Joint R&D and Ops:
a Working Paradigm for SSA

Integrity ★ Service ★ Excellence

23 July 2017

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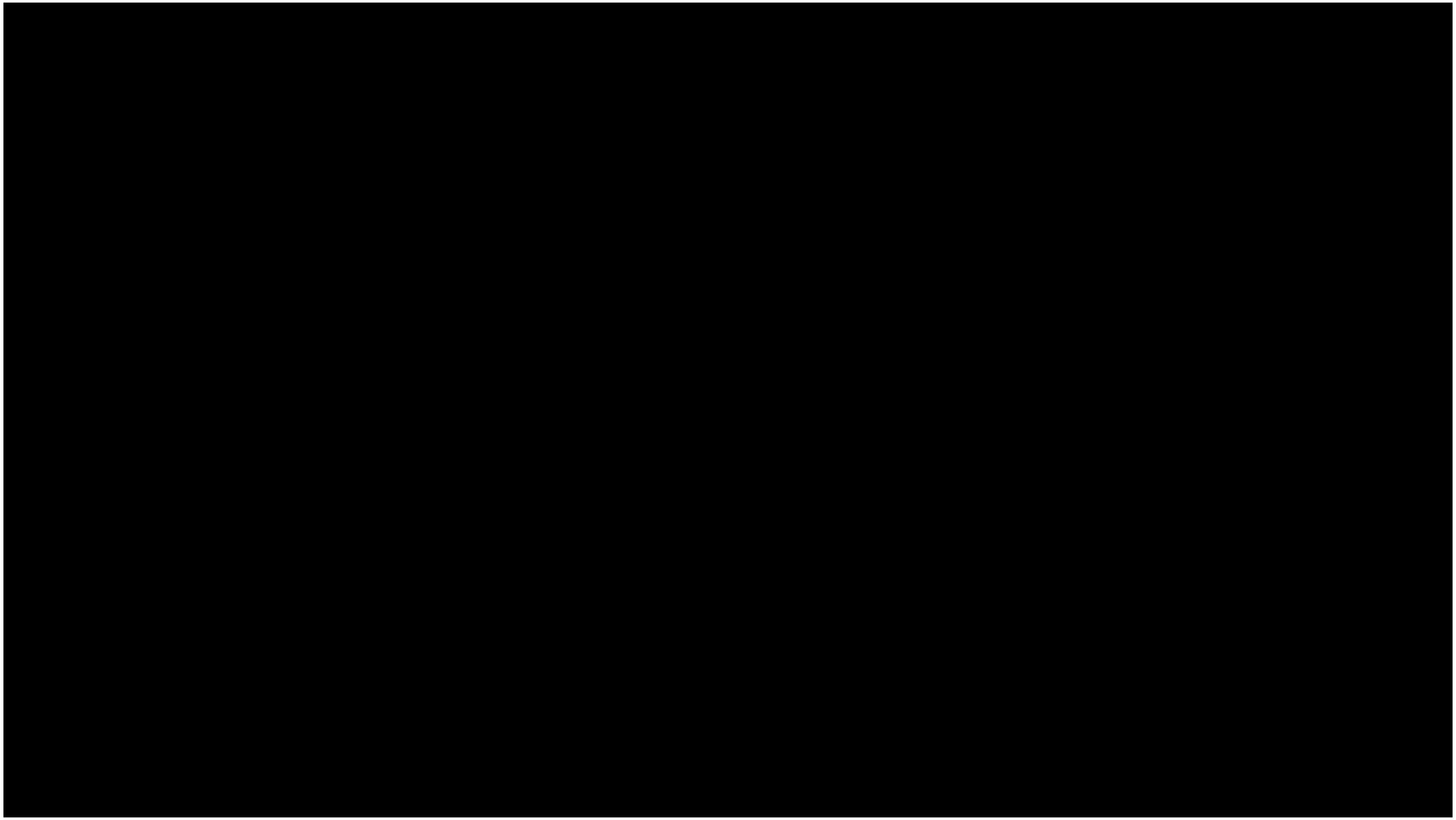


Joint R&D & Ops: Innovation Engine

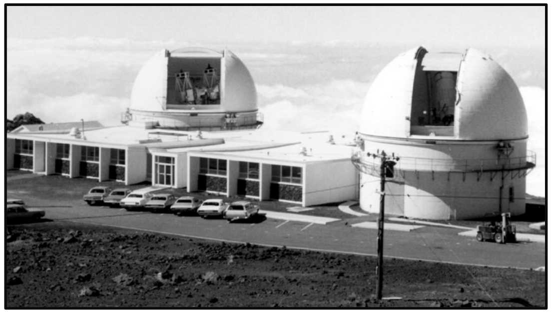
- ***AMOS Overview:* History**
  - **Joint R&D and Ops site**
- ***Operations:* Contributing Sensor on SSN***
  - **LEO Images**
  - **GEO Metrics**
- ***R&D:* Innovation Engine Examples**
  - **R&D improves Ops**
  - **Ops improve R&D**

**** Space Surveillance Network***

AMOS History

Over 50 Years of Service to the Department of Defense

1963 Construction begins on **Advanced Research Projects Agency** (ARPA) Midcourse Observation Station (AMOS) atop Haleakala.

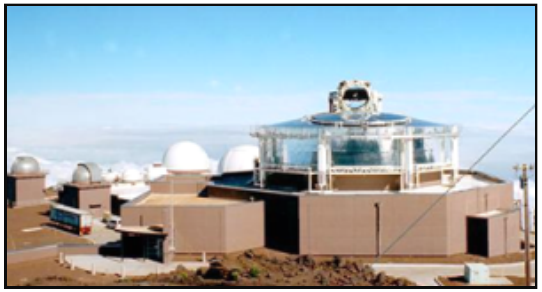


1982 Compensated Imaging System installed on the 1.6 m telescope, one of the earliest applications of **adaptive optics**

1984 Site transition **from DARPA to USAF**

1990 The Relay Mirror Experiment was conducted; it was the **first successful relay of a laser** from a ground station to an orbiting relay mirror and back

