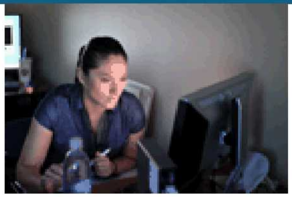
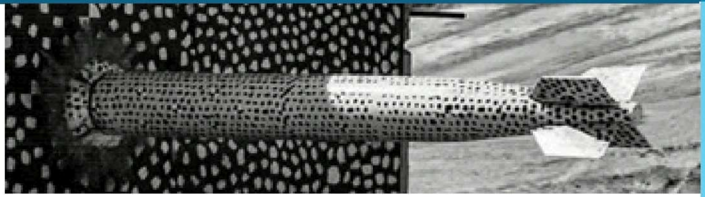
This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

SAND2019-3665C

Spectral and polarimetric remote sensing for CBRNE applications





PRESENTED BY

Julia Craven

16 April 2019

SPIE Defense and Commercial Sensing

The views expressed here do not necessarily reflect the views of the United States Government, the United States Department of Energy National Nuclear Security Administration, Sandia National Laboratories, or Los Alamos National Laboratory.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Contributors to the technical talk

- **SNL Advanced Remote Sensing Group**
  - **Innovative optical remote sensing system modeling, design, development and realization**
  - **Target phenomenology, radiative transport, and scene simulation**
  - **Spectral and temporal data processing, exploitation, and algorithm development**
- Sandia National Laboratories
- Los Alamos National Laboratory
- Bohannan Huston Incorporated
- Silent Falcon UAS
- Our work regularly engages many other collaborators!

Motivation & Outline

- Why optical remote sensing for CBRNE applications?
  - Large area search, safety, accessibility, information integration, …

I. Examples our efforts in this domain
   A. Spectral imagery collection and exploitation for characterizing legacy underground nuclear explosion test sites
   B. LWIR spectropolarimetry for material characterization
   C. SWIR polarimetry for chemical detection

II. SPIE efforts in Equity, Diversity, and Inclusion

A. Spectral imagery collection and exploitation for characterizing legacy underground nuclear explosion test sites

Dylan Anderson[1], Trevor Briggs[2], Julia Craven[1], Robert Dzur[3], Emily Schultz-Fellenz[4], Elizabeth Miller[4], Brian Redman[1], John Vander Laan[1], Steven Vigil[1]

[1]Sandia National Laboratories

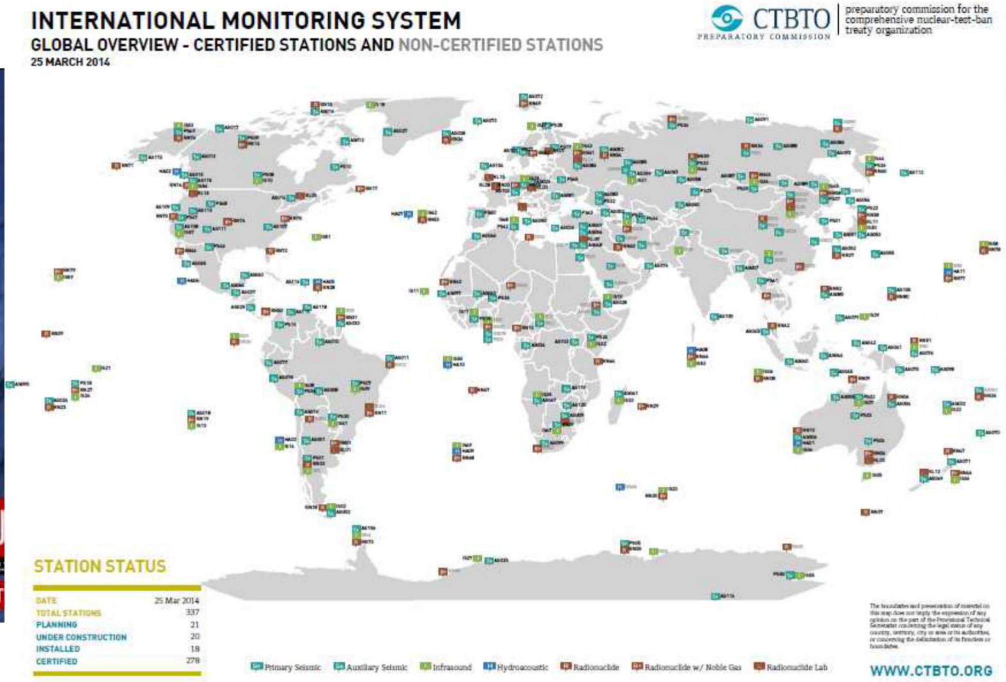
[2]Silent Falcon UAS Technologies

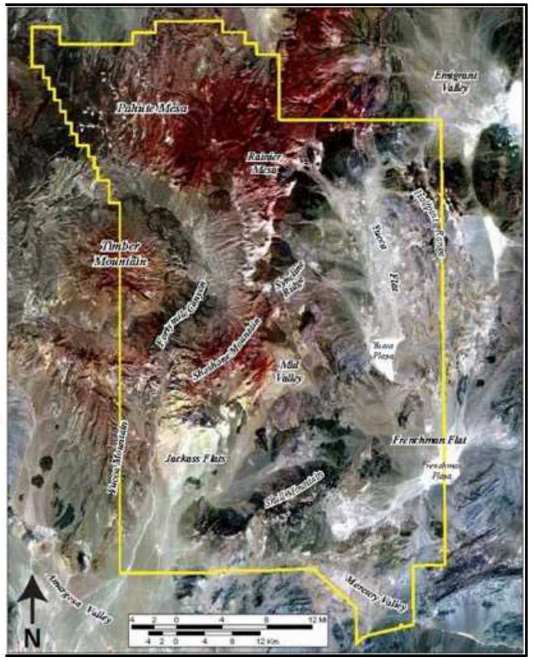
[3]Bohannan Huston Inc.

