SAND2017-2058C

Exceptional service in the national interest

Sandia National Laboratories



Low SWaP Radars for Manned and Unmanned Systems

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Sandia National Laboratories

February 28th, 2017

Sandia Airborne ISR: www.sandia.gov/radar

U.S. DEPARTMENT OF ENERGY | NNSA

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Sandia National Laboratories

Sandia Corporation

- AT&T: 1949–1993
- Martin Marietta: 1993–1995
- Lockheed Martin: 1995–present
- Existing contract expires April 30, 2017

National Technology and Engineering Solutions of Sandia

- Honeywell International, Northrop-Grumman Technical Services, and Universities Research Association: May 01, 2017

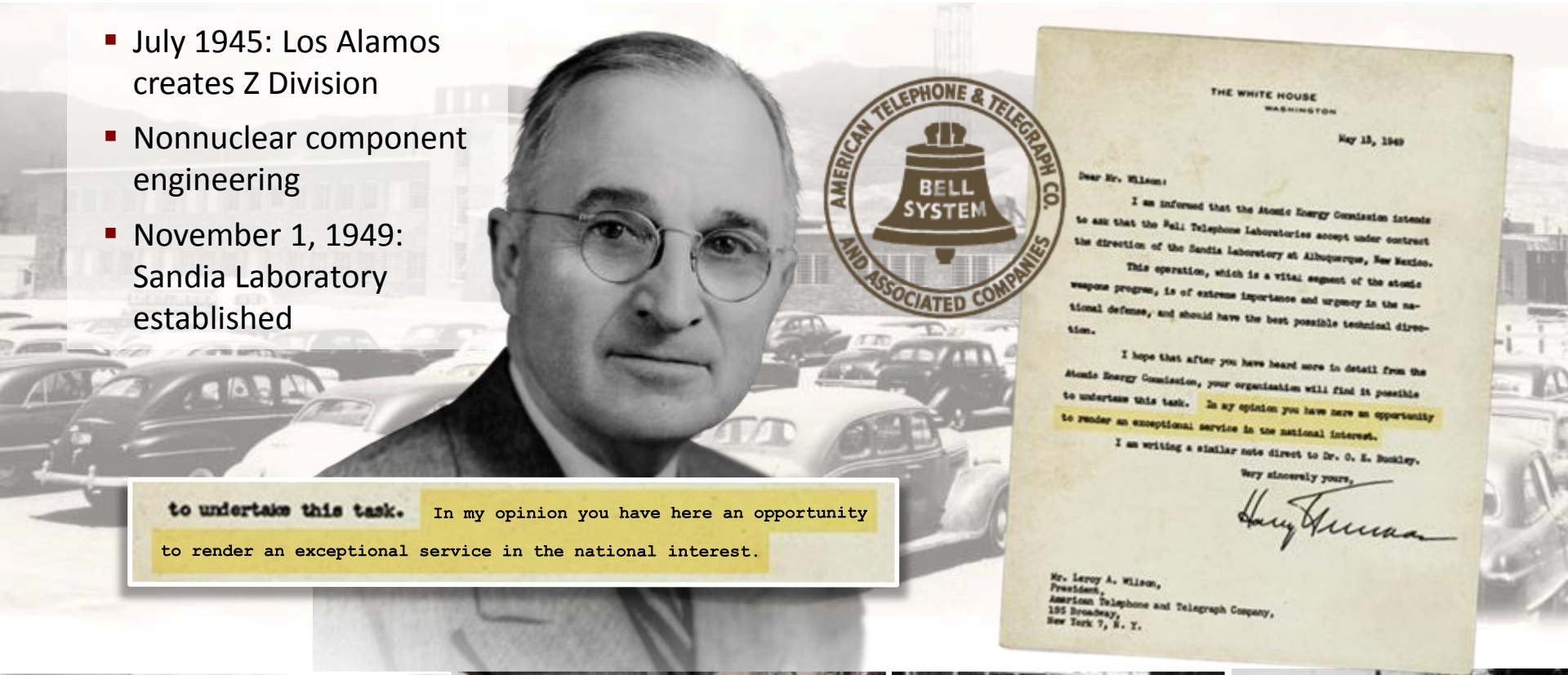
Federally Funded Research and Development Center (FFRDC)
Unique nonprofit entities sponsored and funded by the U.S. government to meet special long-term research or development needs

Sandia is 1 of 39 recognized FFRDCs

Sandia's History

Exceptional service in the national interest

- July 1945: Los Alamos creates Z Division
- Nonnuclear component engineering
- November 1, 1949: Sandia Laboratory established

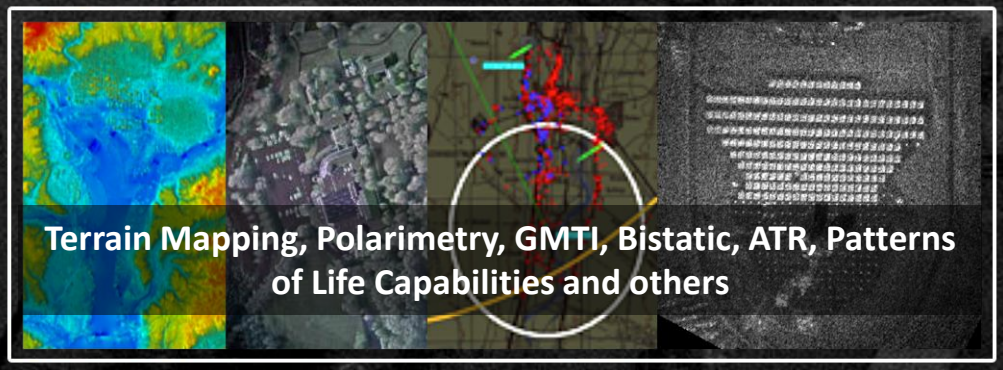


to undertake this task. In my opinion you have here an opportunity to render an exceptional service in the national interest.

Sandia Pursues Pathfinder Airborne ISR Solutions

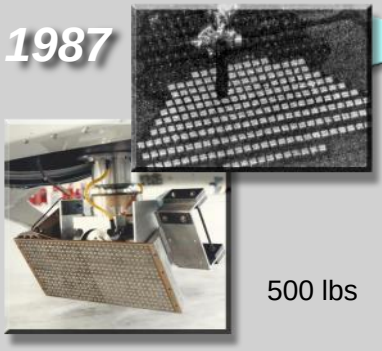
Synthetic Aperture Radar (SAR)

- 3+ decades of experience delivering solutions for complex, urgent national security problems
  - All Weather/Day/Night
  - High Resolution, Optical-like Imagery
  - Persistent
  - On-board, Real-time Processing
  - Flexible platform and TPED configuration



Sandia SAR Evolution

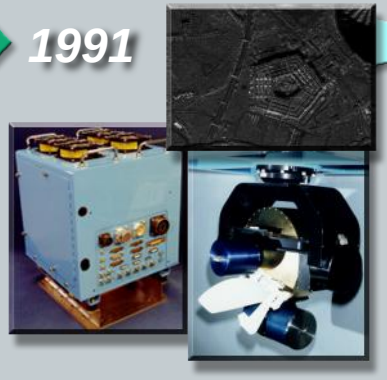
1987



500 lbs

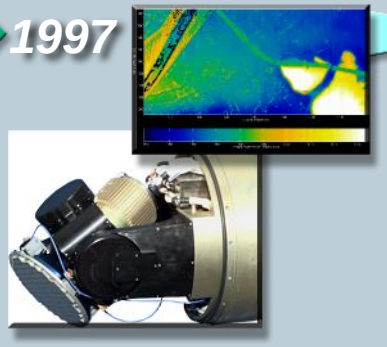
SAR Target Recognition & Location systems (STARLOS)

1991



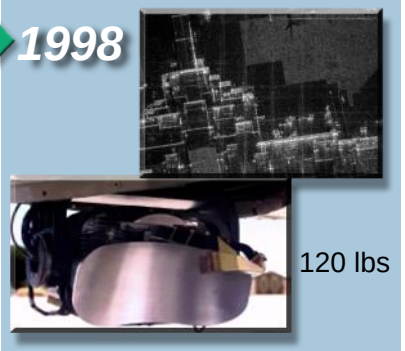
Terminal Fix System (TFS) SAR

1997



Inertial Terrain Aided Guidance (ITAG)

1998

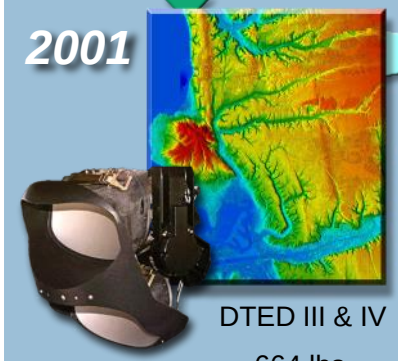


120 lbs

Lynx Multi-Mode Radar

CCD & GMTI

2001

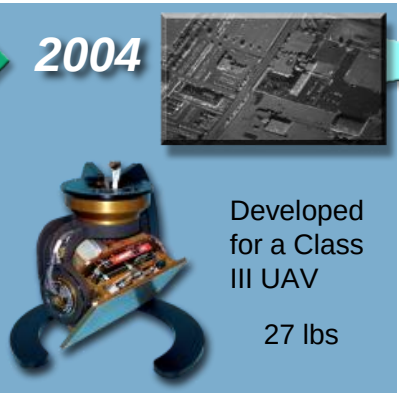


DTED III & IV

664 lbs

Rapid Terrain Visualization (RTV)

