# COMMUNITY-DRIVEN SENSOR METADATA

**Mollie R. Cummins, PhD, RN, FAAN, FACMI**
Professor and Jon M. Huntsman Presidential Chair

SPENCER FOX ECCLES SCHOOL OF MEDICINE
UNIVERSITY OF UTAH

COLLEGE OF NURSING
UNIVERSITY OF UTAH

**Ramkiran (Ram) Gouripeddi, MBBS, MS, FAMIA**
Assistant Professor and Assistant Director, Clinical & Translational Science Institute

# DISCLOSURES

- No relevant relationships with commercial interests to disclose.

# ACKNOWLEDGMENTS

Research reported here was supported in full or in part by

- NIEHS, 1R24ES036134-01 [SMARTER]
- NCATS, UL1TR002538, UM1TR004409 [Utah CTSI]
- NIBIB, U54EB021973 [PRISMS]

Research Computing provided by the Center for High Performance Computing, University of Utah

- CHPC resources is partially funded by NIH Research Instrumentation Award S10OD021644

Content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

# TO EASE COMMUNICATIONS, WE CALL THE PROJECT…

# "SMARTER"

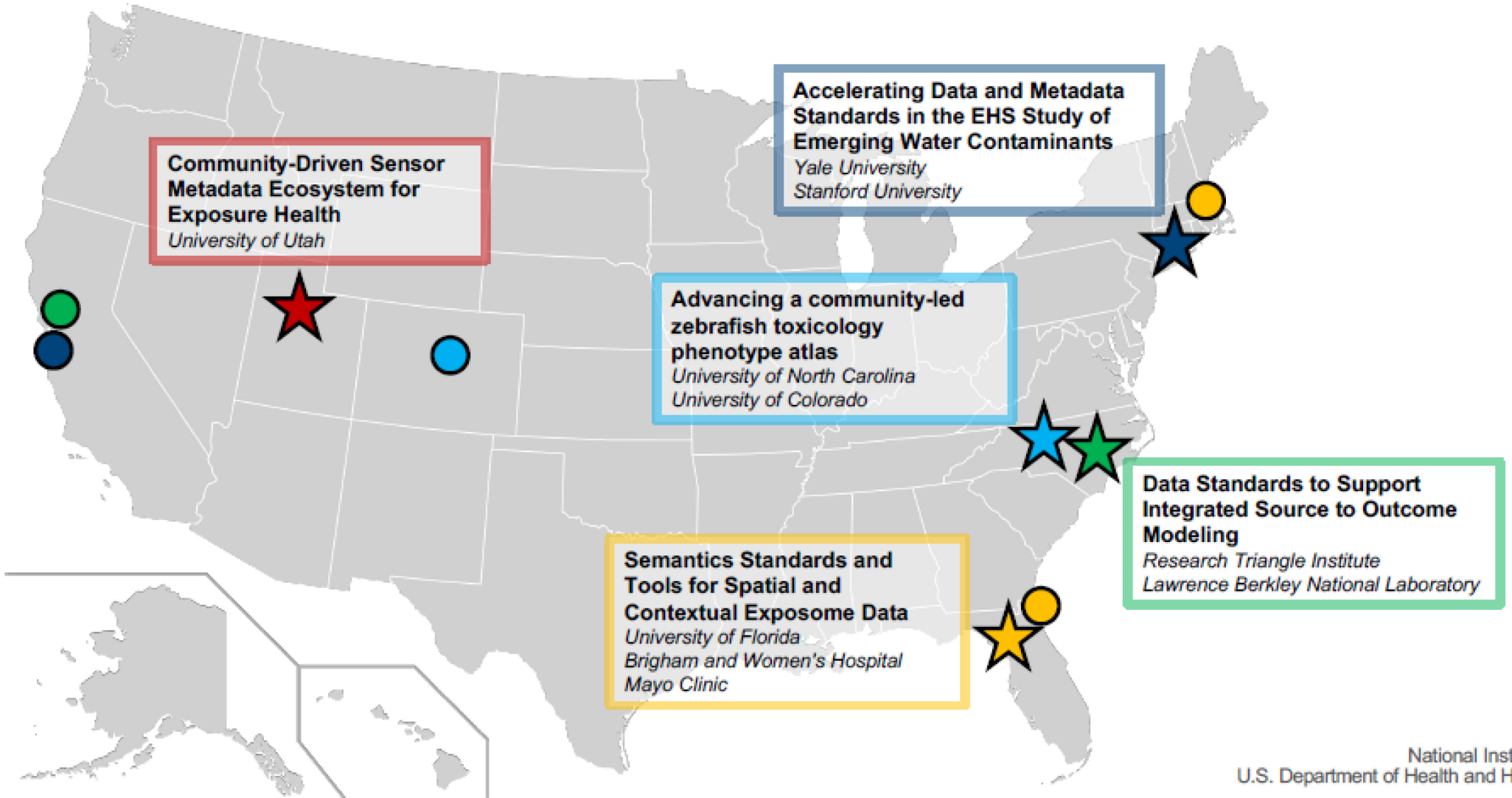
(SENSORS AND METADATA FOR ANALYSIS AND RESEARCH IN EXPOSURE HEALTH)

# NIEHS DATA AND METADATA STANDARDS

- **Data standards** are a priority approach for the NIEHS FY 2025-2029 Strategic Plan
  - Enhance the **rigor and reproducibility** of exposomics
  - Support **FAIR+** principles
  - Improve the **validity and comparability** of health studies and outcomes
  - Lower barriers to effective **data sharing and interoperability**

Source: Material prepared by Dr. C. Duncan/ NIEHS and 2025-2029 NIEHS Strategic Plan: https://www.niehs.nih.gov/about/strategicplan

# FY24-FY28 Accelerating Data and Metadata Standards in the Environmental Health Sciences: New Awards



# BACKGROUND: KEY CHALLENGES

## COMMUNITY-DRIVEN SENSOR METADATA ECOSYSTEM FOR EXPOSURE HEALTH (1R24ES036134) – THE SMARTER PROJECT

- Environmental exposures impact human health; more precise insight requires **integrating data of varied source and scale**.
- Data generated through sensing **usually lacks standardized metadata**, which limits sharing, discovery, and reuse.
- Current metadata **approaches are ad hoc**, non-reproducible, and lack community consensus.
- Researchers **face barriers** due to lack of incentives, standardized models, and accessible tools.
- We **need** harmonized, semantically consistent metadata and reproducible data integration methods.

SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

COLLEGE OF NURSING UNIVERSITY OF UTAH

# SMARTER'S OBJECTIVE

## COMMUNITY-DRIVEN SENSOR METADATA ECOSYSTEM FOR EXPOSURE HEALTH (1R24ES036134) – THE SMARTER PROJECT

**Advance methods for metadata management and event-based modeling in exposure health research and exposomic research**

**Long-Term Objective:** Enhance scientific understanding of environmental exposures by optimizing informatics systems/processes supporting exposure health research

SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

COLLEGE OF NURSING UNIVERSITY OF UTAH

# SPECIFIC AIMS

## COMMUNITY-DRIVEN SENSOR METADATA ECOSYSTEM FOR EXPOSURE HEALTH (1R24ES036134) – THE SMARTER PROJECT

**Aim 1** Develop logical models to harmonize sensor metadata

**Aim 2** Create a user-facing sensor metadata repository (MDR)

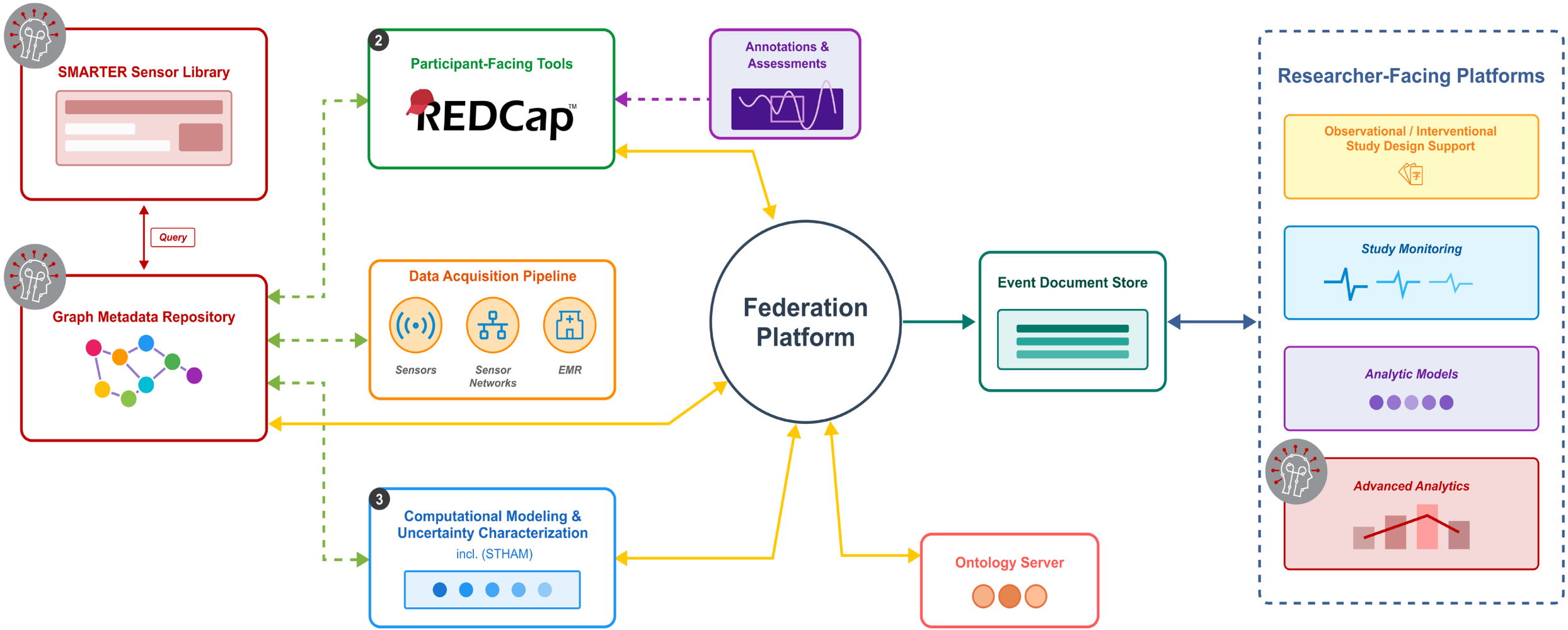
**Aim 3** Enable generation of event-based formats

