COMPANY INTRODUCTION & CAPABILITIES OVERVIEW

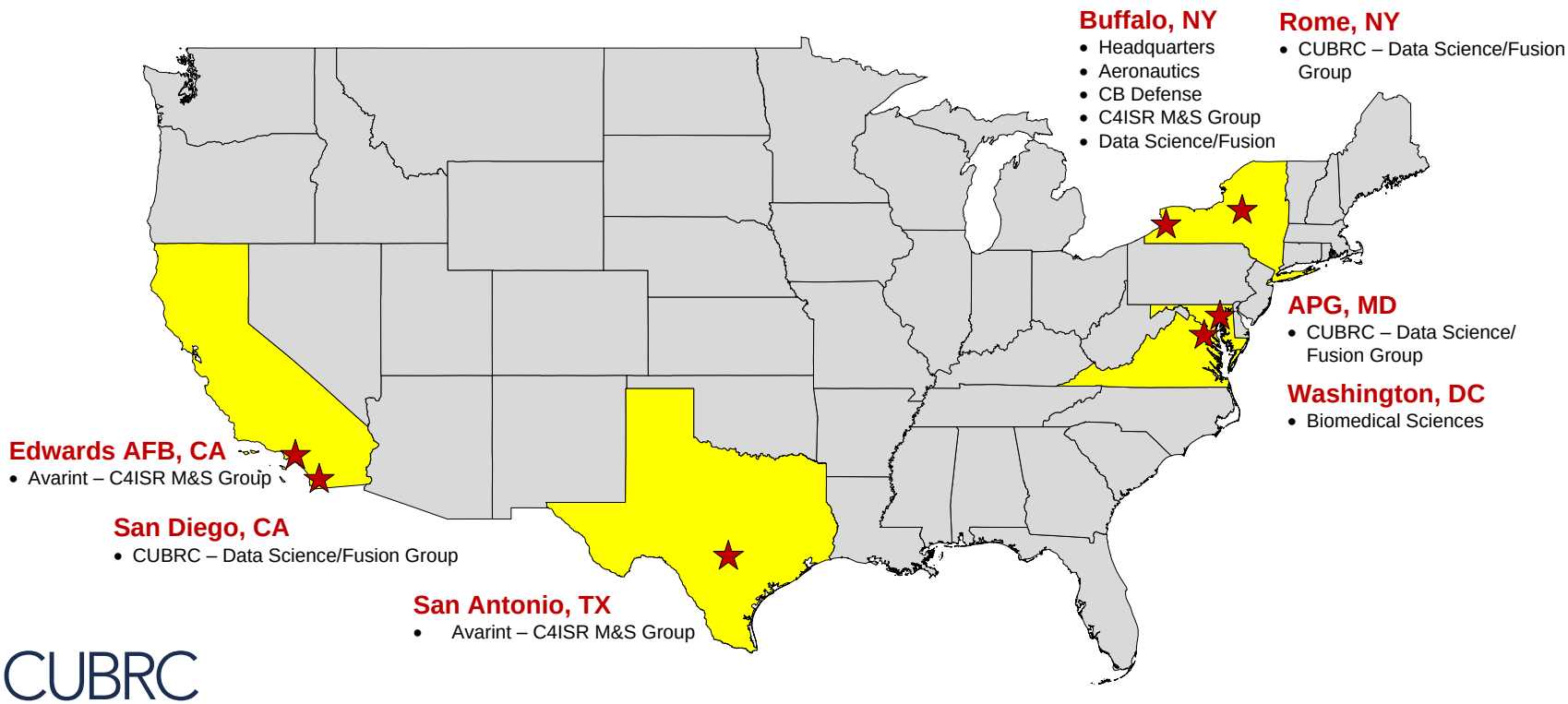
IARPA SINTRA Program

CUBRC
Advantage through technology

August 2022

Introduction to CUBRC and Avarint

- **CUBRC is an independent, scientific not-for-profit corporation established in 1983.**
- **Avarint is a wholly-owned small business subsidiary of CUBRC, established in 2013**
- **Combined CUBRC-Avarint Revenue: ~$57M, 175 employees**
- **Cleared Personnel and Data Processing/Storage Facilities**
- **DCAA Approved Accounting, Purchasing, Property Management Systems**



