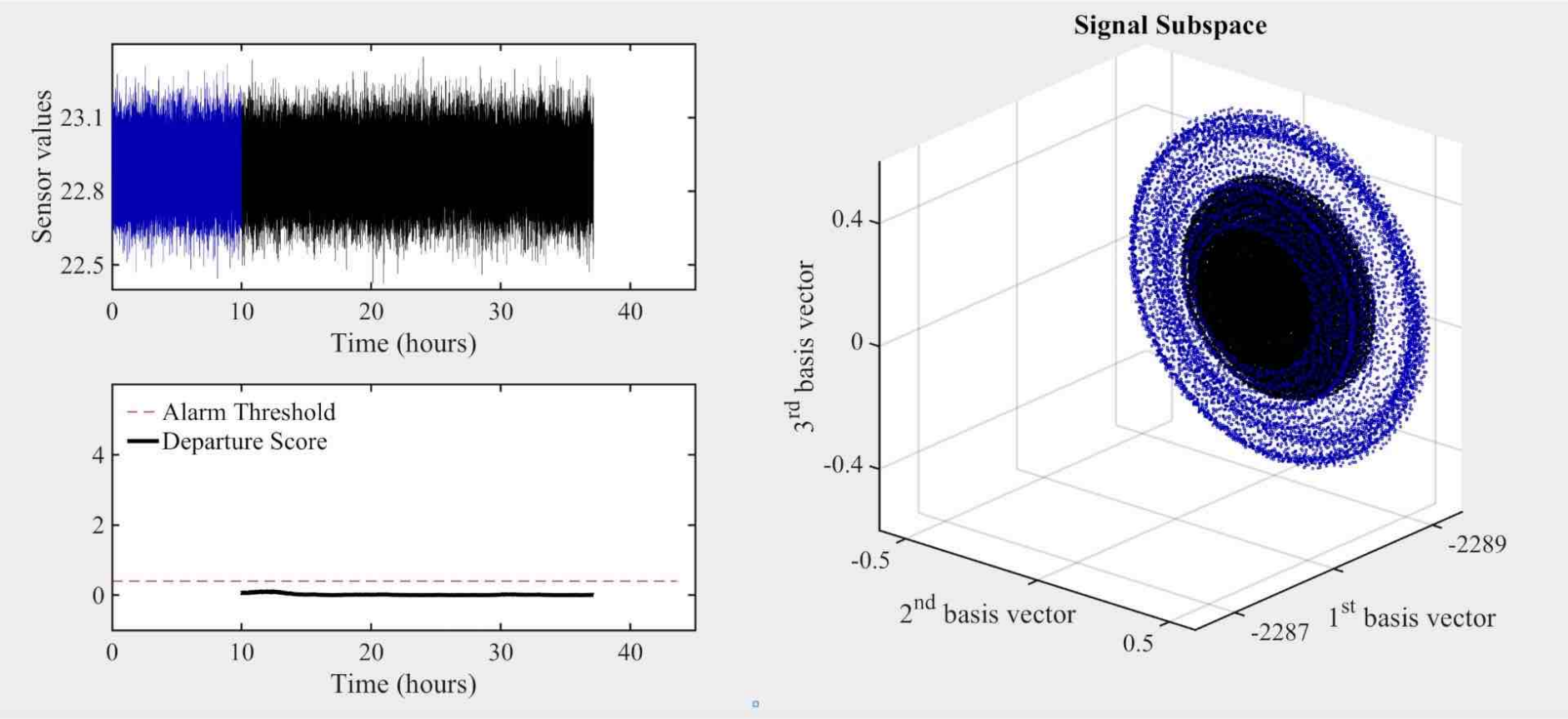


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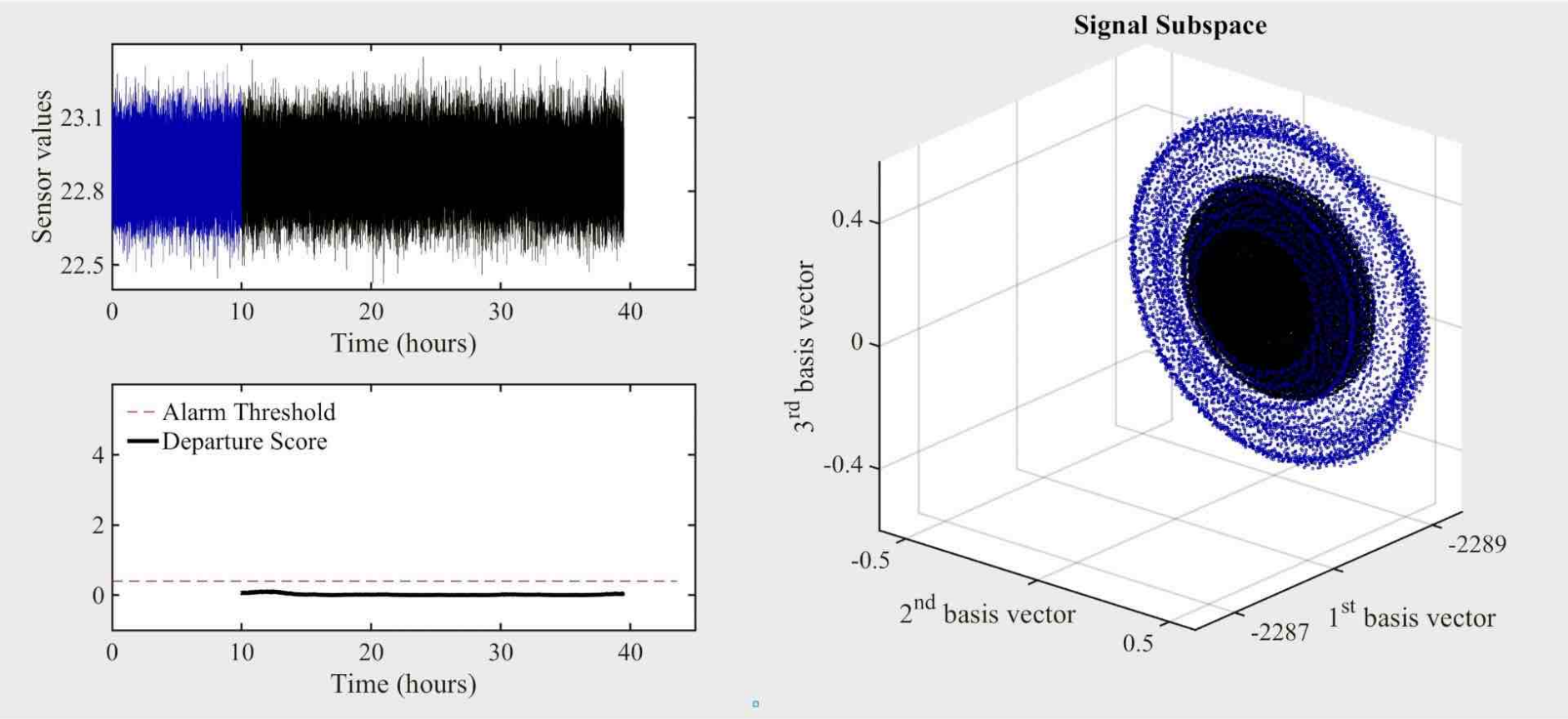