**Aim 4** Develop prototype workflows that leverage the MDR

SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

COLLEGE OF NURSING UNIVERSITY OF UTAH

# BUILDING ON PRIOR WORK: THE EXPOSURE HEALTH INFORMATICS ECOSYSTEM (EHIE)



# **SMARTER** – HOW IT MAKES SENSOR METADATA FAIR

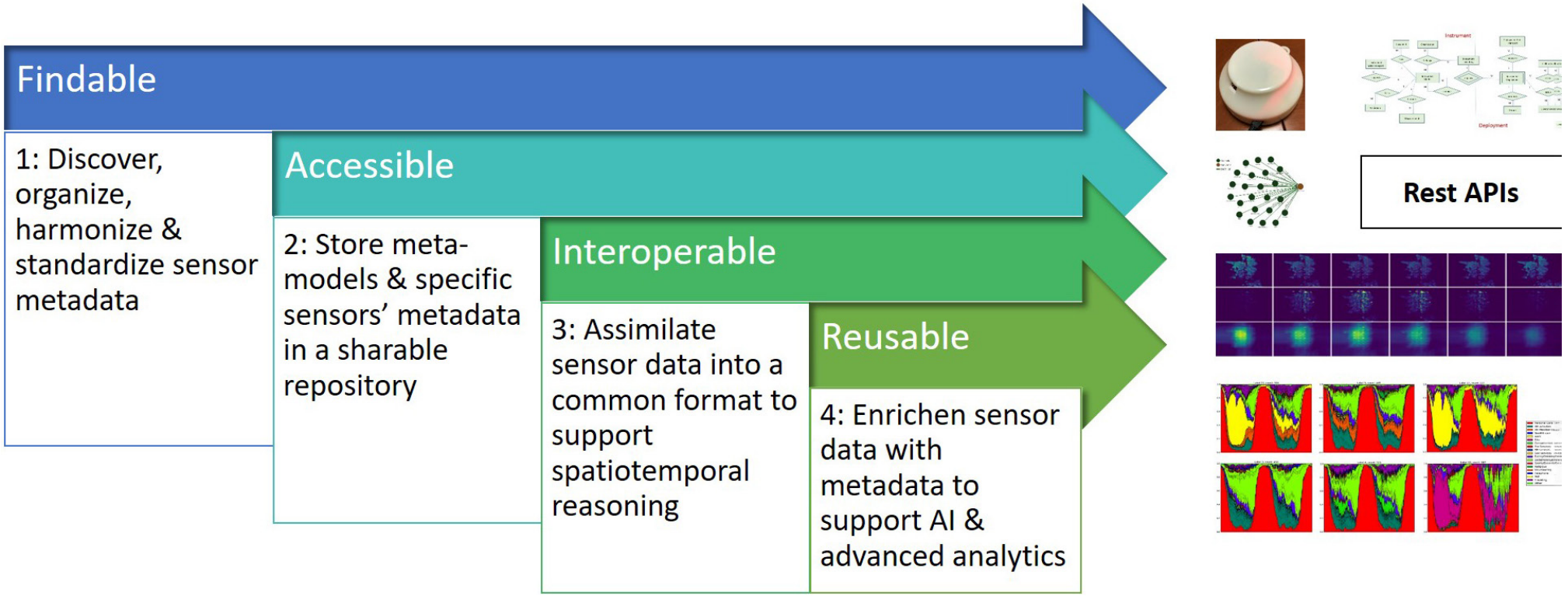



**Figure 2:** Envisioned pathway through proposed Aims 1-4 to create a FAIR ecosystem of metadata resource supporting sensor and sensor discovery, harmonization, integration and generate AI-ready exposure health data.

# CROSS-AIM COMMUNITY ENGAGEMENT IN SMARTER

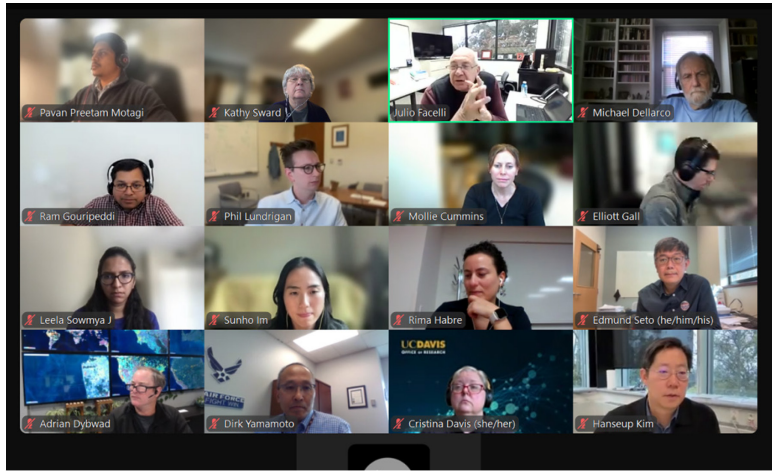
| | |
|---|---|
| **Expert Panel (EP)** | • National panel of exposure health researchers, meets quarterly/ ad hoc to provide input |
| **Public Comment** | • Multiple artifacts for public comment (GitHub/ REDCap) |
| **User-Centered Design** | • Users engaged in requirements analysis, use case development, rapid prototyping, usability assessments |
| **Communications** | • Anchored by web site<br>• Mailing list/ quarterly newsletters<br>• Content created as "blogs" – shared on social media (X, LinkedIn)<br>  • Partner for re-posting/ sharing |

SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

COLLEGE OF NURSING UNIVERSITY OF UTAH

# SMARTER EXPERT PANEL

## COMMUNITY INPUT, GUIDANCE, FEEDBACK




## Our Expert Panel

**Scott Collingwood**
UNIVERSITY OF UTAH

**Hanseup Kim**
UNIVERSITY OF UTAH

**Kerry Kelly**
UNIVERSITY OF UTAH

**Heather Holmes**
UNIVERSITY OF UTAH

**Sneha Kumar Kasera**
UNIVERSITY OF UTAH

**Phil Lundrigan**
BRIGHAM YOUNG UNIVERSITY

**Rima Habre**
UNIVERSITY OF SOUTHERN CALIFORNIA

**Cristina Davis**
UNIVERSITY OF CALIFORNIA DAVIS

**Elliott Gall**
PORTLAND STATE UNIVERSITY

**Edmund Seto**
UNIVERSITY OF WASHINGTON

**Michael Dellarco**
JOHNS HOPKINS UNIVERSITY

**Dirk Yamamoto**
US AIR FORCE

**Adrian Dybwad**
PURPLE AIR

**Elaine Hubal**
ENVIRONMENTAL PROTECTION AGENCY

**Vasu Kilaru**
ENVIRONMENTAL PROTECTION AGENCY

SPENCER FOX ECCLES SCHOOL OF MEDICINE
UNIVERSITY OF UTAH

COLLEGE OF NURSING
UNIVERSITY OF UTAH

# PUBLIC COMMENT

## CASTING A WIDE NET FOR INPUT AND FEEDBACK


September 23 - October 31, 2025

Sensor Common Metadata Specification (v3.0)

Materials Here

**Public Comment 2025.09.23: Sensor Common Metadata Specifications (v3.0)**

We appreciate any feedback and comments from the sensor, exposure health and informatics communities on the current sensor common metadata specification for SMARTER. You can provide your feedback either via email or using a form. The specifications are available for review at: https://github.com/EHIE-CENTER/prisms-sensor-model

The form (12 questions, about 10 minutes time to complete) is available at: https://redcap01.brisc.utah.edu/ccts/redcap/surveys/?s=F3XLDNNA8RFRNXR4.

You can also simply email your feedback to us at: smarterexposurehealth@utah.edu.

SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

COLLEGE OF NURSING UNIVERSITY OF UTAH

# USER-CENTERED DESIGN

## FOR A SENSOR METADATA REPOSITORY THAT RESEARCHERS WILL ACTUALLY USE

SPENCER FOX ECCLES SCHOOL OF MEDICINE
UNIVERSITY OF UTAH

COLLEGE OF NURSING
UNIVERSITY OF UTAH

# COMMUNICATIONS

10/14/25

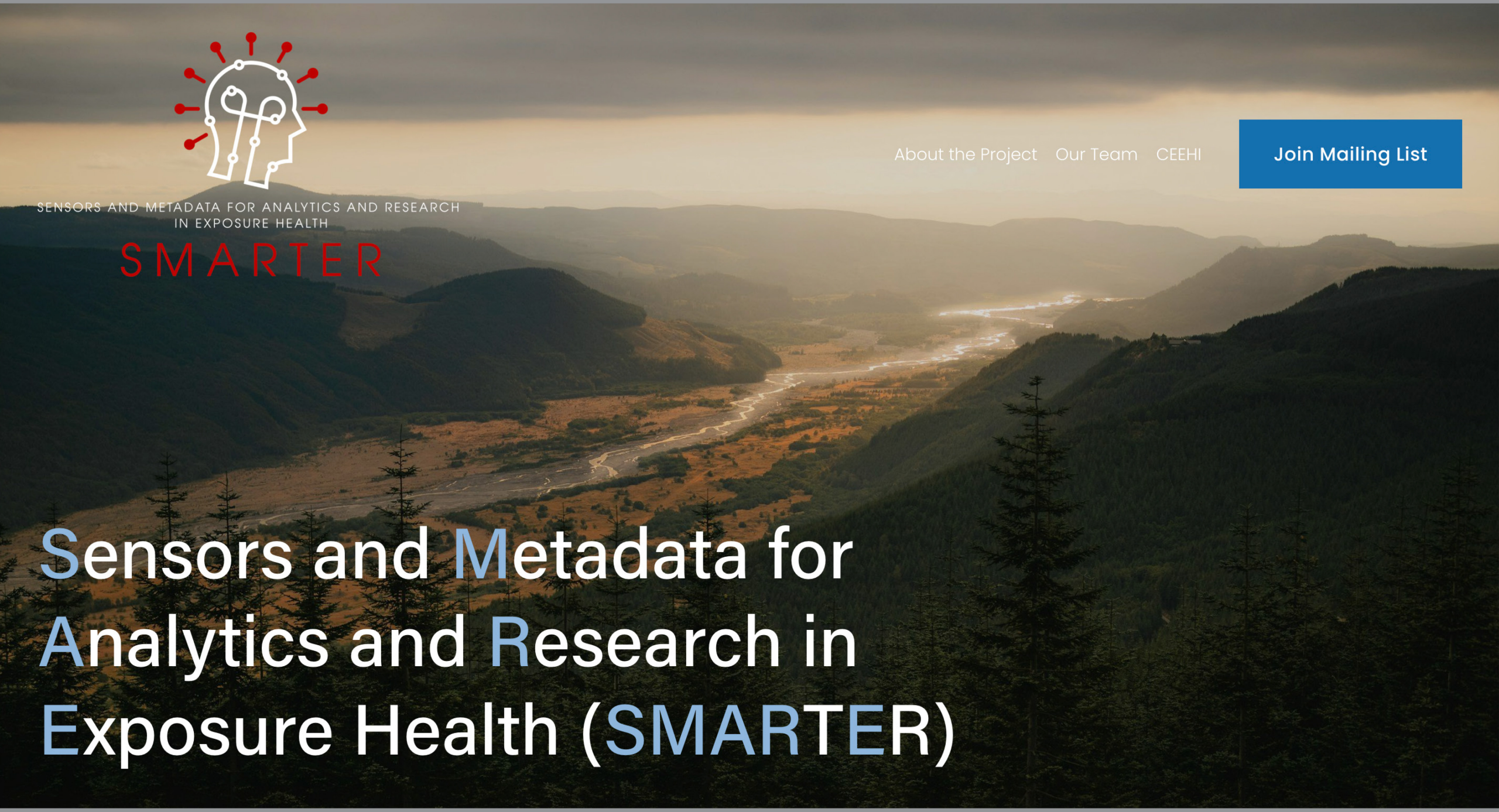
## SMARTER Updates - October 2025

October 2025 updates from the SMARTER team include a new call for public comments, user-centered design efforts, new research findings, ISES-ISEE 2025 presentations, and other news.