[4]Los Alamos National Laboratory

Detect, locate, and identify underground nuclear explosions (UNEs)

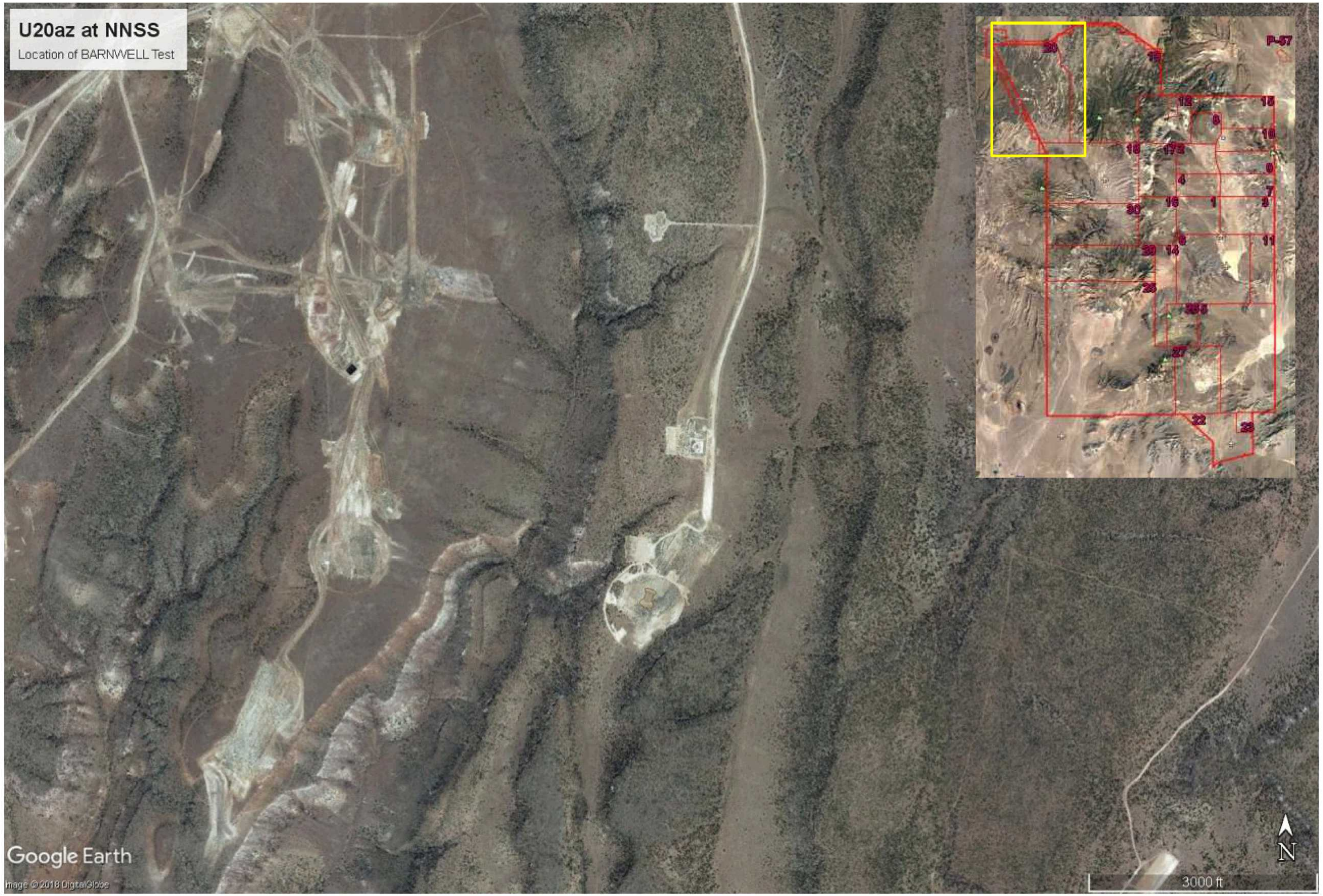
- Hypothesis: Optical remote sensing data products may offer important evidence for confirming the nature of activities at a particular area.
- We focus on collecting: high spatial resolution RGB imagery, high spectral resolution hyperspectral imagery (HSI), and photogrammetry products from an unmanned aerial system (UAS)
- Declared nuclear test sites provide a unique opportunity to collect against UNE test locations.
- Our Approach: Perform comprehensive collections against a single site at the Nevada National Security Site (NNSS); add additional sites to the data library over time.





Approach

- Our Site: U20az, location of the BARNWELL UNE (20-150 kT) in 1989.