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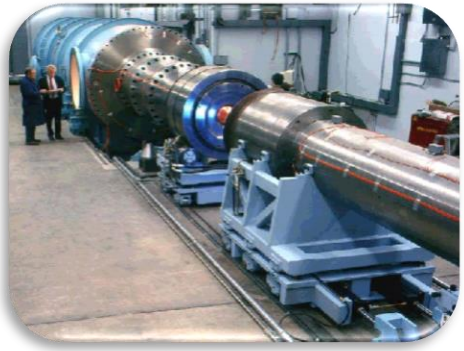
CUBRC Lines of Business



Hypersonic/Aeronautic Research & Testing

- Large Energy National Shock (LENS) Tunnel Facilities
- Computational Fluid Dynamics
- Vehicle and Test Diagnostics
- Dynamic Separation Testing

Chemical & Biological Defense RDT&E

- Live Agent RDT&E Labs
  - Chemical Agents
  - Biological Agents
- Biomedical Countermeasure Drug Development

Information Exploitation

- Data Science, Information Fusion and Intelligence Data Analysis
- Integrated Air Defense System M&S
- Mission Planning and Optimization

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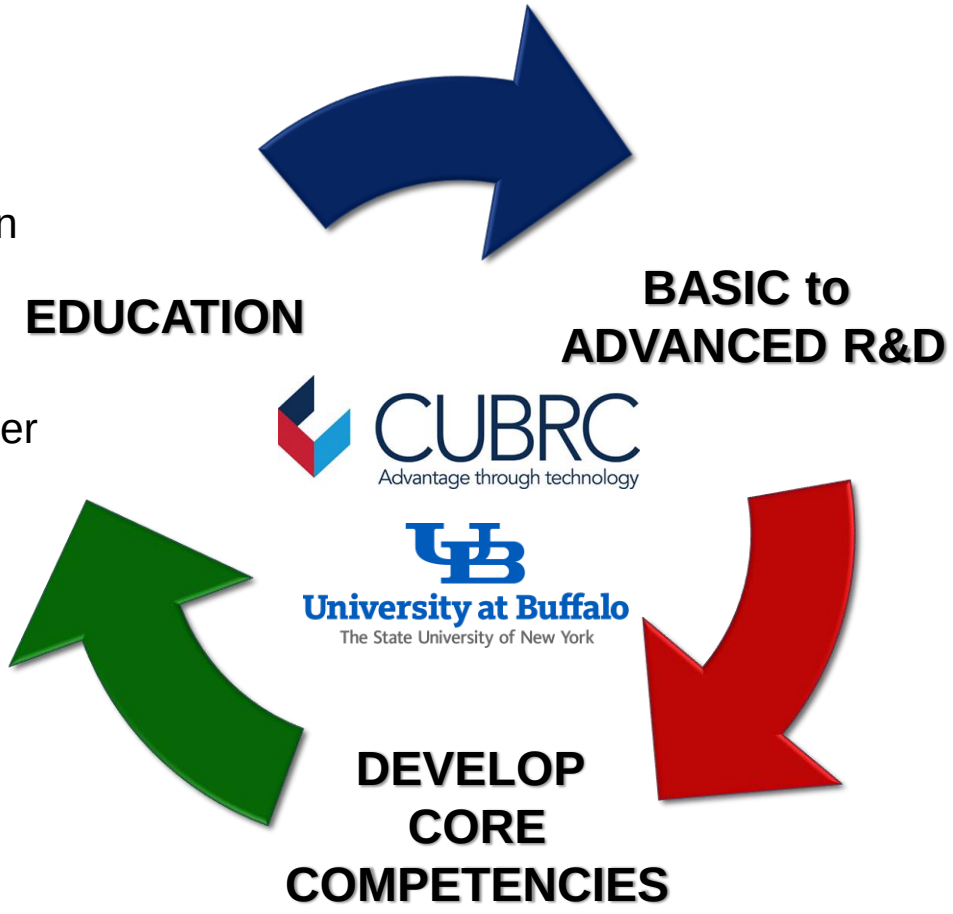
Avarint
A CUBRC Company

