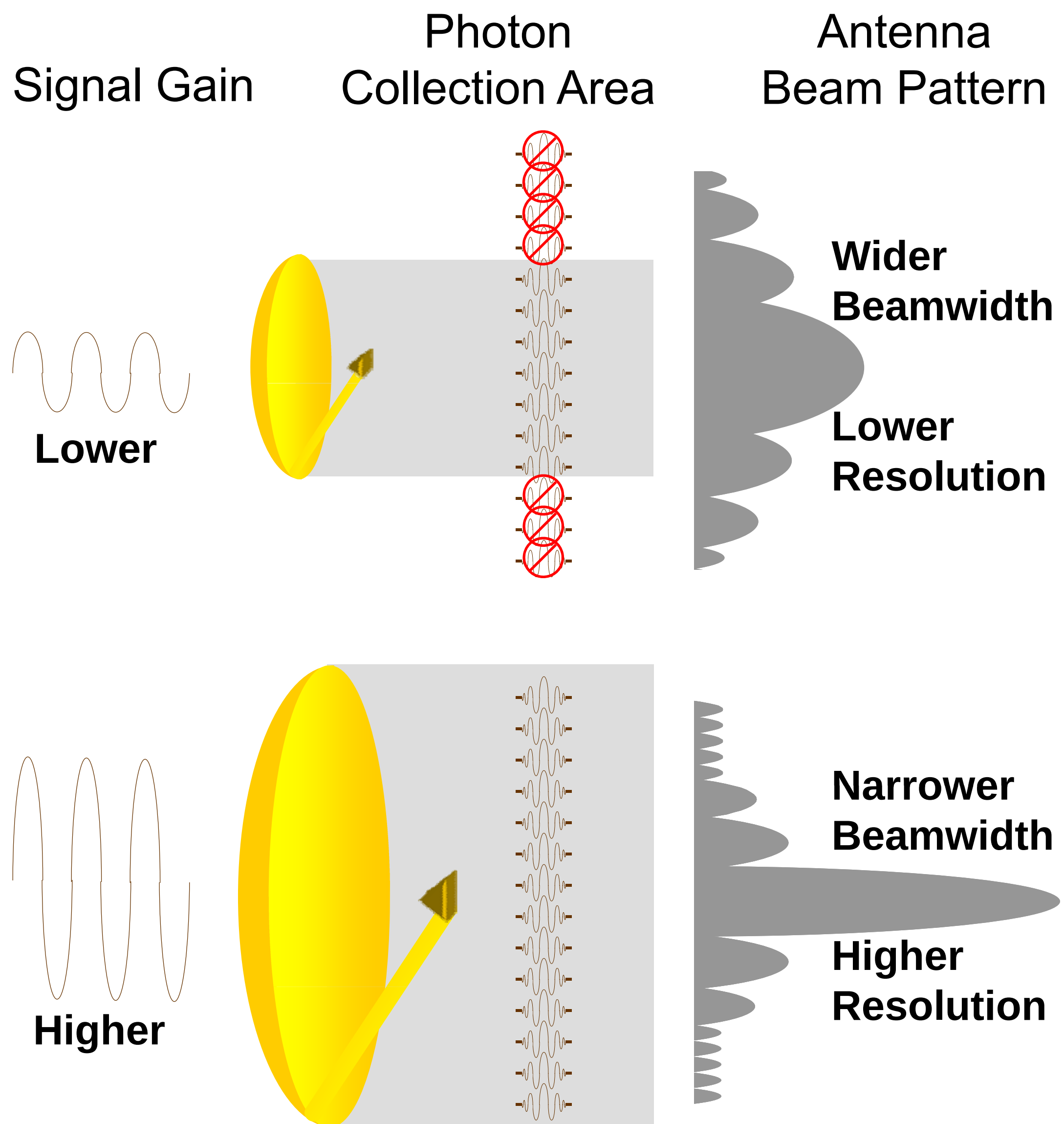
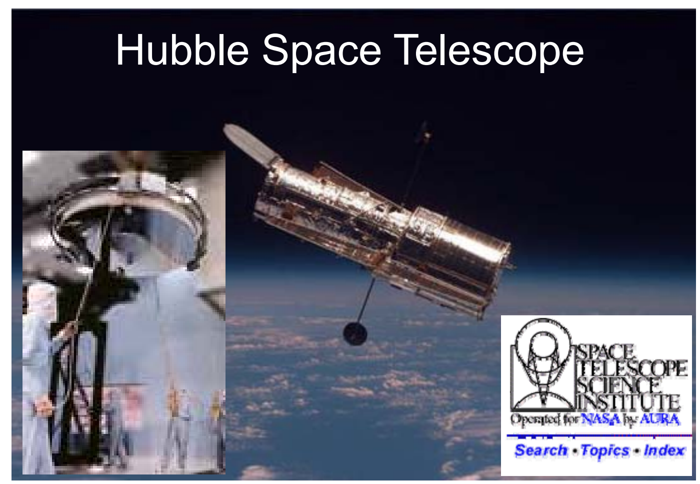
DARPA Investment in Large Apertures

Tim Clark
Defense Advanced Research Projects Agency
Strategic Technology Office (STO)
703-248-1520
timothy.clark@darpa.mil

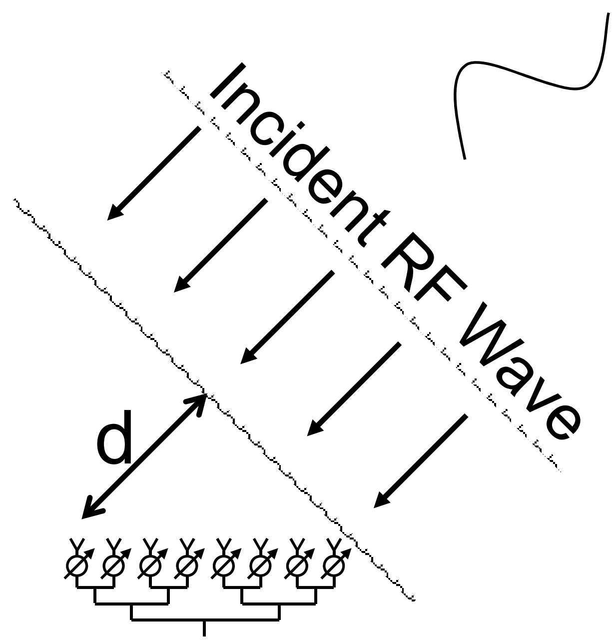
Aperture Is Critical to Photon Collection