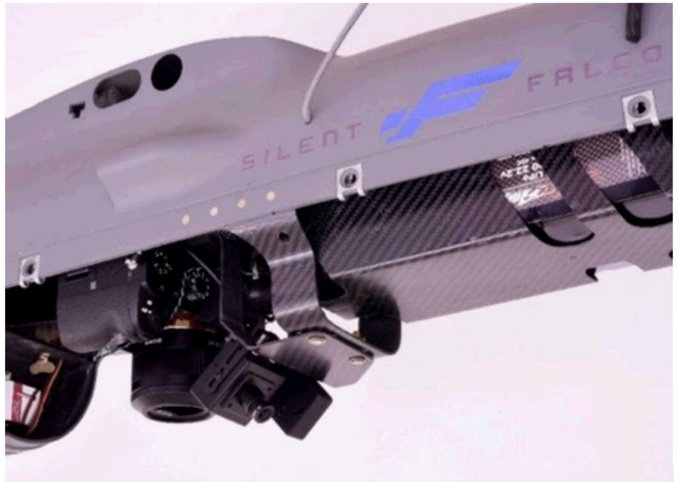


Data Collection: Platforms & Sensors

The UAS platform used for this work is Class 2 fixed wing solar electric system developed by Silent Falcon UAS Technologies

Unmanned platforms carry lighter and simpler payloads but can do so with much greater freedom and at much lower altitude and airspeed. For imagery products, this allows for detection of subtler signatures which would be sub-pixel under traditional collection resolutions.

Specification	Value
Range	100 km
Endurance	3-5 hours
Wingspan	4.4 m
Max Payload Weight	3.3 kg
Max Payload Size	230 mm x 140 mm x 200 mm
Operating Altitude (AGL)	75 m to 6000 m
Speed	45kmh to 90 kmh



Sony Alpha II integrated into UAS

Two optical sensors were deployed by UAS to collect the data products of interest:

- VNIR HSI: Headwall Photonics Nano-Hyperspec; pushbroom; λ = 400-1000 nm; 640 spatial bands; 270 spectral bands.
- RGB Imagery: Sony Alpha II; DSLR with Bayer RGB filter

VNIR HSI Sensor

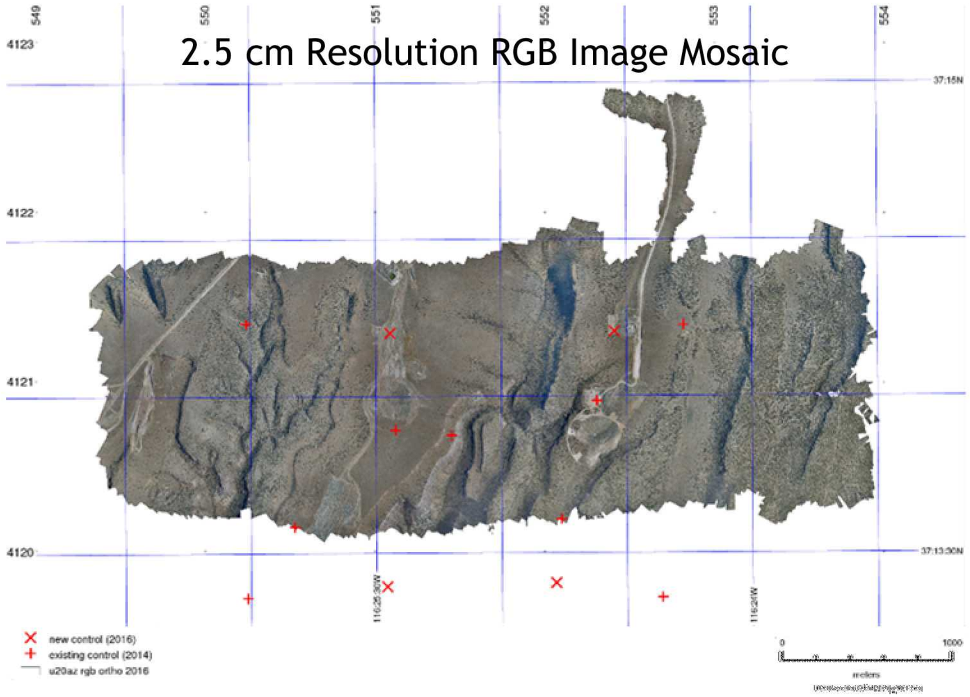
Data Collection: Execution

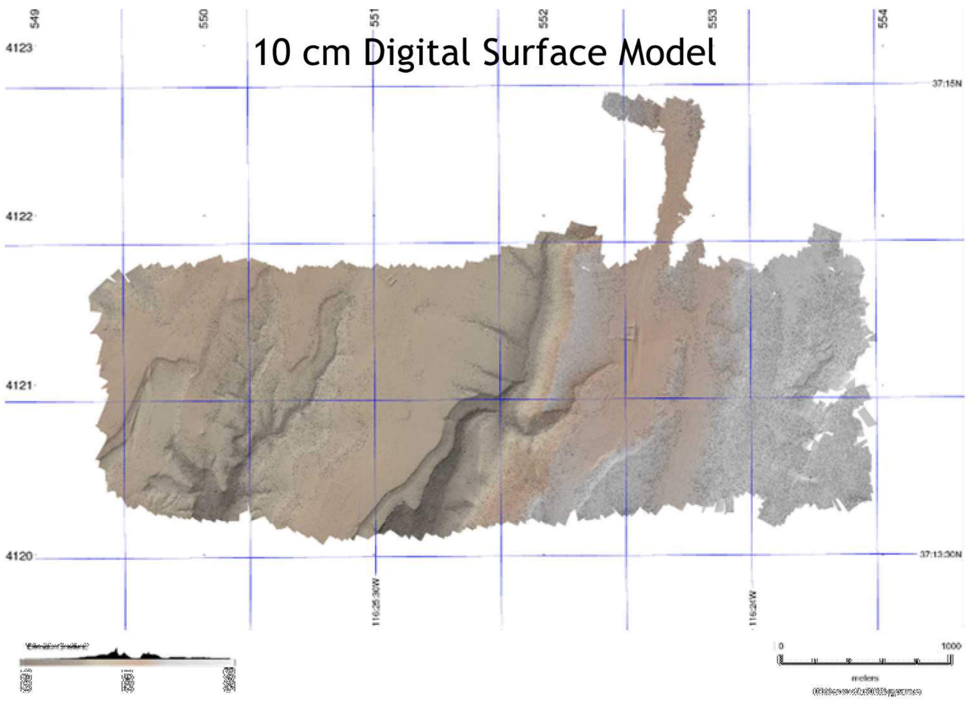
- The AOI spans 4.3 km^2 of high desert terrain, has 240 m of vertical range, and is bisected by a large canyon.
- Flight profile: East-West lines, 200 m AGL, 80% overlap.
- 16 ground geodetic control points were established in a checkerboard pattern around monument points.
- 3 reflectance panel calibration targets, 3 m by 3 m each, were installed near SGZ.
- 200 ground based point spectra collected using an ASD FieldSpec4