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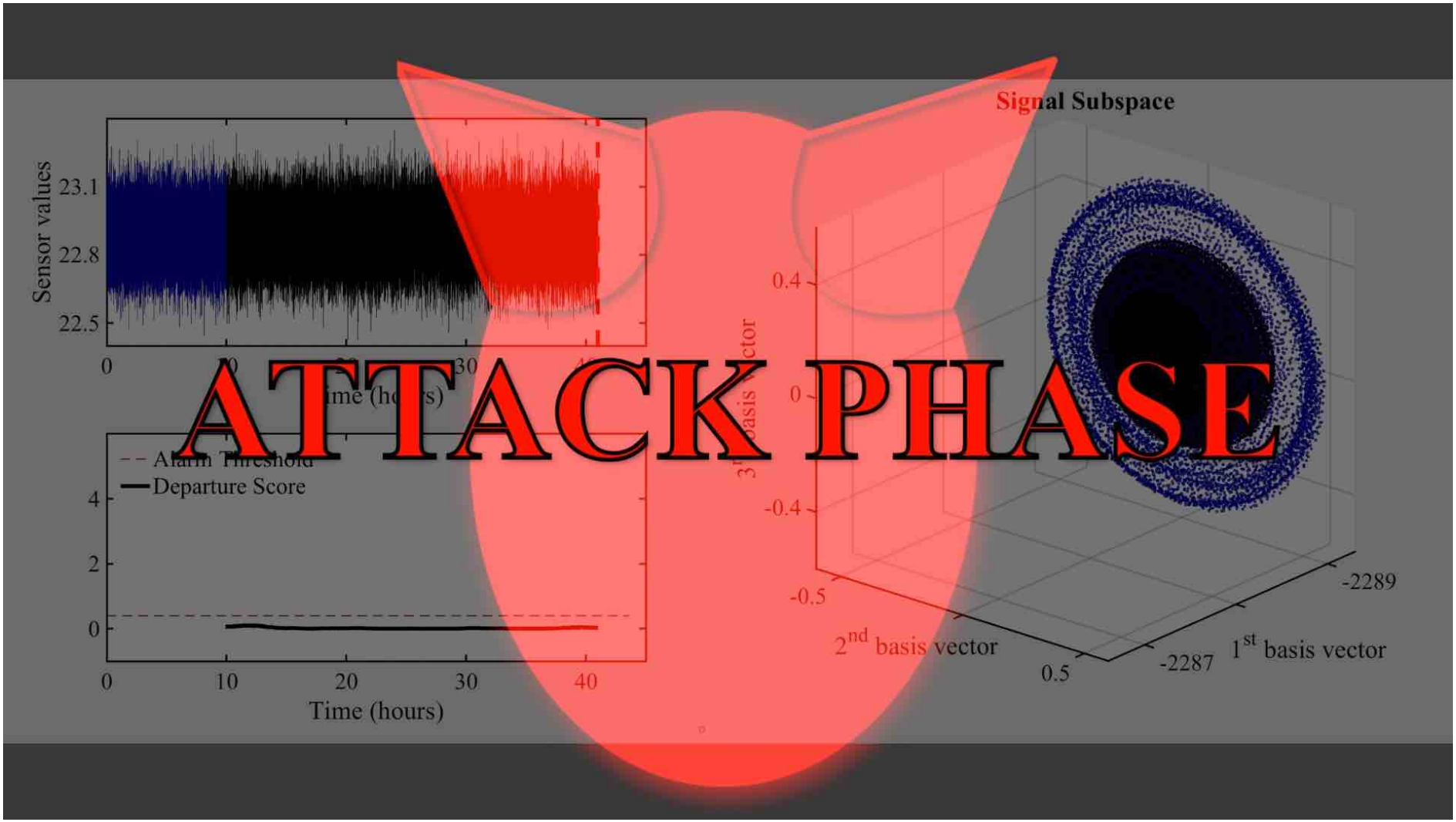


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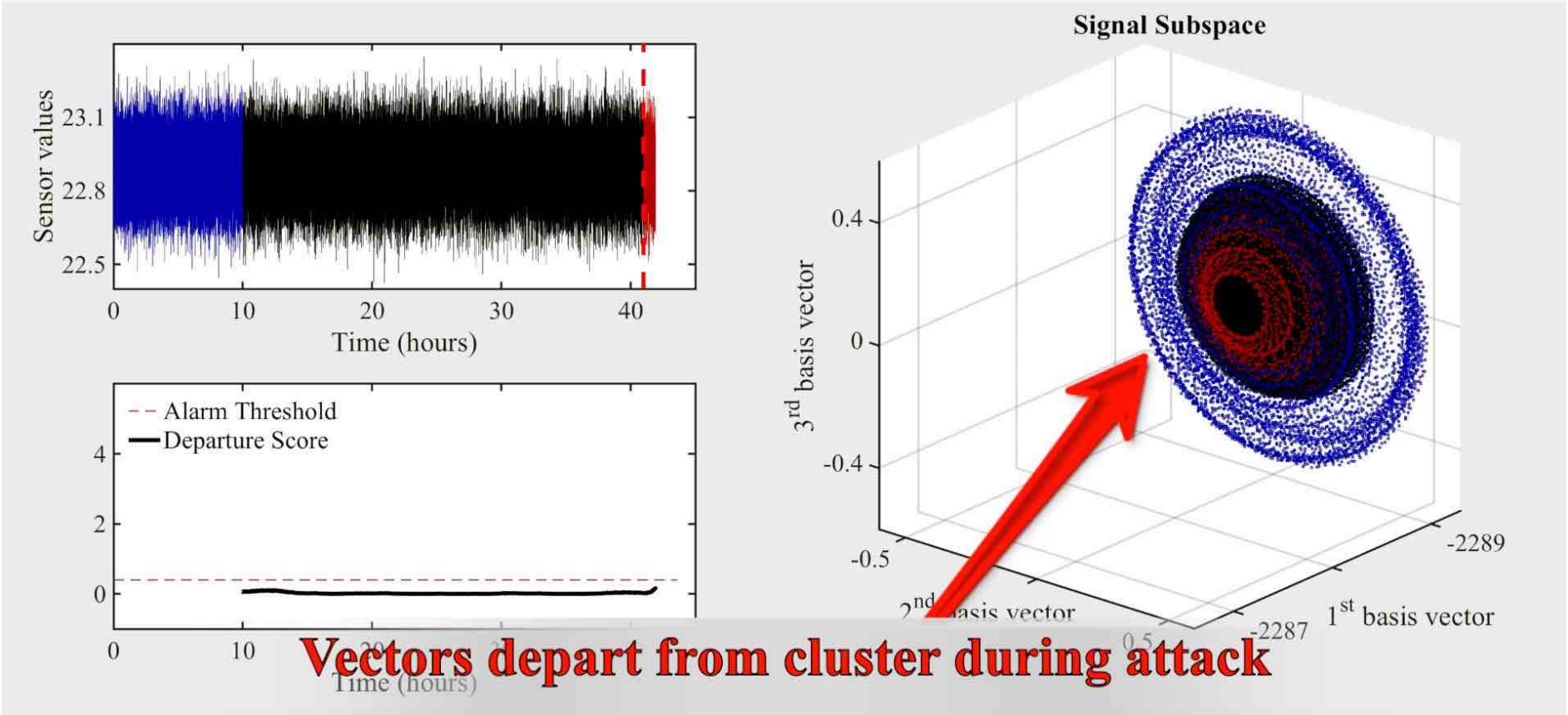