1993 Maui High Performance Computing Center established to provide **high performance computing** capabilities to MSSC

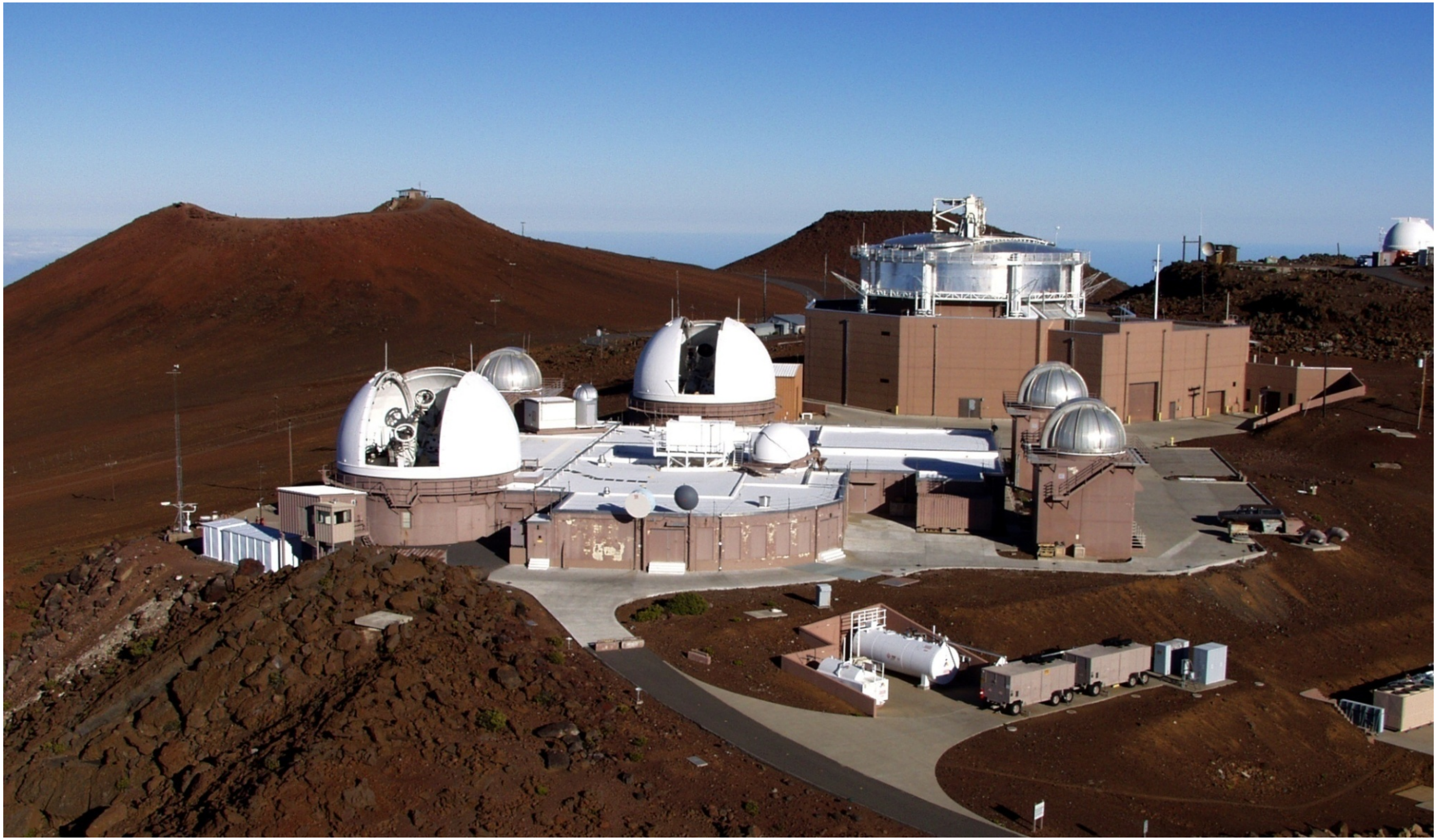


1999 The 3.6 m **Advanced Electro-Optical System (AEOS) telescope** becomes operational

2000 **Air Force Research Laboratory** takes over operations and maintenance of site from Air Force Space Command

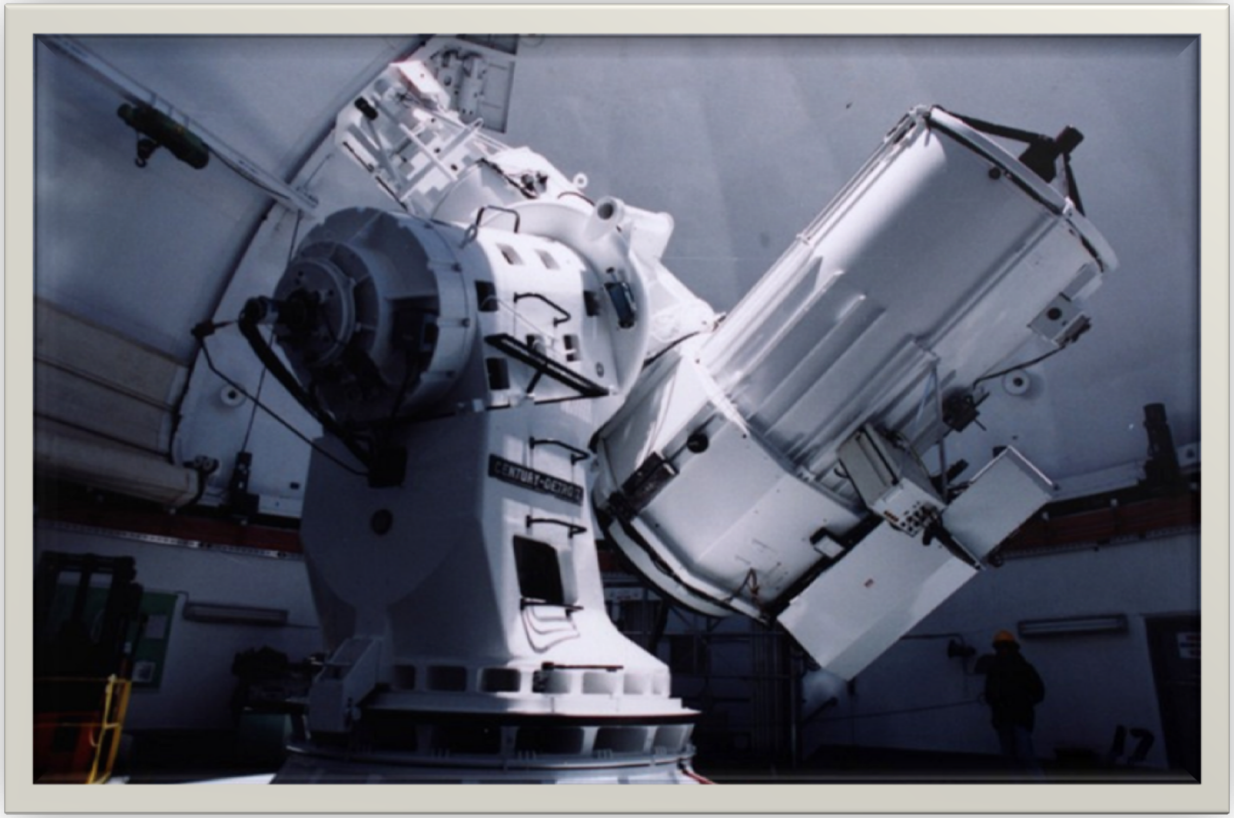
2012 Phased **modernization and upgrades** to the MSSS complete