Collection Type	Date	Time	Num Images
RGB	2016-06-14	10:15 AM – 12:31 PM	2758
VNIR HSI	2016-06-16	9:42 AM – 12:03 PM	431
RGB	2016-06-16	3:30 PM – 6:23 PM	901
RGB	2016-06-18	8:53 AM – 9:49 AM	617

Data Processing: RGB Imagery

- RGB Imagery is used to produce:
  - A high spatial resolution (2.5 cm) RGB mosaic (4.3 km^2)
  - A high quality digital elevation model (10 cm) mosaic (4.3 km^2)

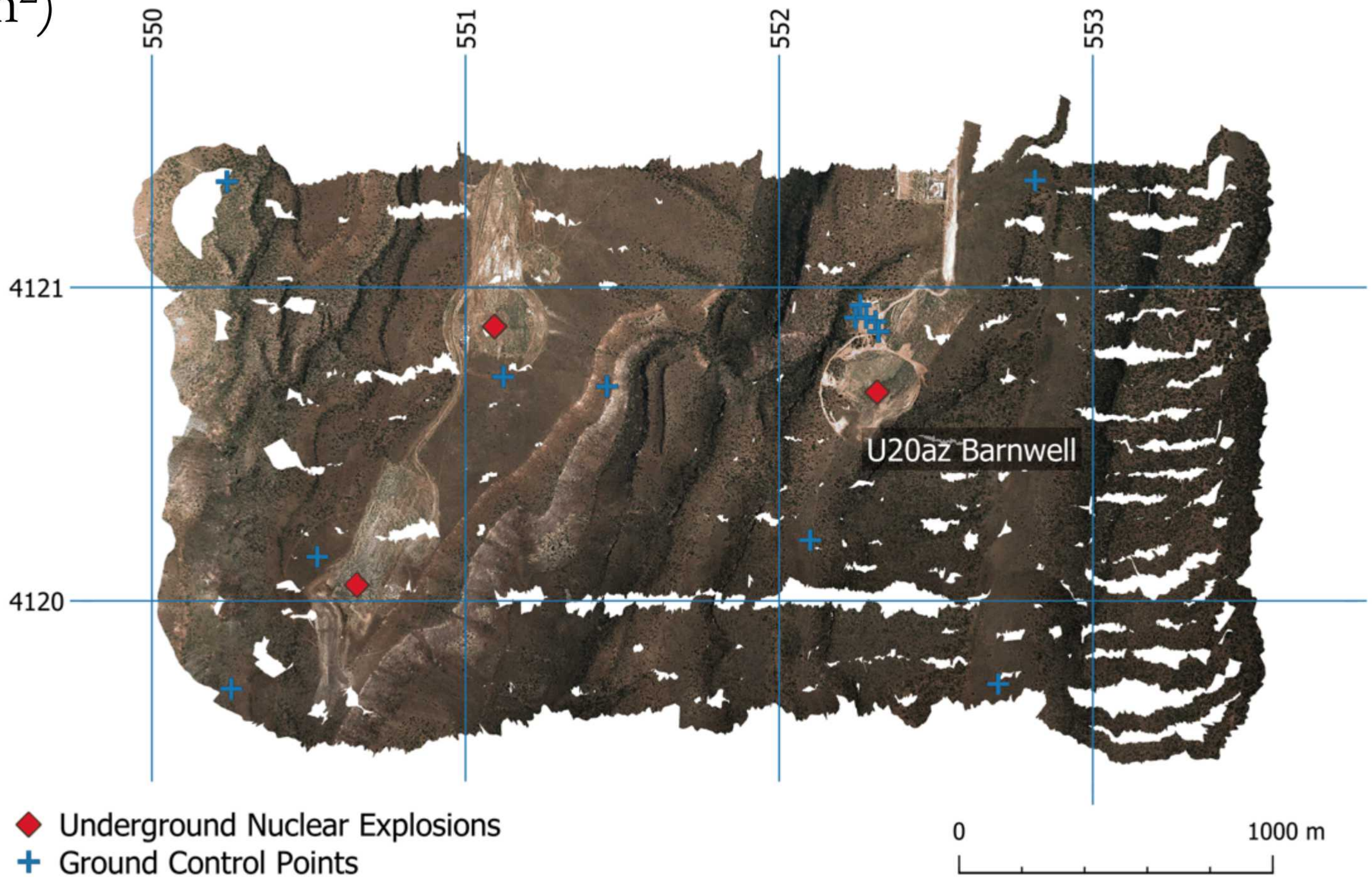




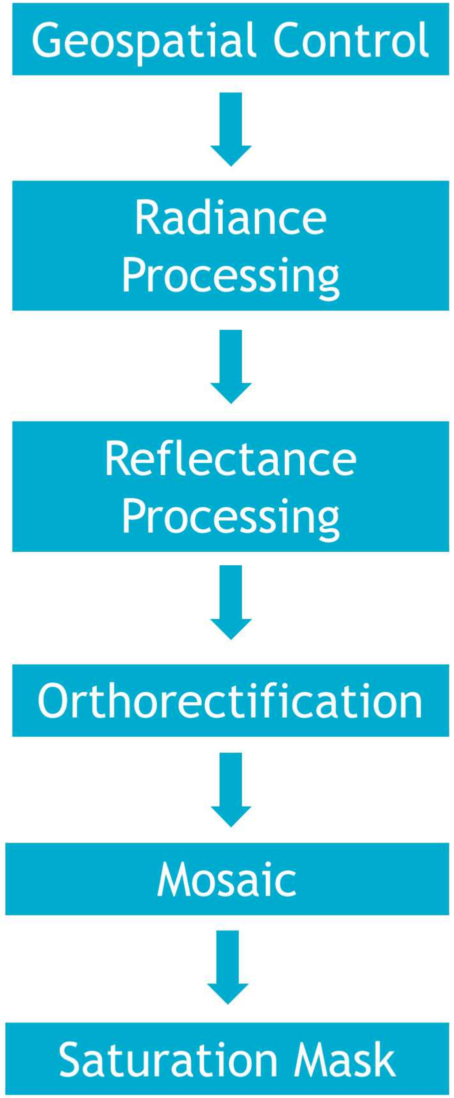
White Balance
↓
Alignment & orientation
↓
Geospatial Control
↓
Point Matching
↓
Orthorectification
↓
Color Balance
↓
Mosaic

Data Processing: HSI Data