2004



Developed for a Class III UAV

27 lbs

MiniSAR

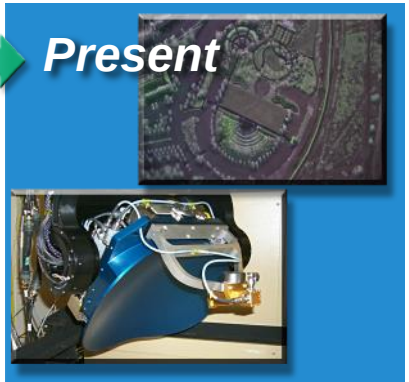
2008

RT Fine Res SAR/CCD

65 lbs

Copperhead

Present



FARAD

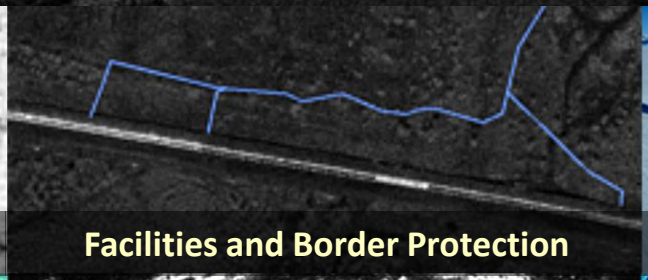
Multi-mode

Variable Resolution & SWAP

Improving radar performance & reducing SWAP for over three decades

Real World Applications

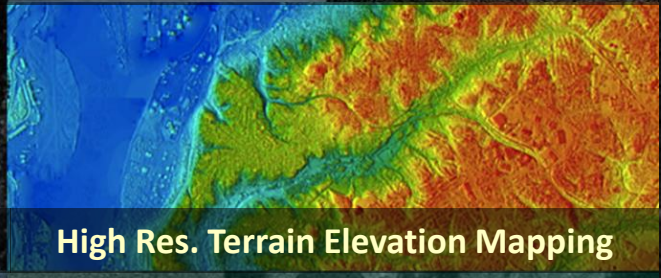

Coherent Change Detection


Facilities and Border Protection


Crevasse Detection

Environmental Monitoring


Space Missions


High Res. Terrain Elevation Mapping


Maritime & Littoral


Vehicle and Dismount Tracking


S&R and Targeting

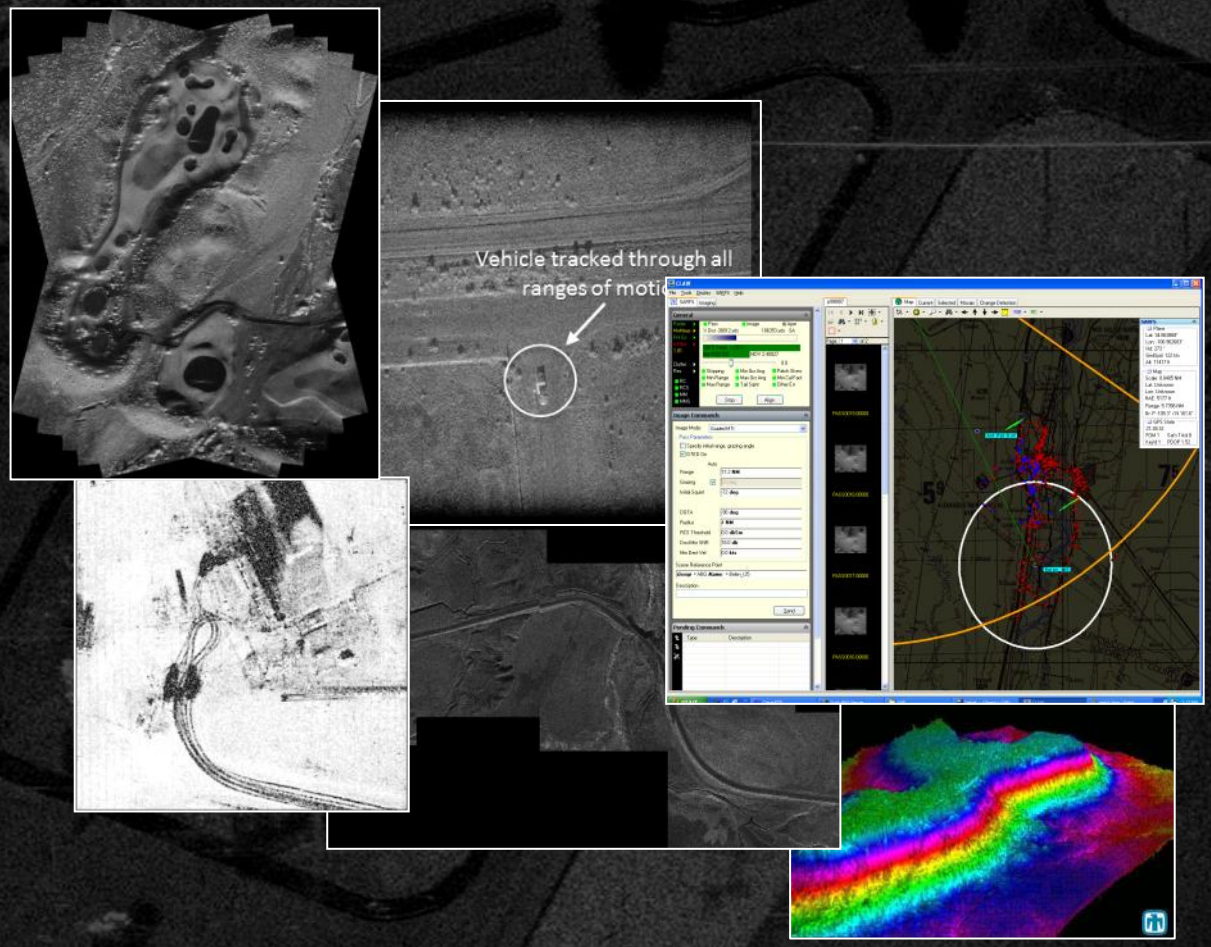

C-IED & Route Reconnaissance


Patterns of Life


Precision Guidance

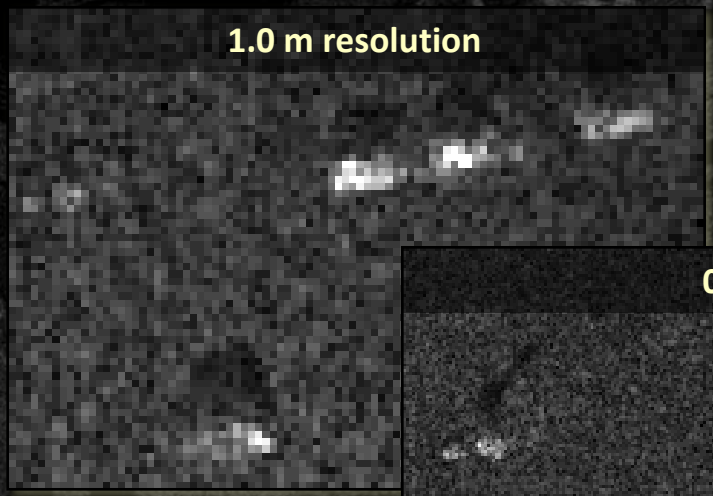
Multi-Mode Functionality

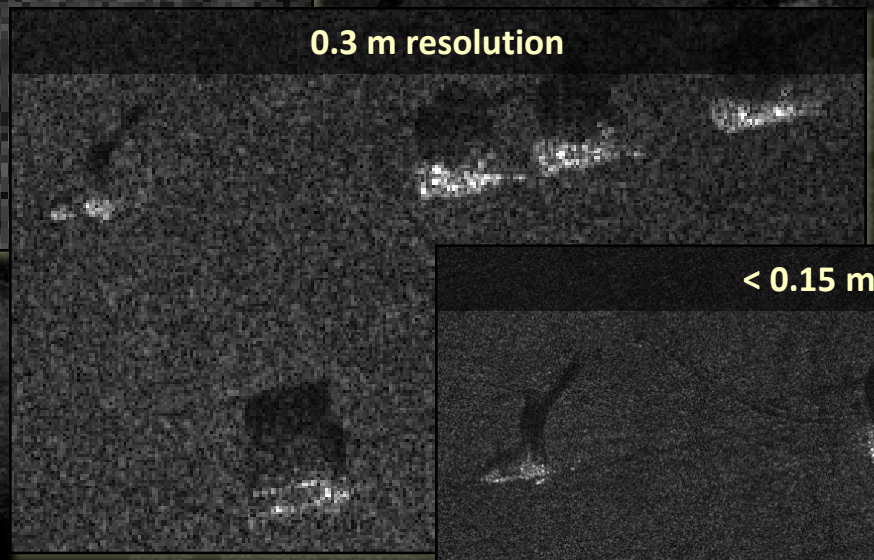
- Spotlight
- SpotDwell
- Circle
- Stripmap
- Arbitrary Stripmap
- CCD/NCP
- IFSAR
- VideoSAR/VICTR
- GMTI/DMTI
- Wide Area Search
- High Range Resolution
- Polarimetry



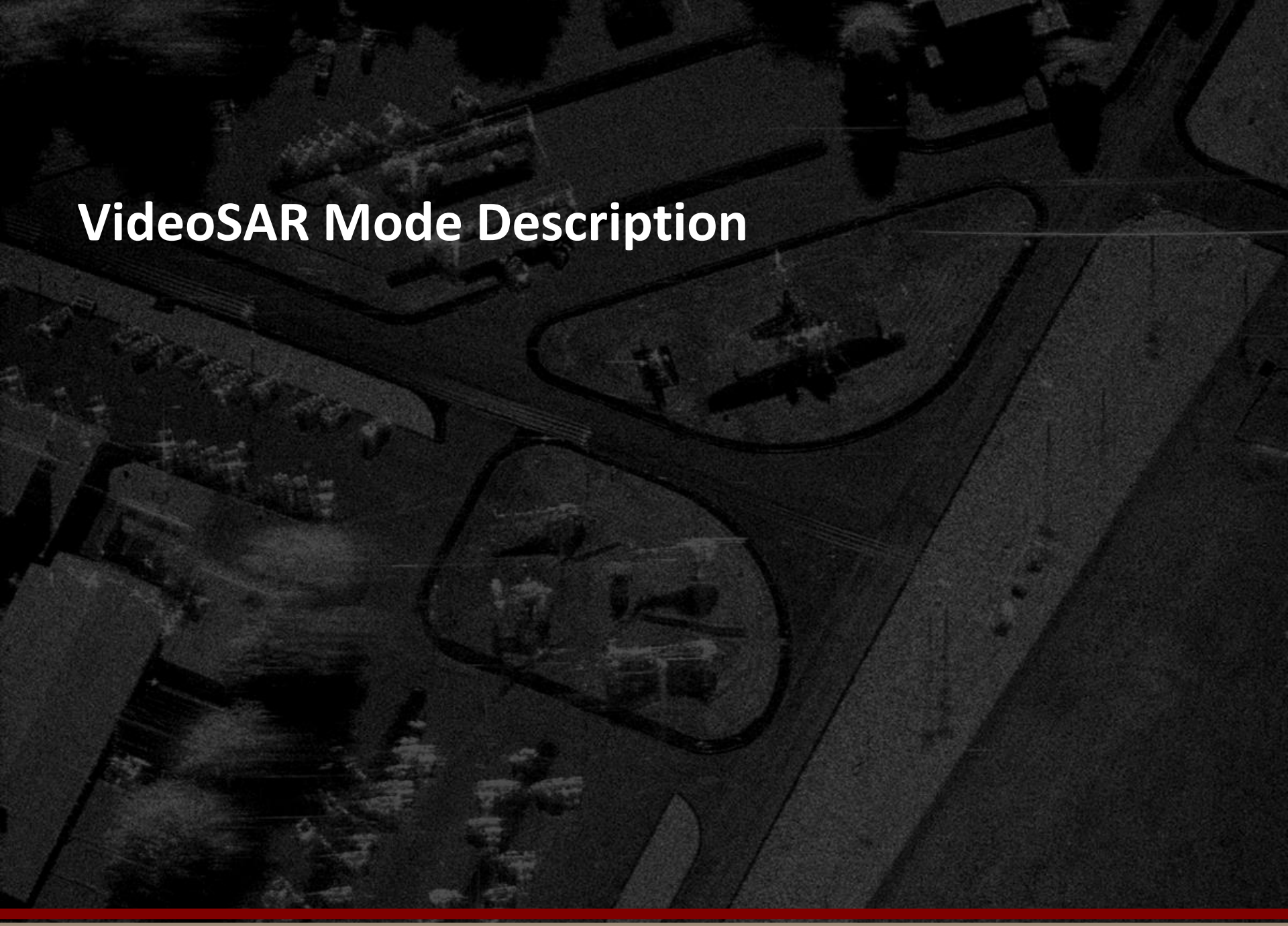
As new radar modes are developed they can be integrated into existing Sandia radars during product improvement phases without redeveloping the entire system

Resolution Matters





VideoSAR Mode Description



Advanced RADAR Mode: VideoSAR

- **Traditional SAR**
  - Phase histories are only collected during real-time apertures
  - Time between images = time to collect real-time aperture + time to process image (many tens of seconds at long ranges)
  - Moving targets disappear or smear, difficult to locate/track

- **VideoSAR**
  - Phase histories are collected continuously
  - Images are formed from overlapping sets of phase histories
  - Time between images is user selectable and is independent of aperture length (0.1 to 0.3 seconds seems best)
  - Slow moving targets (< 15 mph) can often be observed/tracked
  - Latency < 8 sec.

Why VideoSAR?