CUBRC/University at Buffalo (UB) Partnership

- **Current CUBRC/UB Partnerships**
  - University Centers
    - Center for Multi-Source Information Fusion (CMIF)
    - National Center for Ontological Research (NCOR)
    - Center for Space Cyber Strategy and Cyber Security $(CS)^3$
  - Industrial Systems Engineering
    - Intelligence Data Collection Optimization
    - Human Factors R&D
  - Mechanical and Aerospace Eng.
    - Space Situational Awareness (SURI)
    - Transportation Systems
    - Hypersonic and Aeronautic R&D (MURI)

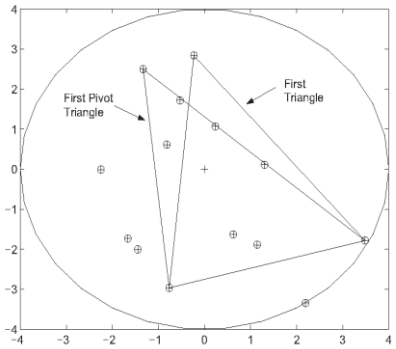


Space Domain Awareness & Missile Defense

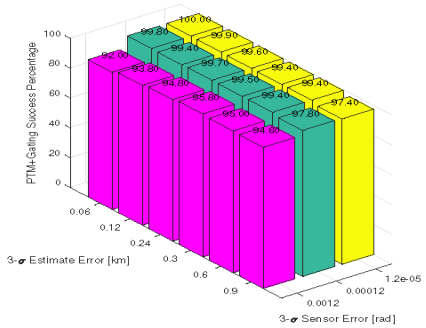
- **CUBRC currently supporting DoD/AFRL initiative to provide advanced indications and warnings to support risk reduction component of SDA**
  - Space Object Characterization, Classification and Identification (CCID)
    - Level 0/1 MASINT reduction to *passively* understand temporo-spatial features associated to space objects
    - Identify, understand and predict potential changes in space object states
    - Performing both theoretical and experimental studies
    - Working with Dr. Crassidis at UB and his students
  - SITA – Situation Identification and Threat Assessment
    - Aggregate feature information with contextual data to identify and assess evolving situations in the combined air-space-cyber domain
    - Project plausible future actions with infer potential impending threats to space assets
    - Dr. Crassidis providing SDA subject matter expertise for effort
  - Space Object Ontology (SOO)
    - Provides a rigorously developed foundation for understanding and leveraging multitudes of data sources across the AFRL space enterprise supporting SDA
    - Working with Drs. Crassidis and Smith
- **Missile Defense Agency**
  - Supporting three efforts aimed at assessing how uncertainty rolls up and factors into ballistic missile defense
    - Supporting development of a flexible testing and evaluation framework leveraging probabilistic relational models
    - Incorporate the effects of second-order uncertainty into decision making processes, i.e. track association, track fusion, classification, etc.

Detection/Data Association

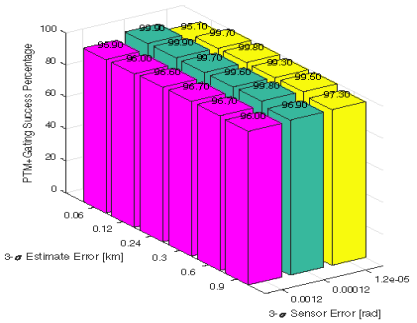
- **Measurement-to-Track association is foundational to developing quality tracks**
  - Typical methods involving gating consider objects only in a pairwise fashion
  - Novel approach leverages methods for star identification to enhance overall process to Space Objects
  - UB developed method for efficient, robust star identification using planar triangles [1], which was then enhanced for Space Object DA
    - Space Object Catalog used to create a “Star Map” for the time of observation
    - Angular separation, area, moment of inertia used to create “observables” from space objects in view
    - Search “star map” based on these observables (efficient process)



Focal plane measurements



(a) Without false detections



(b) With false detections

Use of Planar Triangle Method (PTM) yields near perfect association results of Space Objects even in the presence of false detection (clutter)