- HSI data is used to produce:
  - Spatially resolved (10 cm) VNIR spectral radiance (270 band) imagery
  - A spatially resolved (10 cm) VNIR spectral reflectance (270 band) mosaic (5.7 km^2)



VNIR Reflectance Pseudocolor (r=667 nm, g=538 nm, b=478 nm)

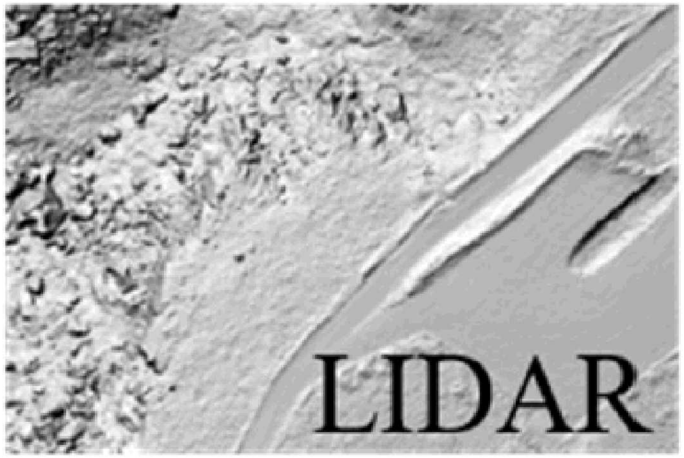


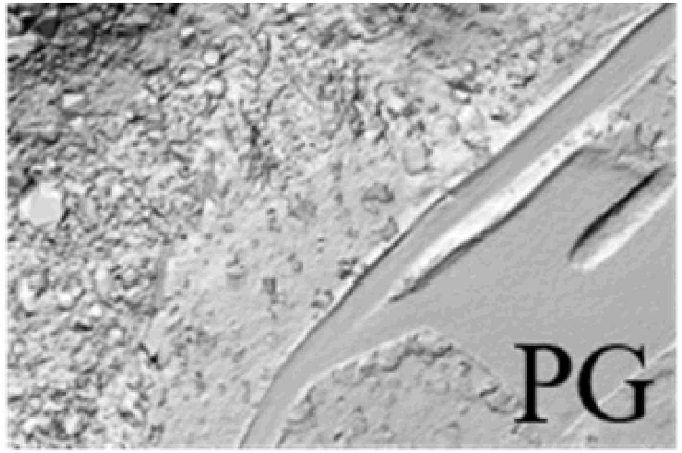
Analysis: UAS Photogrammetry vs. LIDAR Elevation Products

- Objective: Evaluate the quality of fixed-wing UAS-based photogrammetry (PG) digital elevation models (DEMs) versus DEMs produced by manned rotor-based LIDAR systems.
- LIDAR data collected over the U20az area in 2014 provided a performance baseline.