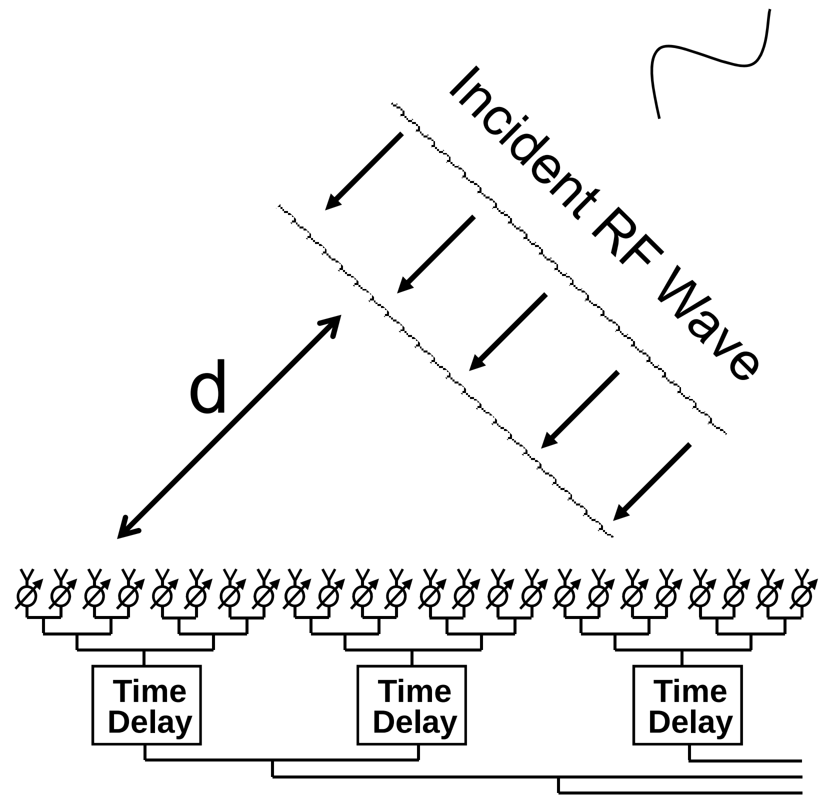
Antenna Architecture Challenges

Phase Shifters ⇒ Narrowband



Extra Phase = $360^{o} \times d/\lambda$

True Time Delays ⇒ Wideband



Extra Time = d/c

Time Delay Options
- **Digital**
- **Photonics**

Investing in Aperture Verses Power

- Search is a function of P·A
  - Performance grows equally with improvements in either Power or Aperture

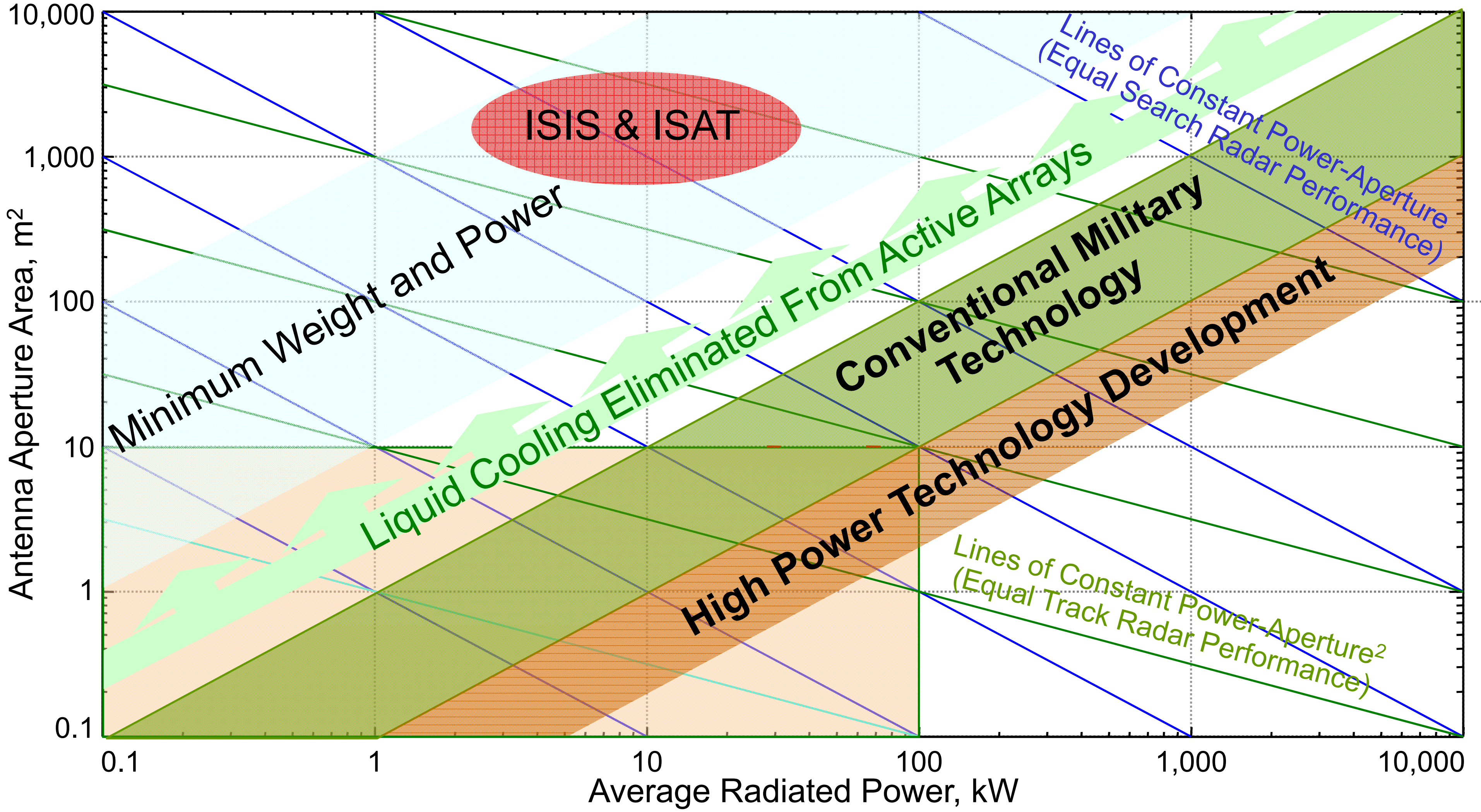
$$\frac{P_{avg}A}{kT_{sys}L} = \frac{(Area\ Search\ Rate)\left(\frac{S}{N}\right)_s R^2 \sin(\theta_{Grazing})4\pi}{\sigma_{\text{Target}}}$$

- Track is a function of P·A^2
  - Performance grows faster with Aperture

$$\frac{P_{avg}A^2}{kT_{sys}L} = \frac{N_{Tracks}\left(\frac{S}{N}\right)_T R^4\lambda^2 4\pi}{T_{\text{Update}}\sigma_{\text{Target}}}$$

Limited aircraft real-estate → prior investments in higher P

STO Working Low Power-Density ESAs



Requires Significant Platform Real-Estate

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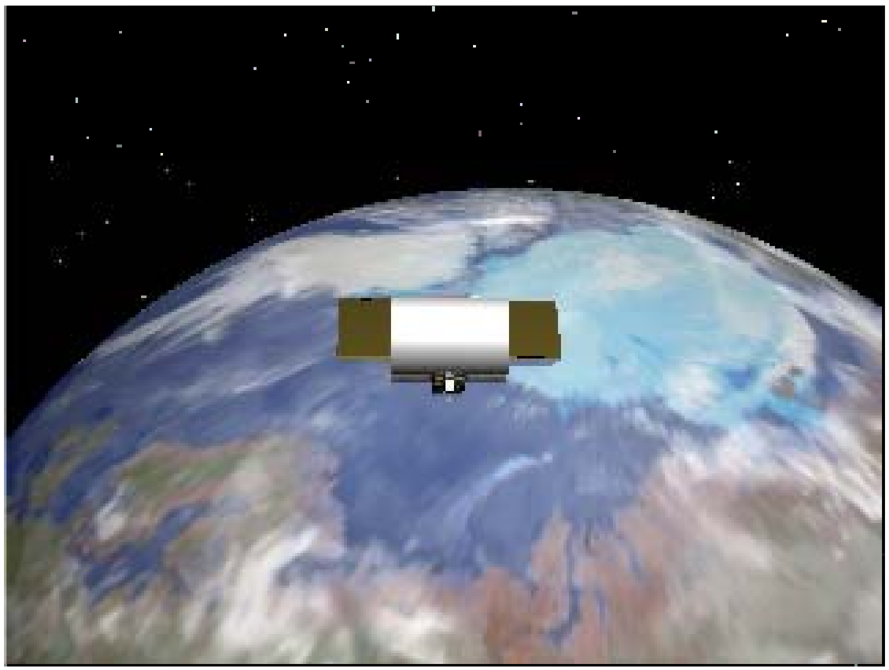
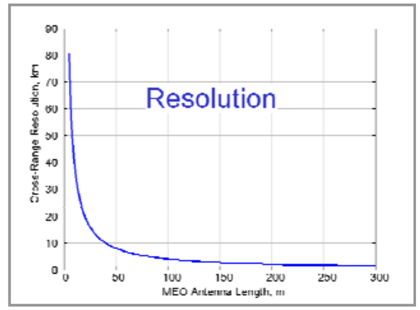
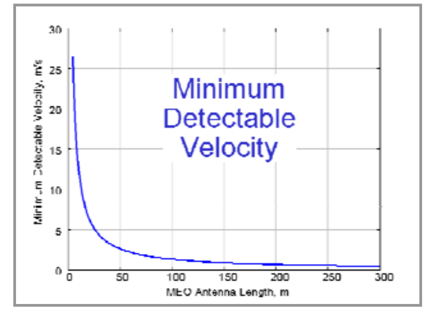
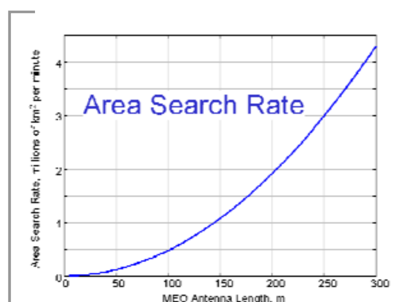
Benefits of Going Big