World Class Observatory with Ideal Viewing Conditions



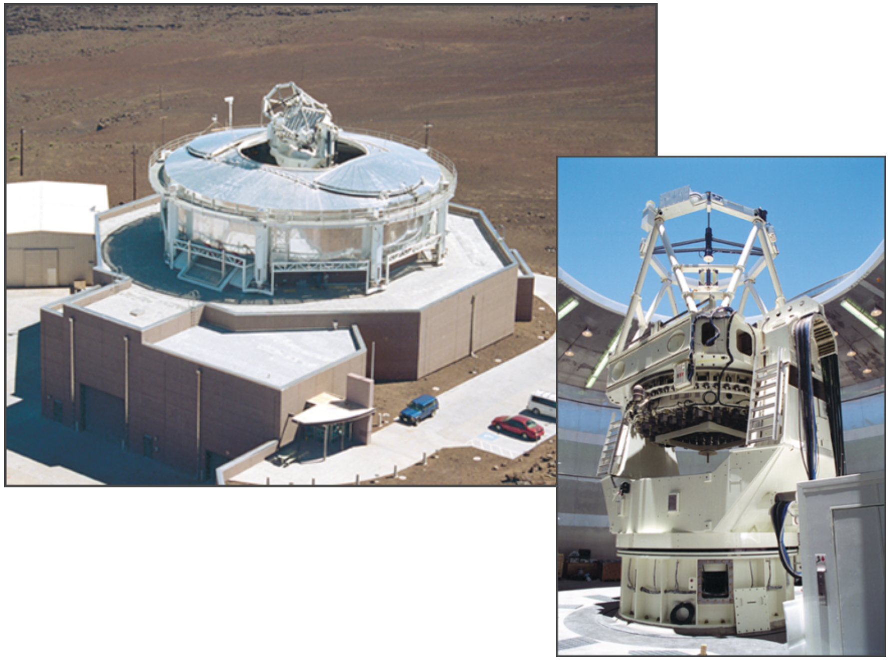
3.6 meter Telescope

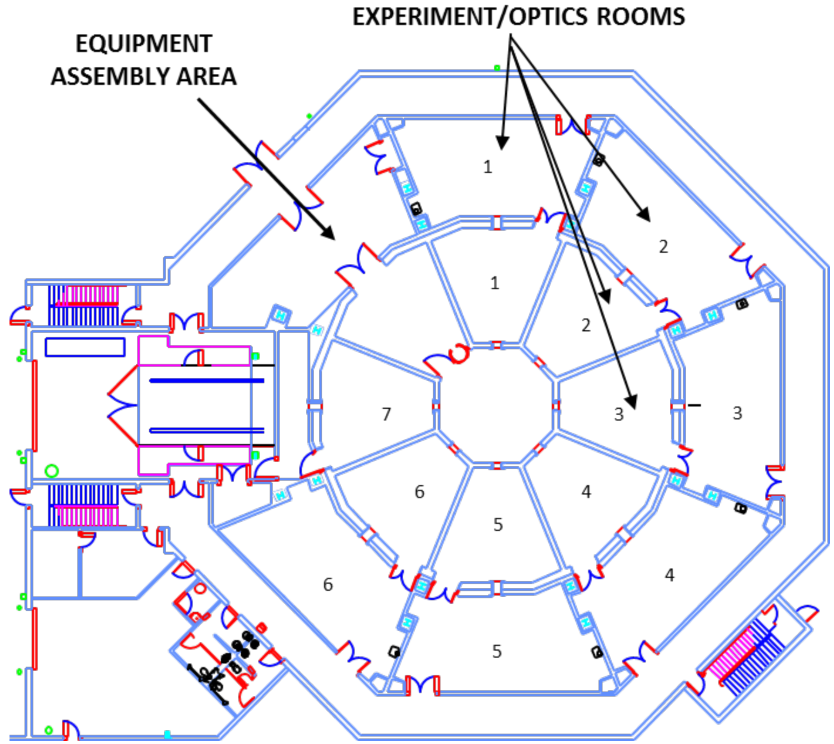
1.6 meter Telescope



1.6-meter telescope, inside standard dome

Versatile Electro-Optical System





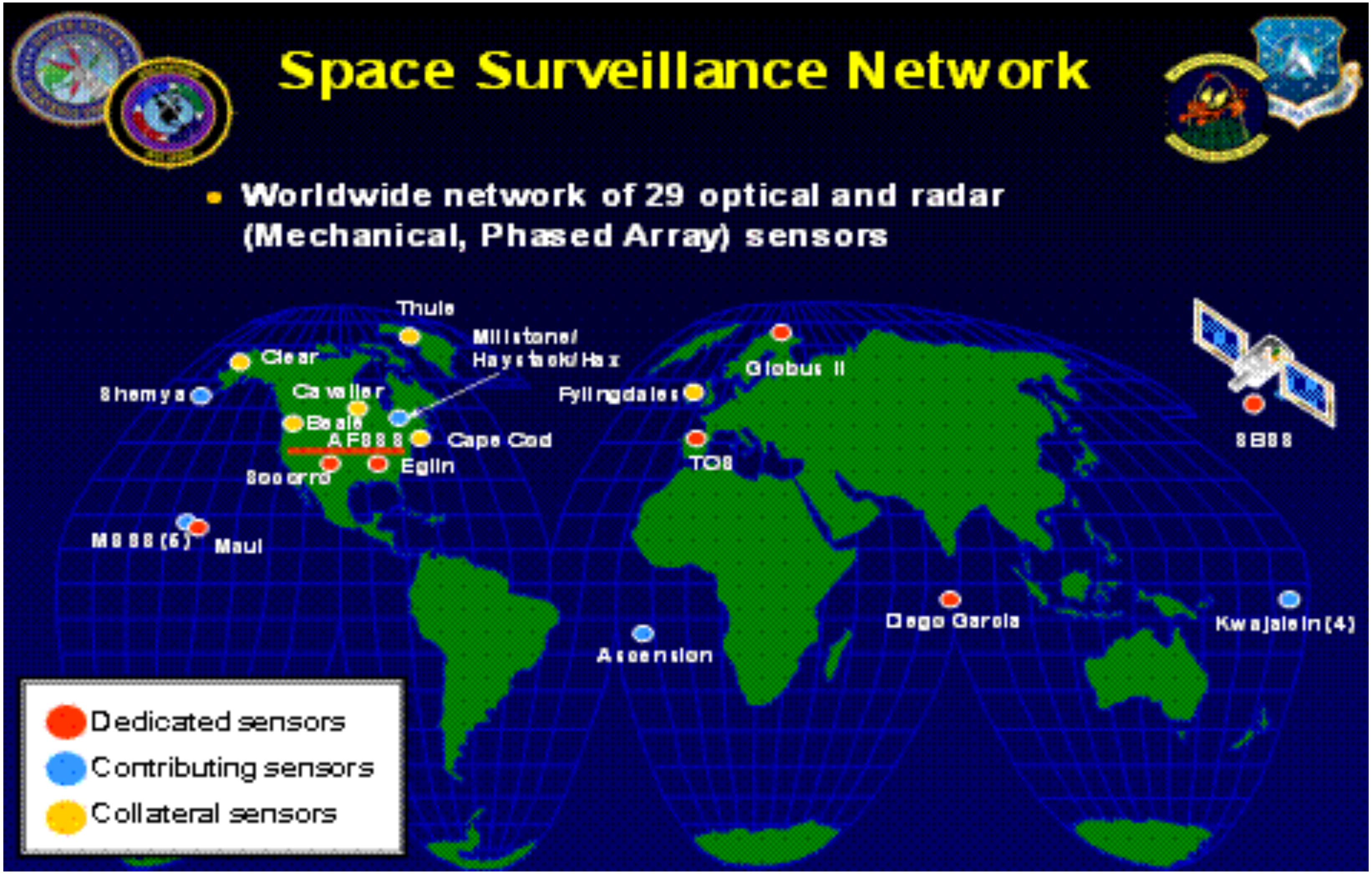
Unique configuration enables

- **Largest aperture telescope capable of tracking low earth objects**
- **Ability to support multiple observers seamlessly**

Timely response to multiple customers

AMOS Operations

AMOS Contributing Sensor to Space Surveillance Network



AEOS Visible Imager

3.6m Telescope

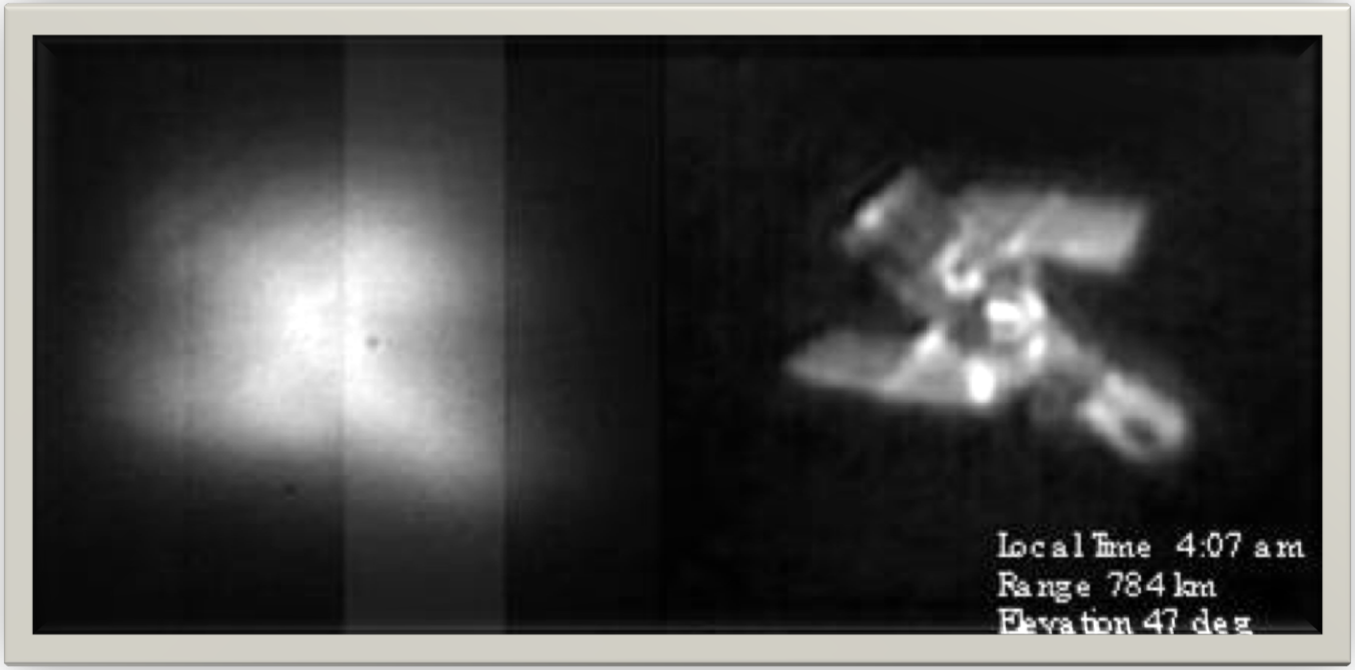
- Adaptive optics compensated
- Derotated
- Dispersion corrected
- High-res terminator images