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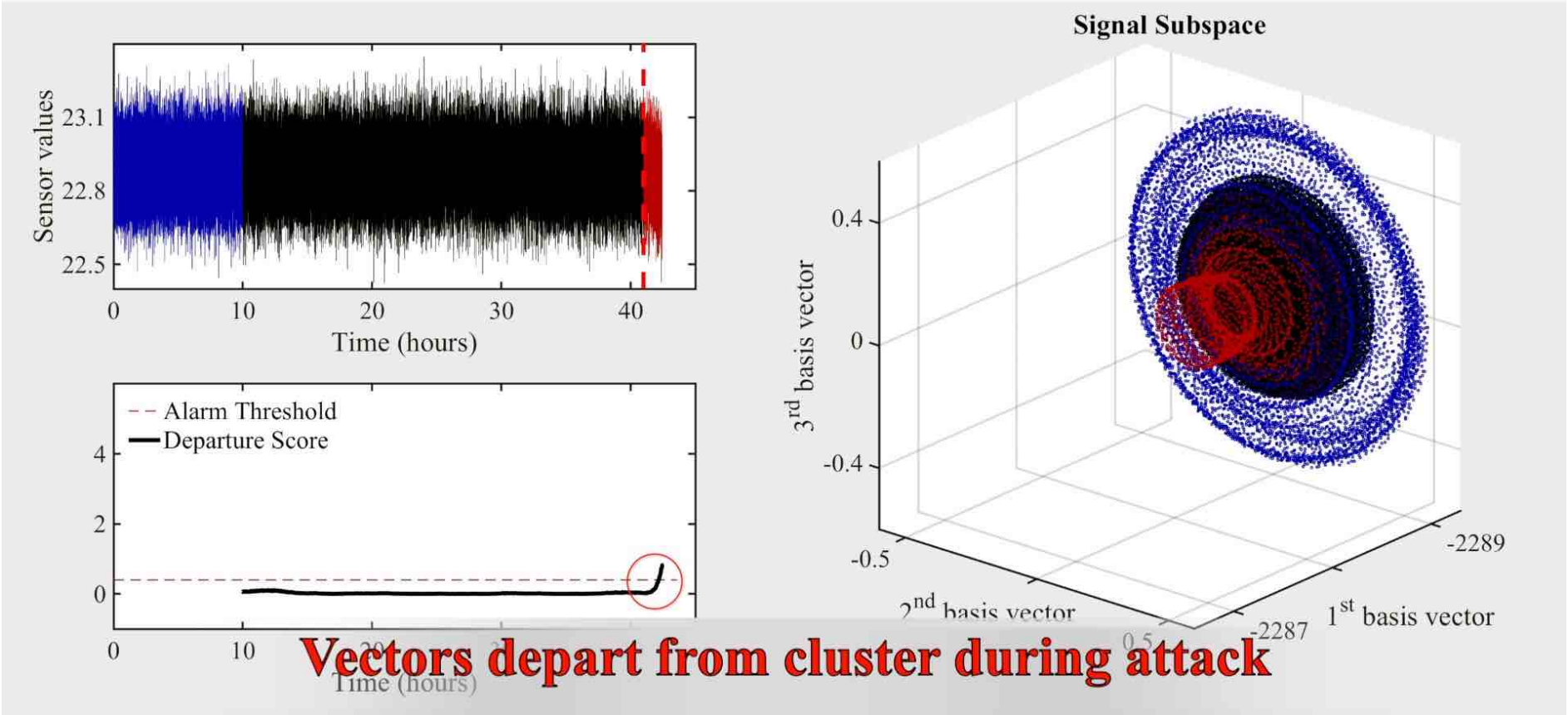


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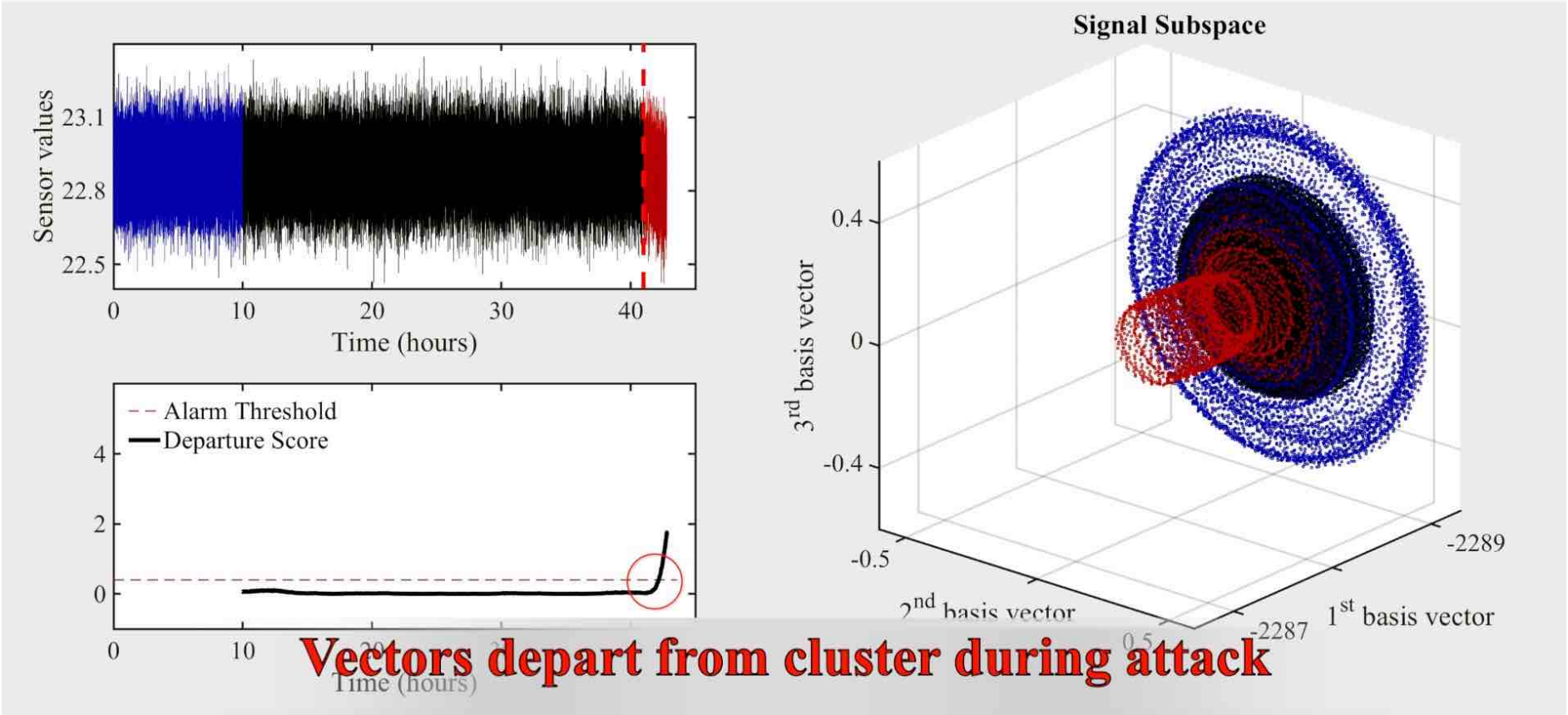