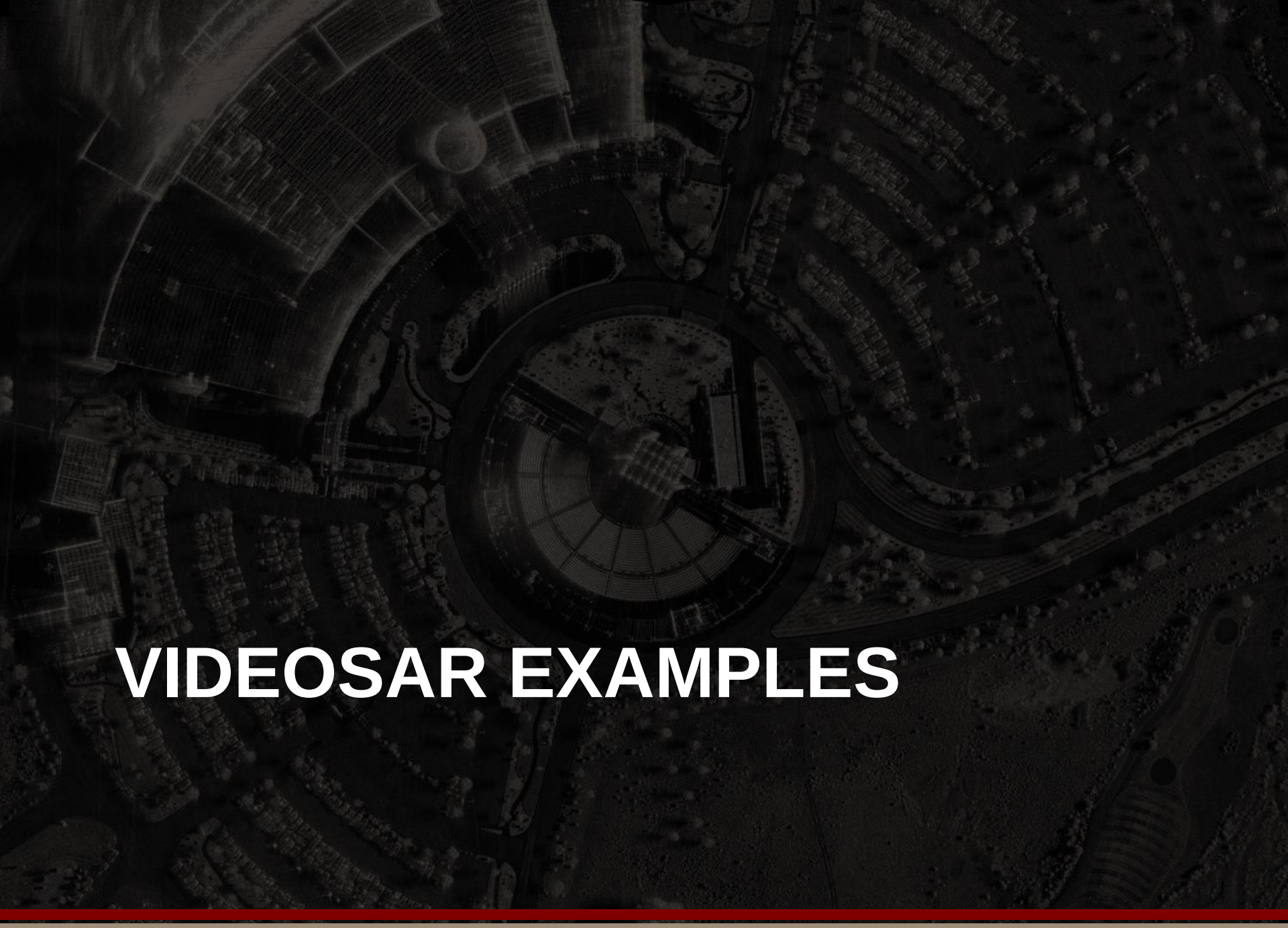
VideoSAR offers the following advantages over traditional MTI:

- Minimum detectable velocities down to 0: targets are visible when they are stationary or mobile
- Minimum detectable RCS << 10 dBsm: VideoSAR relies on the shadow of moving vehicles for detection.
- Azimuth resolution < 1 m: vehicle location is known to within the geographic precision of the SAR image
- Moving targets shown in relation to stationary clutter: much more situational awareness than from traditional MTI

VideoSAR bridges the gap between SAR and GMTI for slow moving targets.

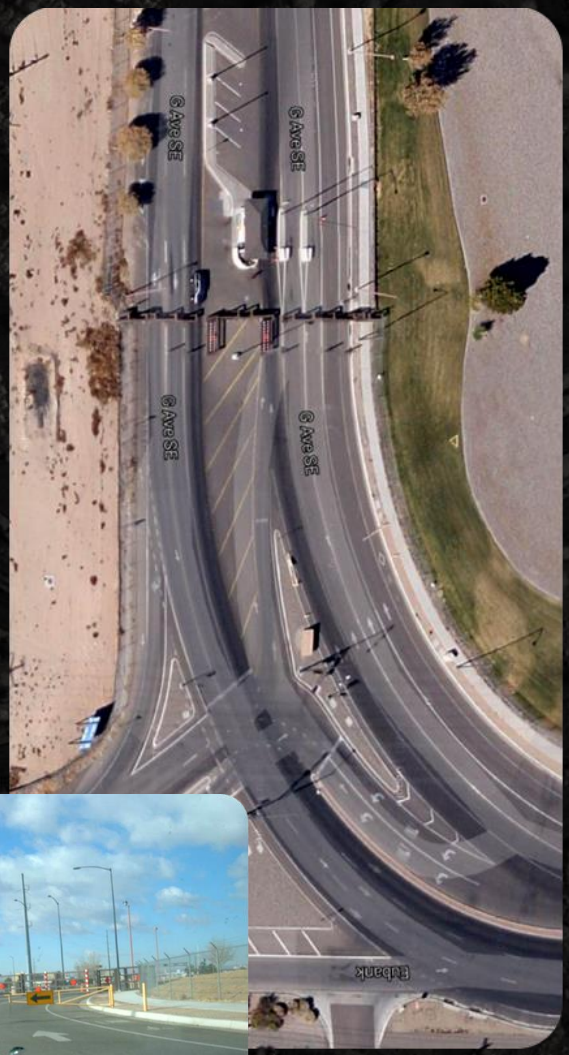
Sandia VideoSAR Background

- **1999 - Initial Concept**
  - Wanted complete situational awareness of fixed and moving targets
  - The processing power need was 10-100X more than for just SAR - waited on Moore's law, but concept demonstrated with post processed data
- **2009 – Patent 7,498,968** – "Synthetic aperture design for increased SAR image rate", Bielek, Timothy; Thompson, Douglas G.; Walker, Bruce C.
- **2010 – Deployed on Manned Platform Ku-Band Radar**
  - Began delivery of 9 operational and fielded systems
  - On-board, commercial GPU-based real-time VideoSAR
  - VideoSAR part of common radar architecture
- **2012 – Real time VideoCCD fielded**
- **2013 – Polarimetric VideoSAR successfully demonstrated**
- **Present**
  - Multiple systems deployed on both manned and UAV platforms
  - Multi-band, polarimetric testbed radar - FARAD



VIDEOSAR EXAMPLES

VideoSAR Vehicles Example



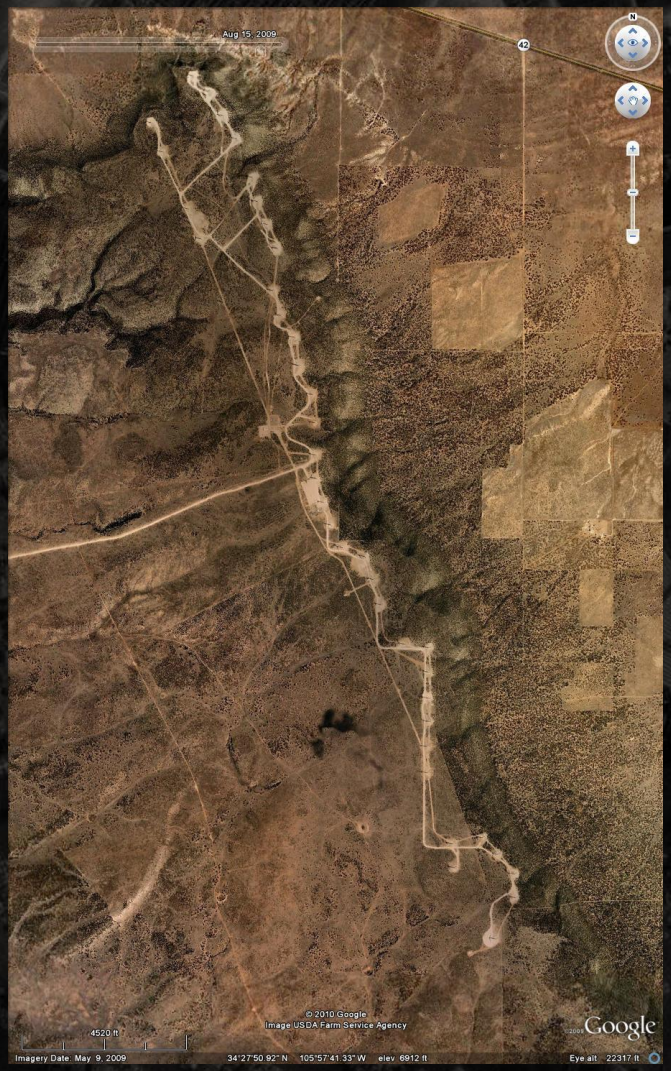
High Lonesome Wind Ranch

- Location: 10 miles SSE of Willard, NM
- Quantity: 40 turbines
- Layout: Line 4.7 miles long oriented NS
- Total capacity: 100 Megawatts
- Turbines:
  - Clipper Liberty Model
  - 2.5 Megawatts
  - 270-ft tall from base to hub
  - 155 foot long blades
  - Blade tip velocity 170 mph at maximum 15.5 RPM

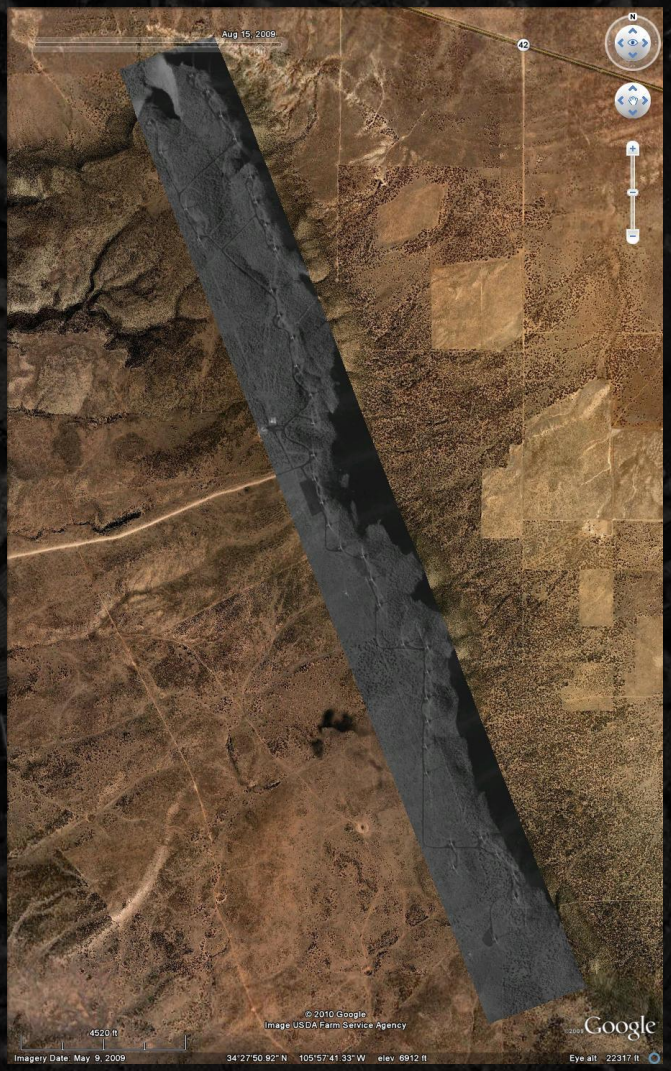
(http://www.newmexicocare.org/1pages/highlonesome.html)