Read More

SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

COLLEGE OF NURSING UNIVERSITY OF UTAH


SENSORS AND METADATA FOR ANALYTICS AND RESEARCH
IN EXPOSURE HEALTH
SMARTER
About the Project
Our Team
CEEHI
Join Mailing List
Sensors and Metadata for Analytics and Research in Exposure Health (SMARTER)

# USER-CENTERED DESIGN

# WHAT WE KNEW FROM PRIOR WORK

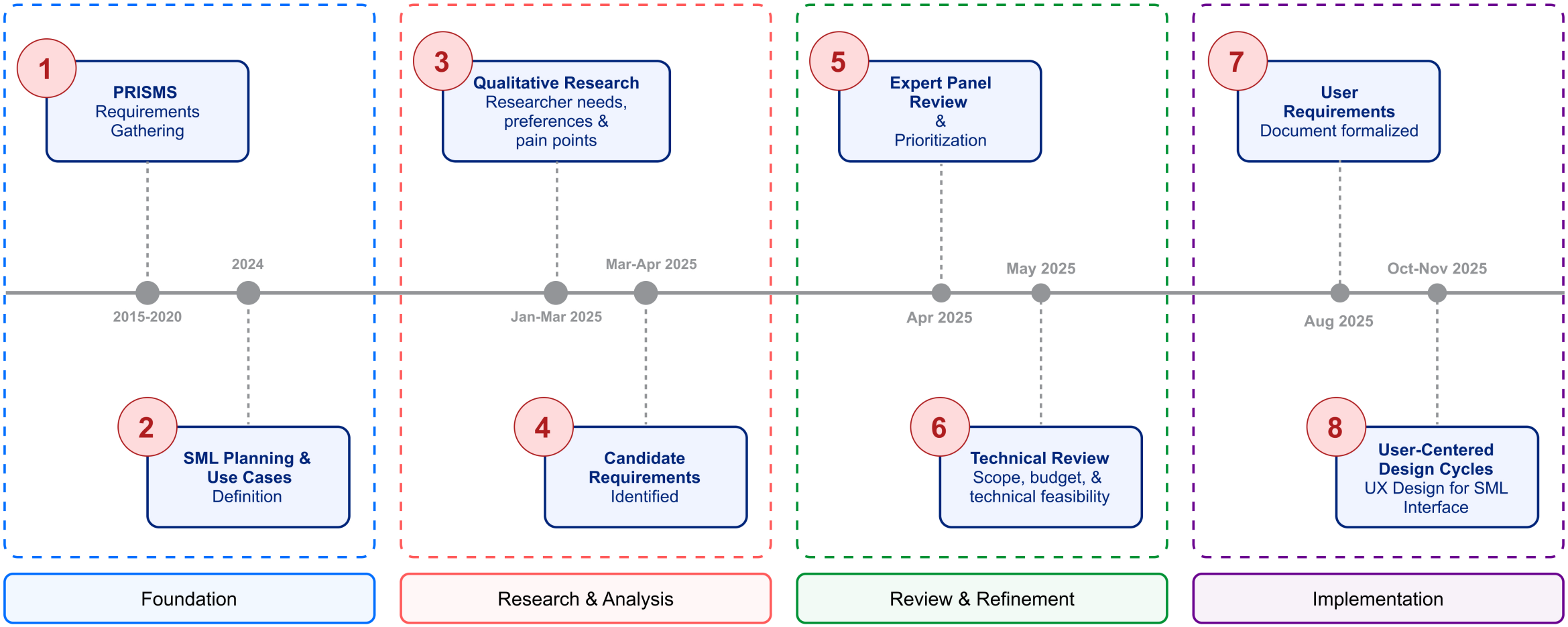
## LEARNINGS FROM THE **UTAH PRISMS (PEDIATRIC RESEARCH INTEGRATING SENSOR MONITORING SYSTEMS) CENTER**

- Metadata is used in multiple stages of environmental health research using sensors:
    - Pre-deployment, Deployment, Post-deployment, and Administrative/ Information
- **Multiple stakeholders/ roles** interact with sensor metadata:
    - Investigator, Project/ Study Coordinator, Data Manager, Statistician, Deployment Specialist/ Coordinator, Sensor Developer, Biomedical Informatician, Study Sponsor
- Basic use cases and requirements as they intersect with the overall function of **EHIE**

SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

COLLEGE OF NURSING UNIVERSITY OF UTAH

# UNDERSTANDING & DEFINING USER REQUIREMENTS



# QUALITATIVE STUDY RESULTS

## YIELDED MULTIPLE INSIGHTS THAT INFORM USER REQUIREMENTS

- Researchers consider multiple characteristics of sensors when selecting sensors for studies, monitoring deployment, or analyzing data:
    - Cost, function, limitations, reliability, suitability for deployment setting, software and data acquisition requirements, usability, training requirements
- Need for support from sensor developers, standardized metadata, flexibility in data transfer and analysis

***"I can never have too much metadata. There's the sensor reading itself, and that's great. But there's so much context around that sensor reading that gets ignored or lost that I wish we could capture."***

***--Sensor Developer***

# USER REQUIREMENTS



## 2.6 Calibration Requirements/ Procedures (REQ-6)

**Requirement:** Users must be able to access detailed calibration requirements and procedures for each sensor or instrument.

"As a Principal Investigator, I want to understand calibration needs so that I can plan for proper sensor maintenance and quality assurance."

**DoD:**

- Calibration frequency requirements specified
- Step-by-step calibration procedures available
- All information when available or status of information access or link to developer contact information and/or documentation

**EHIE:**

- Documentation of unique sensor/ instrument calibration - date/time

SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

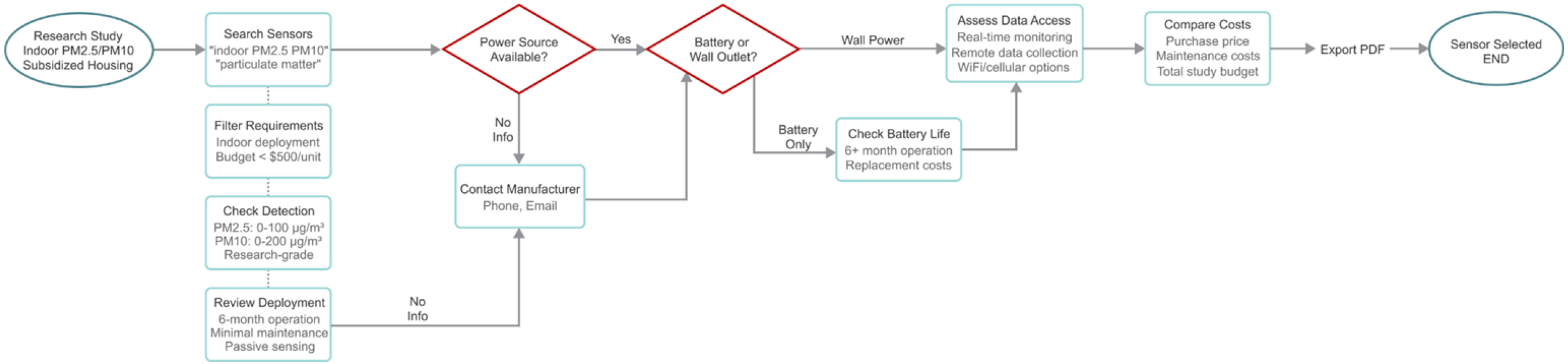
COLLEGE OF NURSING UNIVERSITY OF UTAH

# USER FLOW

## Principal Investigator - Indoor Air Quality Study: PM2.5/PM10 in Subsidized Housing

**Study Context: Indoor PM Monitoring in Subsidized Housing**
- Target: Carpeted apartments with aging HVAC systems
- Duration: 6-month longitudinal study
- Population: Families with children in low-income housing

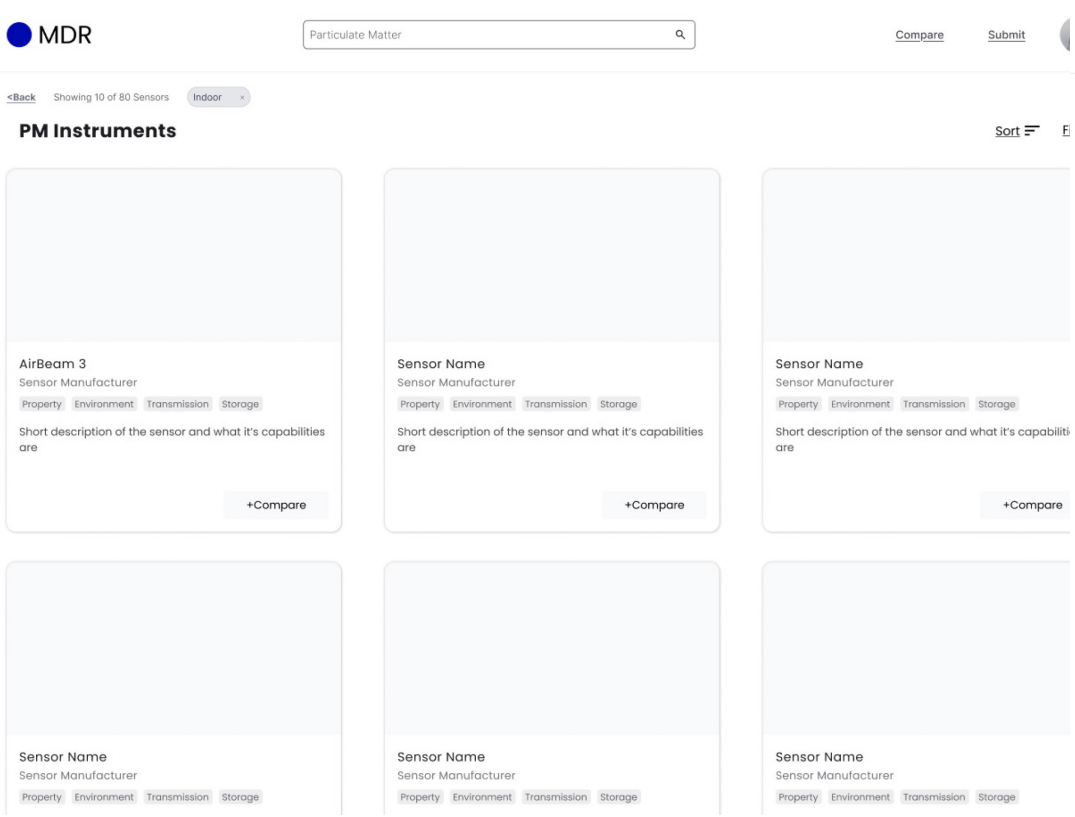
**Key Information Requirements**
- Detection accuracy for indoor PM levels (research-grade validation)
- Long-term deployment capabilities with minimal resident disruption
- Total cost analysis for grant budget justification