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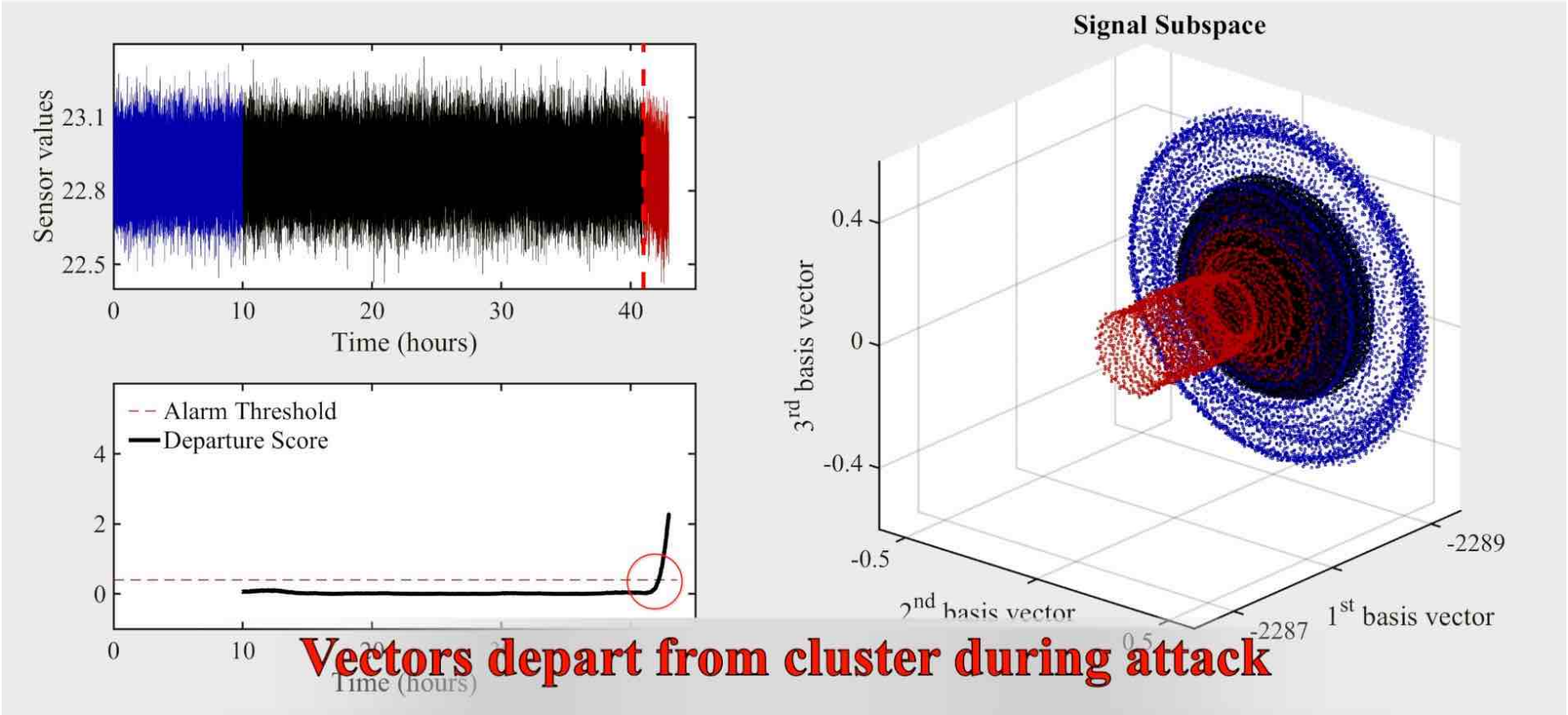


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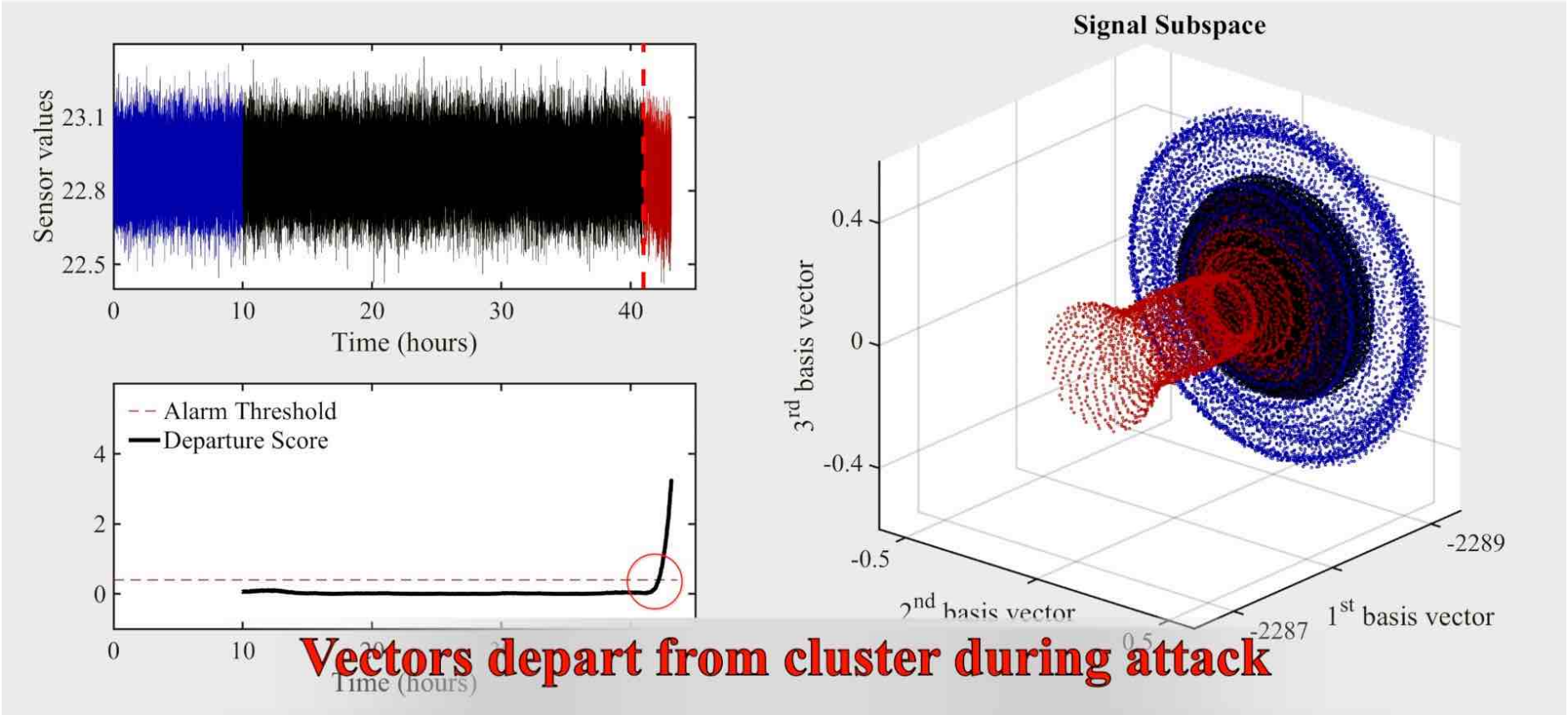