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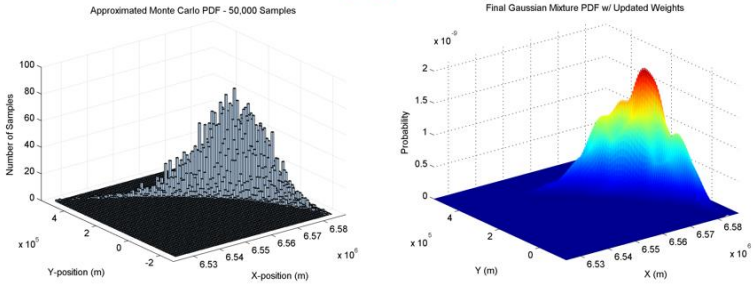
[1] Cole, C.L., and Crassidis, J.L., “Fast Star Pattern Recognition Using Spherical Triangles,” *JGCD*, 2006

Tracking

- **CUBRC/UB have developed enhanced approaches for tracking space objects and accounting for non-Gaussian effects**
- **Methods leverage collections of Gaussians to represent uncertainty in the objects motion**
  - Algorithms based on *accurate uncertainty information* have the potential to rapidly detect changes in orbital state
  - Enables faster sensor response, accurate tracking and collision risk assessment

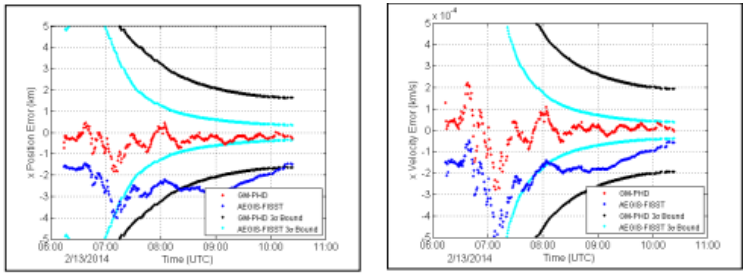
Position Uncertainty After 1 Orbit in LEO



50,000 Monte Carlo Samples | *Adaptive Gaussian Sum Mixture*

- **Entropy-Based Data Association/ Uncertainty Quantification**
  - Information theory-based metrics enhance accuracy of measurement-to-track association over conventional algorithms

- **Multi-Target Bayesian Filtering**
  - Applicable when tracking multiple targets within a scene
  - Alleviates measurement-to-track association problem and allows for target (dis)appearance



GMM-PHD Tracker produces consistent state estimates and uncertainties

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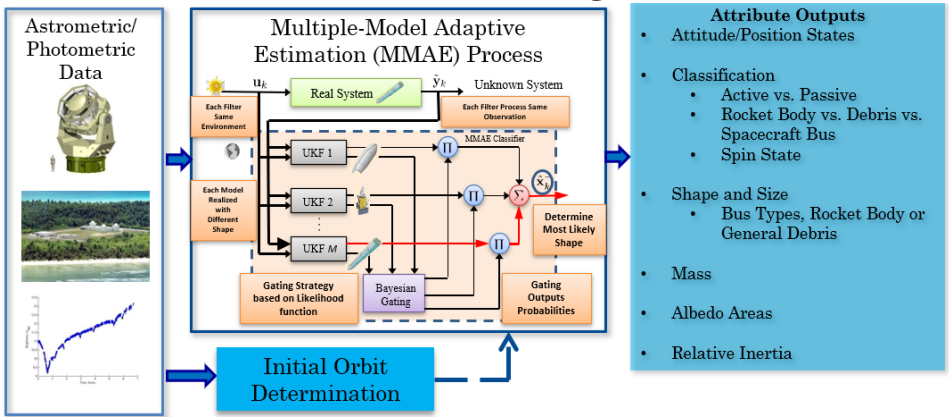
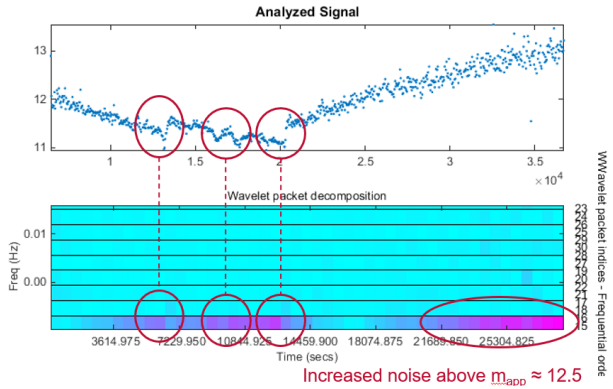
Attribute Estimation and Characterization