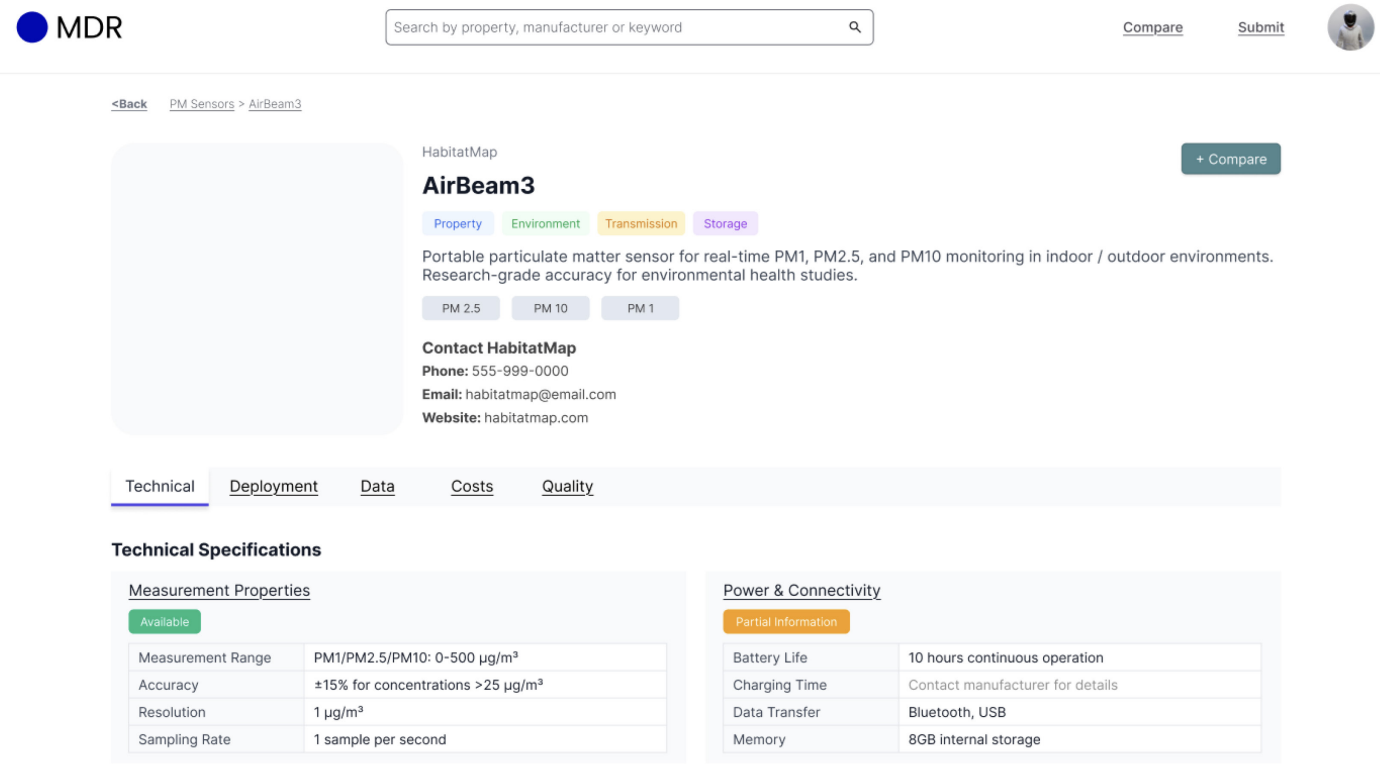



**Legend:**

Start/End | Process | Decision | Input/Output

# WIREFRAMES




SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

HEALTH UNIVERSITY OF UTAH

# YOU INPUT NEEDED

**Sign up for mailing list** for updates and announcements about opportunities for:

- Public comment
- User testing

www.smarterexposurehealth.org




SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

COLLEGE OF NURSING UNIVERSITY OF UTAH

# DATA MODELING, DEVELOPMENT & IMPLEMENTATION

UTAH CTSI
© UNIVERSITY OF UTAH HEALTH
CLINICAL & TRANSLATIONAL SCIENCE INSTITUTE

Center of Excellence for Exposure Health Informatics
THE UNIVERSITY OF UTAH

HEALTH
UNIVERSITY OF UTAH
Biomedical Informatics

COLLEGE OF NURSING
UNIVERSITY OF UTAH

# KEY REQUIREMENTS

Agnostic

Abstracted

Heterogeneous

Support life-cycle of sensor use

Multiple metadata service support

- Researcher browsing
- Publishing
- Integration

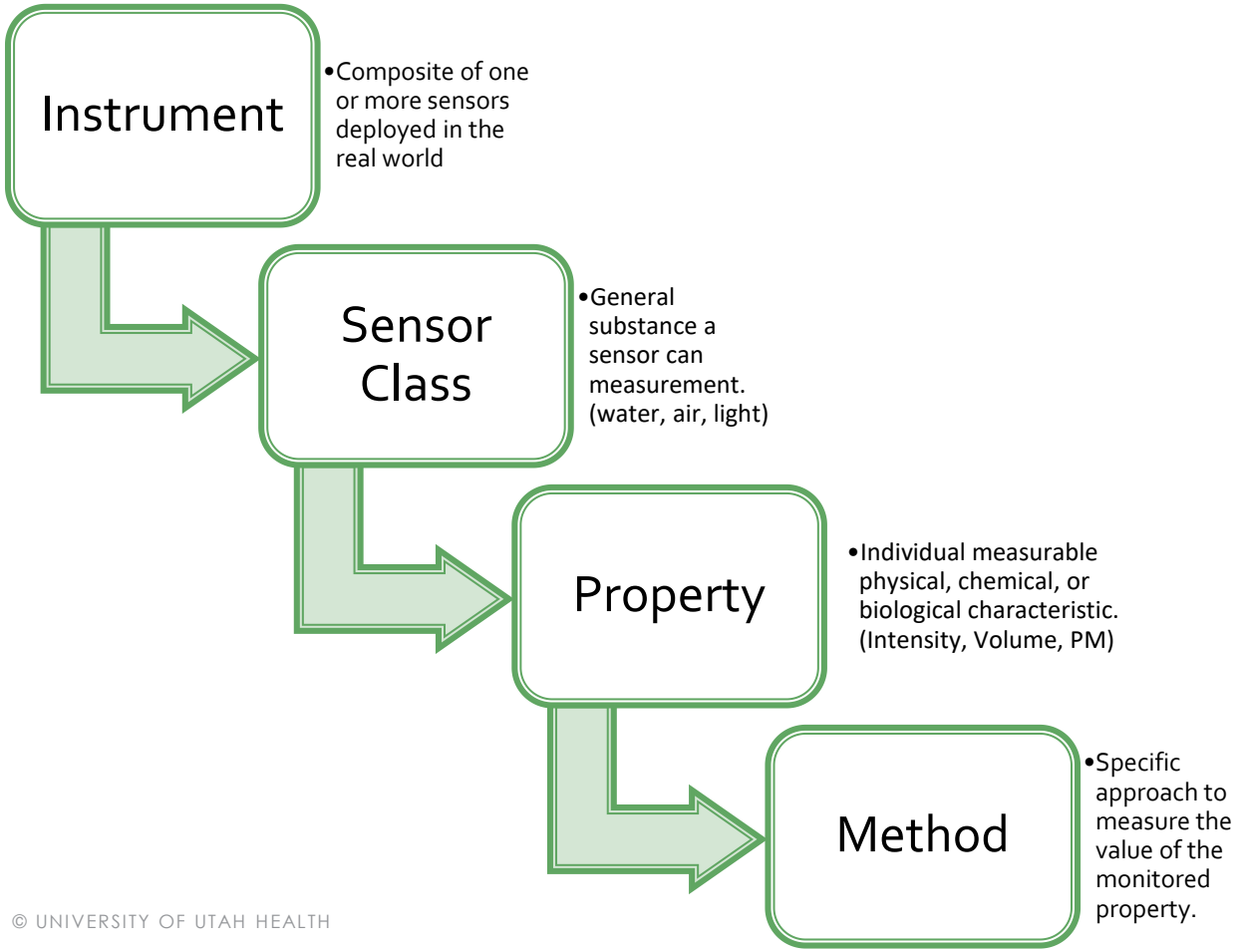
# REFINED SENSOR COMMON METADATA SPECIFICATION (SCMS)

- Updated entities, attributes and relationship based on the requirements and UCD analysis

*Complete specification including attributes and implementation guide available at: https://github.com/EHIE-CENTER/prisms-sensor-model*

# SENSOR TYPES - HETEROGENEITY

- Sensor: A device that produces an output signal by measuring a property of an object in the real-world. (NIST, NIBIB, IEEE, Oxford)

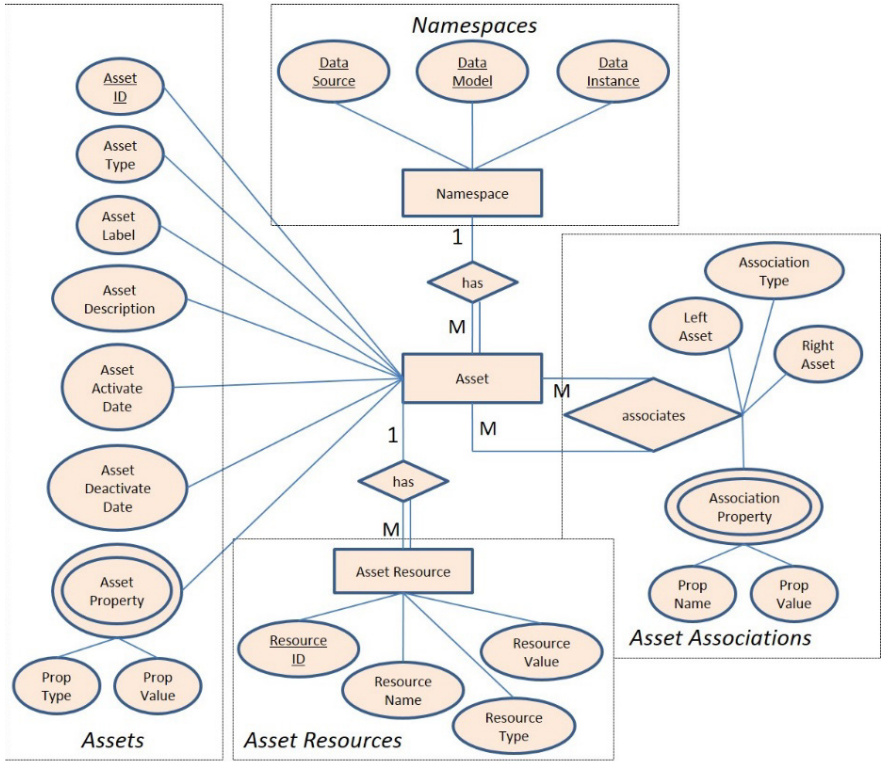



- Nanosensors <–> Satellites
- Physical, Chemical, Biological properties
- Personal (mobile), Immediate (in-home), General Environment (EPA monitors)
- General, Specific, Personal Exposome
  - Environment <-> Physiological responses