Hubble Space Telescope Adaptive Optics (AO) plus multi-frame blind deconvolution processing

High-resolution Visible Imagery

Speckle Imaging, Post Processing

1.6m Telescope

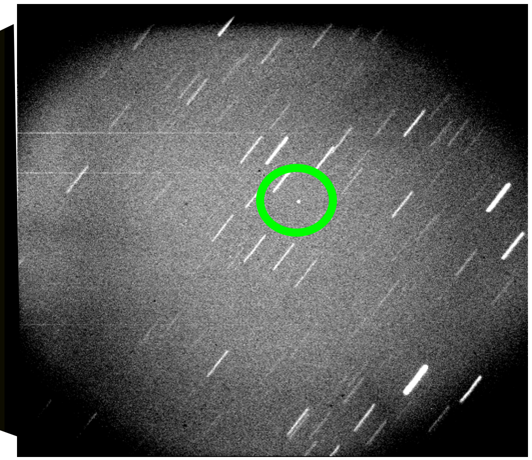


Single short-exposure **Speckle-processed**

Daytime and Terminator Imagery

RAVEN
Autonomous Deep-space Tracking

0.4m Telescope



Capabilities

- Accurate deep space metrics
  - ~125m at GEO
- Autonomous operations
  - 3000 tracks/month
- Photometric observations
  - 17^{th} M_v(magnitude)

Employed Techniques

- COTS equipment
  - Telescope and sensors
- Astrometry
  - Accurate positions from star field
- Autonomous control
  - Telescope and dome
  - Data dissemination

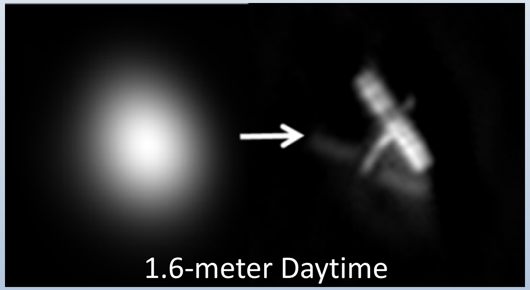
GEO Metrics and Tracking

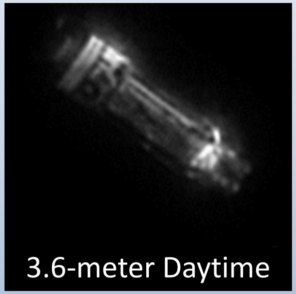
AMOS R&D

SSA R&D Focused on Imaging, Characterization, and Tracking

Resolved Imagery

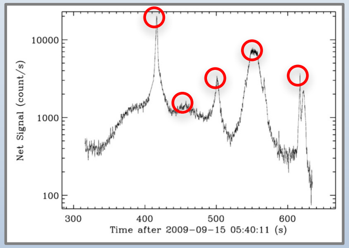
- High-res images of LEO Satellites





Characterization

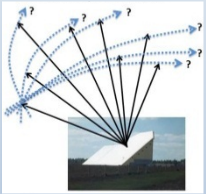
- Non-resolved Photometry
  - Periodicity measures
  - Shape and Attitude



Temporal Photometry

Detect & Track

- Orbits from Uncorrelated Tracks (UCTs)
  - Discover new objects
  - Find lost objects