Aerial and ground photographs of site

Wind Farm SAR Stripmap

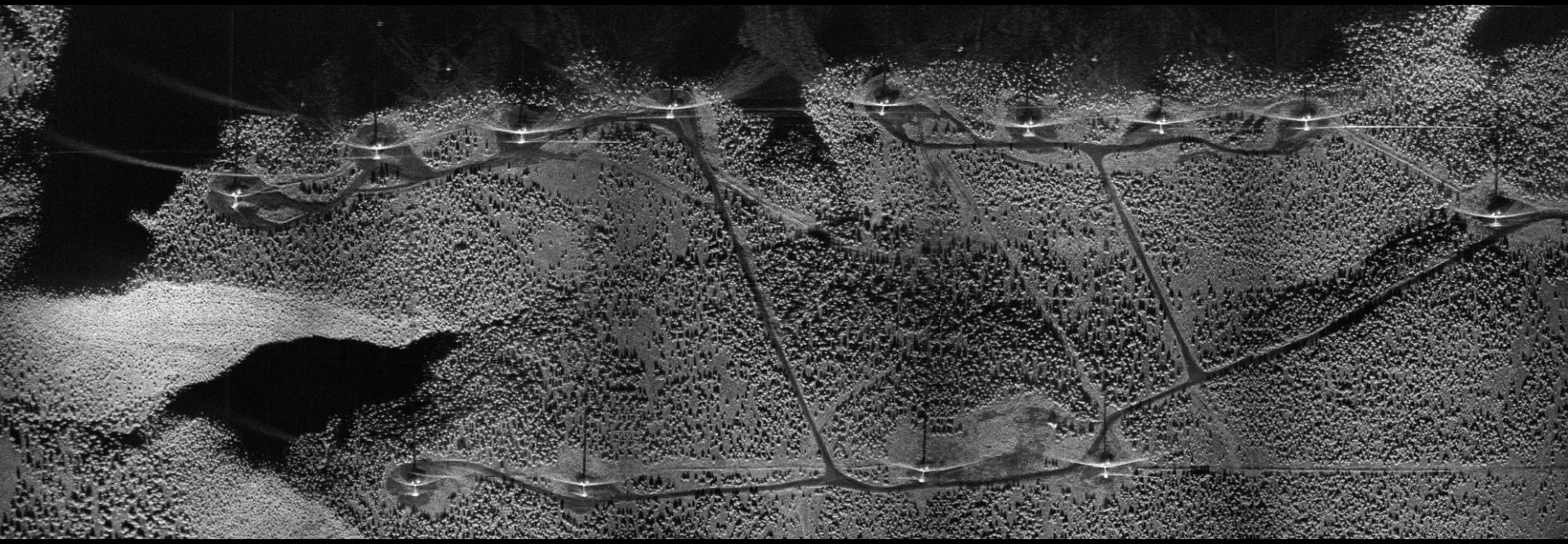


Google Earth Image of High Lonesome Wind Farm from August 15, 2009



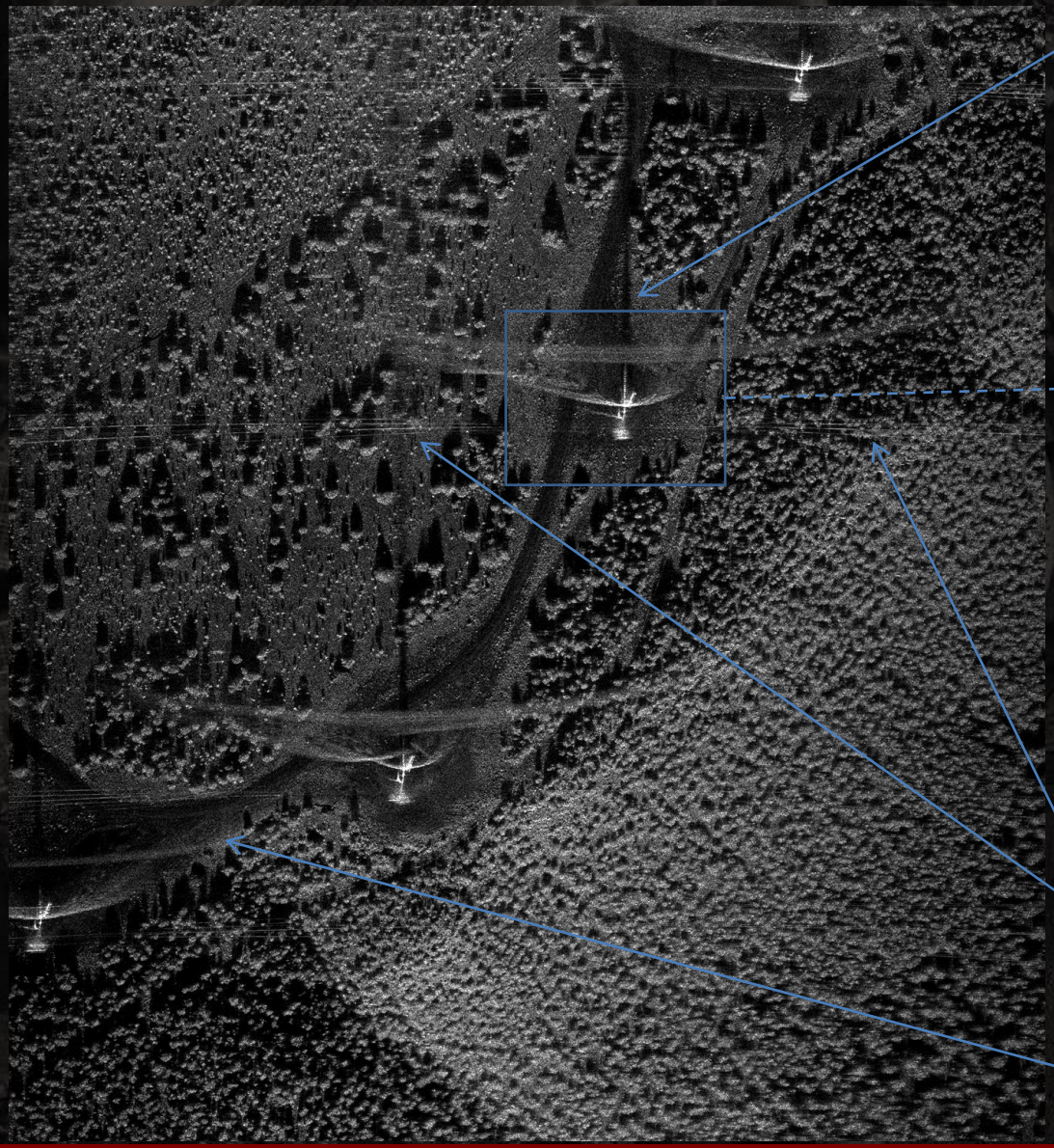
Same Image with Mosaic of SAR Stripmap Patches Overlaid

Wind Farm 1-Foot Resolution SAR Stripmap 5 Patches



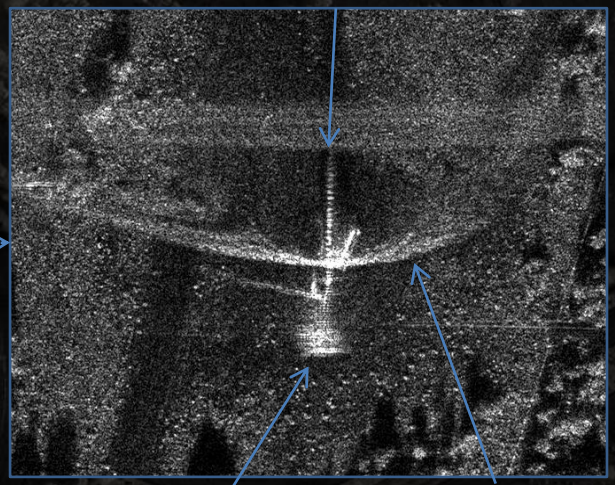
- Bright corresponds to areas of high radar return and dark corresponds to areas of low radar return
- Source illumination is from the bottom of the image, and is at an elevation angle of 11 degrees from the ground
- Shadows are very pronounced due to the low grazing angle

Wind Farm 8-Inch Resolution SAR Linear Spotlight Mode



Shadow from tower

Series of radar returns periodically delayed in time resulting from the signal bouncing back and forth inside the nacelle



Bright arch is multipath between ground and the cylindrical tower

Outer structure of the nacelle (objects above the ground appear to layover toward the source)

Turbine blades where the blade rotation imparts additional Doppler shift to the radar return and smears the blade response across the SAR image creating horizontal bright lines

Ground and tower higher order bounce multipath occurs later in range with characteristic curvature and larger spread

VideoSAR Imagery of Wind Turbines

Mission Examples

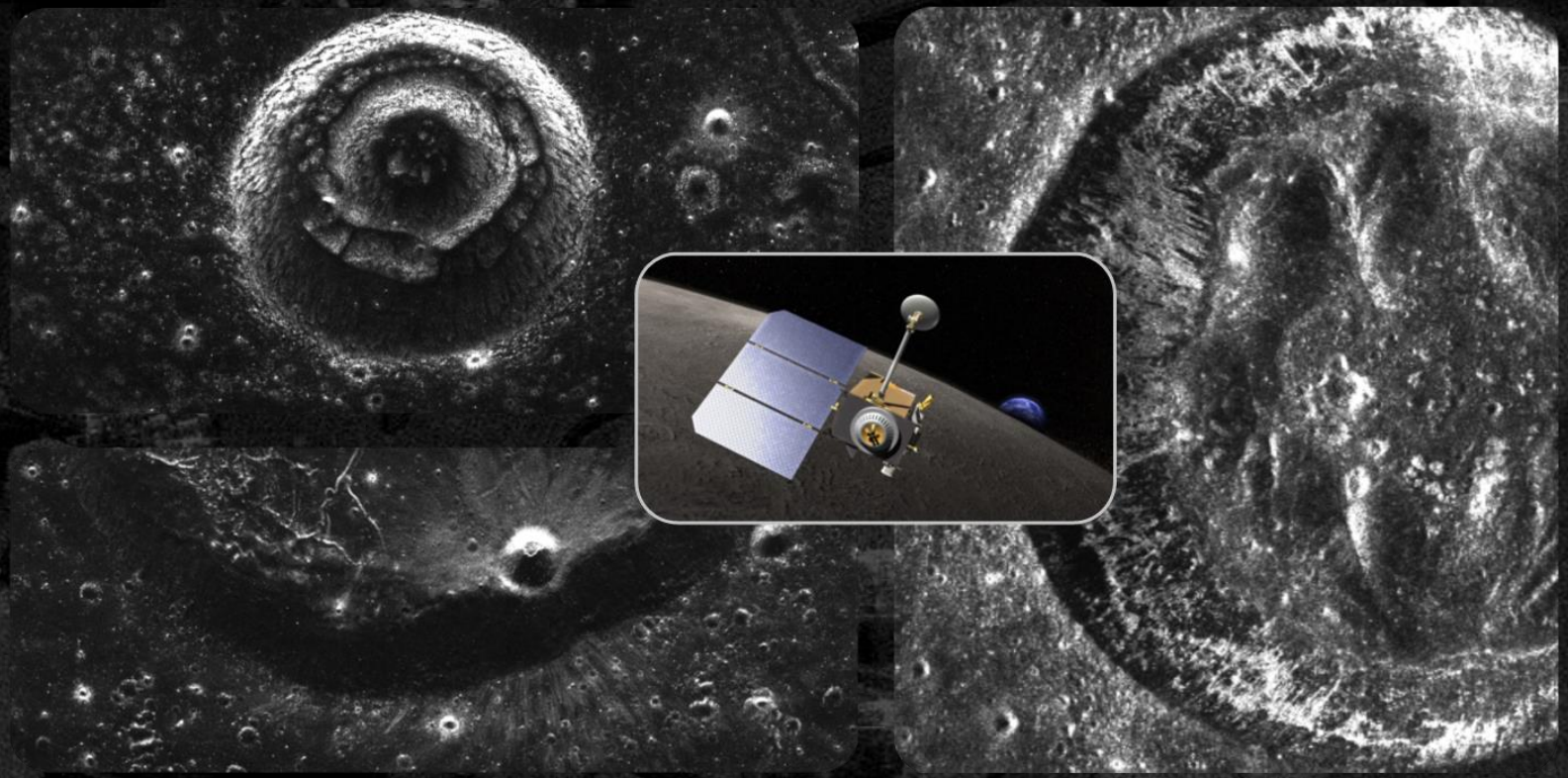
Unmanned Systems (Past and Present)