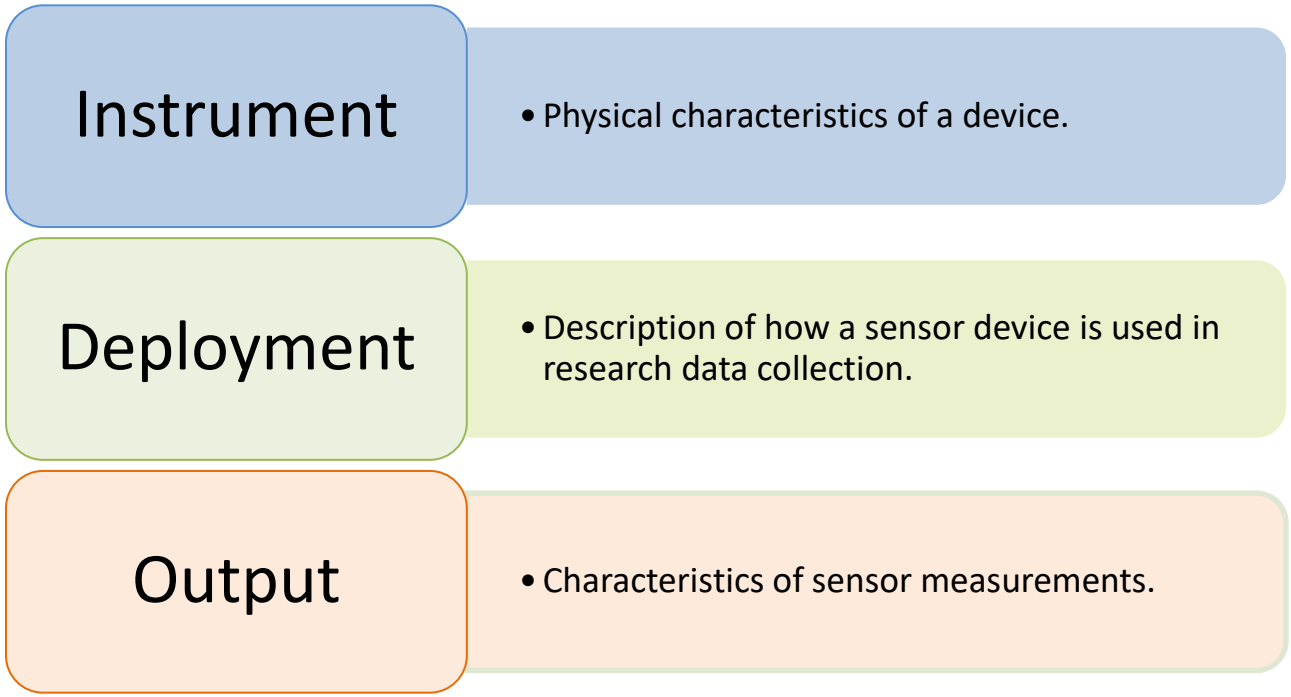
# SCMS – ABSTRACTED METADATA CONCEPTUAL MODEL

- Highly generic and abstracted entity relationship model combining OMG, DublinCore, ISO metadata specifications

- Six core elements of MDR
  - *Assets*: Things or elements we describe
  - *Properties:* Descriptions of assets
  - *Associations:* Relationships between assets
  - *Associations Properties:* Descriptions of the associations
  - *Asset Resources:* Artifacts describing assets that require extended storage
    - E.g. XML Files, Images, URLs
  - *Namespace: Containers to organize Assets.* Every Asset belongs to one namespace

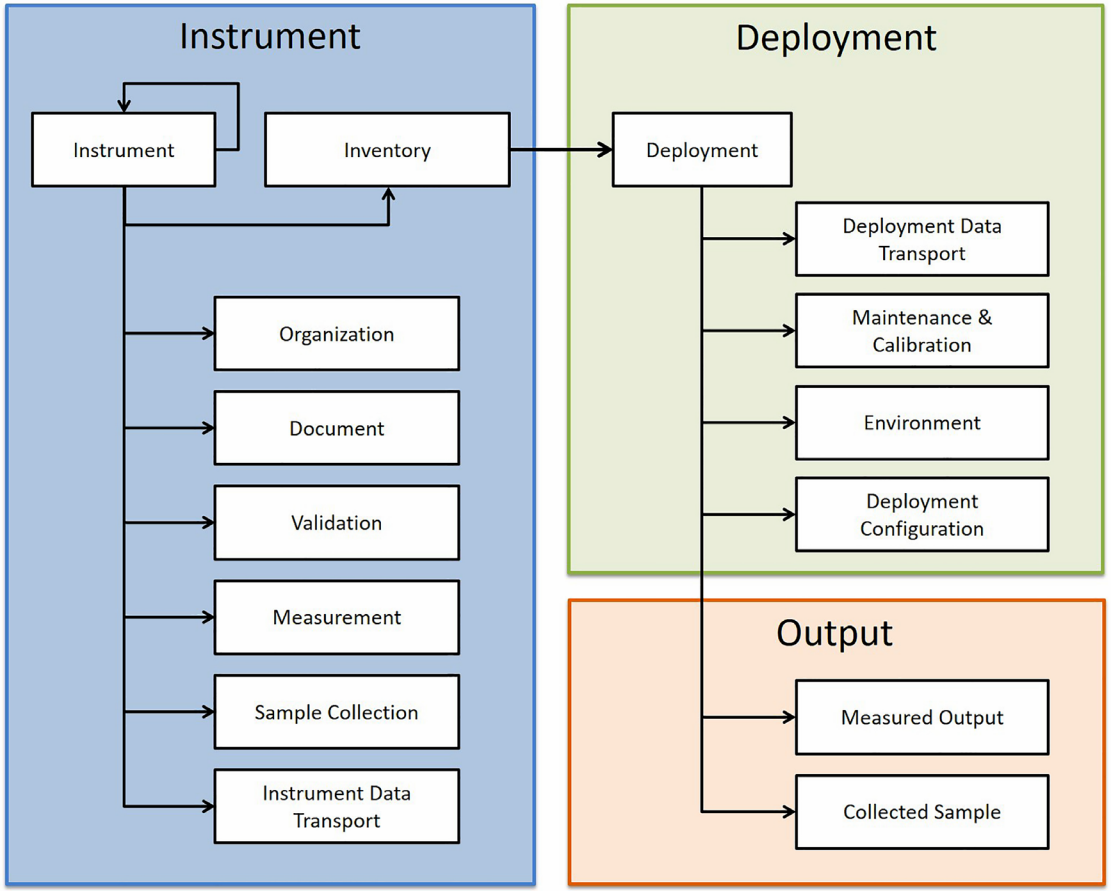


# SCMS – SENSOR LIFECYCLE SUPPORT




Principal domains and entities of the sensor common metadata specification.
*Complete specification including attributes and implementation guide available at: https://github.com/EHIE-CENTER/prisms-sensor-model*

# SCMS CORE DOMAIN & ENTITIES




Principal domains and entities of the sensor common metadata specification.

*Complete specification including attributes and implementation guide available at: https://github.com/EHIE-CENTER/prisms-sensor-model*

# EXAMPLE SENSORS

## Prospective Collections

- Sensor deployment as part of a study

## Existing Resources

- Regional
- Environmental Protection Agency
- Citizen's Network
- Global
- Satellites

Aethlabs

AirU Sensors (Kelly et al. 2017): Particulate matter.

Exhaled Breath Condensate Metabolomic Sampler

- UC Davis (Schivo et al. 2013; McCartney et al. 2017; Hichwa and Davis 2018)

Stationary Sensors

- Columbia University (Cox et al. 2019).
- Particulate matter composition, black carbon, temperature, relative humidity, accelerometry and volatile organic compounds levels.

**Wearable Air Quality Sensor**

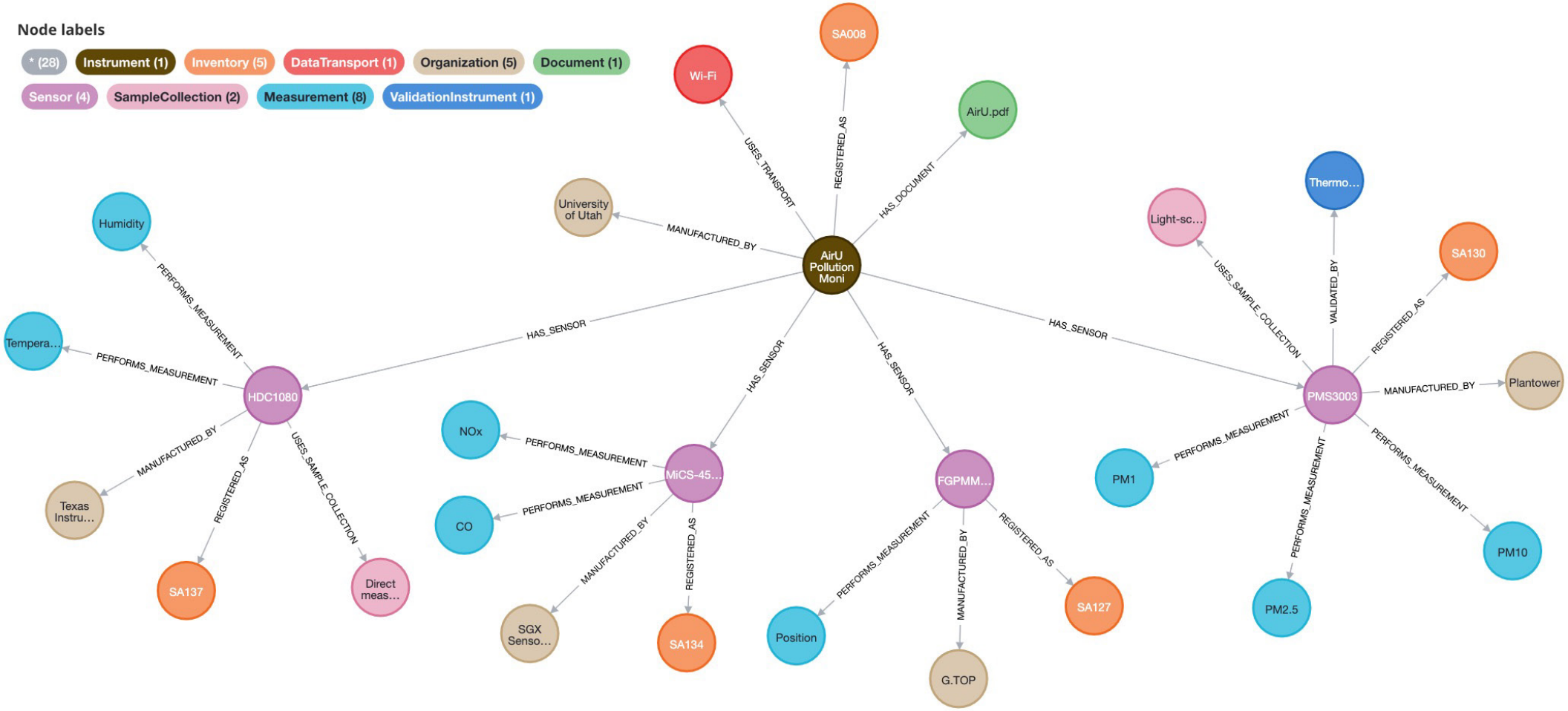
- George Washington University (Li et al. 2019)
- Nitrogen dioxide, ozone, ambient temperature, formaldehyde, other aldehydes, and relative humidity.