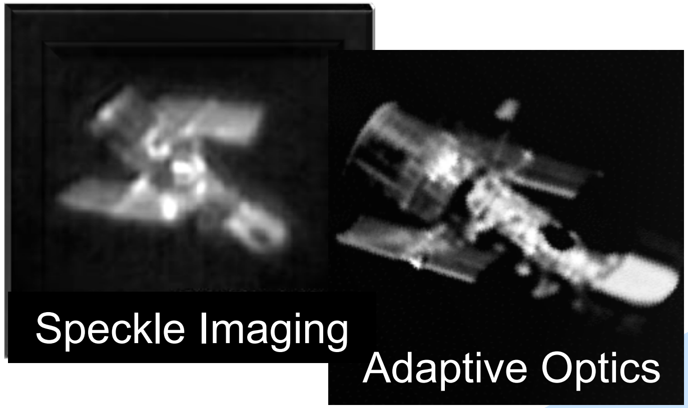


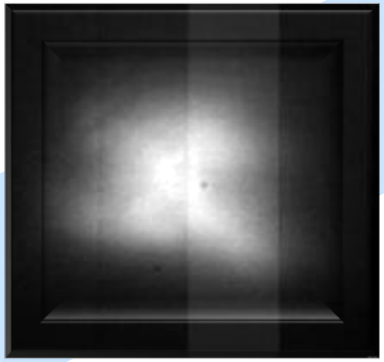
Connecting the Dots to build orbits

S&T mission focused on current SSA challenges

Evolution of Imaging Capability

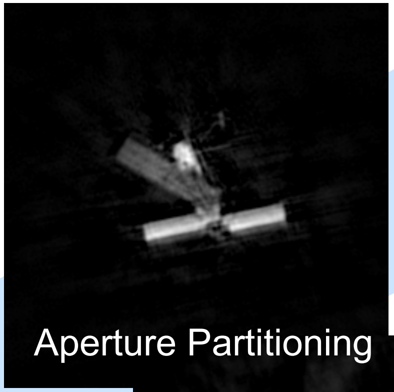
1982 - Terminator

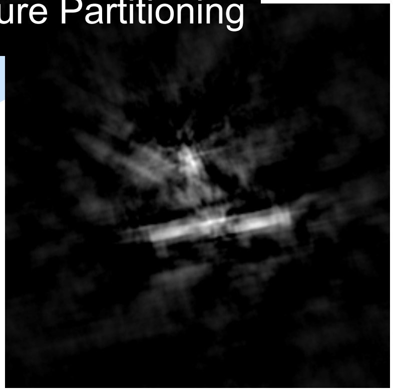




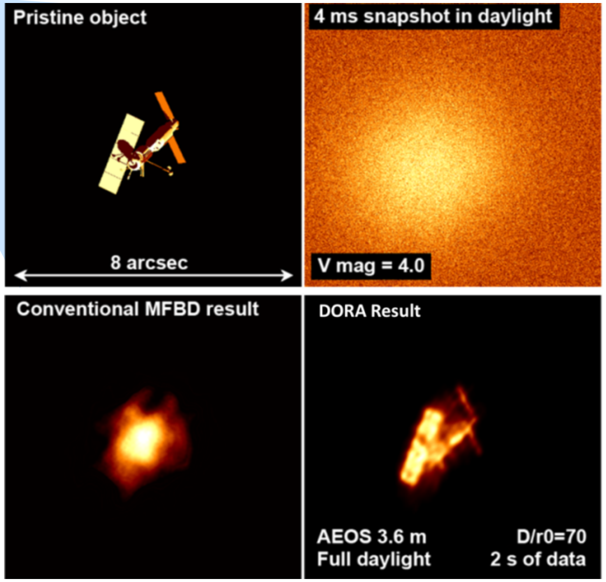
Atmospheric Blur

2015 - Daytime





Strong Turbulence

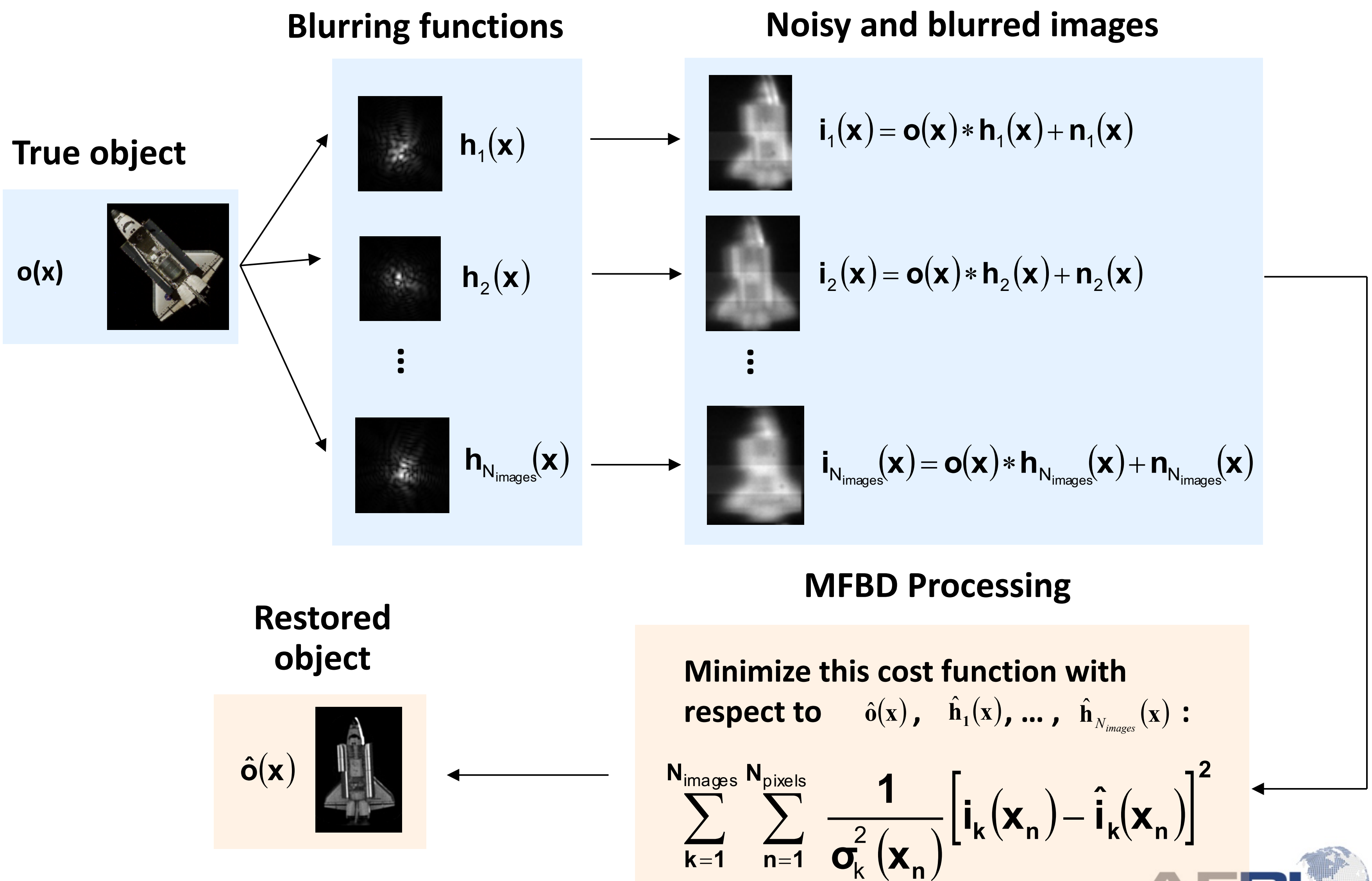


DORA
(SBIR - Daylight Object Restoration Algorithm)

R&D continues to shape the operational limit

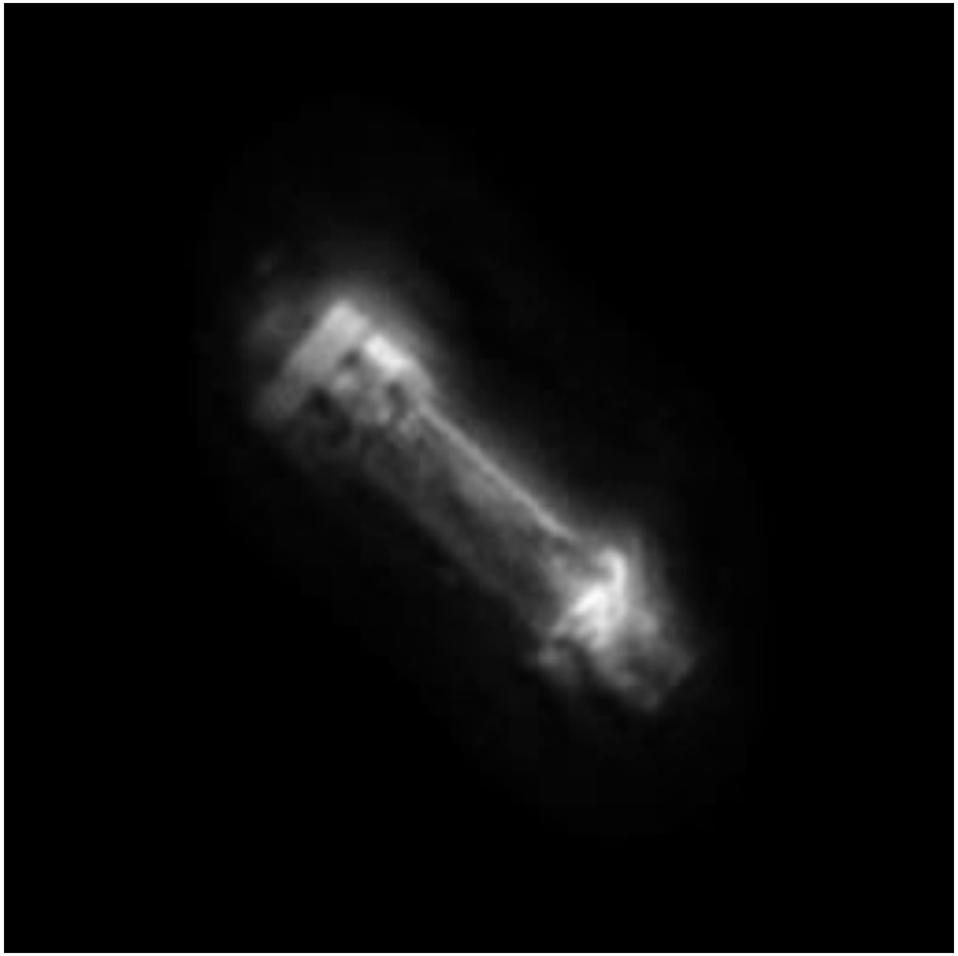
Speckle Imaging

Multi-Frame Blind Deconvolution (MFBD)

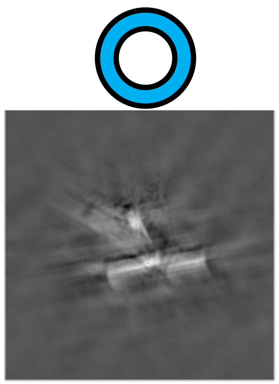


Atlas Centaur Rocket Body

Collected under full daylight conditions on AEOS using speckle imaging.