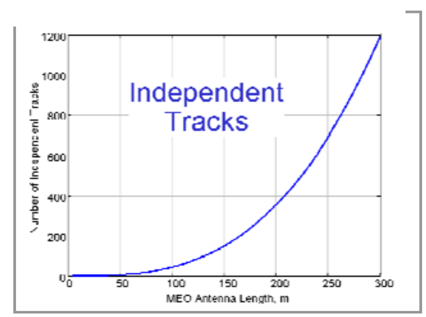
Strategic Technology Office







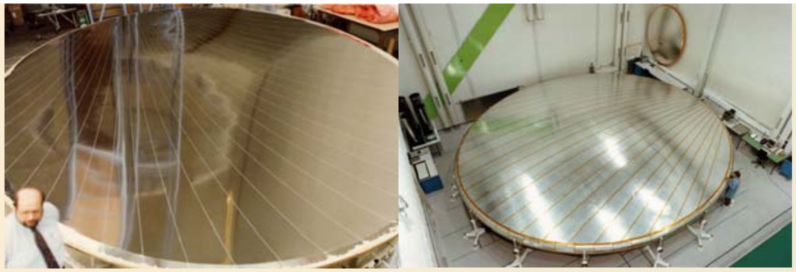




Enabling Technologies

ECHO BALLOONS

1960



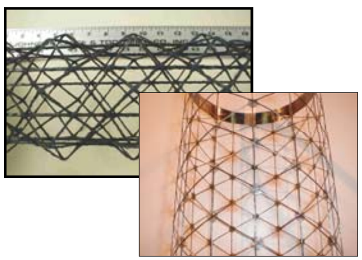
REFLECTOR ANTENNAS

1980

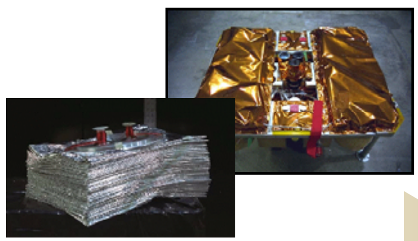
INFLATABLE ANTENNA EXPERIMENT

1996

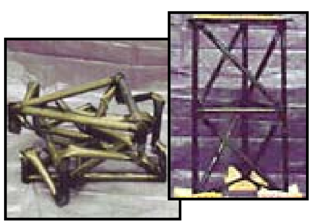
ILC DOVER



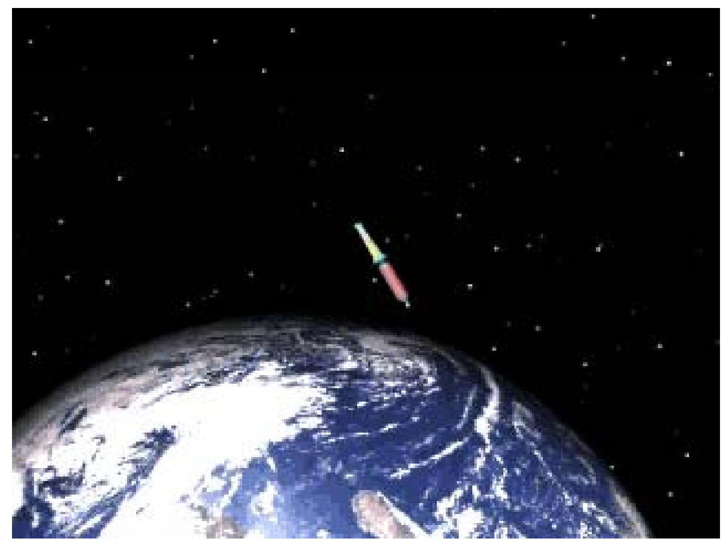
L'Garde



Rigidized inflatables and composite joint materials support large aperture deployments



Foster-Miller



L'Garde deployment concept

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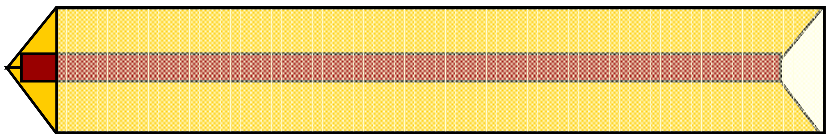
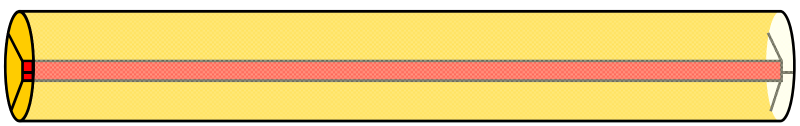
Space-Fed Lens