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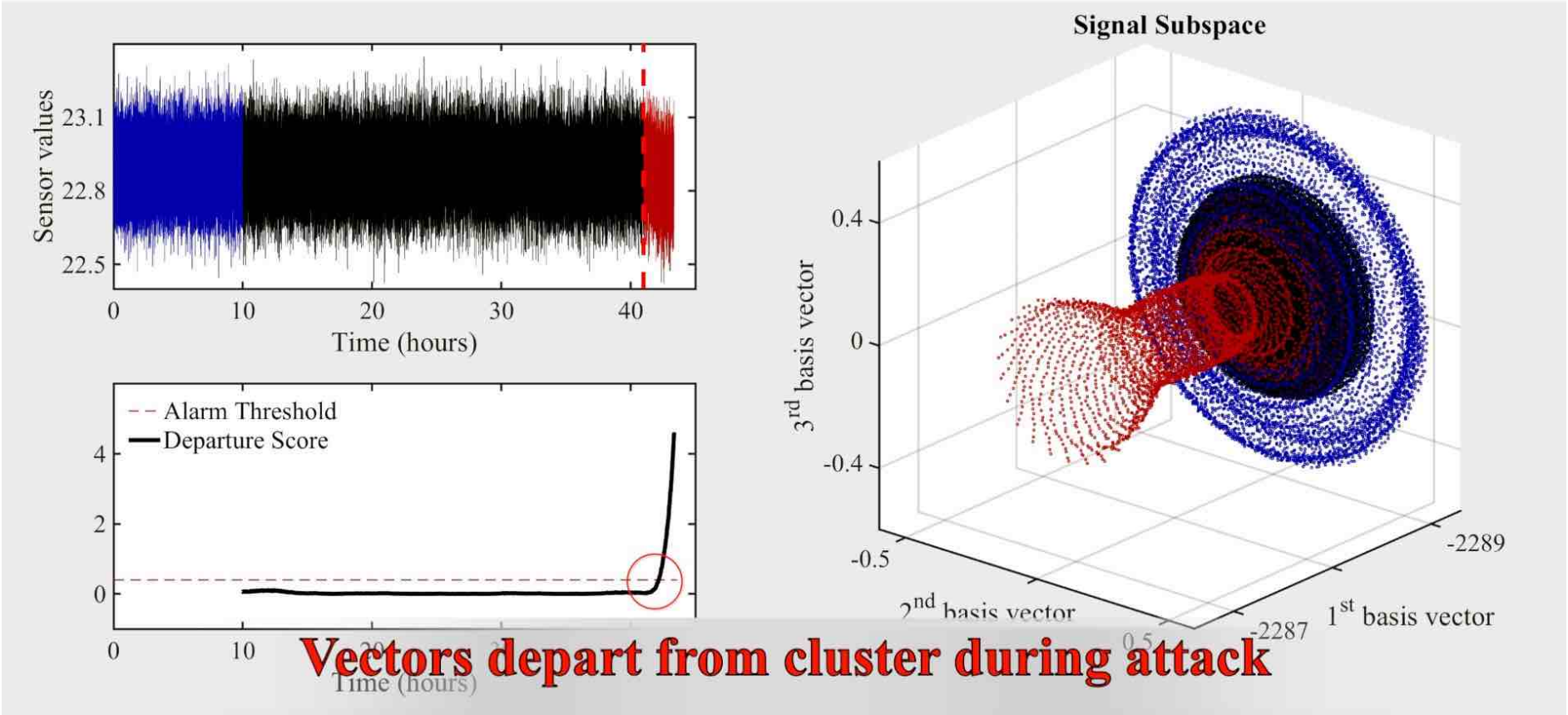


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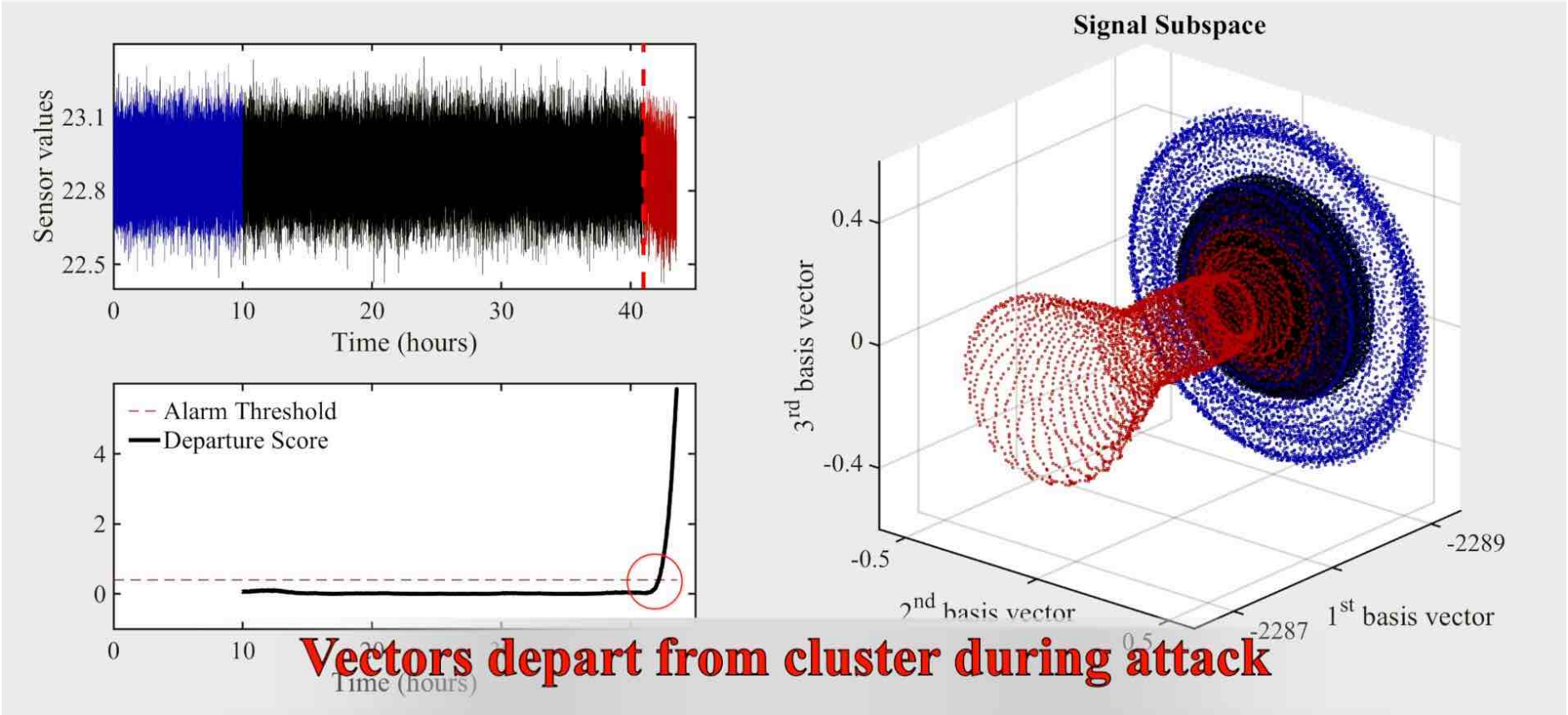