Daylight Imaging with Aperture Partitioning

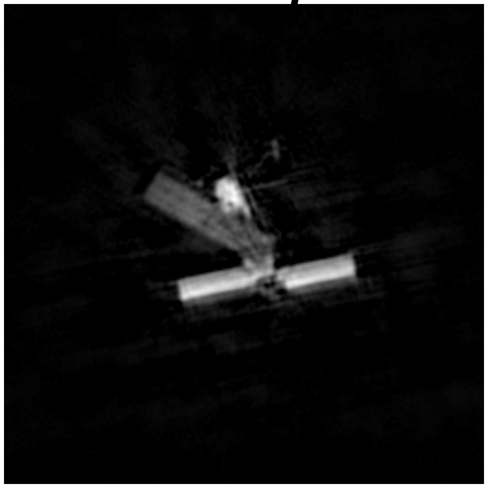


Recon. from outer annulus

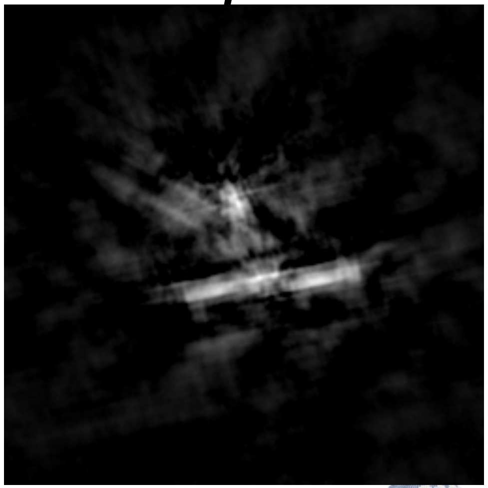
Recon. from inner annulus

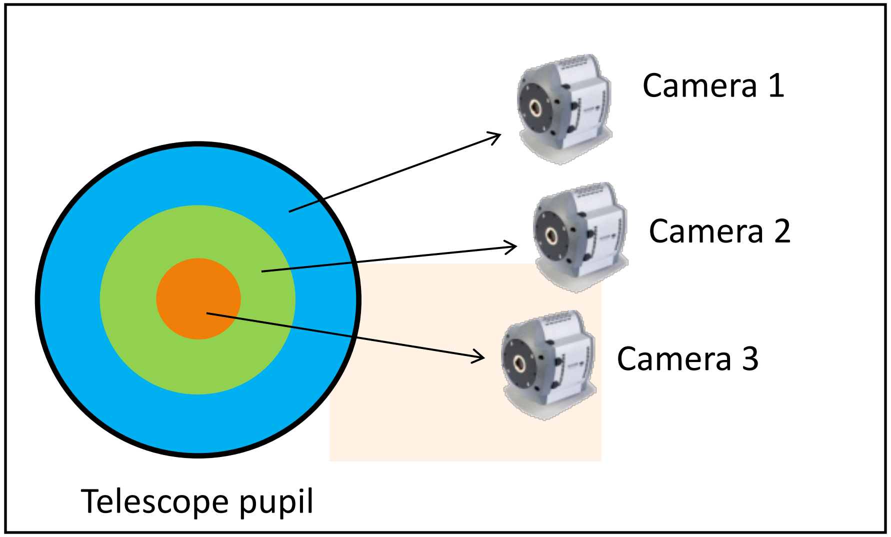
Recon. from inner disk

Partitioned aperture



Full aperture

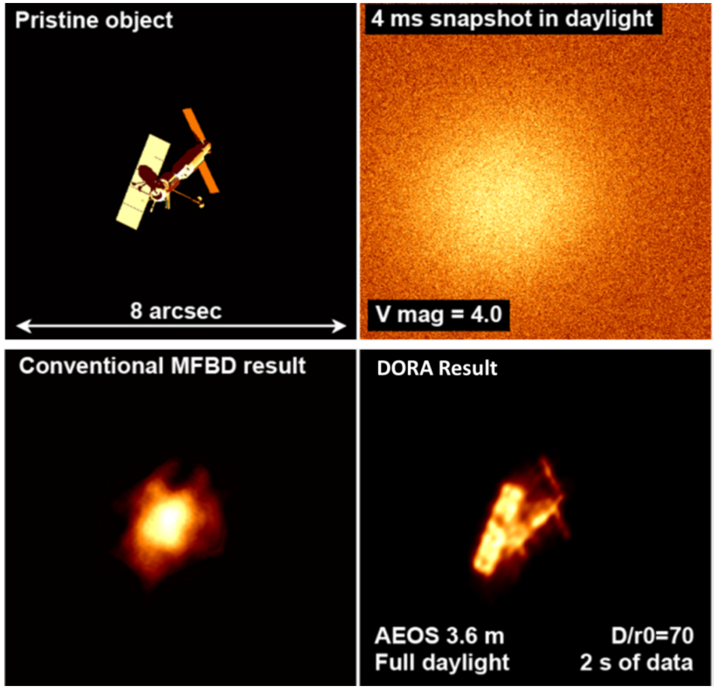




Dr. Brandoch Calef

Daylight Object Restoration Algorithm (DORA)

- SBIR Project
- MFBD Processing
  - Uses high frame rate WFS data to remove turbulence degradation
  - Theoretical validation supports nearly diffraction limited imagery with D/r_o=70



Hart Scientific, Inc.