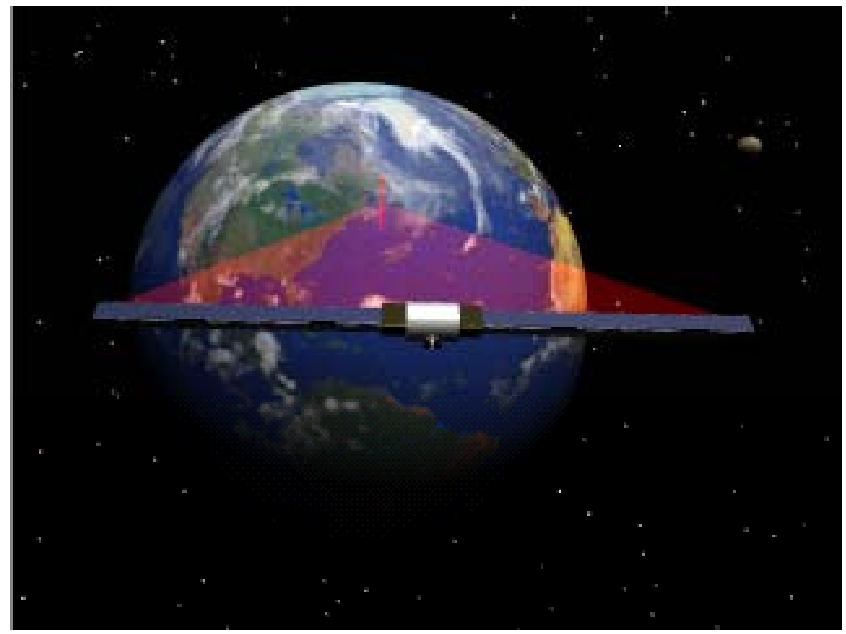


Reflector



Active ESA

Cooperative beacons calibrate aperture within an orbit



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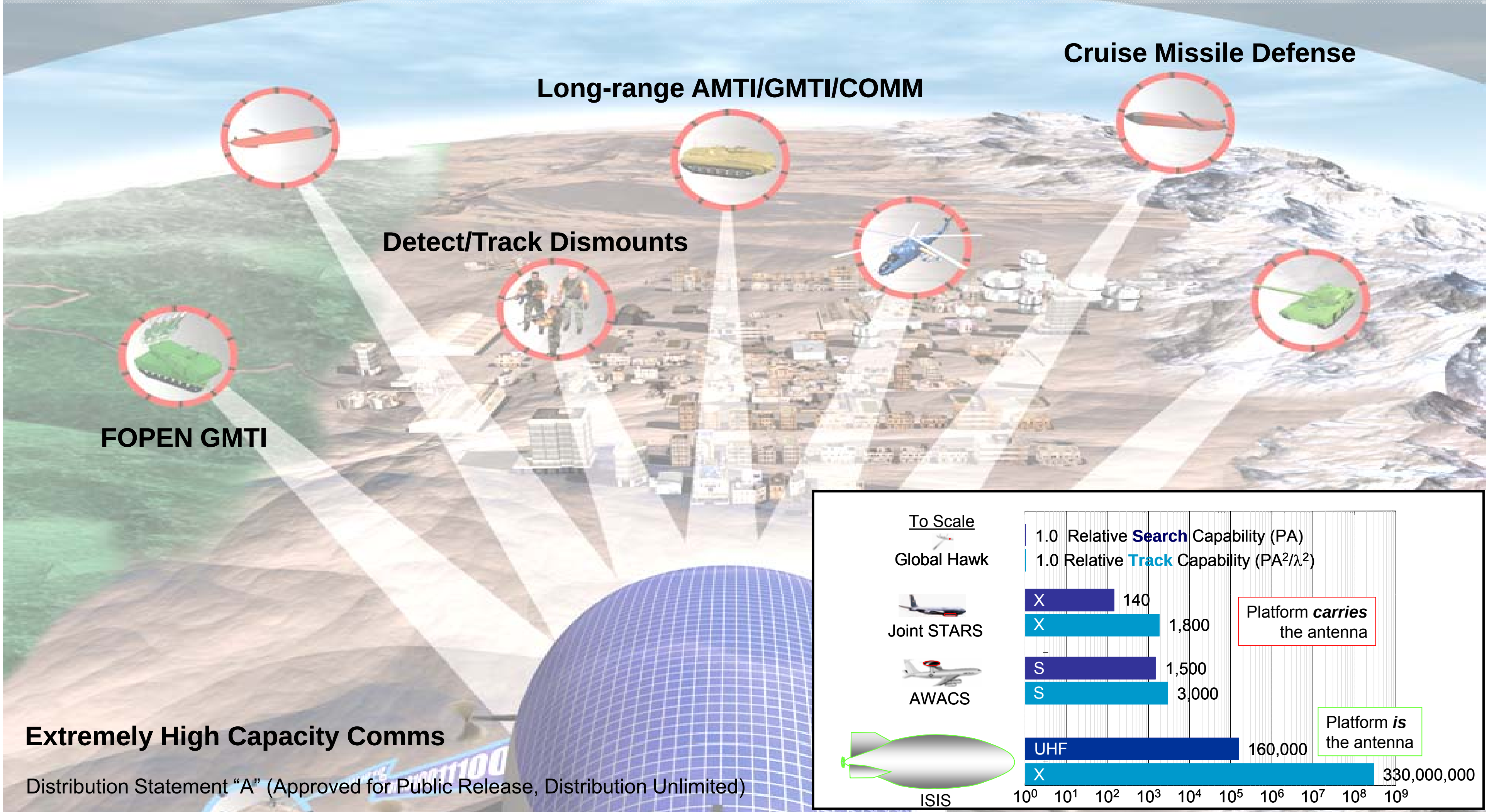
Integrated Sensor Is the Structure (ISIS):
Most Powerful Airborne GMTI/AMTI Radar & Comms Ever Conceived

Strategic Technology Office

Simultaneous AMTI/GMTI Operation via Dual Band (UHF/X-Band) Aperture



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Global Relocation <10 days – 600km Sensor Radius – No In-Theater Ground Support
10+ year Operational Lifetime – 99% Availability for 1 year

Distribution authorized to US Government agencies only

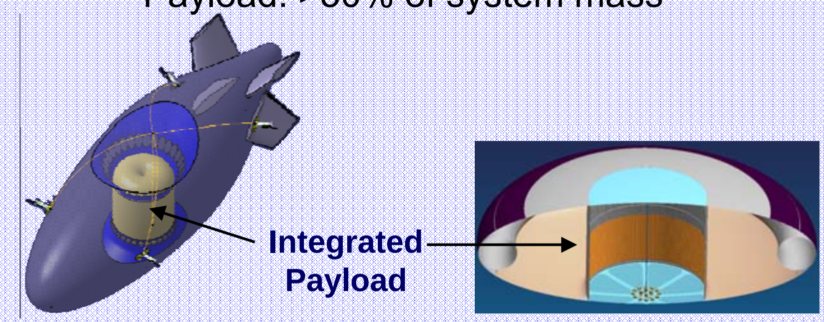
Integrated Airship-Radar

Conventional

Payload: 2-3% of system mass

ISIS New Paradigm

Payload: >30% of system mass



Enabling Technologies	DARPA ISIS Accomplishments
Hull Material	• Improved lifetime by 10x while reducing fabric mass 4x over state-of-the-art
Active-Array Antenna	• Performance from size, not power • Removed heavy high power electronics, cooling • Removed structure: Flexible panels bonded onto pressure vessel • Low-power Transmit/Receive modules based on low-cost “cell phone” technology
Power System	• Solar-regenerative power with fuel cells instead of batteries • Airspeed: 60 knot sustained, 100 knot sprint

FY04 | FY05 | FY06 | FY07 | FY08 | FY09 | FY10 | FY11 | FY12 | FY13

System Study — **Technology Development** — Scaled Prototype System Demonstration — SDD…

TRL 5
MRL 2

TRL 7
MRL 6

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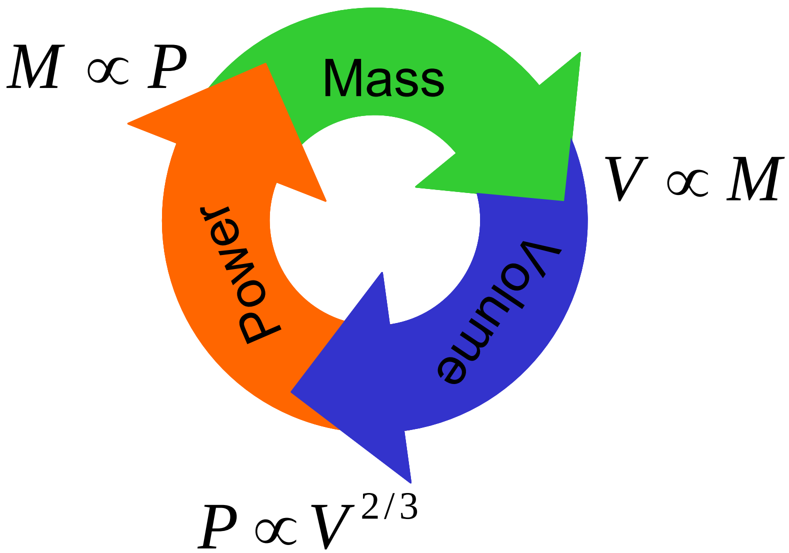
Requires Mass Reductions



- ISIS designs are mass-centric
  - Lifting gas has reached the maximum limit:
    - 0.061kg per 1m^3 of He @ 21km
    - 0.066kg per 1m^3 of H_2 @ 21km
- ISIS focusing on:
  - Removing mass from largest contributors
  - Technologies improving integration