	2014 Rotor LIDAR	2016 UAS Photogrammetry
Collection Altitude (ft. AGL)	1500	700
Collection Time	~1 hr	~2 hr
Collection Area (km^2)	4.3	4.5
Ground Sample Distance (cm)	10	2.5
Horizontal Accuracy (m NSSDA)	0.072 ± 0.042	0.132 ± 0.076
Vertical Accuracy (m NSSDA)	0.027 ± 0.014	0.123 ± 0.063

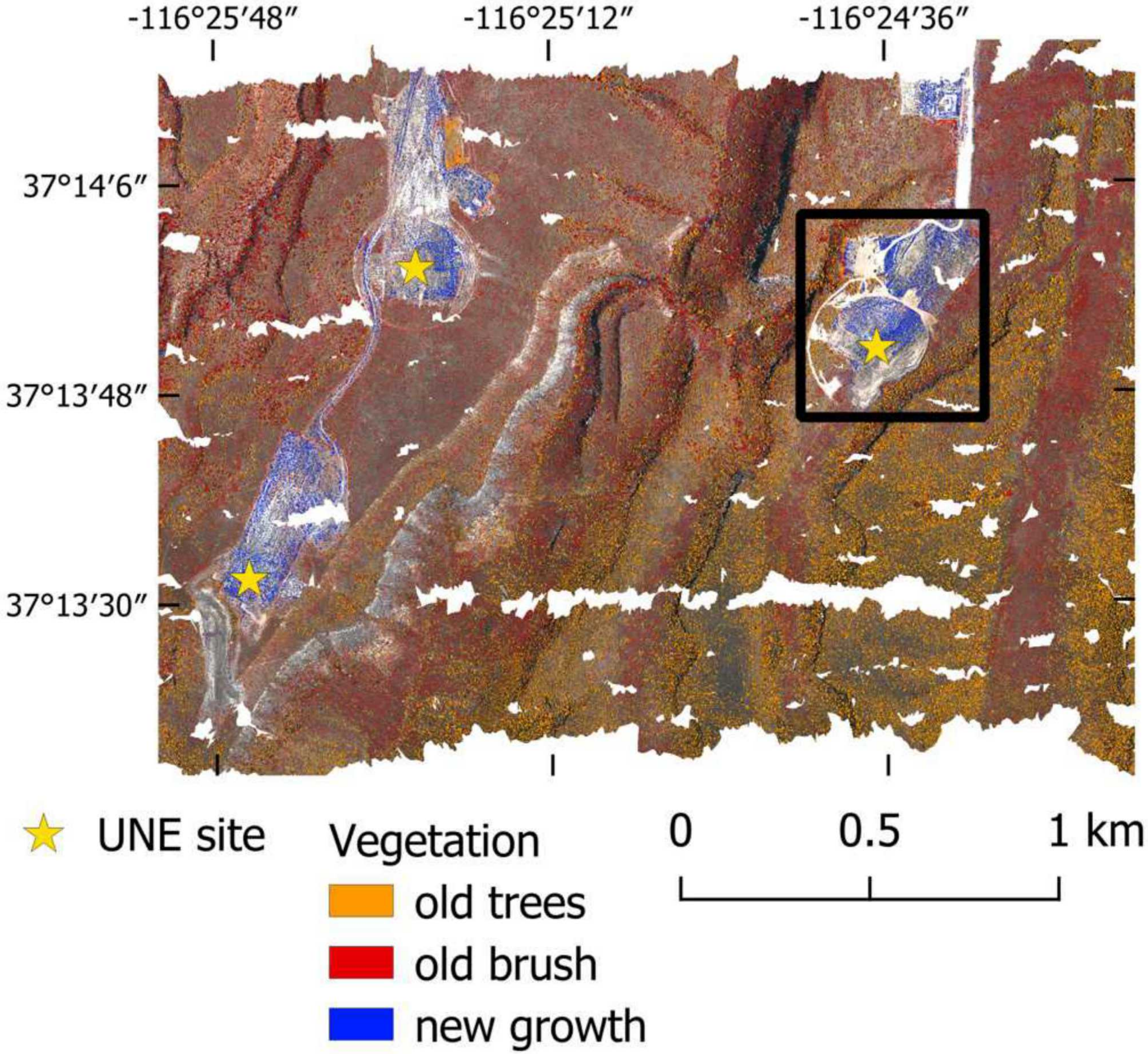
UAS PG method yielded a DEM with relative accuracy comparable to LIDAR





Analysis: Vegetation identification for activity detection

- See Brian Redman's presentation later in this session



Conclusions & Future Work

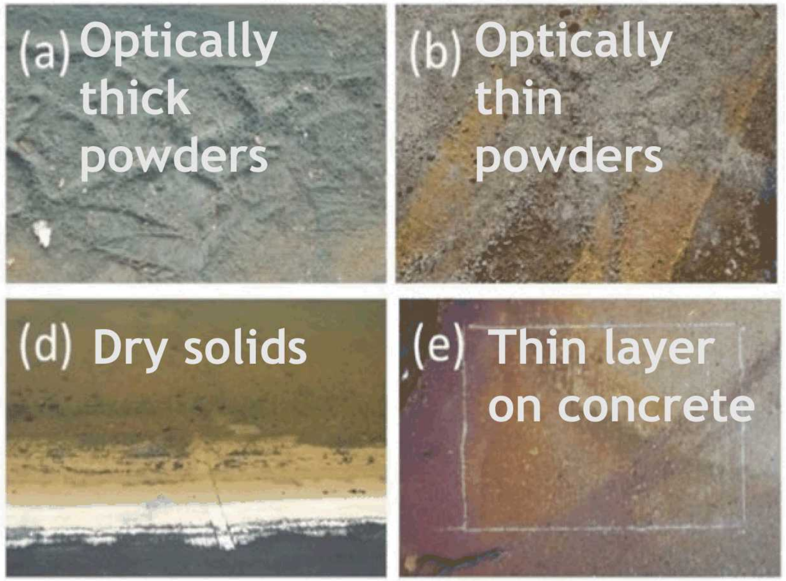
- By utilizing newly developed and long-endurance UAS platforms, airborne remote sensing can now be used to collect at virtually any scale or spatial resolution.
- Hyperspectral imagery provides a standoff material property measurement, enabling mapping of vegetation, minerals, ground disturbances, and cultural artifacts. Mapping UNE relevant signatures, such as non-native vegetation or exotic minerals, facilitates site location and identification.
- Future work should:
  - Apply the systems and techniques described here to other locations of interest to the application area, such as other test site locations at the NNSS
  - Integration with other relevant modalities collected for the site, such as commercial satellite imagery to test how additional data fusion may impact results.
  - Consider how alternative HSI architectures may enable collections without intensive post-processing.