**Wearable Air Quality Sensor**

- Arizona State University (Wang and Tao 2017)
- Ozone, volatile organic compounds, ambient temperature, relative humidity, accelerometry, nitrous oxides, formaldehyde and particulate matter.

| Property Measured | Method | Related Literature Title |
|---|---|---|
| Activity Levels | Accelerometer | Accelerometer-derived physical activity and mortality in individuals with type 2 diabetes |
| Broad range of biological and chemical threat agents | Plasmonic sensors | Plasmonic Sensors for Monitoring Biological and Chemical Threat Agents |
| Chromium (Cr) | Hyperspectral imaging technology | Regional Inversion of Soil Heavy Metal Cr Content in Agricultural Land Using Zhuhai-1 Hyperspectral Images |
| Environmental noise levels | Mobile "smart" phones | Evaluation of mobile smartphones app as a screening tool for environmental noise monitoring |
| Light Exposure | Actiwatch Spectrum Pro | Intra- and Inter-Model Variability of Light Detection Using a Commercially Available Light Sensor |
| Multiple air pollutants | Personal air quality monitors (PAMs) | Using low-cost sensor technologies and advanced computational methods to improve dose estimations in health panel studies: results of the AIRLESS project |

# GRAPH IMPLEMENTATION OF SCMS




*AirU Sensor as an example depicted here*

# SMARTER METADATA REPOSITORY ARCHITECTURE

Sensor Library

*Browsing, selection, submission of sensor metadata*

Metadata Repository

*Data integration, sensor deployment management*

DATA PIPELINES

*Exchangeable formats for export/import & publication*

{JSON}

# EXPOSURE HEALTH INFORMATICS ECOSYSTEM (EHIE)

**Data Acquisition Pipeline**

- Hardware and software, wireless networking, and protocols to support easy system deployment for robust sensor data collection in homes, and monitoring of sensor deployments.

**Participant Facing Tools**

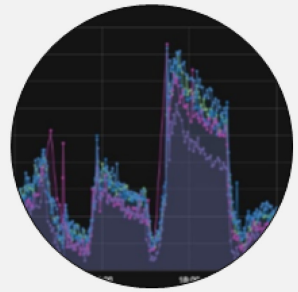
- Annotate participant generated data, display sensor data, and inform participants of their clinical and environmental status.

**Computational Modeling & Uncertainty Characterization**

- Generate high resolution spatio-temporal data in the absence of measurements as well as for recognition of activity signatures from sensor measurements.
- Characterize uncertainties associated with collected or computed data

**Central Big Data Integration Platform**

- Standards-based, open-access infrastructure that integrates study-specific and open sensor and computationally modeled data with biomedical information along with characterizing uncertainties associated with these data.

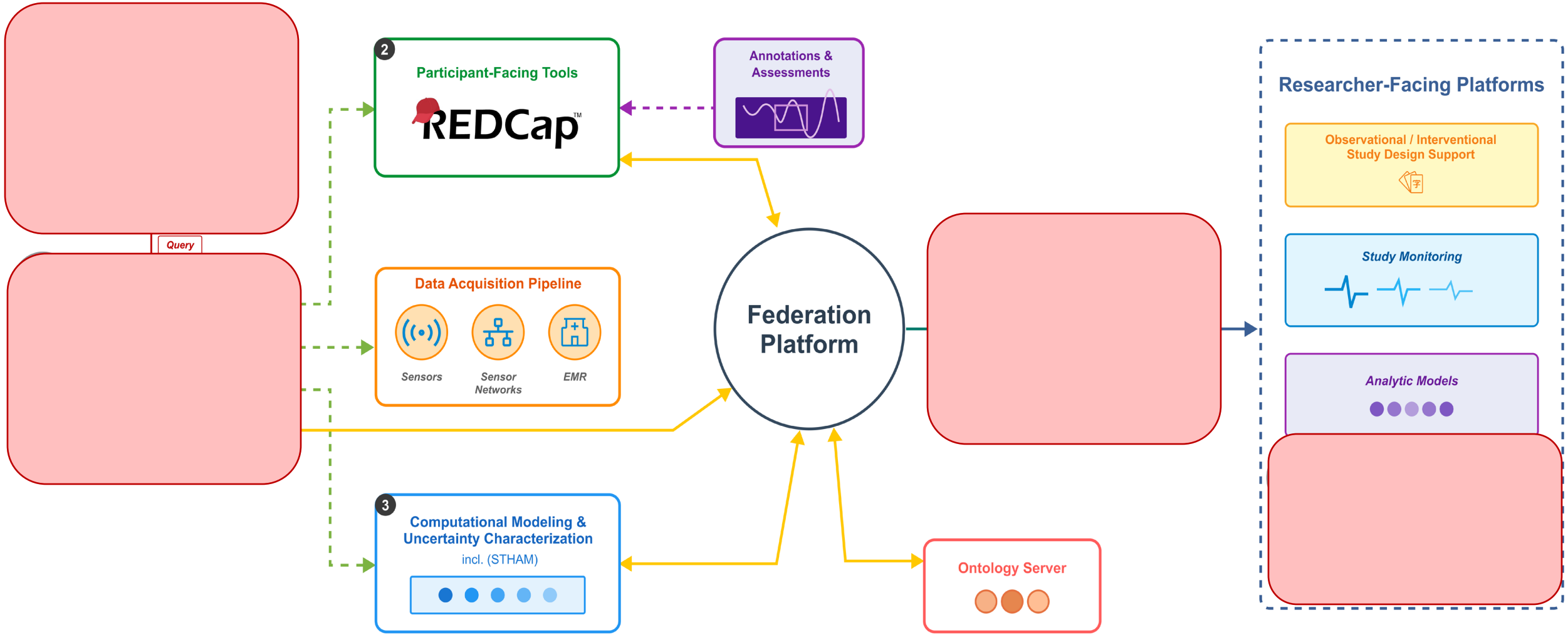


**Researcher Facing Platforms**

- Tools and processes for researchers performing exposomic studies of a variety of experimental designs.

Gouripeddi, Ramkiran, Philip Lundrigan, Sneha Kasera, Scott Collingwood, Mollie Cummins, Julio C. Facelli, and Katherine Sward. "Exposure Health Informatics Ecosystem." In *Total Exposure Health*, pp. 233-278. CRC Press, 2020.

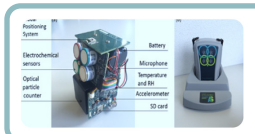
# SMARTER IN ACTION



# SCALING EHIE WITH SENSOR MDR

- Agnostic to


Measured Properties


Sensor Technologies

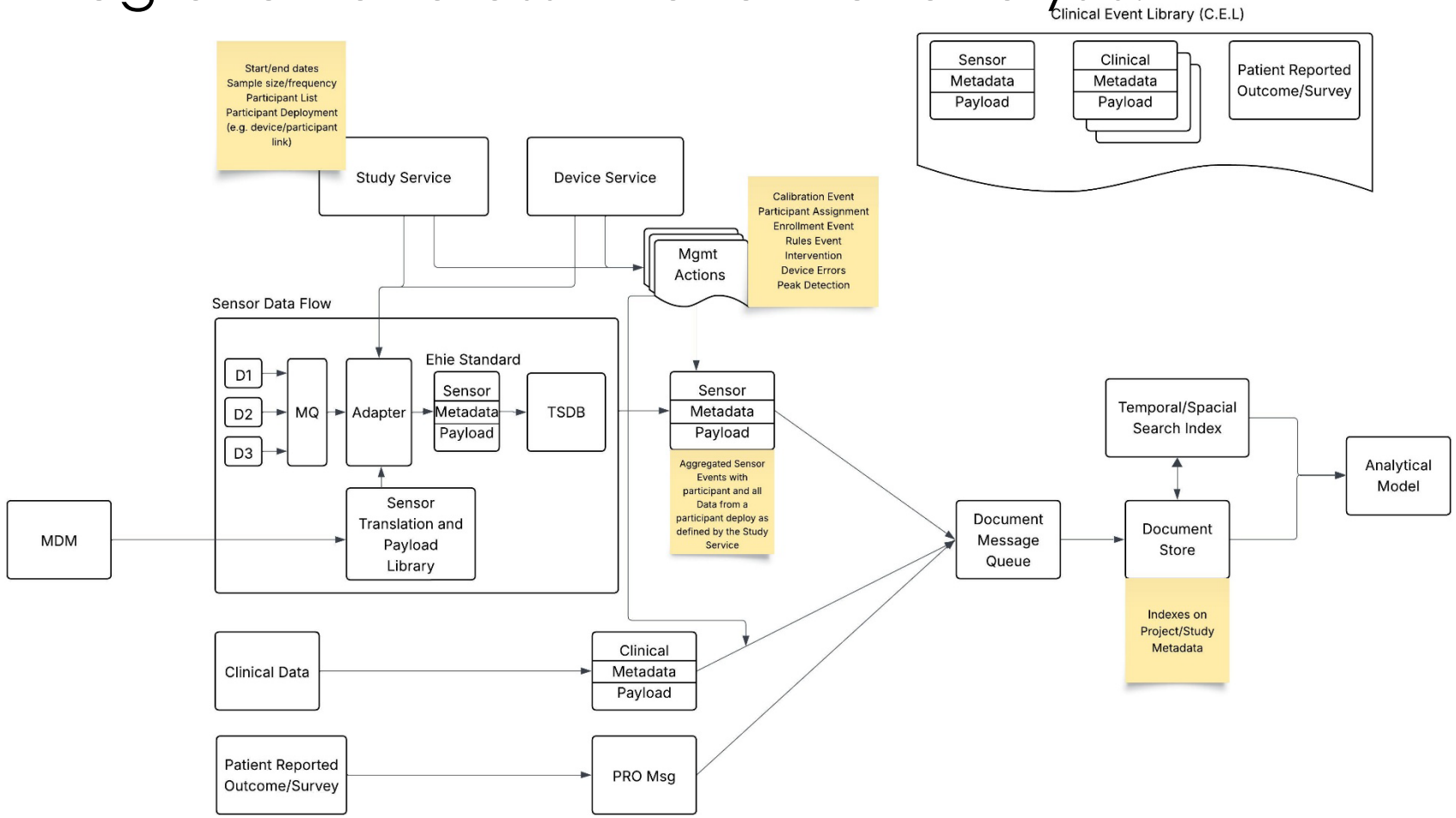

Study Designs


Local IT Infrastructure

- Metadata-centric architecture
  - Pipeline resiliency
  - Automated IoT device enrollment