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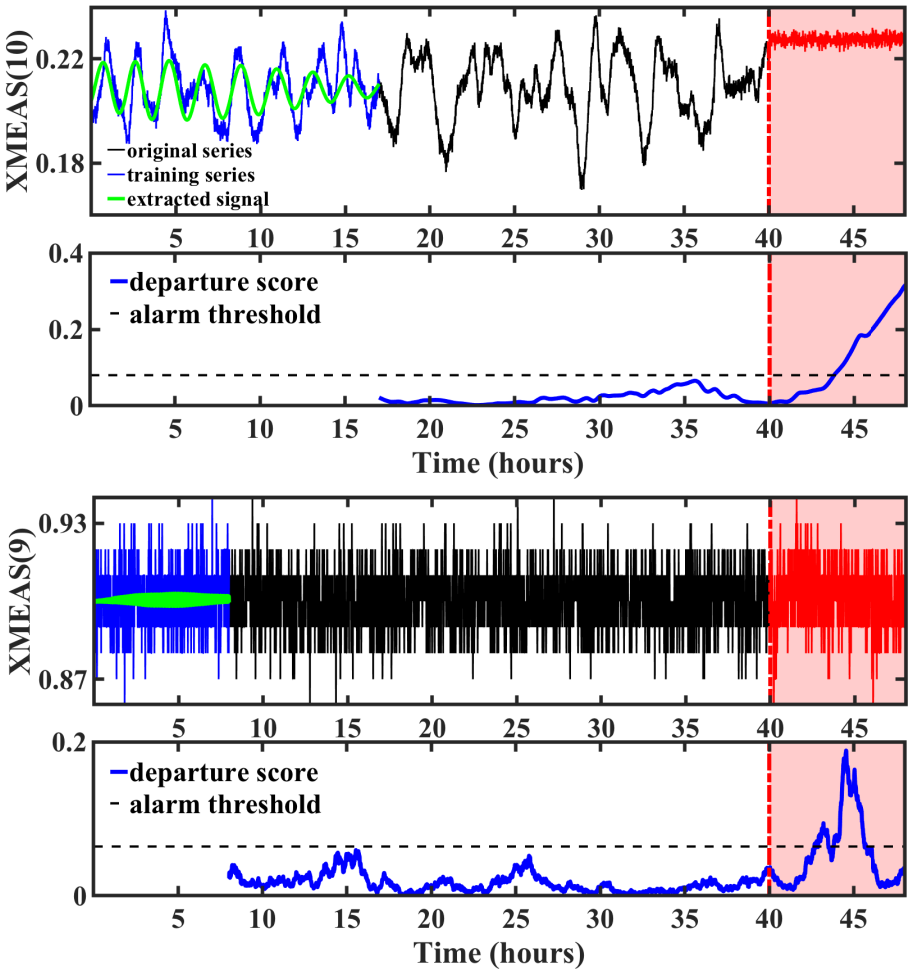
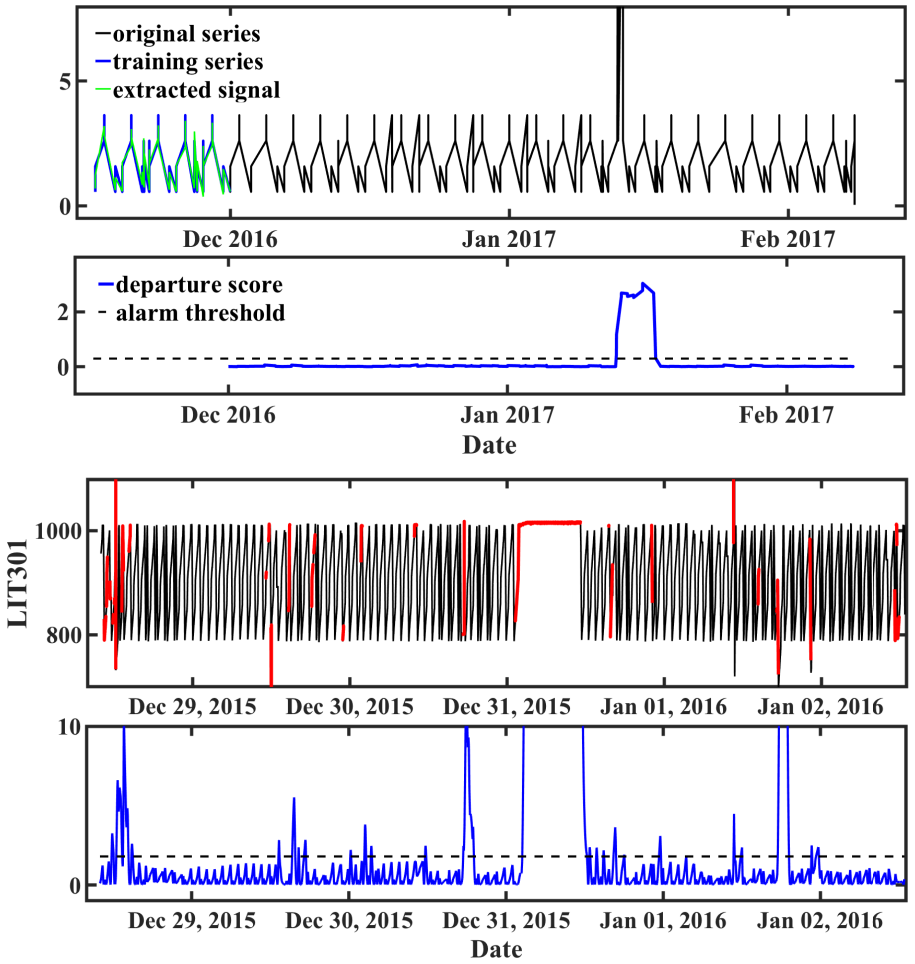
# Validation — Evaluation on Various Systems



# Deploying a Prototype in a Real Environment

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## Deployment in a real control system

- A full-fledged PASAD prototype was deployed in a paper factory in Sweden.
- System operation was monitored for 75 days.

# Challenges

## Challenges include

- dealing with an unknown environment;
- achieving high performance and low footprint;
- maintaining system stability;
- trust and data access issues.

## Overview

- Bro for network parsing
- Parsing of Modbus data
- Buffer for event synchronization
- PASAD for analysis

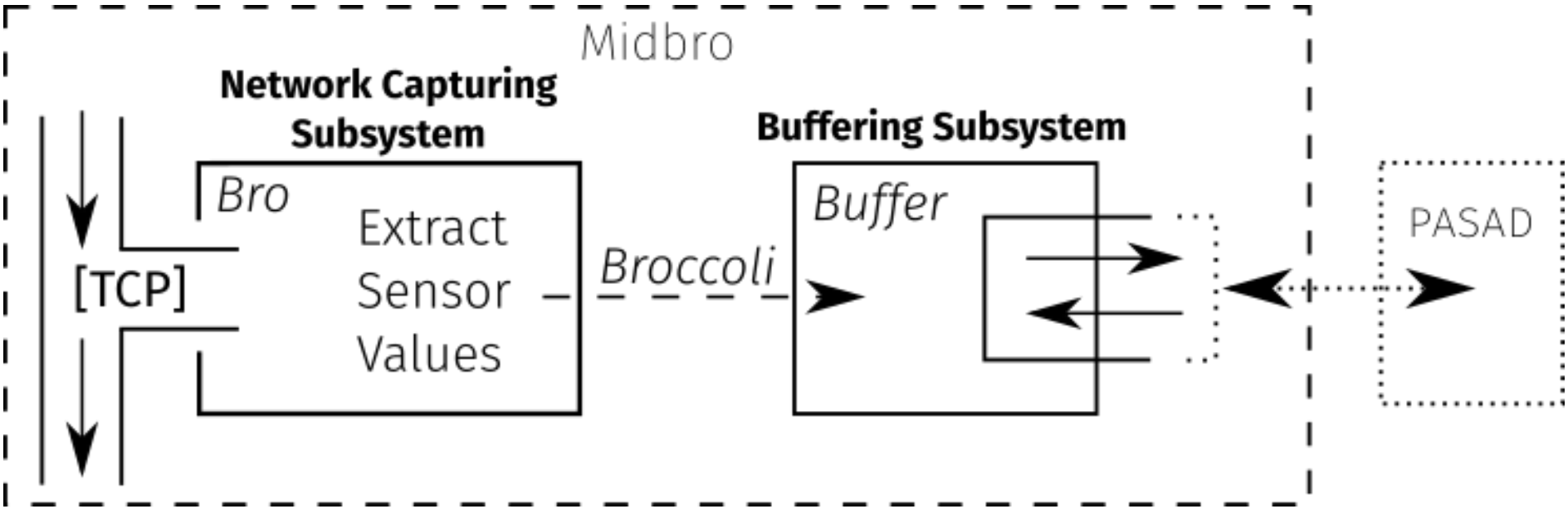


Figure: System overview

## Network Capturing Subsystem

### Handling Modbus Traffic with Bro

- There exist several variants of the Modbus protocol.
- The communication is Client-Server based.
- Nodes are identified using UID and IP addresses.
- Transaction ID (TID) is needed to match requests and responses.