DORA promises dramatic improvement in daylight imaging

Synergy of R&D and Ops

Innovation Engine: Joint R&D and Ops

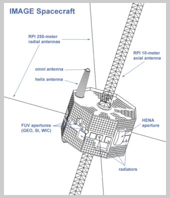
Ops

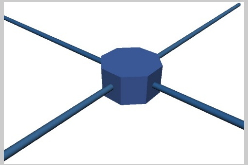
SSN Contributing Sensors

3.6-meter

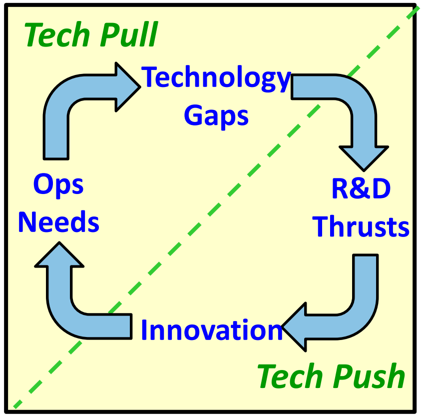
1.6-meter

Real-world Questions





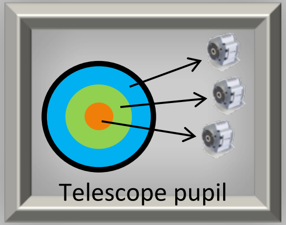
Ops Experience influences R&D



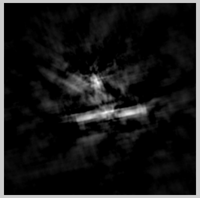
Rapid testing of R&D concepts

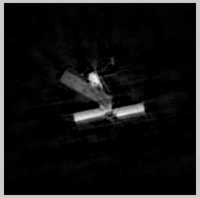
R&D

Experimental Sensors



Experimental Algorithms



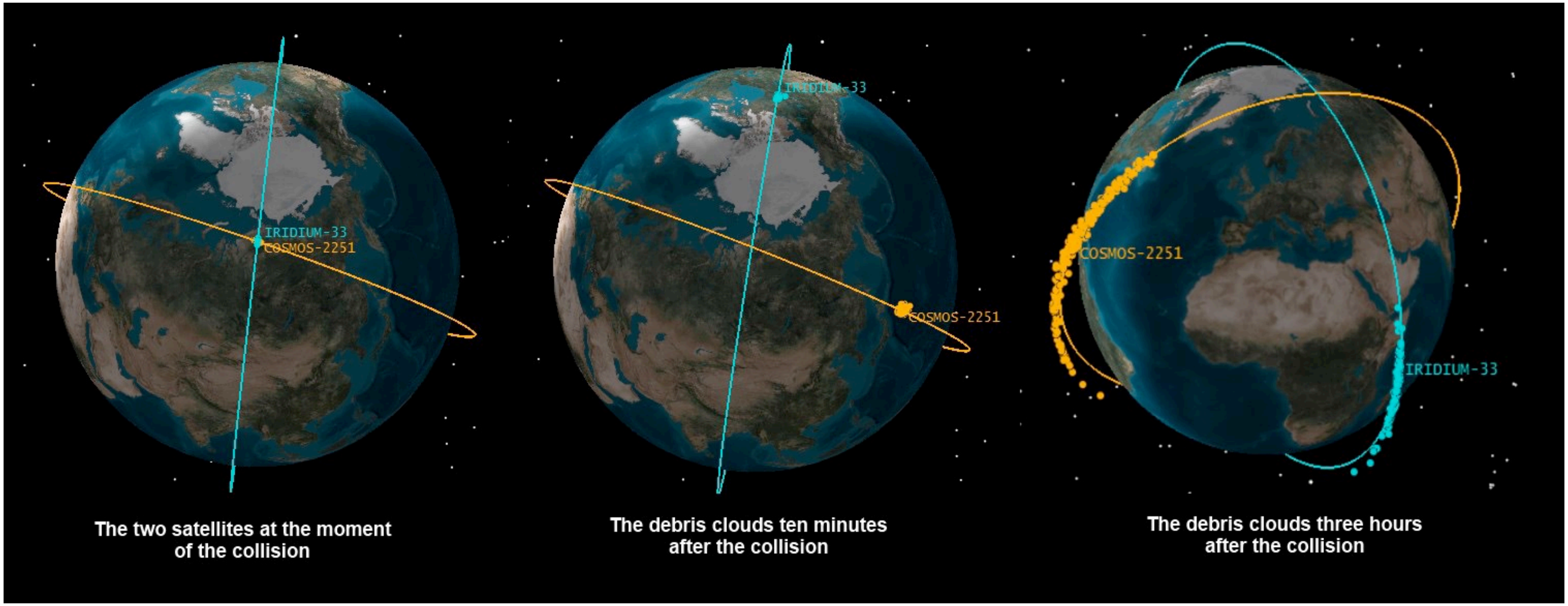


R&D improves Ops – Ops improve R&D

Ops Improve R&D

Uncorrelated Track (UCT) Resolution

2009 Iridium-Cosmos Collision

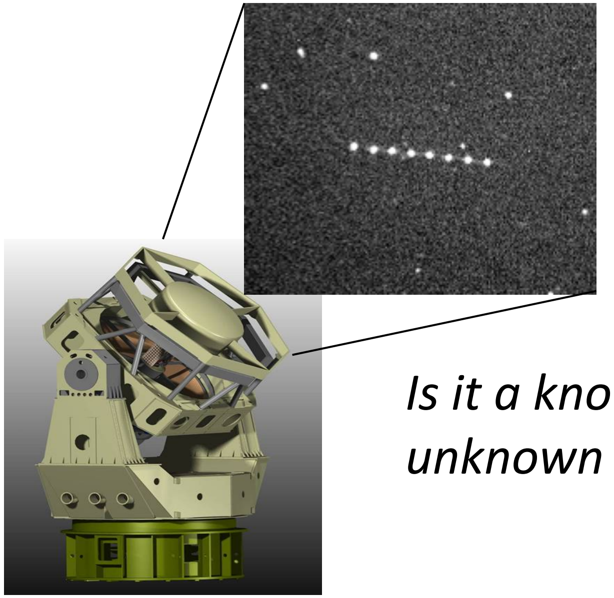


The collision produced ~2000 pieces of debris > 10 cm

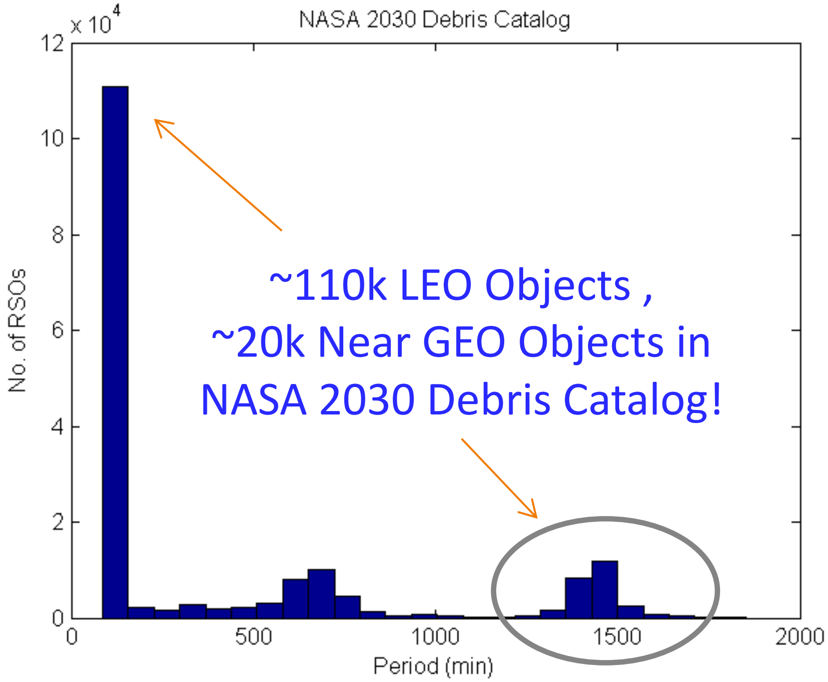
Source: Secure world foundation

UCT Processing Critical to SSA

- Need to quickly restore order after fragmentation event
  - Iridium-Cosmos collision
- Must reduce the number of unknown objects
  - Easier to spot new objects
  - Easier to regain custody of lost objects

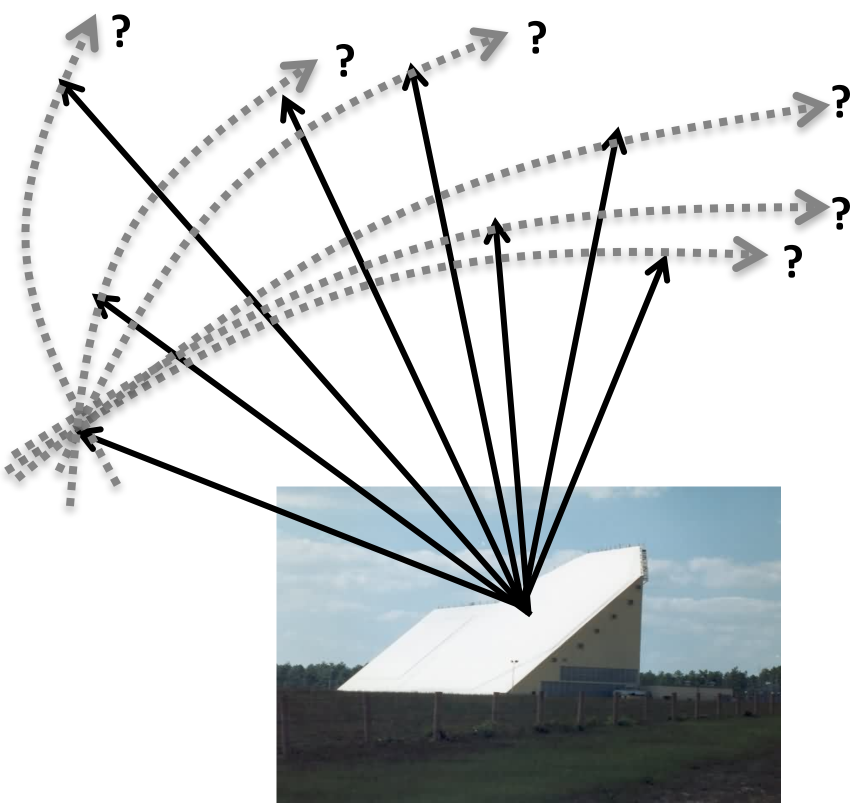


Is it a known or unknown object?



Space Fence Radar Data

2 observations, but which two?



2 observations
6 scalars ⟹ (x y z v_x v_y v_z)
6 scalars

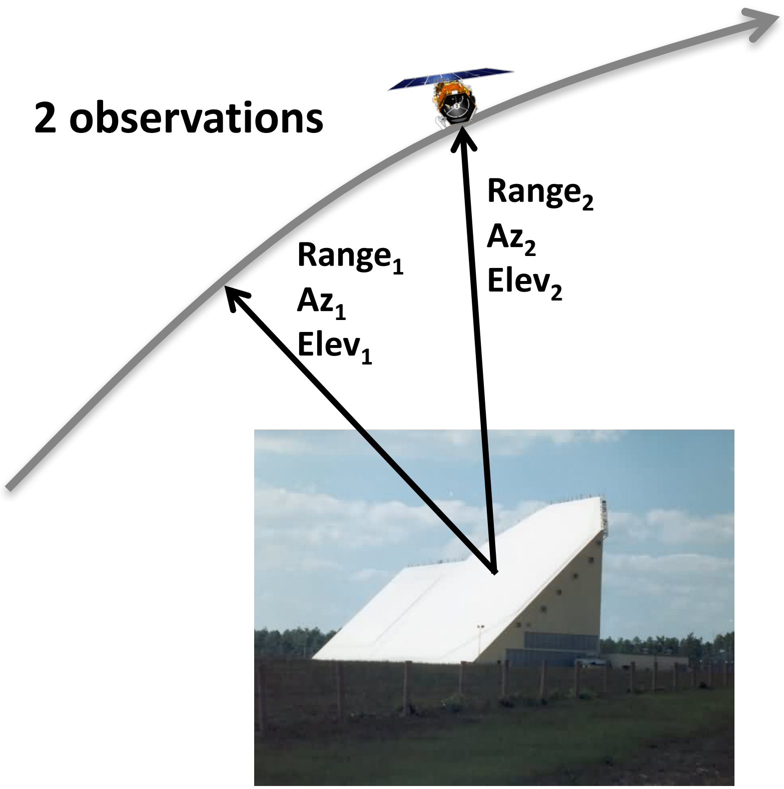
- **Problem has N^2 complexity**
  - Must test all possible observation pairs