MiniSAR Sky Spirit™ UAS Demonstration

- **First Ever Demonstration of Fine Resolution (<0.15 m) Real-Time SAR on a small ("Class III") UAV (October 2006)**
  - SNL and LM Maritime Systems and Sensors Partnership
  - Spotlight, Stripmap, Circle modes (real time)
  - CCD (post processed)
  - Down-linking of RT images formed onboard
    - Raw data also recorded for post-flight processing

Location: Camp Ripley, MN

Lunar Reconnaissance Orbiter (LRO)
NASA Program



- Sandia and partners developed the high-resolution Mini-RF SAR imaging system on board the LRO which imaged 98% of the lunar surface (S-Band), including high-resolution imagery of permanently-shadowed regions.
- The system aided in location of subsurface water-ice deposits.
- LRO mission launched in 2009

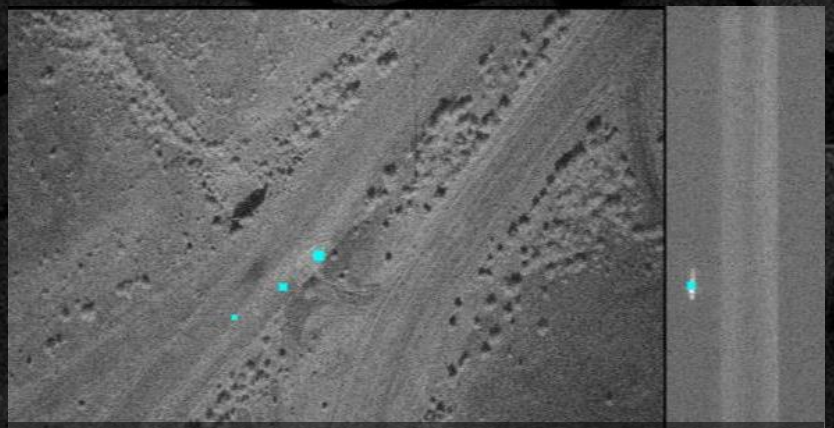
Copperhead

- **Mission**
  - Counter - IED ISR (C-IED ISR)
- **Copperhead Provides:**
  - Change Detection - capable of detecting very small surface disturbances
  - Modes: Route Following Strip-map, Circle (Spotlight) images
  - Onboard Processing and compression
  - Images meeting quality specifications in high-relief terrain
  - Automatically-created flight plans for route following and disturbance verification missions

Size	Volume: 1.53Ft^3 (REA inside UAS), 0.83Ft^3 for the radome
Weight	< 65lbs
Power	< 650W peak
Frequency Band	Ku-Band
Platform	NAVAIR Extended Tigershark; transferred to Hunter

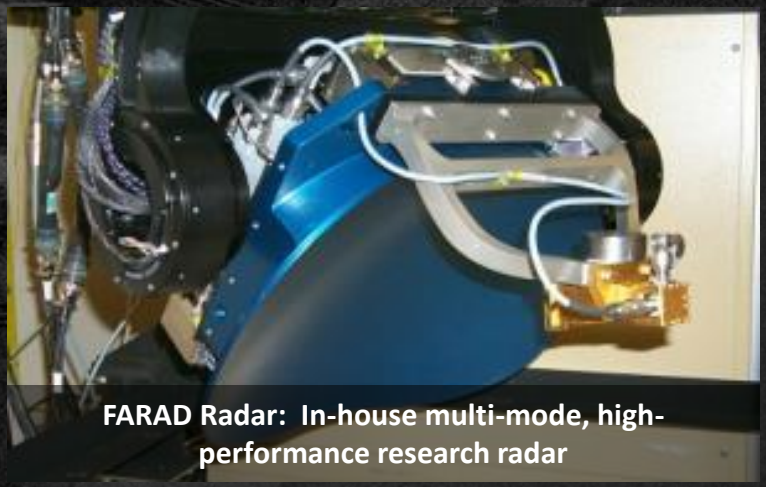
Where are we headed?

Fully Polarimetric VideoSAR/CCD



Simultaneous VideoSAR/GMTI with automated tracking of movers including repointing the antenna (VICTR)

Multi-look SAR



FARAD Radar: In-house multi-mode, high-performance research radar

Polarimetric SAR

Generating “Photorealistic” SAR Products From Fully-Polarimetric Data

- Pseudo-color application that tends to “comfortably” map to natural subject interpretability
  - Enabled by model-based decompositions, such as G4U
  - Utilizes the following scattering mechanism color mapping

    Red: Surface

    Green: Volumetric

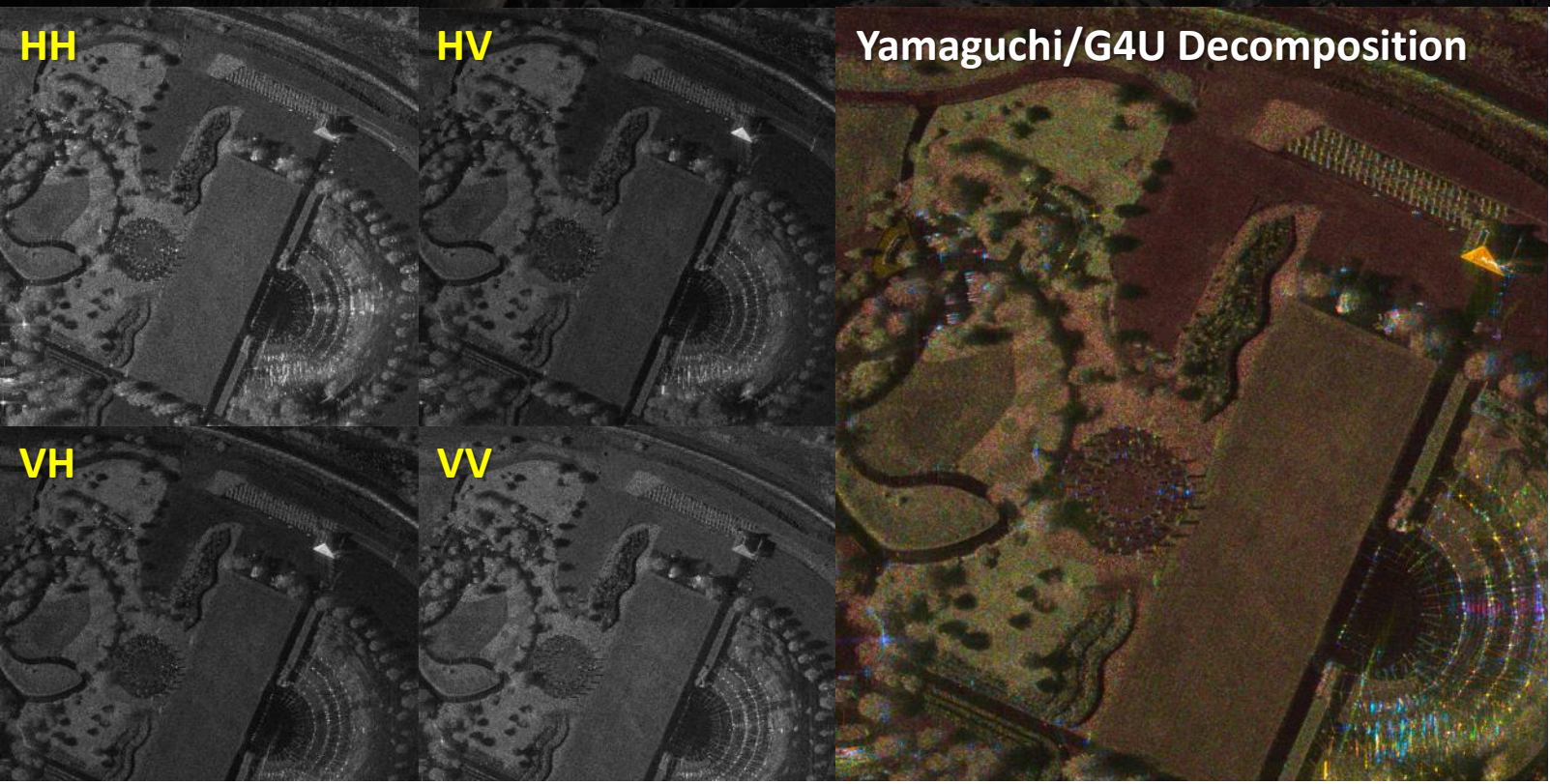
    Blue: Dihedral

    Yellow: Helical
  - Result: natural scatterers tend to occupy green and brown hues; unnatural scatterers will be less natural “looking” (bright blues, yellow/orange, magentas, etc.)
- Reduction of speckle to improve detail texture while still preserving spatial resolution
  - Enabled by multi-aspect angle, multi-look collections and non-coherent registration/ warping algorithms
  - Utilizes multi-aspect averaging for clutter, which will reduce speckle texture due to non-coherence from aperture-to-aperture
  - Utilize localized multi-aspect maximum hold techniques to preserve specular scattering signatures
- Following data has been collected using the SNL X-Band fully polarimetric FARAD/PhoeniX SAR system

Role of Polarimetric SAR Decomposition

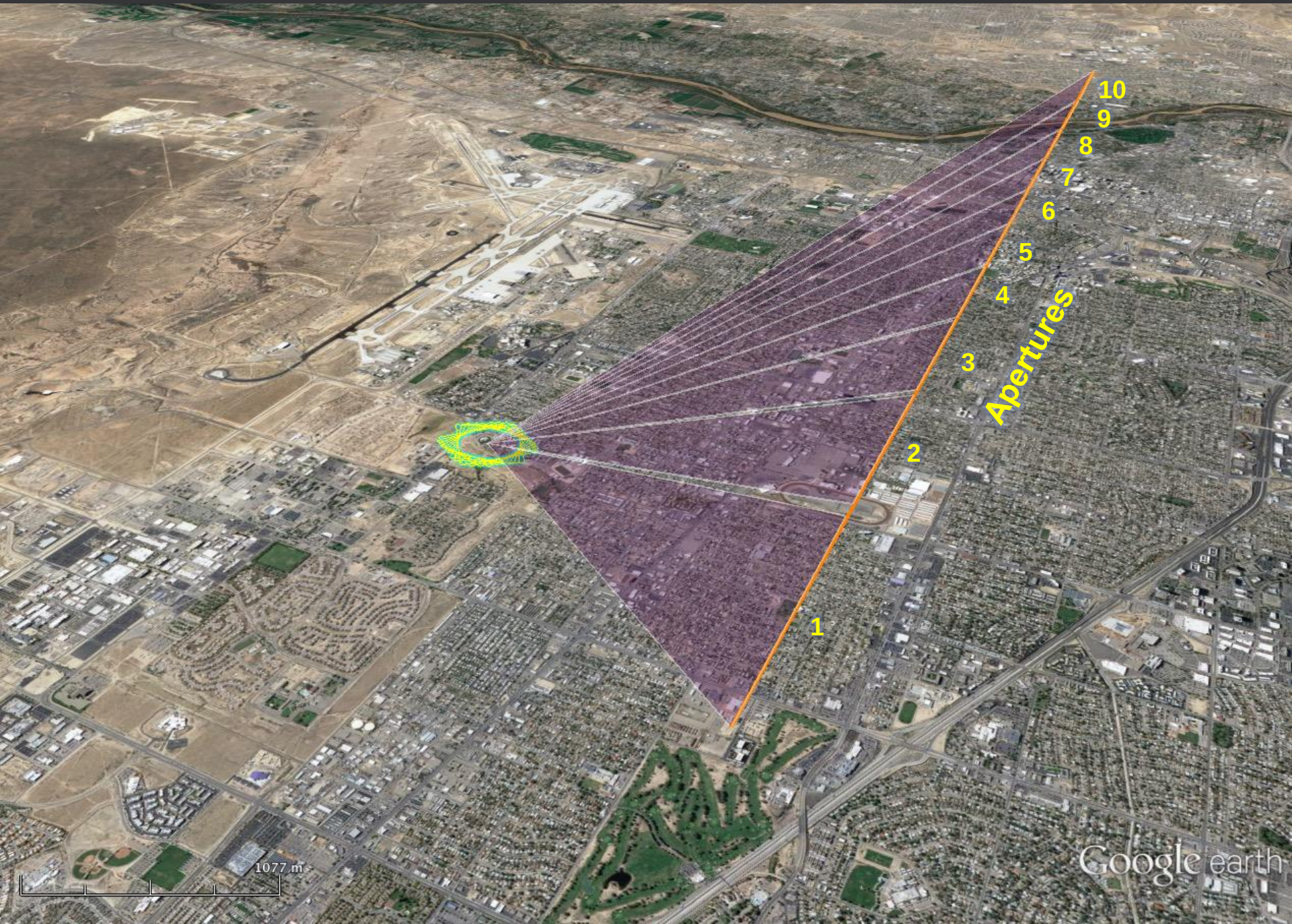
Each Fully-Polarimetric Aperture Can Produce Four Complex Images