## Network Capturing Subsystem

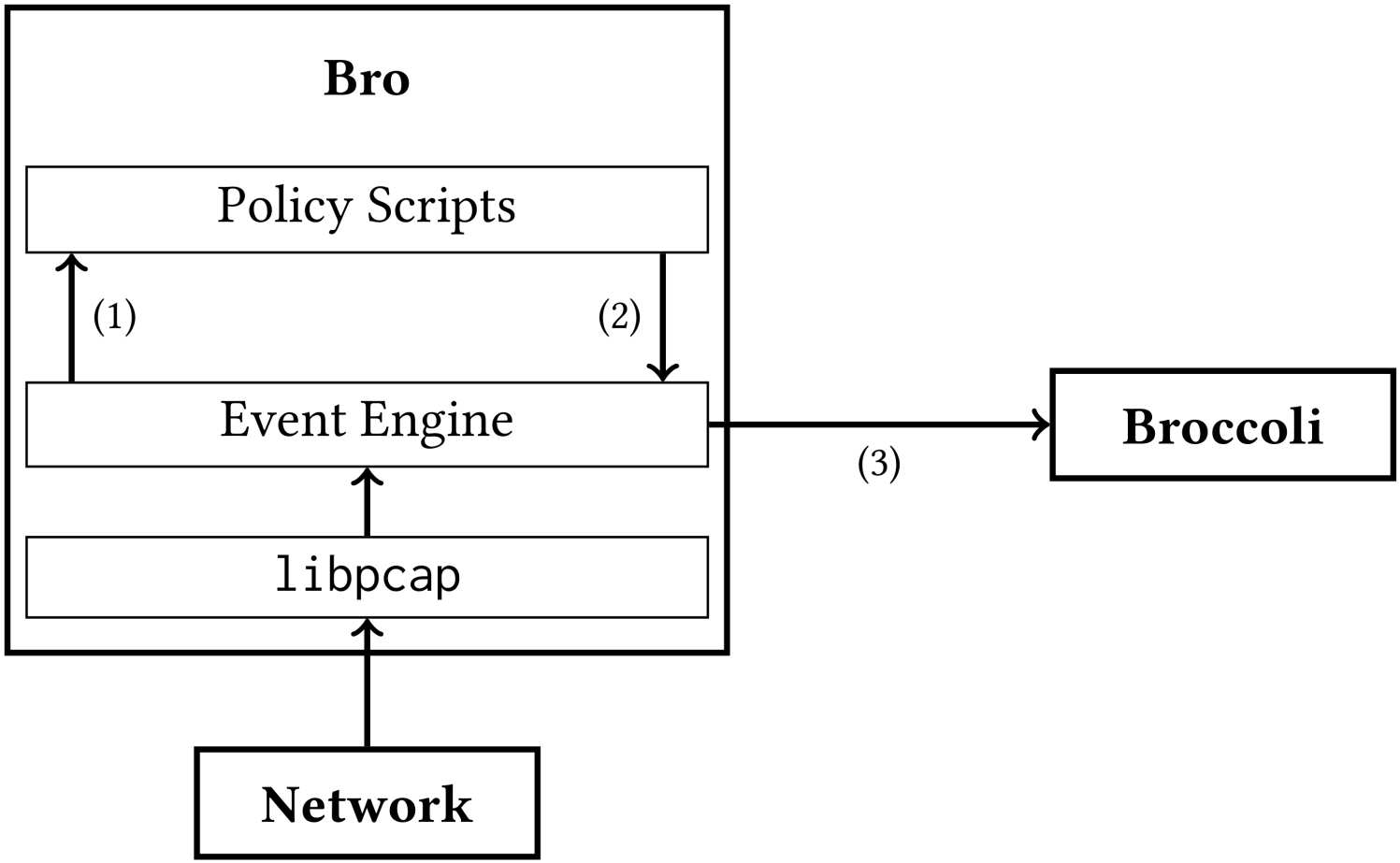


Figure: The Bro framework.

# Midbro System Architecture

## Buffering Subsystem

- Synchronizes Bro events with PASAD.
- Receives Bro events via a socket (broccoli library).
- Stores values in a bounded buffer.
- Provides interface to PASAD.

# Experiments

## The key to success: a local testbed

- Used real Modbus/TCP traffic from water distribution plant.
- Captured traffic was replayed over a small network.
- Stress testing the prototype.
- Emulating packet drops.
- Identifying unexpected behaviours.

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# The Factory

## The Factory

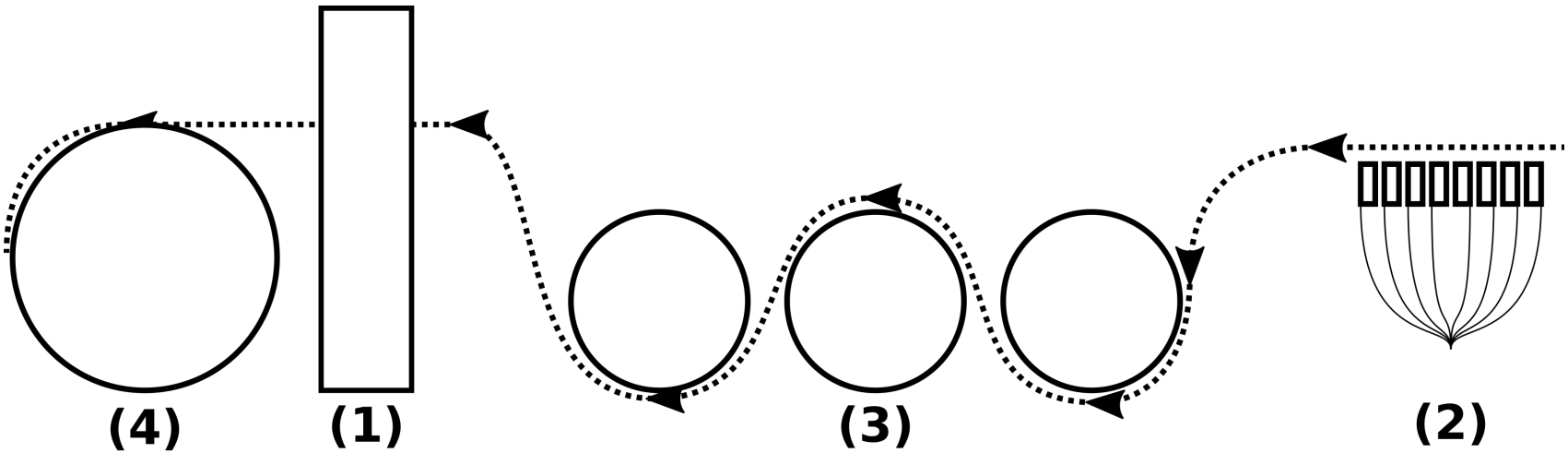


Figure: Production line.

## The Factory


Figure: **(1)** The control frame with sensors.

## The Factory

Figure: **(2)** The actuators for the water valves.

## The Factory

Figure: **(3)** The drying process.

## The Factory


Figure: **(4)** The paper roll.