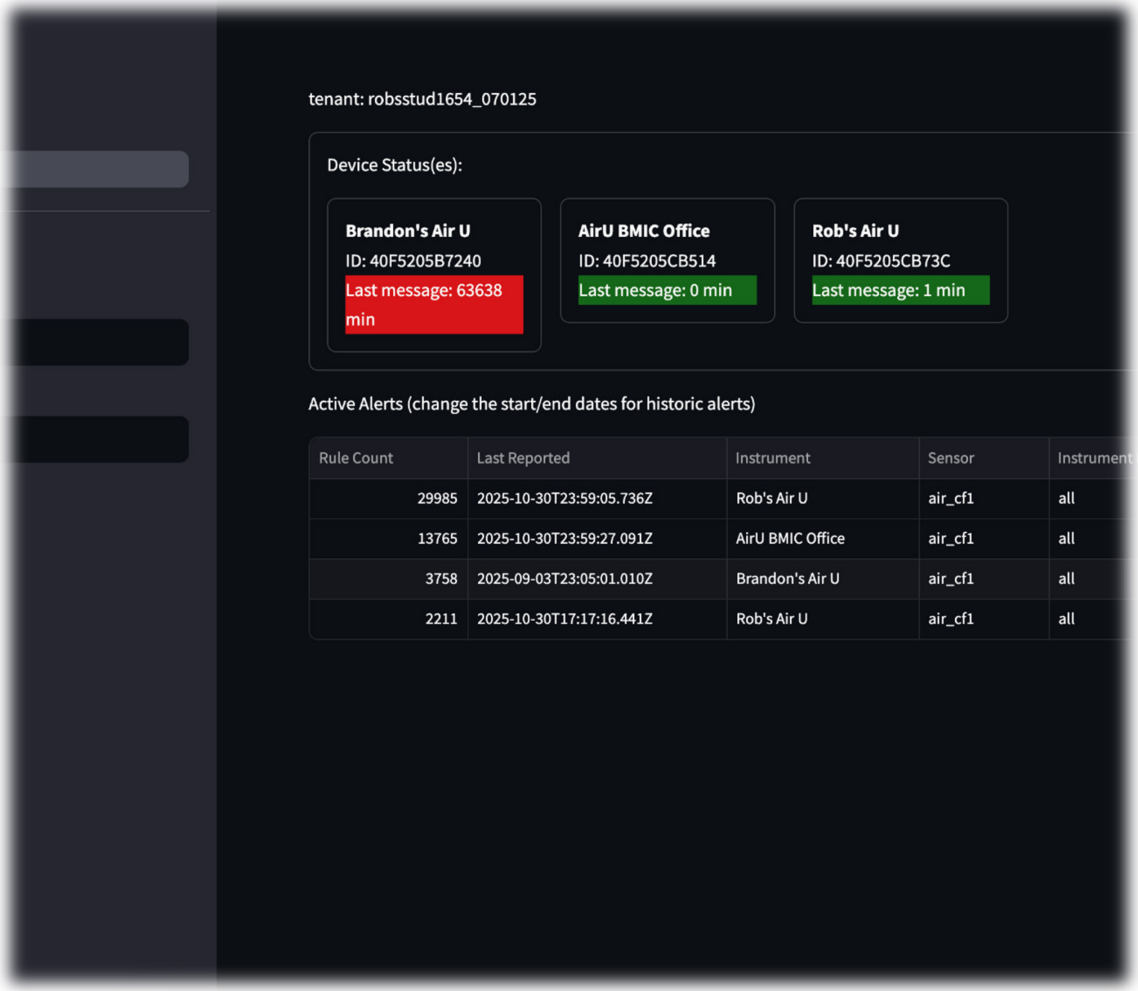
# ABSTRACTING TO METADATA-CENTRIC ARCHITECTURE

- Future studies will need to describe the metadata about their sensors and data sources into the metadata store, which will then be leveraged for study operations and sensor deployments, as well data integration and assimilation for analysis.



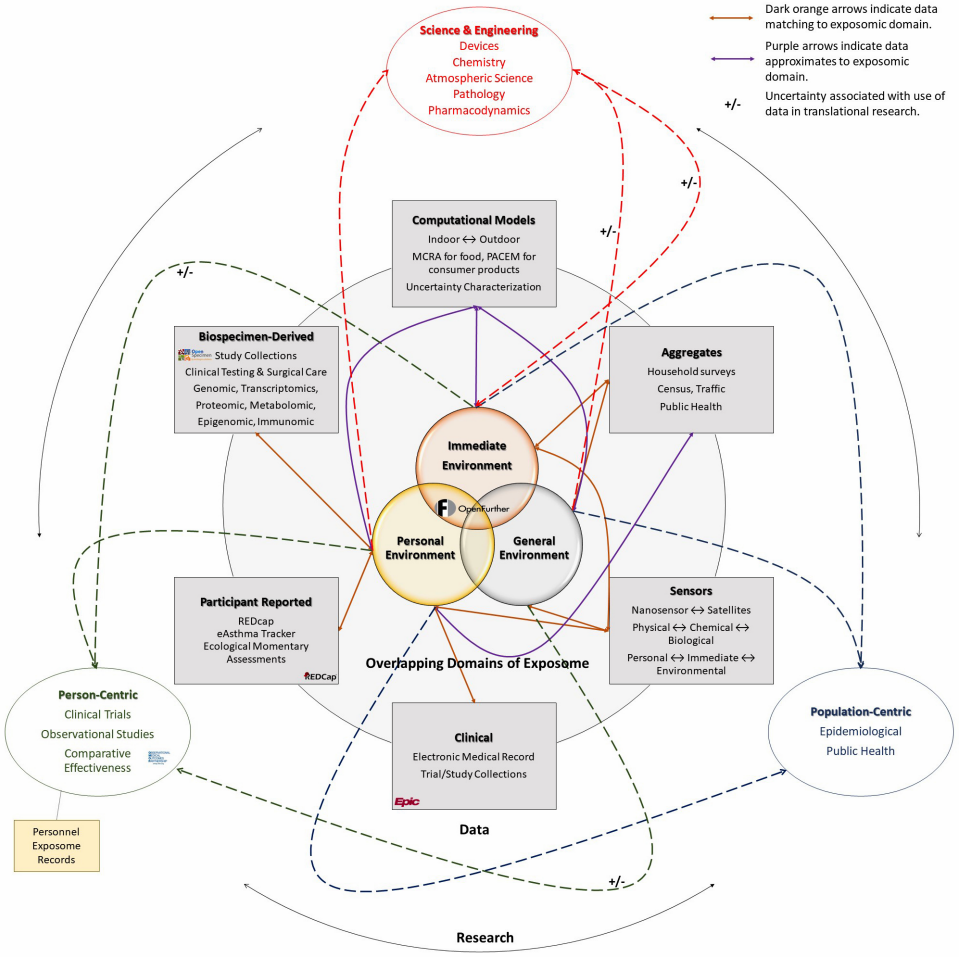
# SENSOR DEPLOYMENT MANAGEMENT

- Sociotechnical complexities of managing sensor deployments in the real-world - costlier than sensors, resource intensive.
- Observability of sensor functionality and data streams critical to success of studies.

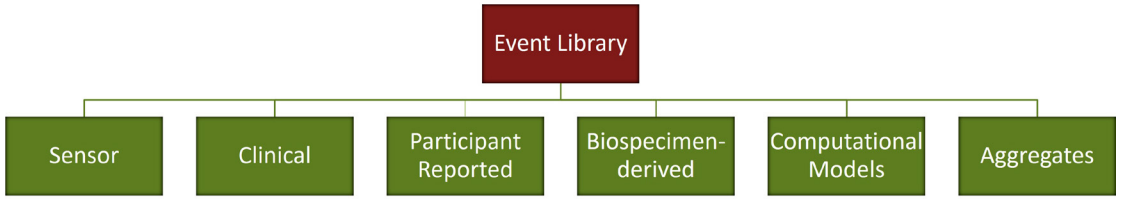



**Sensor Dashboard**: https://app1-ehie.ctsi.utah.edu/dashboard

# ENABLE GENERATION OF EVENT-BASED FORMATS FOR DATA INTEGRATION




Conceptual Domains of the Exposome



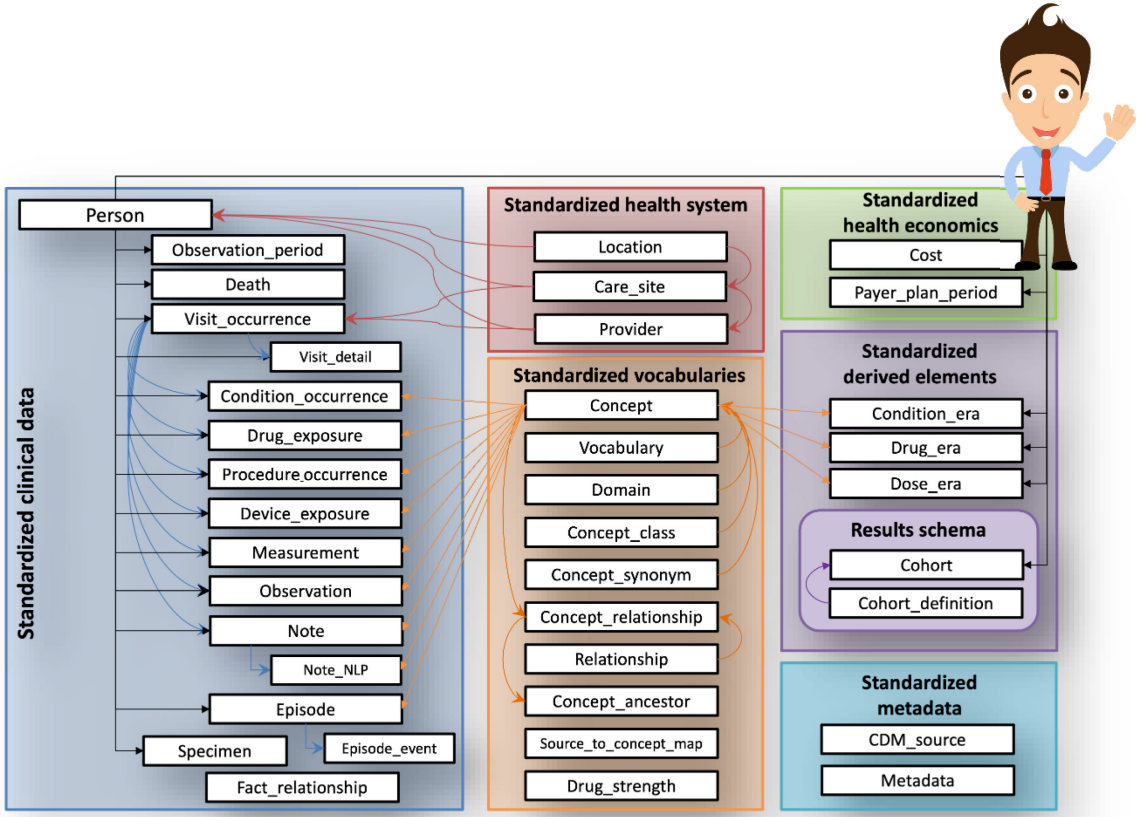

Event types representing different domains in exposure health.

Develop metadata specifications and logical models for events.

Develop transformative functions and generate exemplar sensor and clinical events.