Value of polarimetric SAR is not in visual comparison of individual channel (HH, VV, HV, VH) backscatter intensity maps, but rather in the inference of underlying scattering mechanisms from these independent phase coherent measures

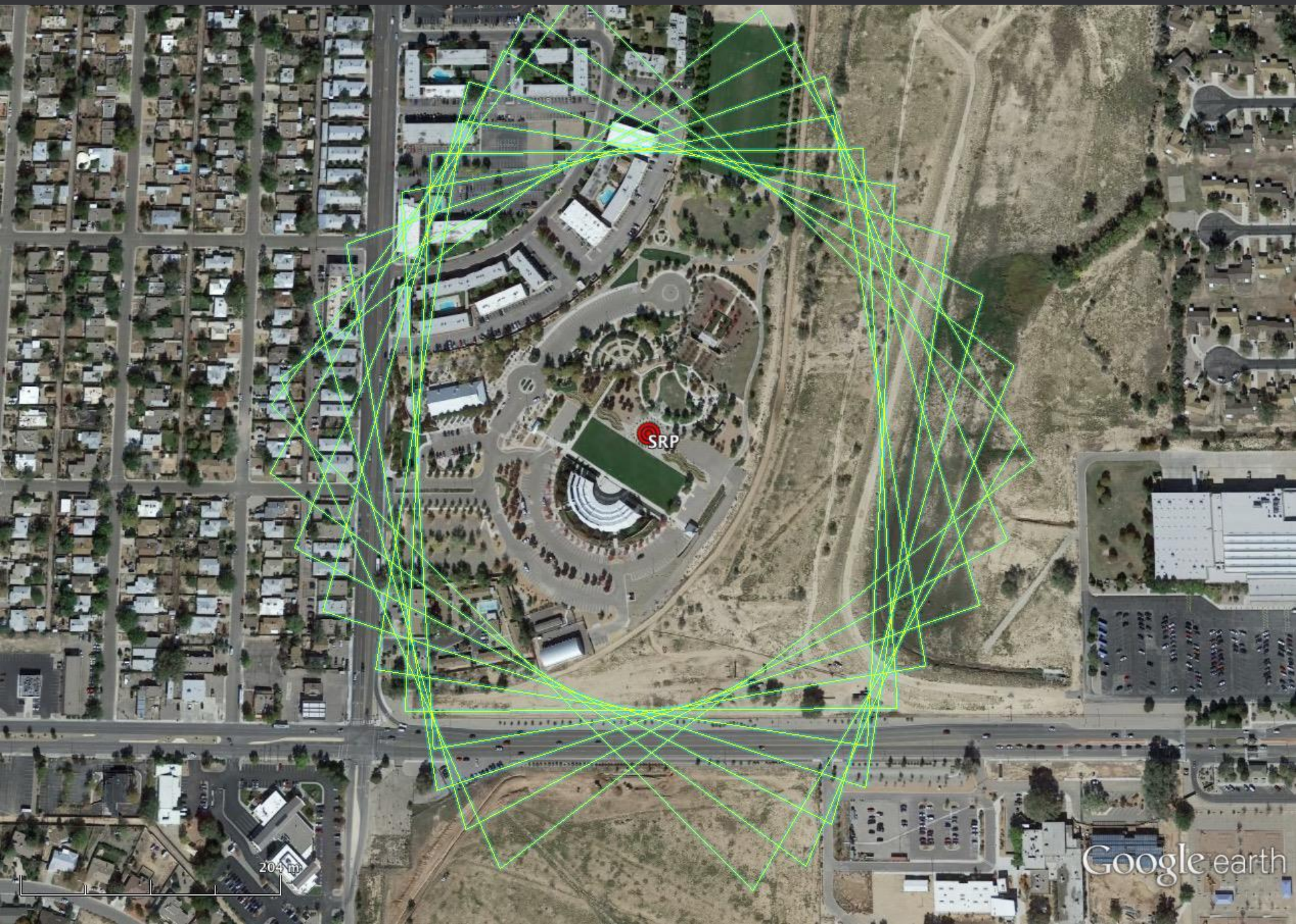


SNL FARAD, X Band, 0.2m Full-Pol Imagery of New Mexico Veterans Memorial, Model Based Decomposition Example

Spotlight Mode Aperture Sequence – Enables Speckle Reduction and Specular Enhancement

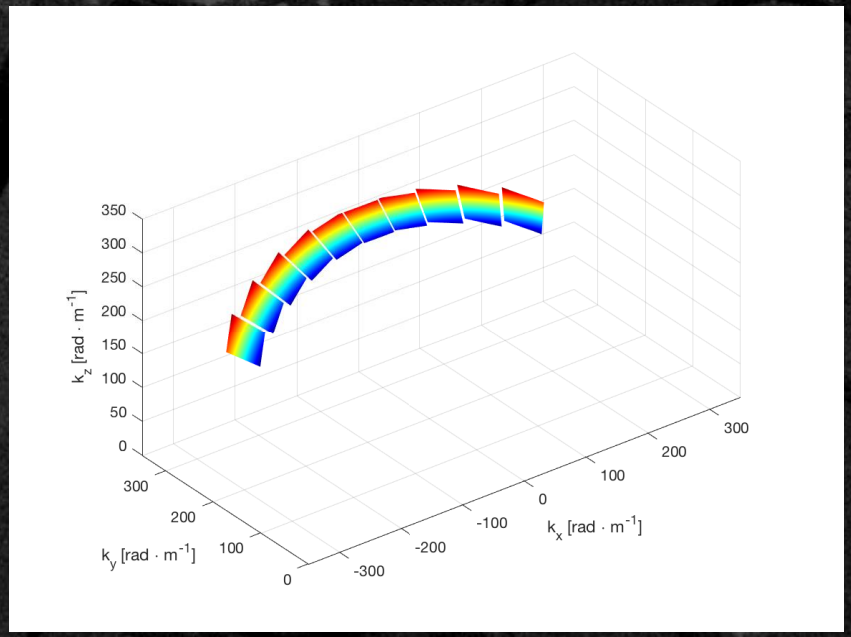


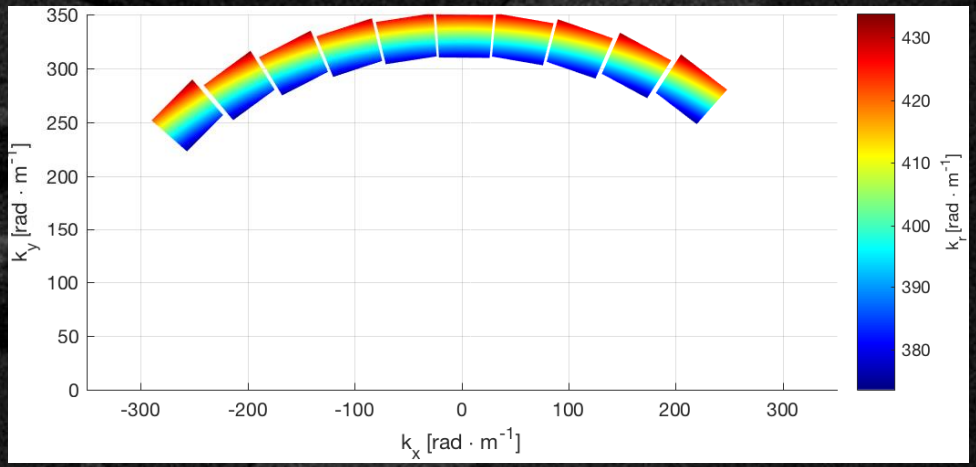
Formed Multi-Aperture Image Coverage Over Scene



k-Space Coverage of SRP From Multiple Apertures on Straight/Level Flight Line

- Azimuth look angle changes between apertures
- Grazing angles also change between apertures
- Layover will be projected in the same azimuth direction across apertures
- Nominal range wavenumber coverage is similar across apertures
- Curvature in range wavenumbers (k_r) is result of real-time motion compensation



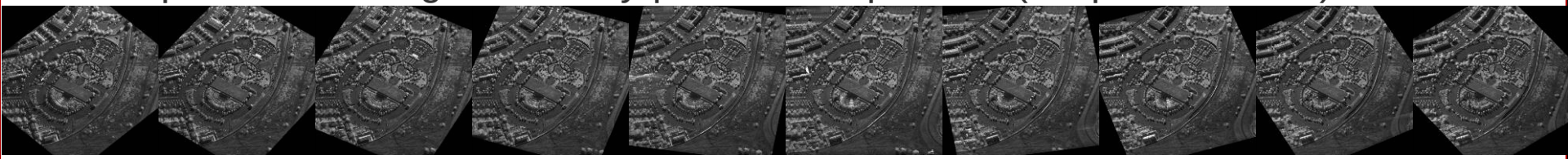


Preparation for Multi-Aperture (multi-aspect, multi-look) Product Formation

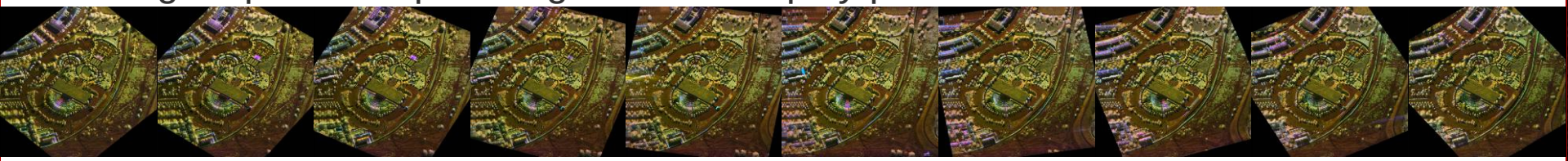
Original sequence of fully-polarimetric patches (projected into native slant planes)

Multi-Aspect Registration / Warping to Common Reference
HH,HV,VH slaved to VV-pol registration

New sequence of co-registered fully-polarimetric patches (VV-pol reference)