## Deployment

- Raspberry Pi 3+
- Gigabit Ethernet
- 1.4 GHz quad-core processor
- 1 GB RAM
- Rasbian OS

# Process Monitoring

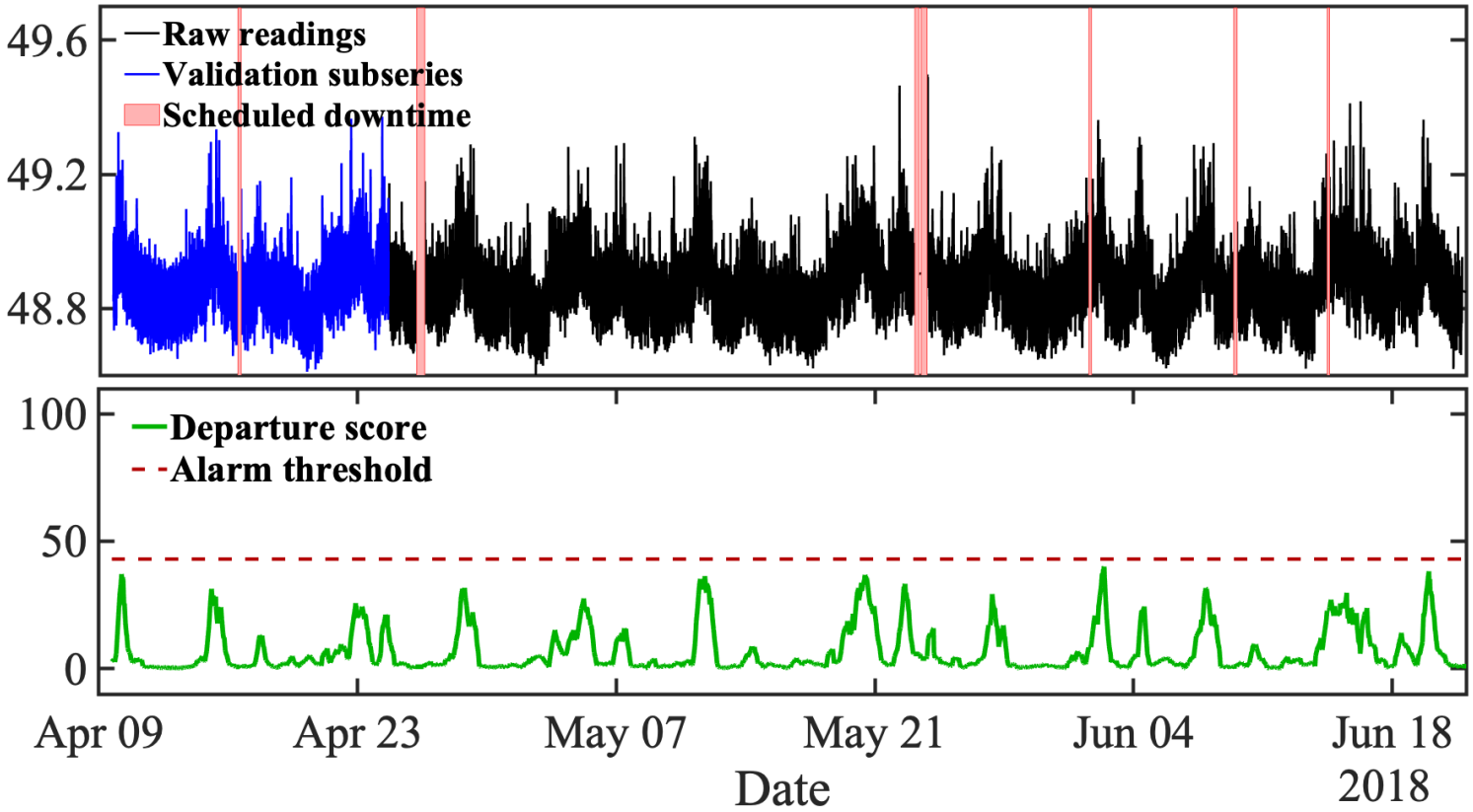


Figure: Sensor readings and departure score from PASAD.

## System Load

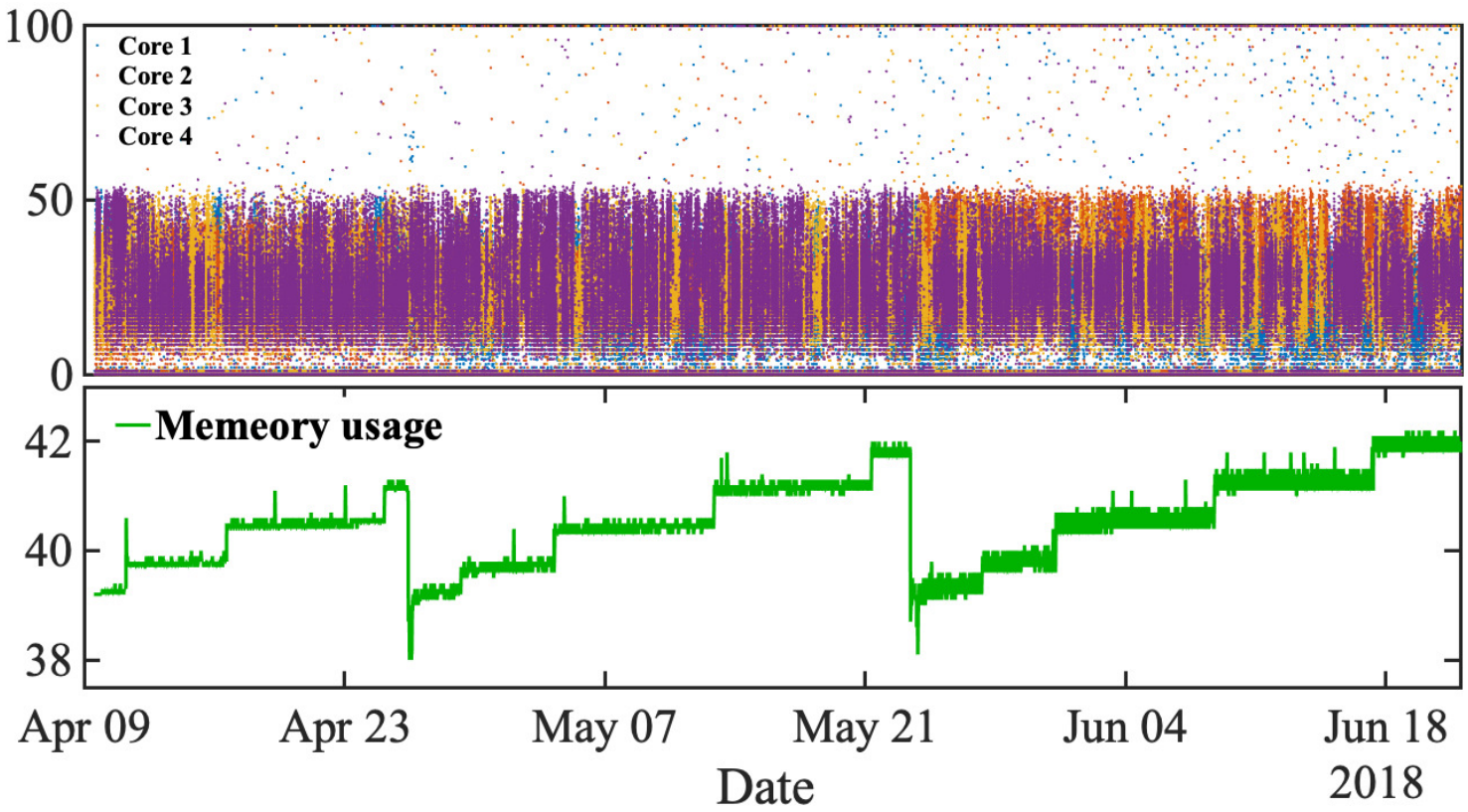


Figure: Processor and memory usage.

# Conclusions

## Lessons Learned

- Process agnostic does not mean plug-and-play.
- Signal data interruptions are tolerable.
- Bro was easy and versatile for Modbus parsing.
- Buffering is valuable, especially with Bro.