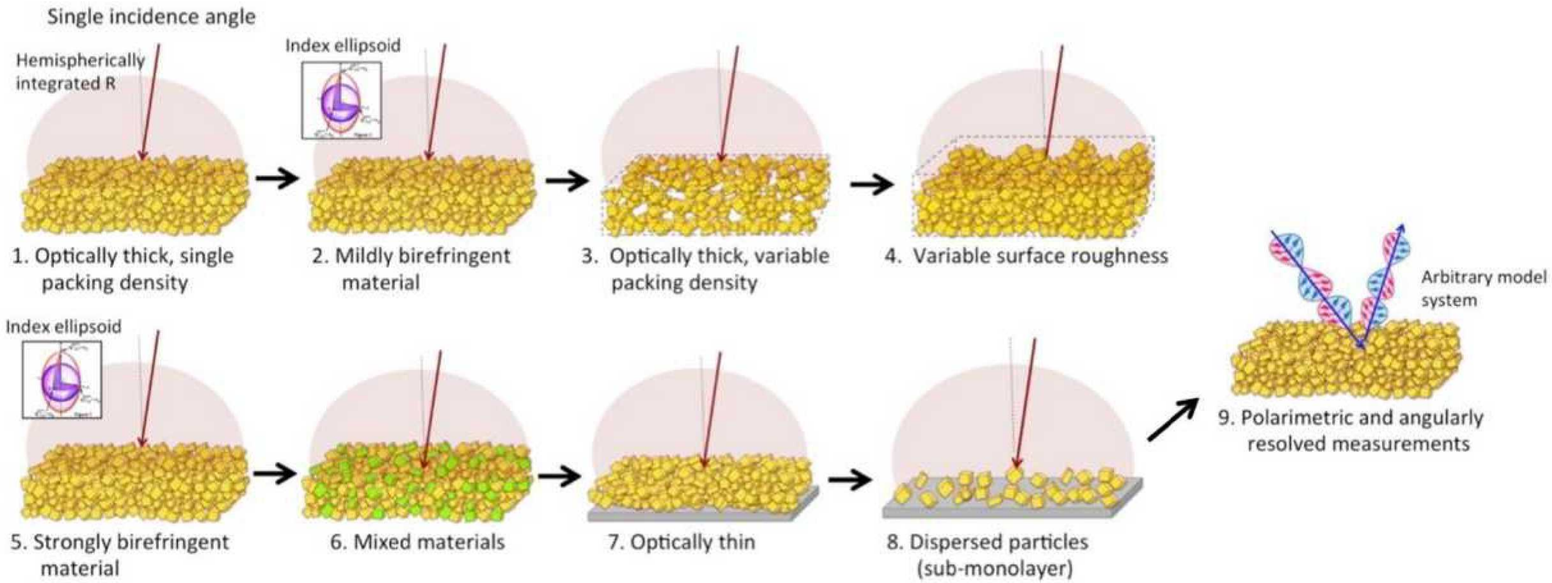
B. Long wave infrared spectropolarimetric directional reflectometer for material characterization

Charles F. LaCasse, Kyle H. Fuerschbach, Julia M. Craven, Jacob W. Segal, John D. van der Laan, Jeremy B. Wright, Steven M. Grover, Jessica M. Pehr, Thomas A. Reichardt, Thomas J. Kulp

Radiative-transfer model development

- Observed spectra depend on both intrinsic material properties (i.e. complex index of refraction) and extrinsic material properties (surface morphology).
- Radiative transfer models that incorporate morphology and material properties need input and validation.
- Developed a research instrument to provide lab measurements to support model development.