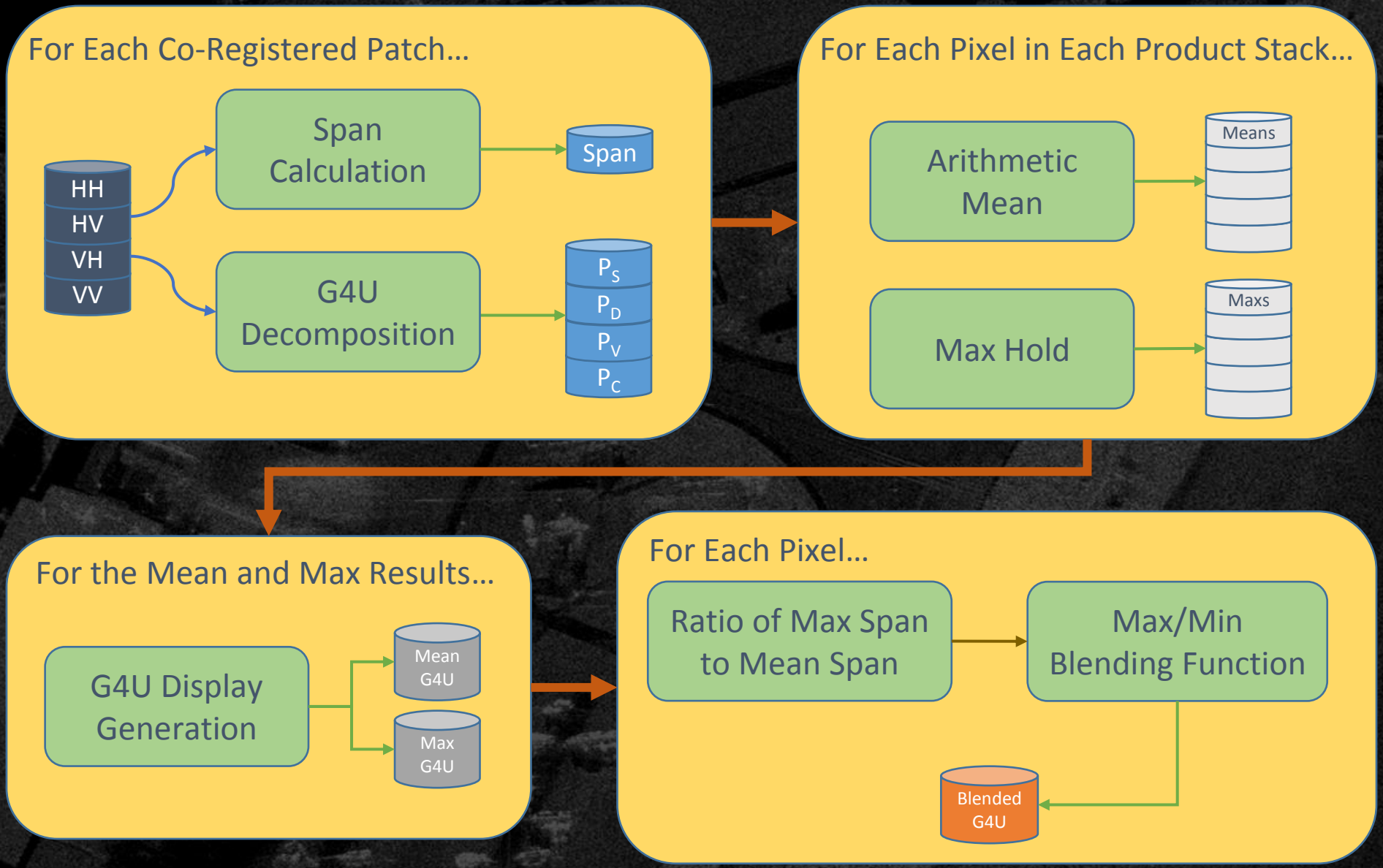


Resulting sequence of pixel-aligned G4U display products

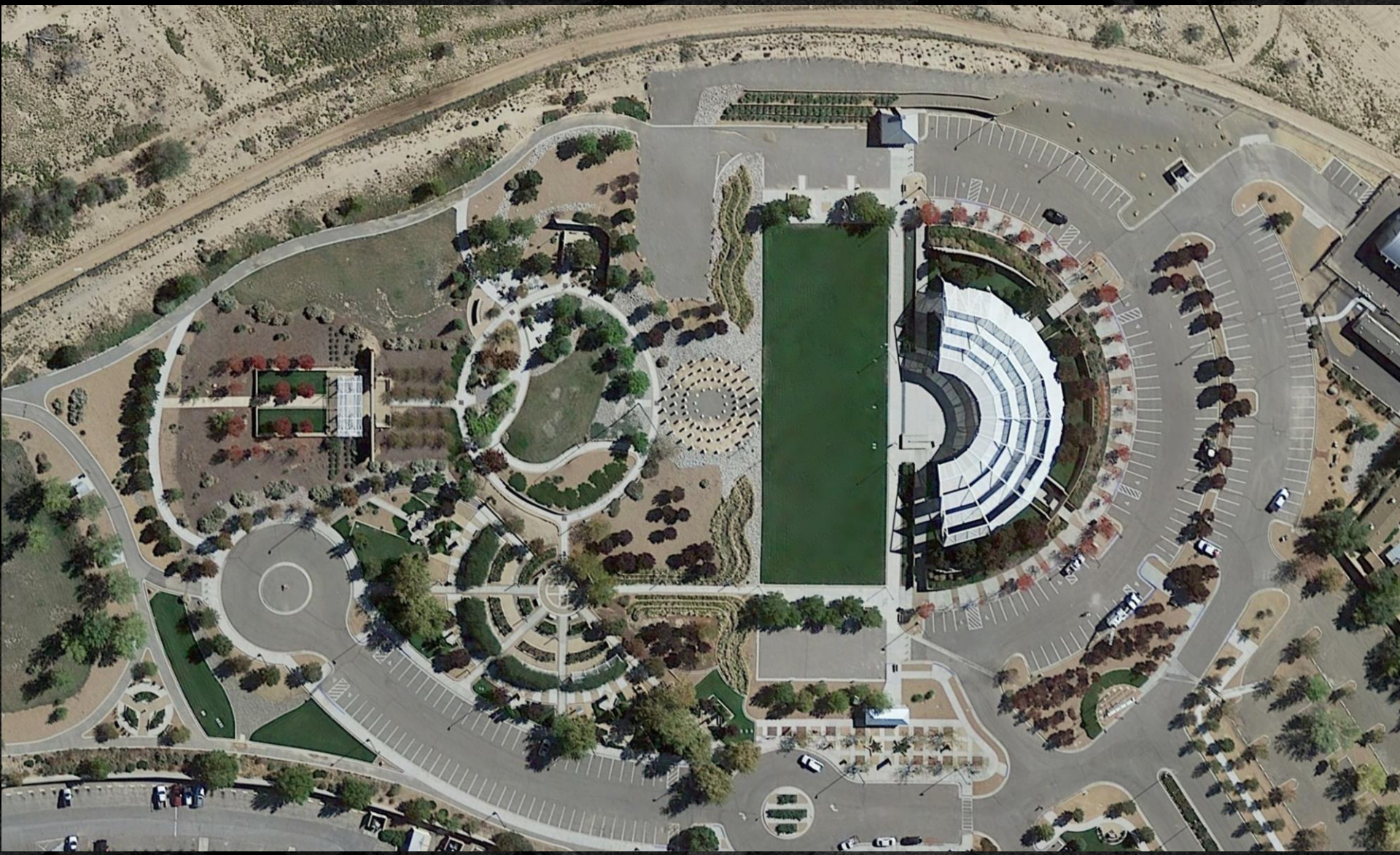


SNL Multi-Aspect Multi-Look G4U Product Generation

A 100% data driven, repeatable process!