- **Attributes and characteristics play a vital roll in space domain awareness**
  - Aid in data association problem, particularly in cluster/multi-target situations
  - Used to enhance dynamic modelling (e.g. mass, area) for improved tracking
  - Change detection for active objects
- **Two approaches developed, tested and verified using real data**
  - Model-based
    - Multiple Model Adaptive Estimation-based (MMAE) approach uses a collection of candidate models
    - Coupling of orbital and attitude dynamics result in observability of a wide range of features
  - Data-driven wavelet analysis
    - Considers only the light curve signal from an observed satellite
    - Wavelets are a class of functions that are fit to the data by translation and scaling in time
    - Easily able to identify changes in spin rate, and attitude maneuvers
    - Real data (GOES-R) used to verify approach (potential to anticipate orbit maneuver “left of the event”)





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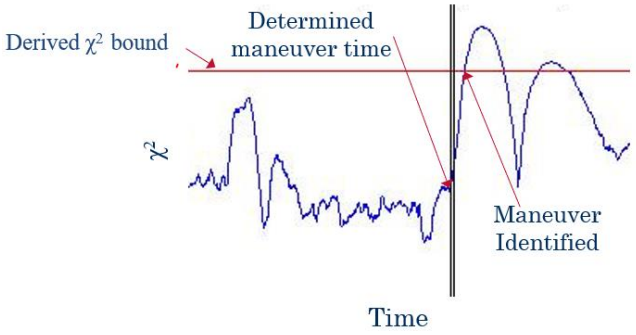
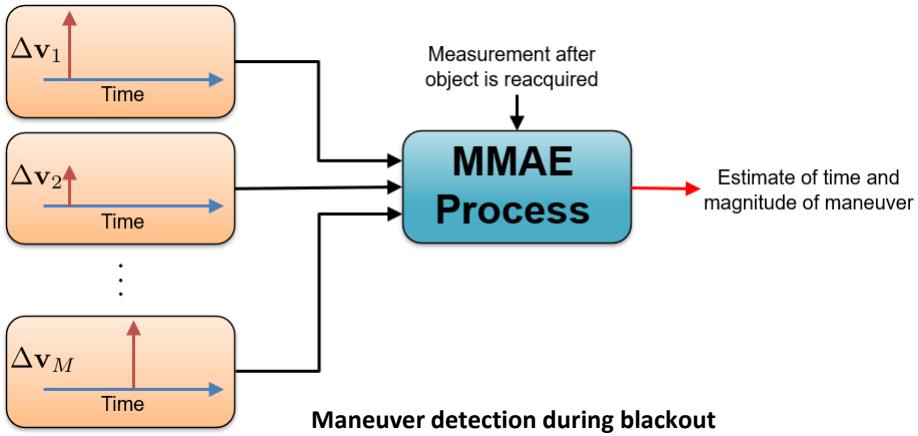
Maneuver Detection

- **Near real-time maneuver detection algorithm using sequential-state estimation**
  - Maneuvers identified in real-time (no batch filtering necessary)
  - Physics-based filtering approach – no training needed
  - Works best for orbit changing maneuvers but has also been successfully applied to station keeping
  - Maneuver identified as occurring when χ^2 bound breached
  - Can also be adapted to estimate $\Delta\mathbf{v}$
- **Maneuver estimation during blackout periods**
  - Based upon MMAE concept where collection of models is different maneuver profiles
    1. Identify that a maneuver has occurred using sequential estimation
    2. Instantiate MMAE process to estimate the maneuver



Maneuver Detection Approach



Maneuver detection during blackout

The maneuver detection approaches have been validated using real-world data for several GEO cases, but the approach is extensible to LEO

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