Integration

$$M_{displacedir} = M_{liftinggas} + M_{structure} + M_{radar} + M_{power} + M_{propulsion} + M_{avionics}$$

$$M_{ISIS} = \rho_{gas} V + c_h \rho_{hull} V^{2/3} + \rho_{aperture} A + \frac{\rho_{power}}{\eta_{power}} \left(P_{radar} + \frac{\rho_{air} C_d V^{2/3} v^3}{2\eta_{propulsion}} \right) + M_{propulsion} + M_{avionics}$$

Components

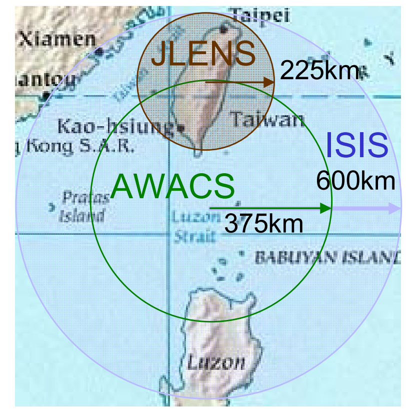
Single Integrated Picture

"High-Definition" Picture of All Moving Targets → 10x Resolution Improvement

Global Relocation <10 days – 600km Sensor Radius – No In-Theater Ground Support
10+ year Operational Lifetime – 99% Availability for 1 year

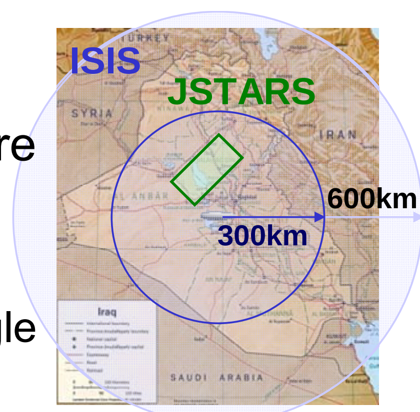
Complete Air Picture

- AWACS (70's) and E-2 (60's) – designed for hard targets of their day
- ISIS is designed for the theoretical limit at the radar horizon
  - Single-platform search, track, and fire-control



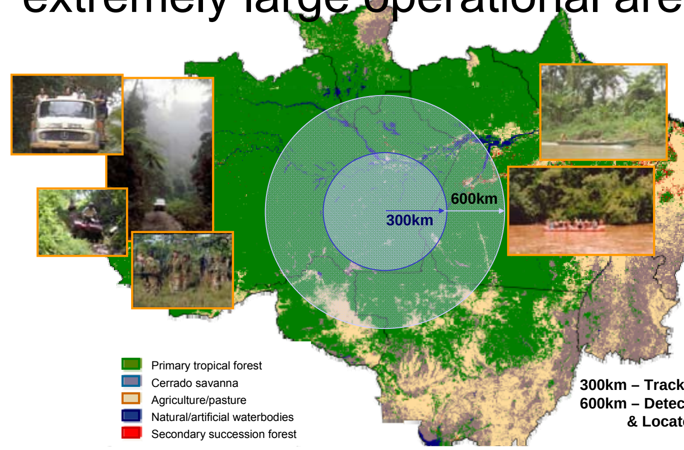
Unobscured Surface Target

- Joint STARS (70's) designed for tanks in the Fulda Gap
- ISIS is designed for dismounts across the entire Line-of-Sight
  - LSRS-like resolution
  - 300km @ 3° grazing angle
  - 600km line-of-sight



Wide-Area Foliage Penetration GMTI

- Joint STARS precision across an extremely large operational area



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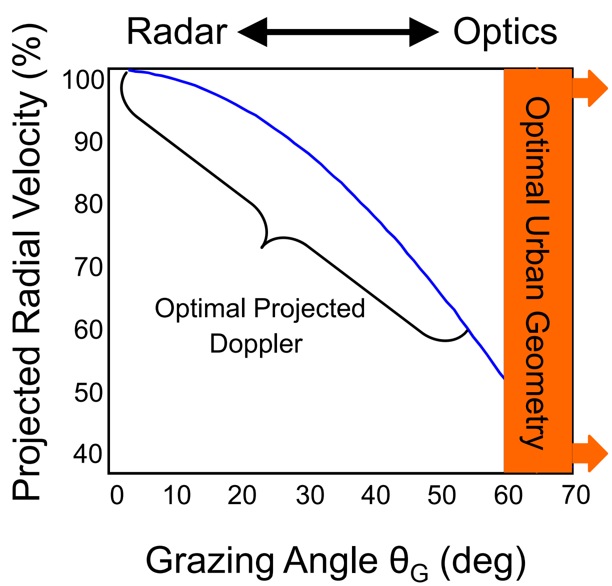
Tactical GMTI in Dense Urban Areas

- Problem: Wide-Area **Urban** GMTI
  - Detection and tracking of moving vehicles in dense urban areas
  - High-confidence identification for intercept and targeting

Lots of slow-moving traffic in each resolution cell

Terrain blockage/high-grazing angles

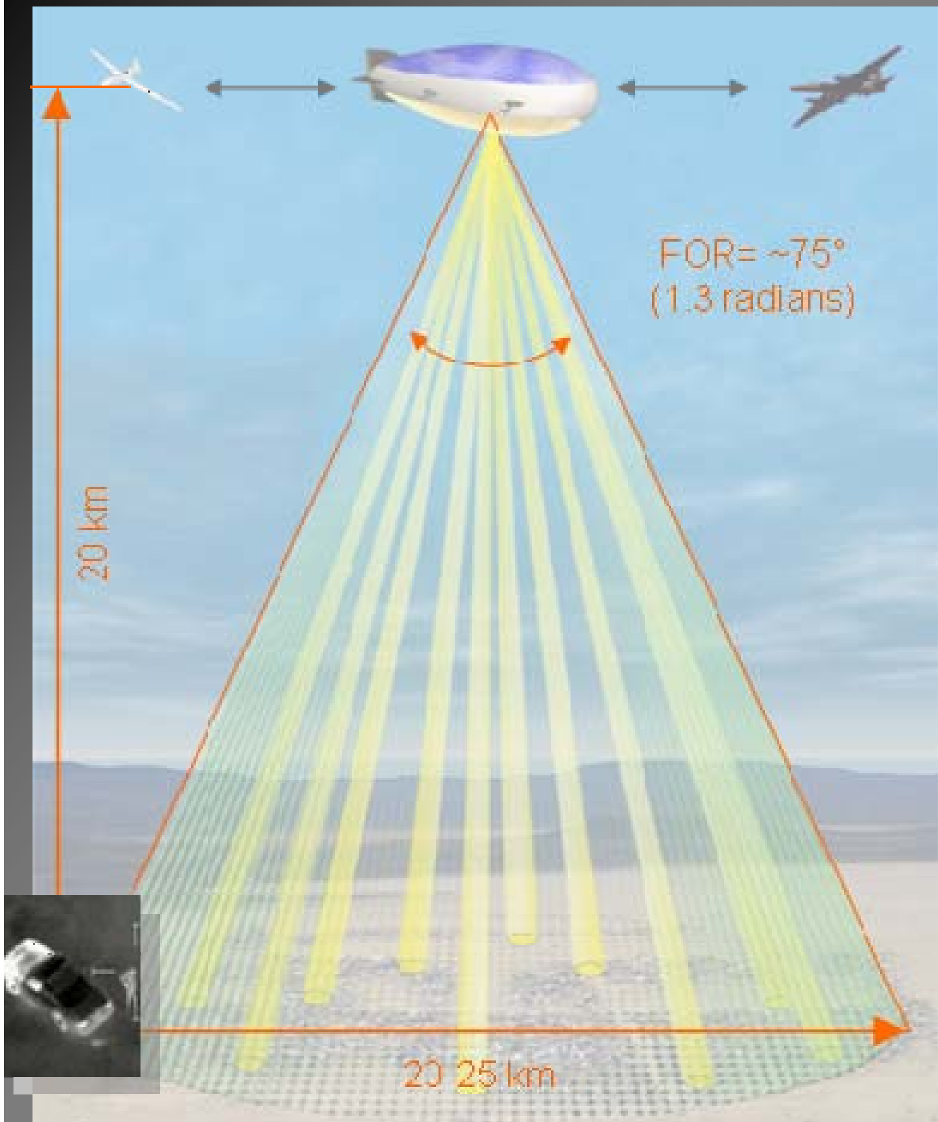


Good target access;