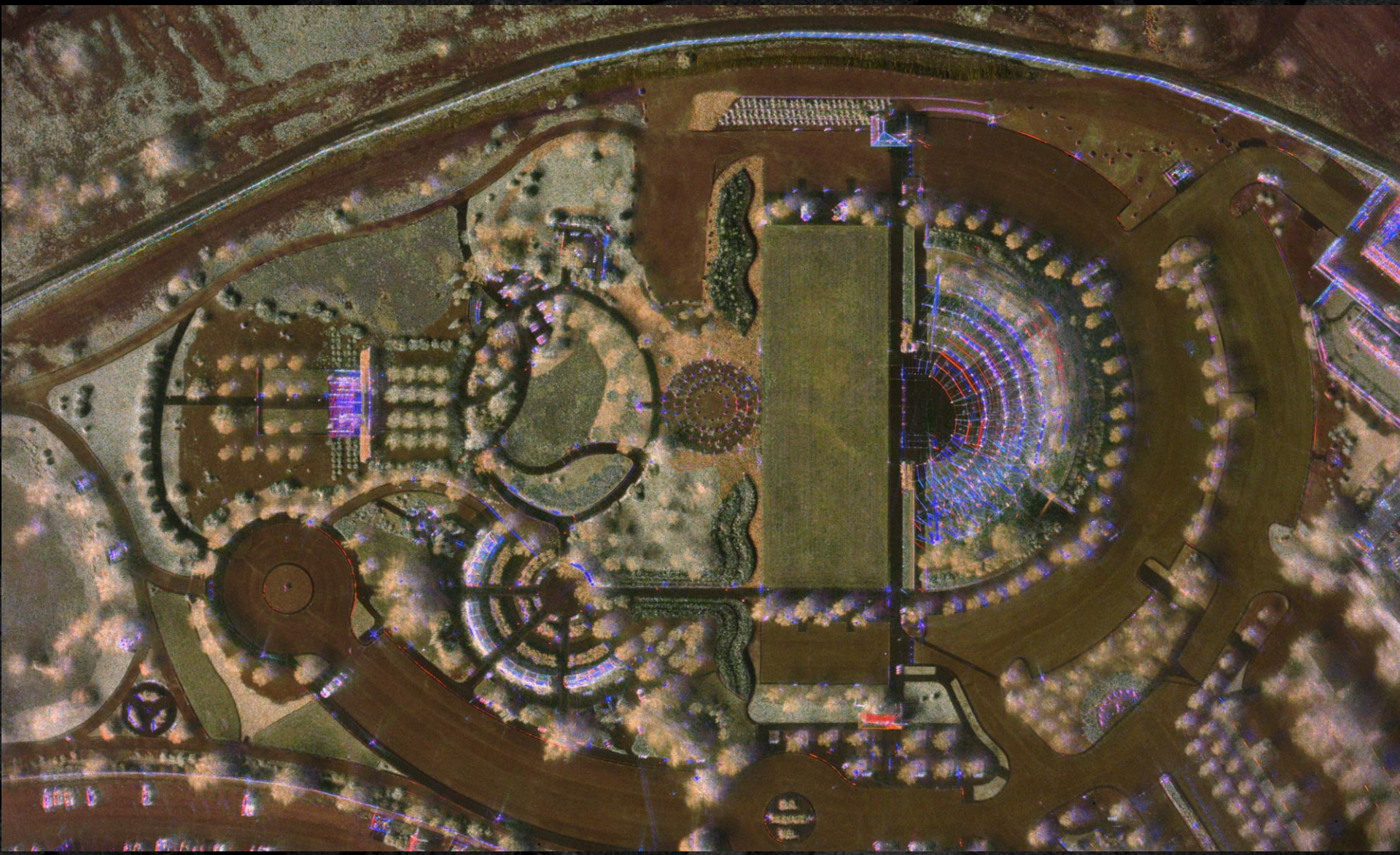


Comparative EO Image



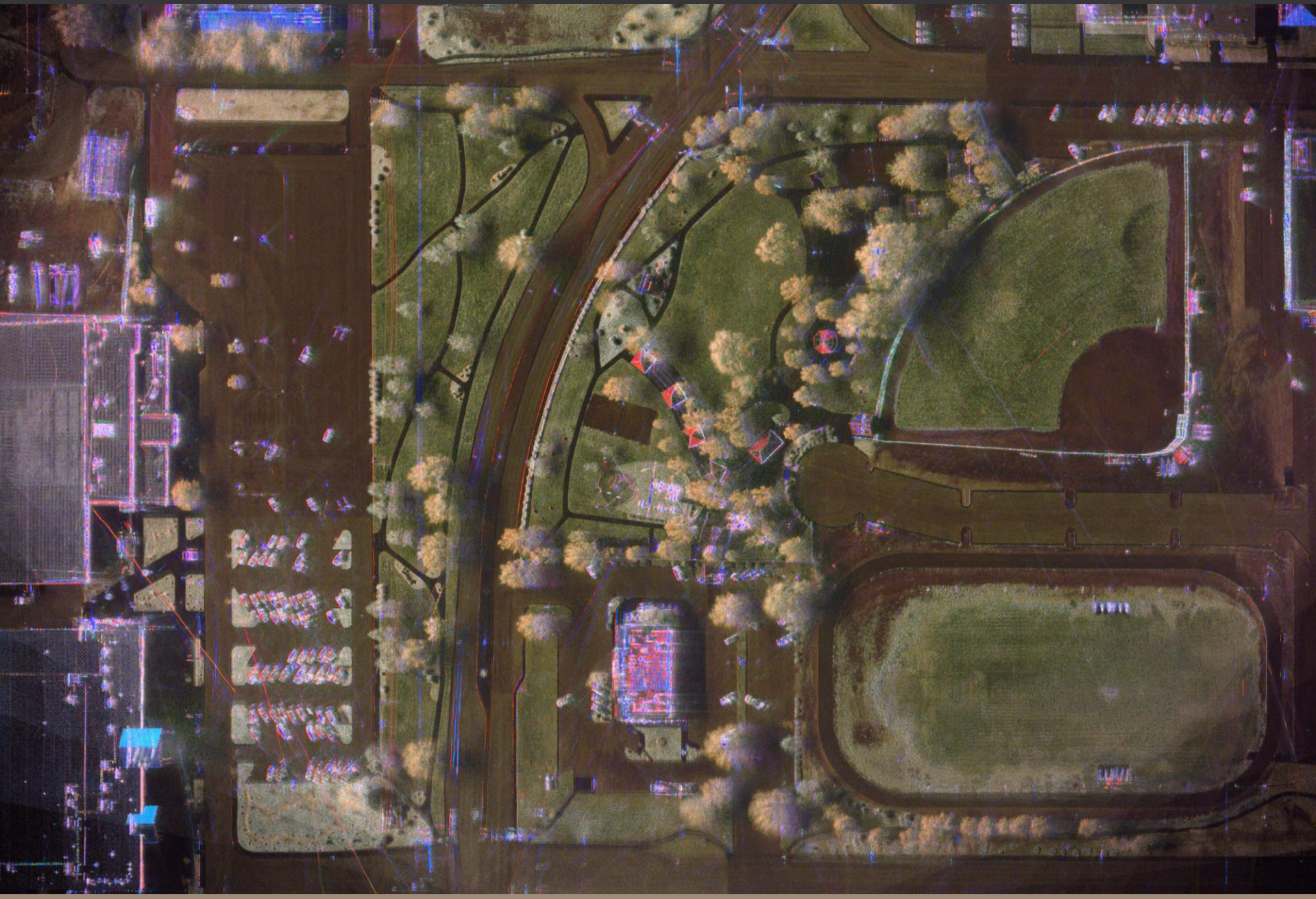
Comparative VV-Polarization Single-Look Display Product (ρ = 0.15m, ϕ = 35°)

Comparative Fully-Polarimetric Multi-Aspect G4U Display Product (10 aspects, $26^\circ \leq \phi \leq 35^\circ$)



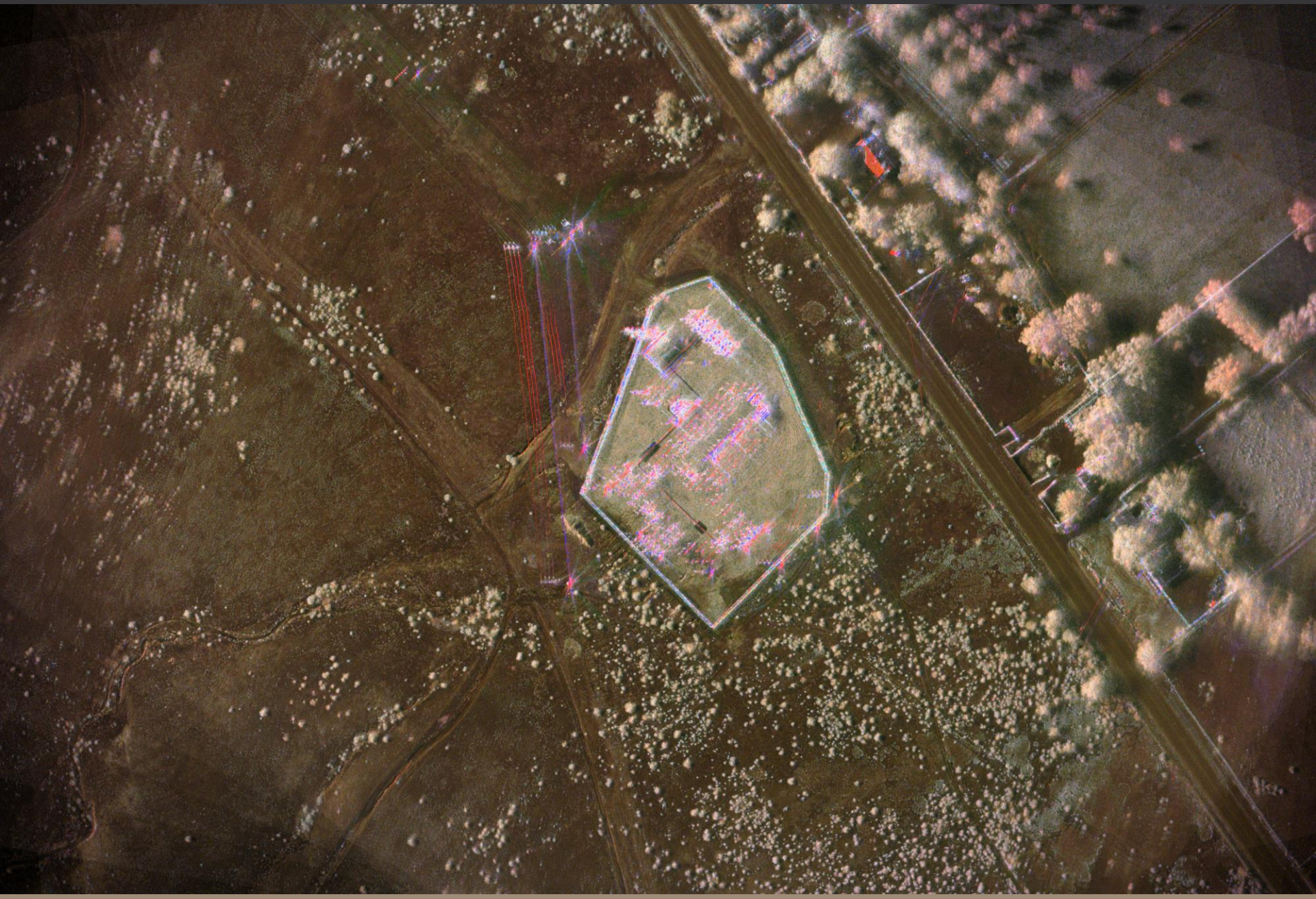
KAFB Flag Field – Single-Look VV-pol (ρ = 0.15m, ϕ = 35°)

KAFB Flag Field – Multi-Aspect G4U (10 aspects, $26^\circ \leq \phi \leq 35^\circ$)



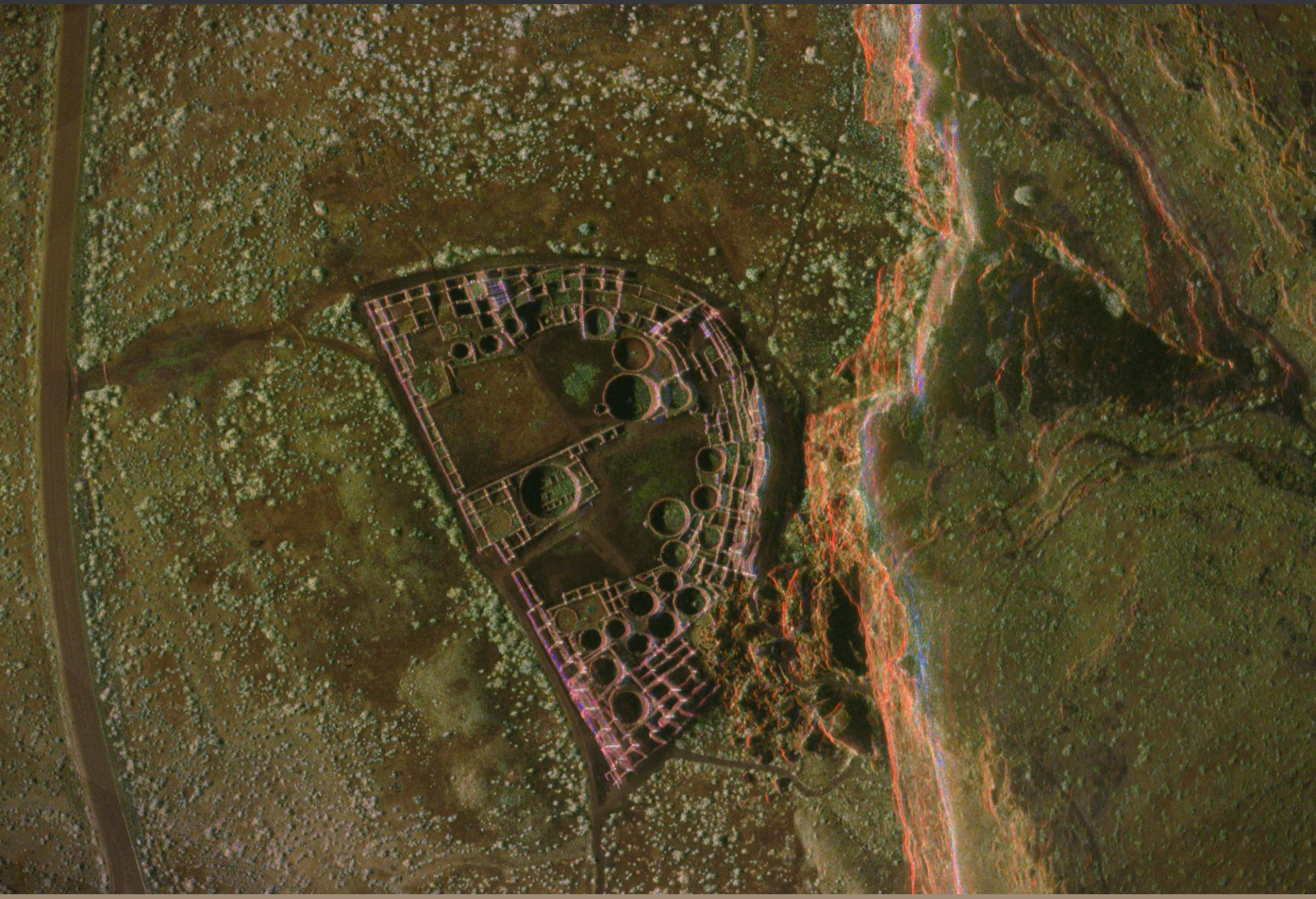
Power Substation – Single-Look VV-pol ($\rho = 0.20$m, $\phi = 30°$)

Power Substation – Multi-Aspect G4U (10 aspects, $22^\circ \leq \phi \leq 30^\circ$)



Pueblo Bonito (Chaco Culture NHP) – Single-Look VV-Pol (ρ = 0.15m, ϕ = 30°)

Pueblo Bonito (Chaco Culture NHP) – Multi-Aspect G4U (7 aspects, $22^\circ \leq \phi \leq 30^\circ$)



Polarimetric SAR

- The Sandia Polarimetric SAR development effort is demonstrating the “art-of-the-possible”
  - High quality image display products
  - Enables the determination of the underlying scattering mechanisms – a significant addition in furthering ATR
- The Sandia FARAD testbed radar system is foundational to the PolSAR development effort
  - Data shown was collected with the SNL X-Band fully polarimetric FARAD/PhoeniX SAR system
  - Testbed radar approach facilitates “prove-in” of new technologies as a precursor to RT implementation on other platforms (to potentially including UAS)


THANK YOU