Gouripeddi, R., Burnett, N., Cummins, M., Facelli, J. C. & Sward, K. A Conceptual Representation of Exposome in Translational Research. in AMIA 2017 Annual Symposium (2017).

# INTEGRATING DATA REPRESENTING DISTINCT OBJECTS IN EXPOSURE HEALTH




Clinical Data

https://ohdsi.github.io/CommonDataModel/


Exposure Data

# INTEGRATION CHALLENGE

- How do you consistently represent data that is:

Multi-scale, & multi-model

Represents different root objects

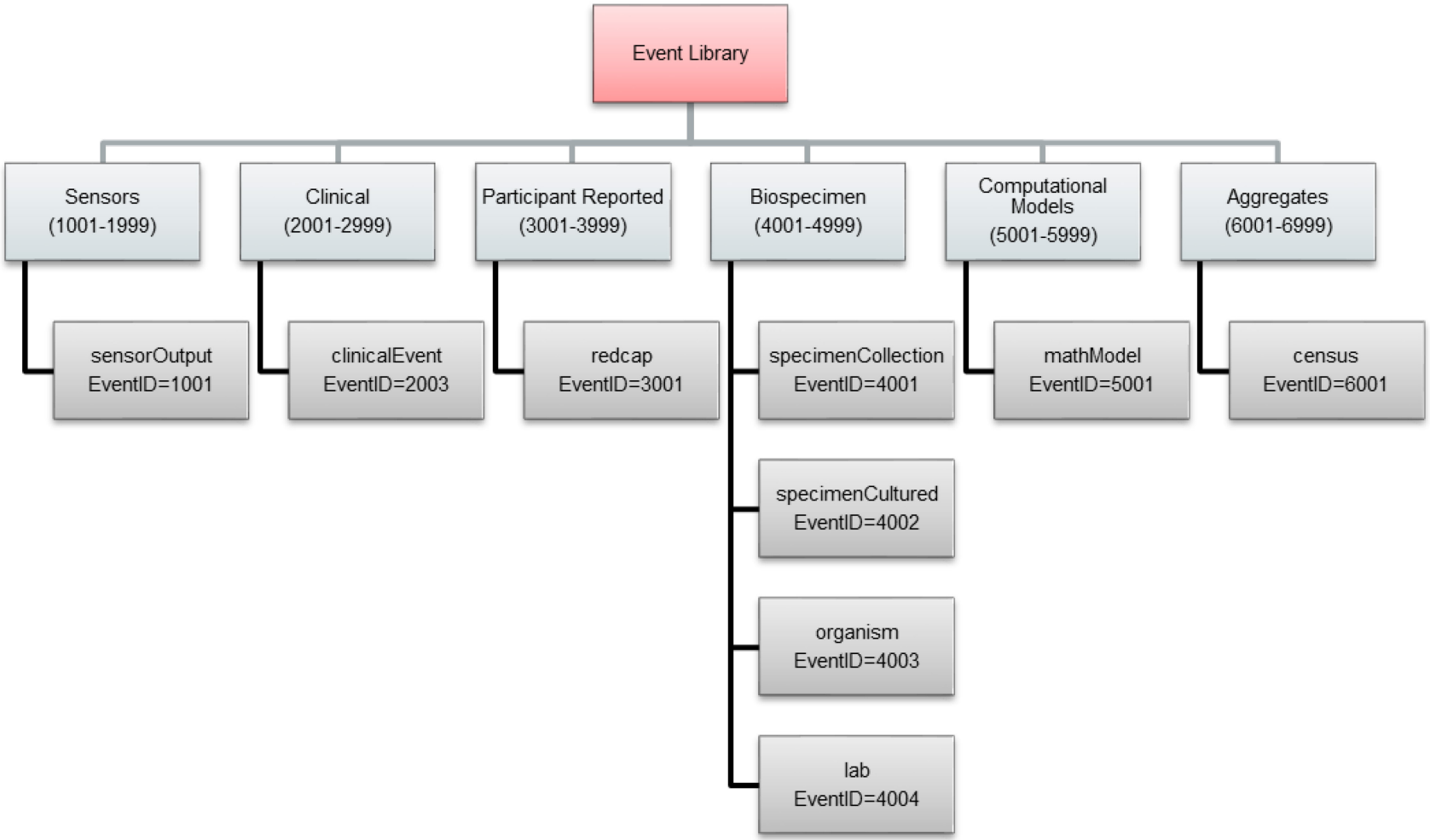
- Person
- Environment

Have different temporal resolutions.

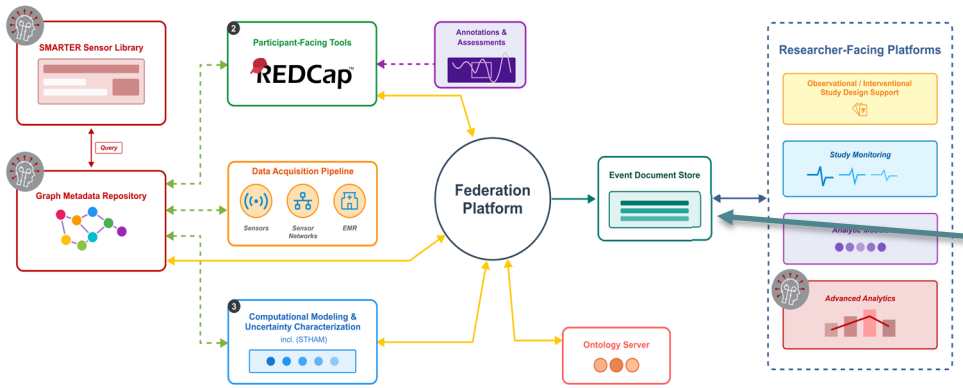
# EVENT

- Definitions:
  - Something that happened or happens.
  - Fundamental entity of observed physical reality represented by a point designated by three coordinates of place and one of time.
- *Event: {Entity of observed physical reality, Spatial coordinates, Temporal coordinate}.*

# CONCEPTUAL REPRESENTATION OF EVENTS



# SENSOR EVENT - TEMPERATURE





```
[
  {
    "prisms": {
      "creationDT": "2018/07/20 06.34.40",
      "docID": "integration::16",
      "endTime": "201703312359",
      "integrationID": 16,
      "sources": "NWS Temperature,",
      "startTime": "201703010000",
      "study": "0"
    }
  },
  {
    "prisms": {
      "dataSource": "nws",
      "docID": "sensorOutput::1792607",
      "eventID": 1001,
      "eventName": "sensorOutput",
      "integrationID": 16,
      "location": {
        "altitude": 4783,
        "latitude": 41.11112,
        "longitude": -111.96229,
        "stateProvince": "UT"
      },
      "observationDT": "2017-03-01T00:03:00Z",
      "species": "air_temp",
      "uom": "Celsius",
      "value": -2
    }
  },
```

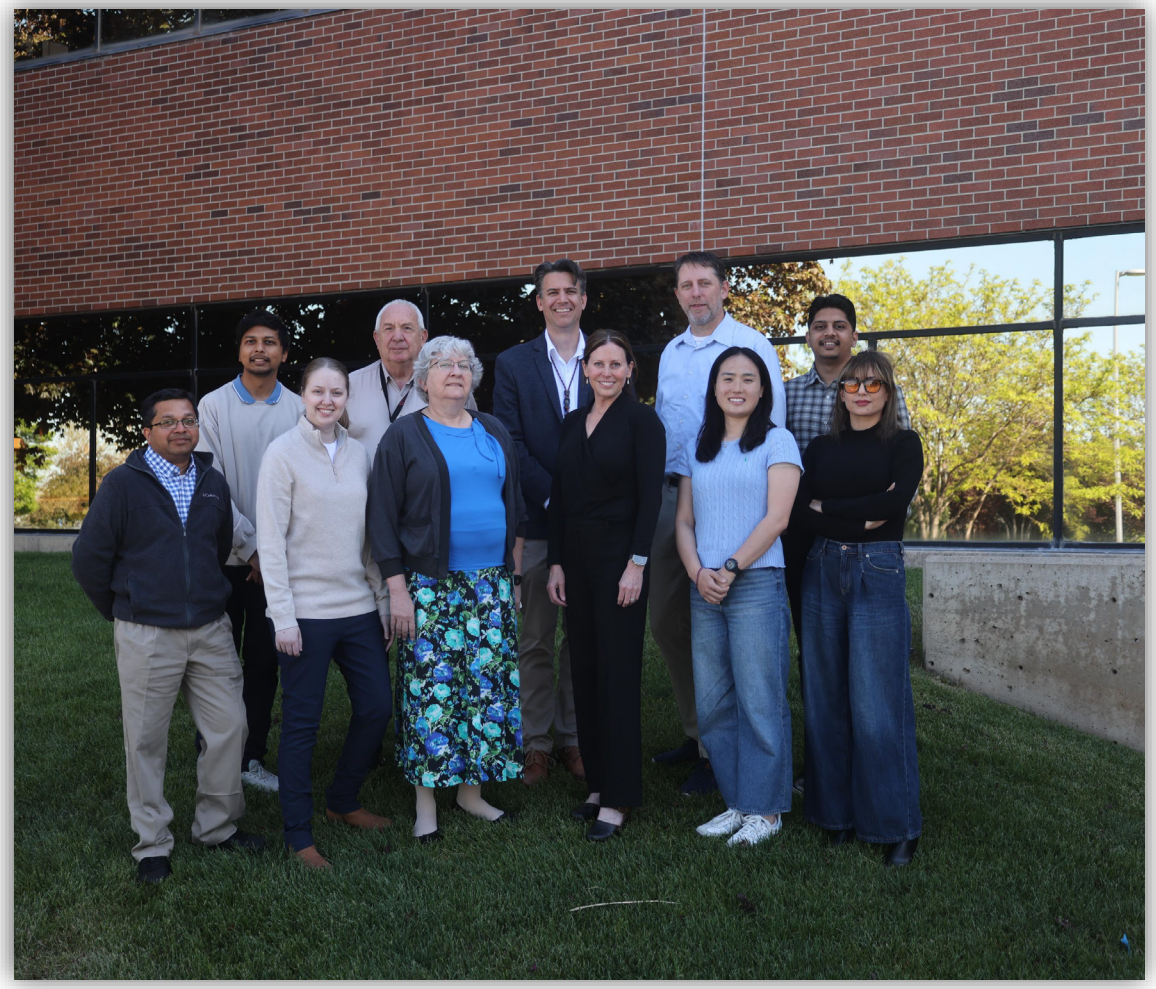

Location

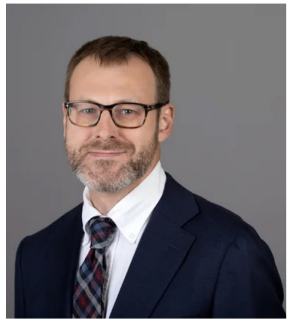
Time

Observed Entity

# CLINICAL EVENT - CONDITION

# THE TEAM





- Partners, Experts and Collaborators

SPENCER FOX ECCLES SCHOOL OF MEDICINE UNIVERSITY OF UTAH

COLLEGE OF NURSING UNIVERSITY OF UTAH