GMTI via change/motion detection

LACOSTE

Bringing Joint STARS-like performance into the urban landscape



Program Goals

Wide-area persistent day/night tactical-grade GMTI across a city

- Track up to 10,000 targets
- Precision for engagement on a large number (~100)
- Radar-like area coverage with optical precision

Actionable intelligence

Achievements

Computational Imaging Algorithms

- Demonstrated computational algorithms with multiple, simultaneous look directions
- Testing scaled diffraction system in the visible wavelengths
- Simulated dynamic coded apertures

System Designs

- Developed objective and demonstration system designs
- System modeling independently validated by AF

Potential Users

- USA, USAF
- Use in Constant Hawk, Angel Fire, and other programs


Image © 2007 DigitalGlobe
©2007 Google™
Pointer 37°58'50.23" N 23°40'13.29" E elev 77 ft Streaming |||||||||| 100%
Eye alt 989 ft

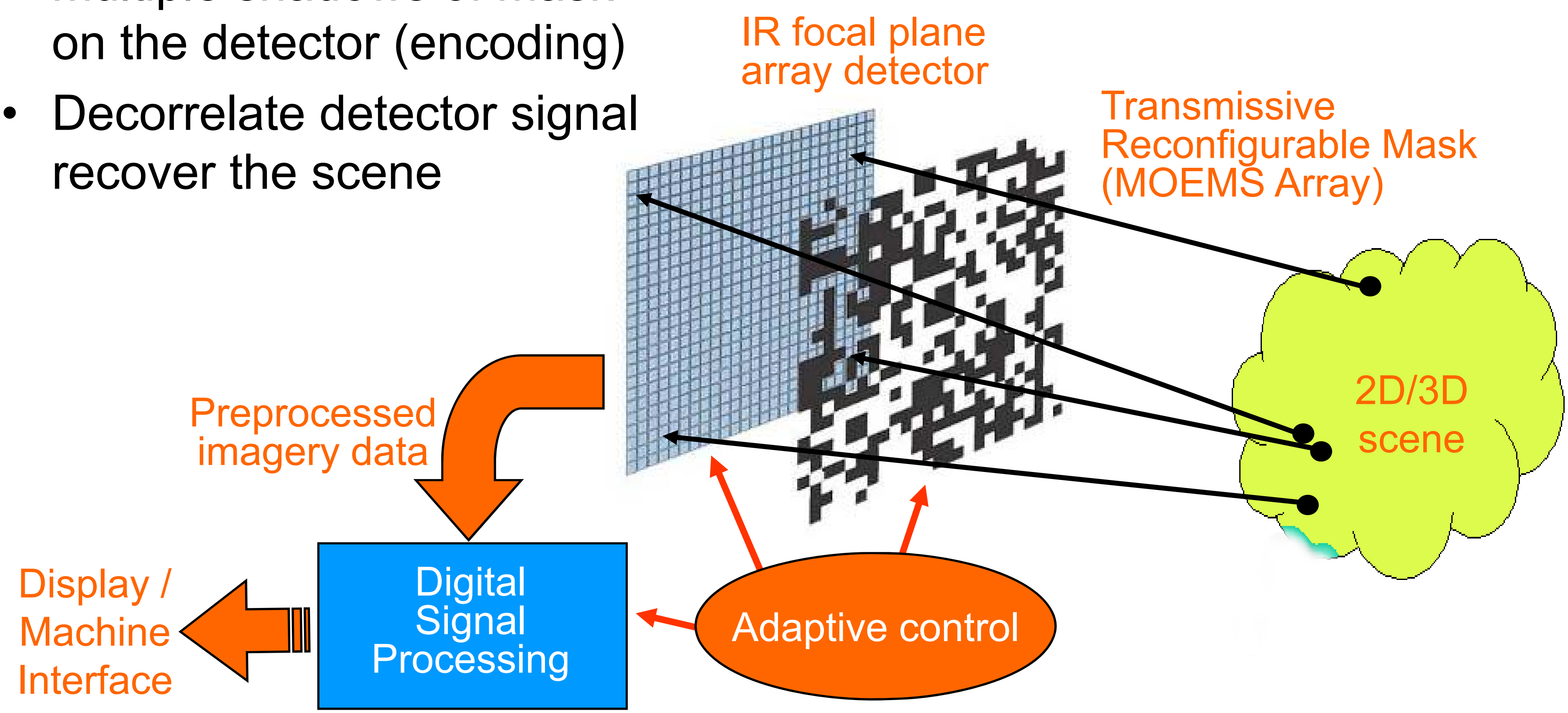
Finding Movers Across a Wide-Area

- We already know how to take wide-area high-resolution images in the visible
  - Traditional optical engineering problem
  - Single sensory Day/Night (e.g. MWIR) is trickier plus much more expensive and heavier
- We already know how to do frame-to-frame change detection
  - Process is slow and data intensive
- Goal: Day/night location and tracking of moving objects
  - Need: Sensing movers directly, reducing data

New Information Needs → New Sensing Concepts

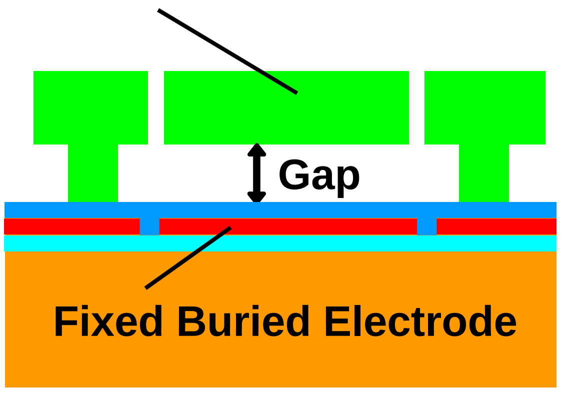
Concept 1: Adaptive Coded Aperture Imaging

- Points from scene cast multiple shadows of mask on the detector (encoding)
- Decorrelate detector signal recover the scene

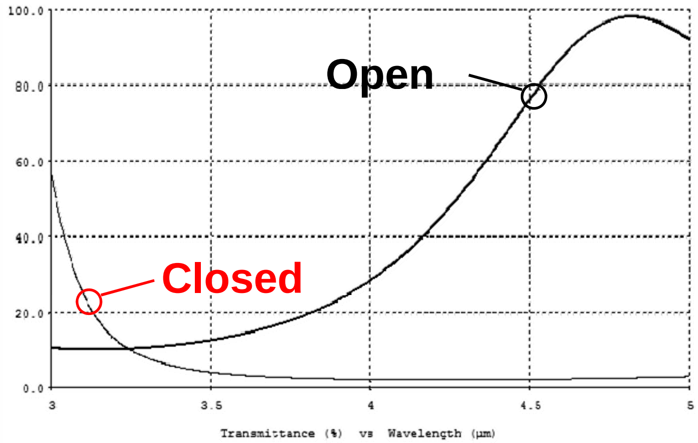


MOEMS Microshutter Concept

- Bi-static transmissive polysilicon etalon modulator
  - transmission modulated via interference
    - asymmetric etalon structure
    - electrostatically adjust gap by changing potential between electrodes to tune
  - small pixel sizes for speed and robustness
  - fabricated using standard polysilicon surface micromachining techniques