UCTs are a difficult manual process:

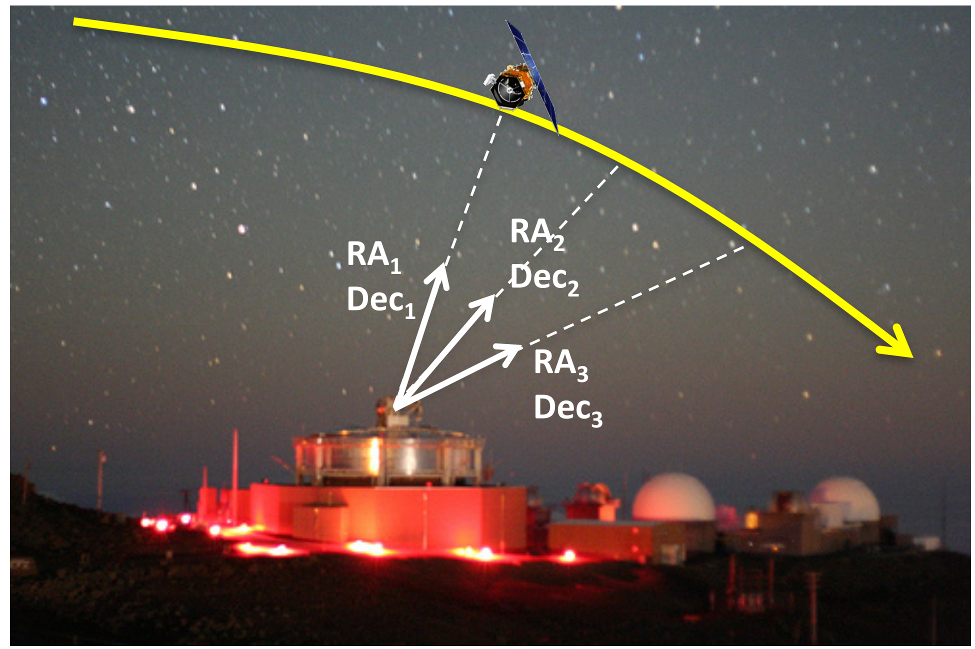
- Resolving thousands of new objects can take months
- Need for parallel processing
- High capacity required (> 100,000 observations)
- Full automation (catalog re-build)

Operational need drove R&D effort on UCT resolution

Basic Track Initiation:
Radar vs. Optical



3 observations



2 observations
6 scalars ⇒ $(x\ \ y\ \ z\ \ v_x\ \ v_y\ \ v_z)$
6 scalars

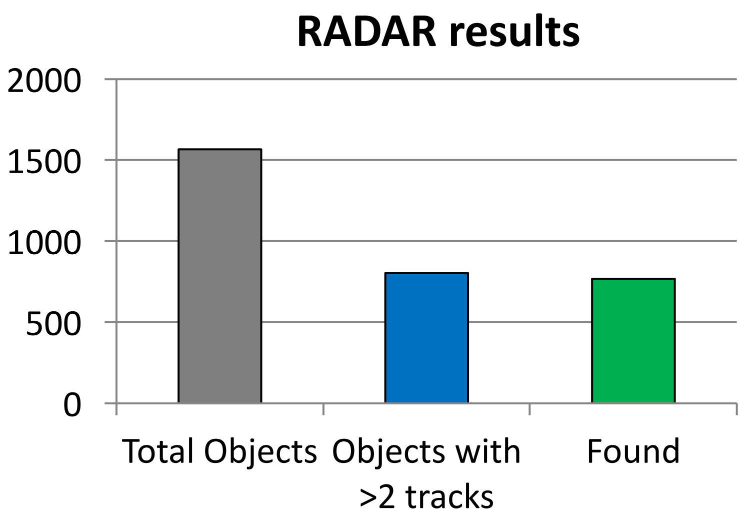
3 observations
6 scalars ⇒ $(x\ \ y\ \ z\ \ v_x\ \ v_y\ \ v_z)$
6 scalars

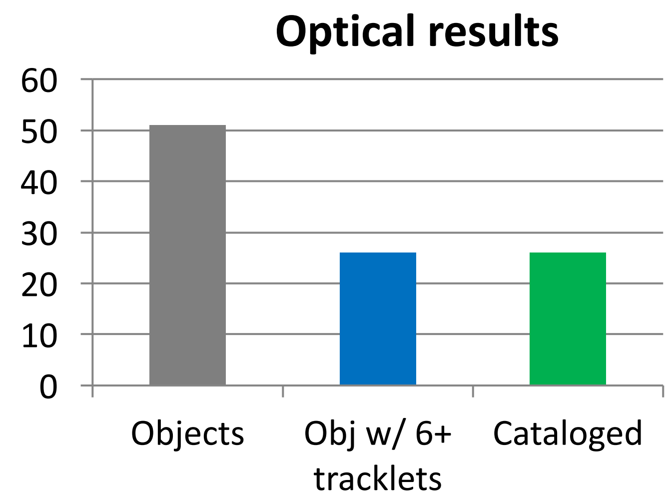
Without range information, optical requires 3 observations

AMOS Parallel-processing Solution Developed

Search And Determine Integrated Environment (SADIE)

Catalog-ready orbits from all data types in all orbit regimes



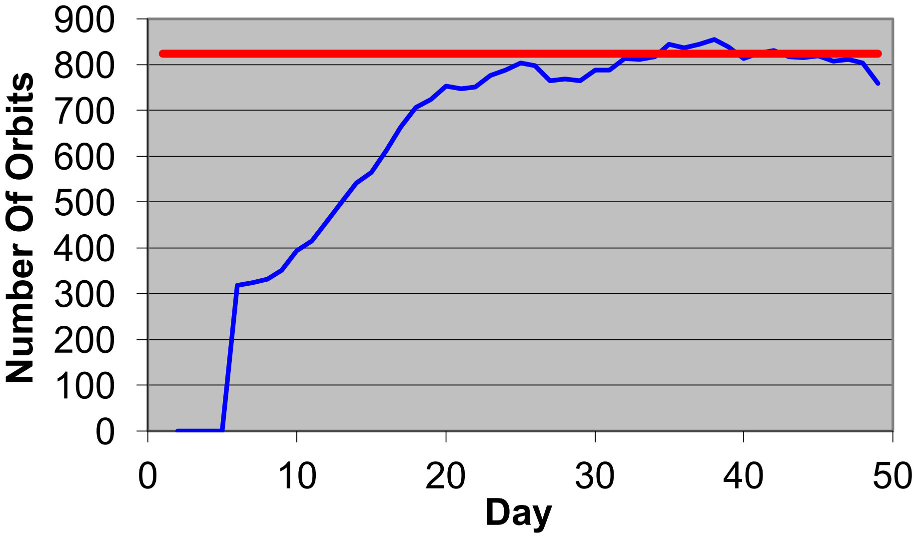


SADIE recovers almost every object with few false alarms

Automatic UCT resolution is a breakthrough

SADIE Being Tested at Dahlgren

- **Tests done on actual breakup data**
  - Resolution time reduced from months to real-time
- **Known breakup objects recovered in blind test**
  - Data fed to SADIE in daily batches as were originally received
  - All objects were recovered, automatically w/o human intervention



Automatic Generation of Catalog-Ready Orbits from Real Iridium-Cosmos Data

- **Collaboration with DSC2 Dahlgren continues**
- **Tests continuing on current data**

Summary

- **AMOS is a joint R&D and Ops site**

- **Ops benefits from the latest R&D advances**

- **R&D is exposed to Ops needs and insight**