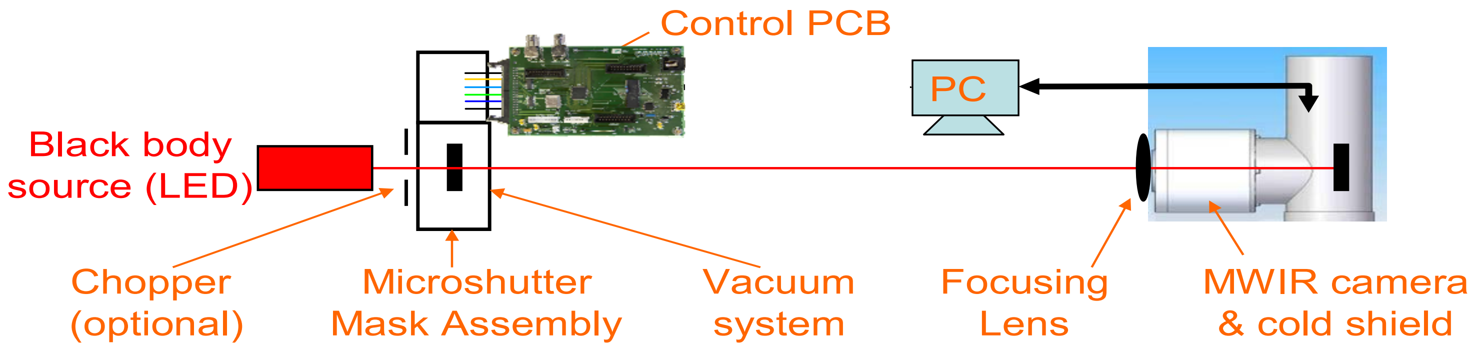


- High peak transmission
  - high contrast and broad band tuned to an atmospheric window
  - almost independent of angle, polarization and temperature



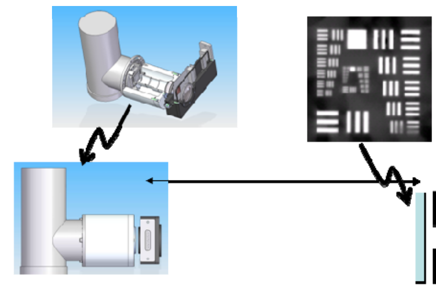
Mask Transmission Tests (MWIR)

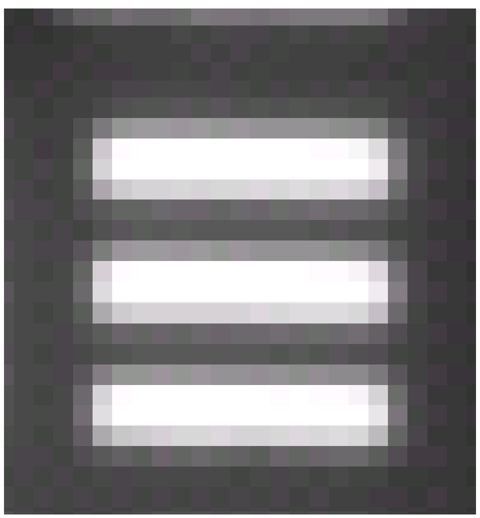
- 2 x 2cm MOEMS chip with 560 x 560 elements assembled onto custom ceramic header with ASICs in vacuum jig
  - Mask imaged using IR camera and black body source



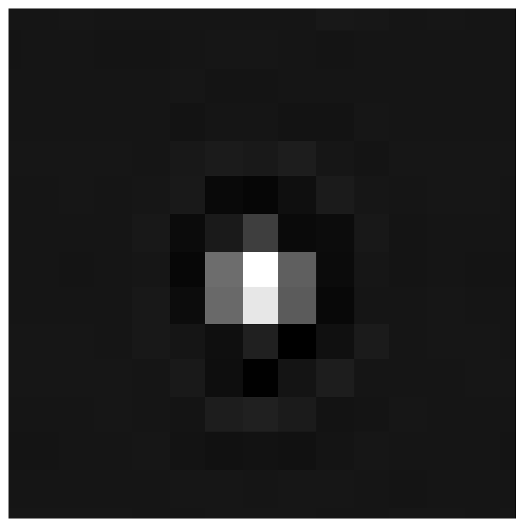
Experimental Data

- Similar experimental configuration to previous
  - MOEMS SLM coding, bar chart target, 640x480 cooled InSb FPA
- Multiframe pseudoinverse algorithm for resolution enhancement
  - Exploits knowledge of sub-pixel point system point spread function
  - Resolution improvement factor ≤ N (number of independent masks used), up to system diffraction limit

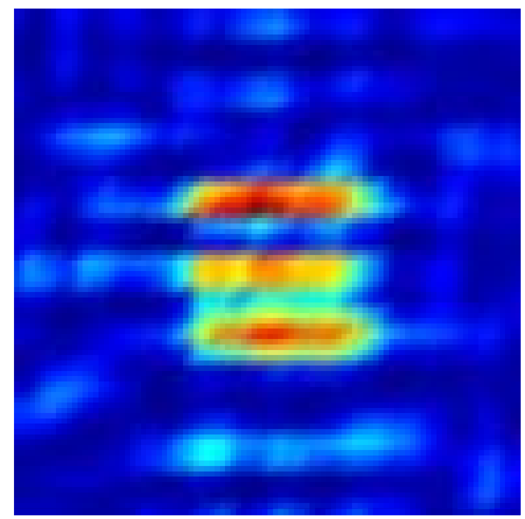




Target object

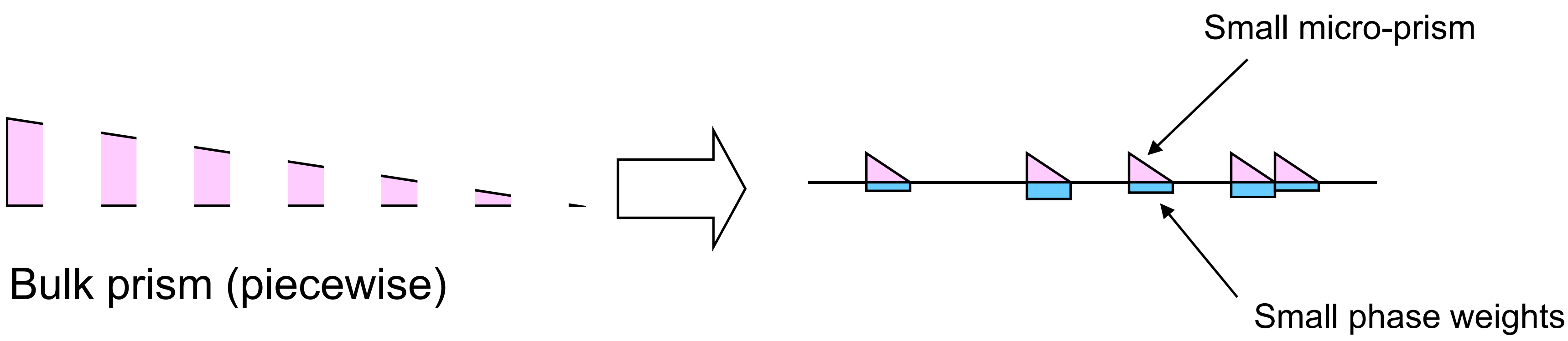


Multiframe Tikhonov decoding. Target is not resolved. Detector limited resolution.



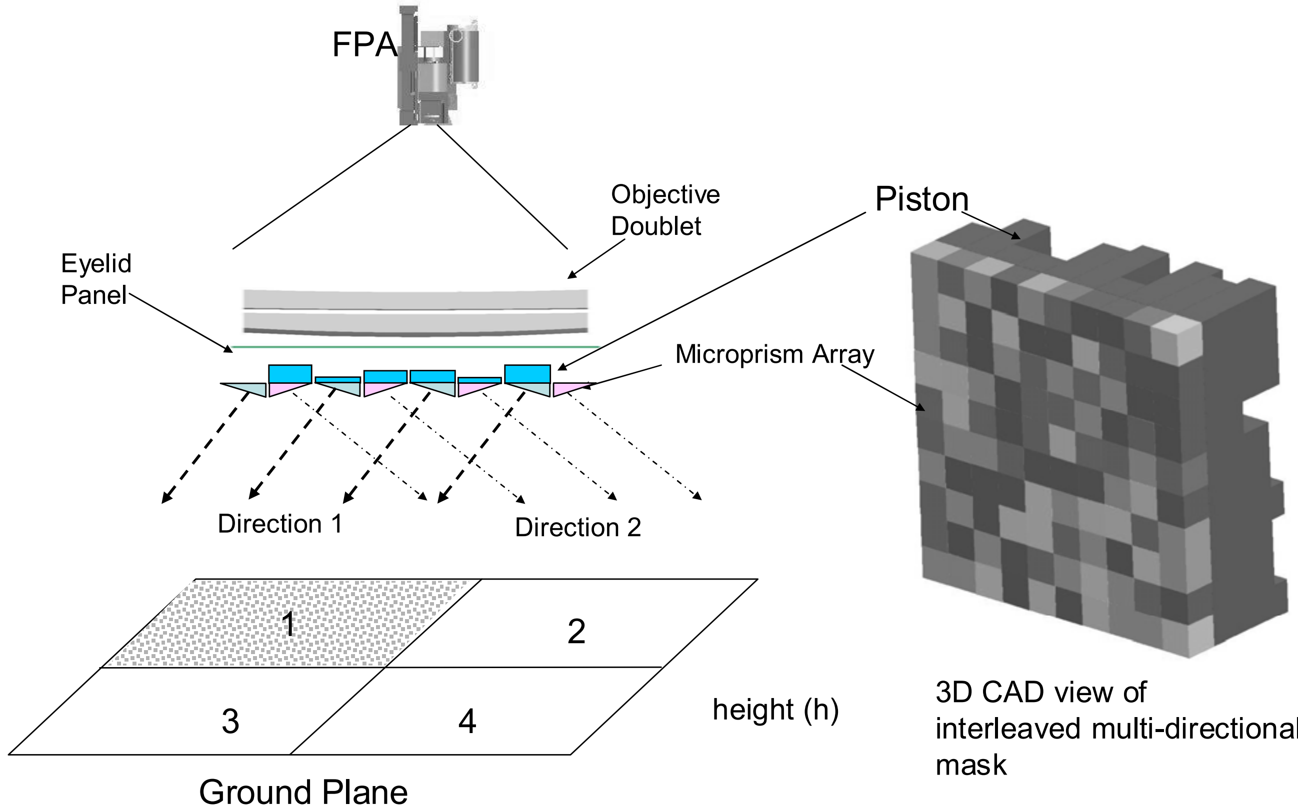
Pseudoinverse result. 32 frames. 4.5x L increase in resolution. System diffraction limited resolution

Concept 2: Beam-Steering Using Micro-Pistons



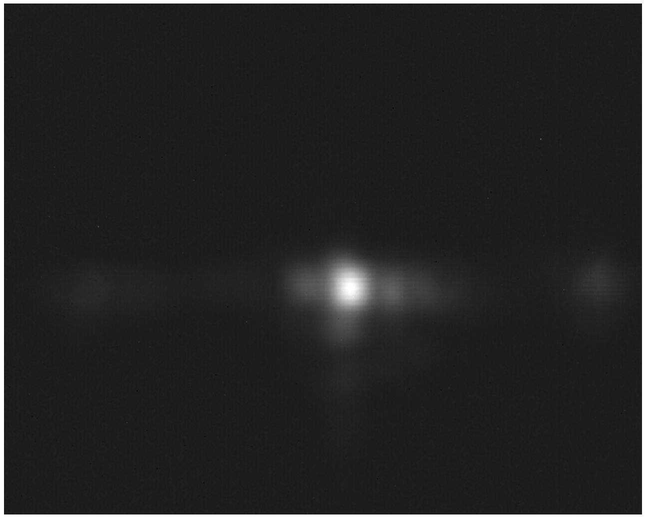
- The pistons required for an array of micro-prisms to act coherently as one "large prism" are difficult to manufacture
  - They follow the slope and dimension of the large prism and create large surface variations
- The look direction can be steered using a set of small phase-delays instead of large pistons
  - Optimize complex weights to form a directional beam while minimizing the effects of wavelength and chromaticity
  - Results in relatively small (order of wavelengths) surface structure that is easier to make

Multiplexed look directions using Interleaved Sparse Aperture

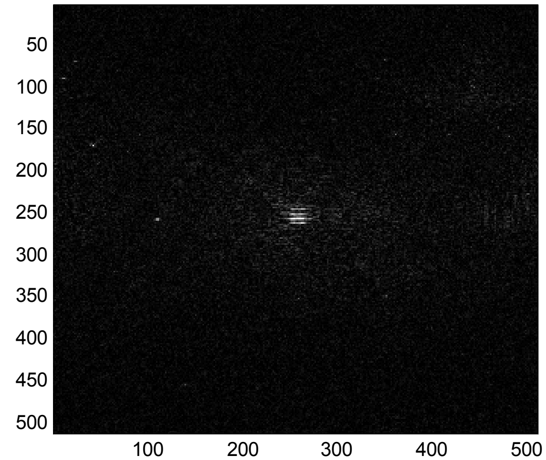


- The aperture is designed as a set of interleaved sub-apertures that multiplex several look directions on the same FPA.
  - The pointing function is realized using micro-prisms and micro-pistons,
  - an active device is used to shutter (open or close) different look directions.
  - Image decoding and restoration techniques are used to recover the images and reconstruct the original scene
- Architecture originally conceived by Prof. David Brady

End-to-end image of 2X bar pattern

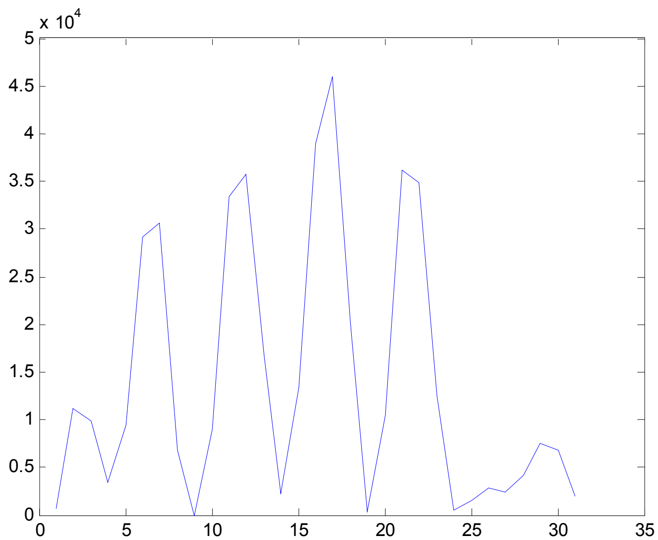


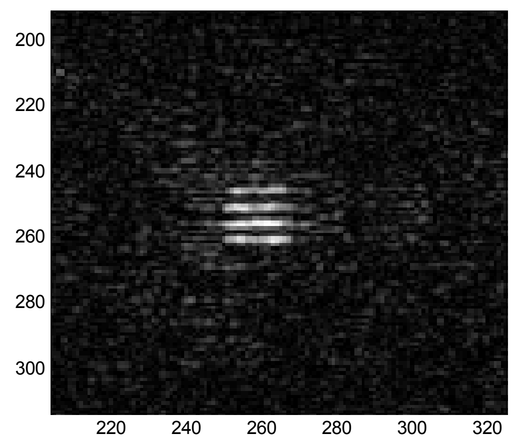
Measured image



Restored image

Intensity Cross Section





Zoomed image