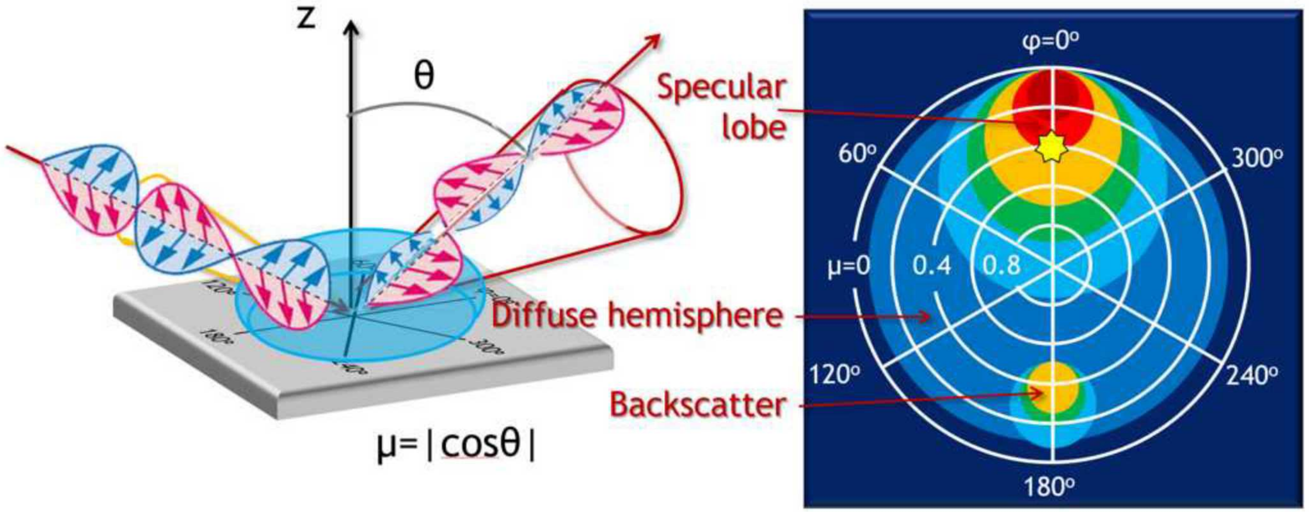


Reichardt, T. A., & Kulp, T. J. (2016, May). Radiative transfer modeling of surface chemical deposits. In *Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXII* (Vol. 9840, p. 98400M). International Society for Optics and Photonics.

Kulp, Thomas J., et al. "Ideal system morphology and reflectivity measurements for radiative-transfer model development and validation." *Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXII*. Vol. 9840. International Society for Optics and Photonics, 2016.

Instrument concept

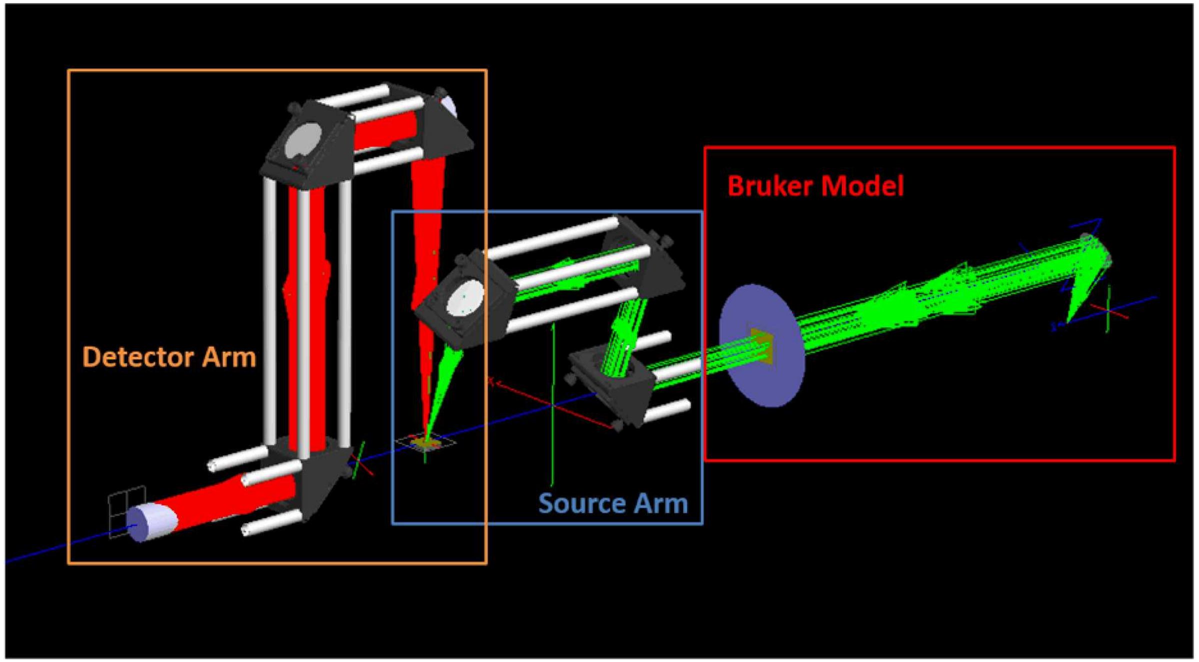
- Goal: Measurements to support model development
  - Powder/liquid/film measurements
  - Polarimetric measurements
  - Spectrally resolved measurements
  - LWIR is priority
  - Want capability to measure all 4 angles of BRDF to study asymmetric samples



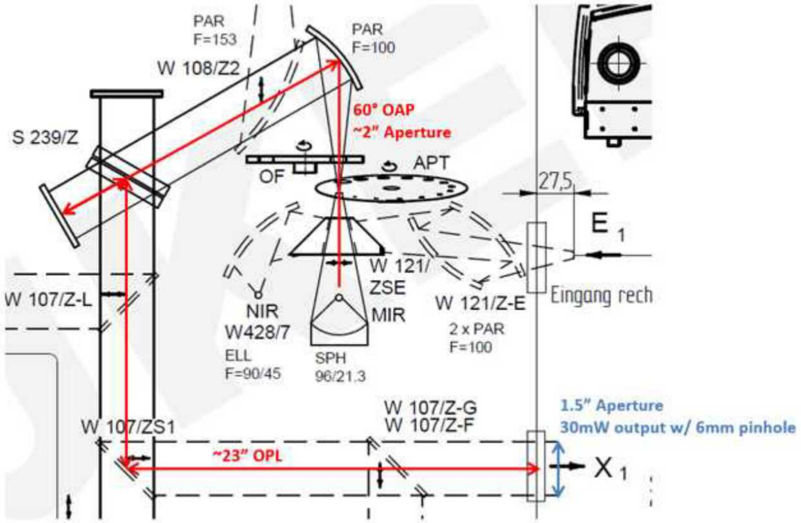
Bidirectional reflectance distribution function

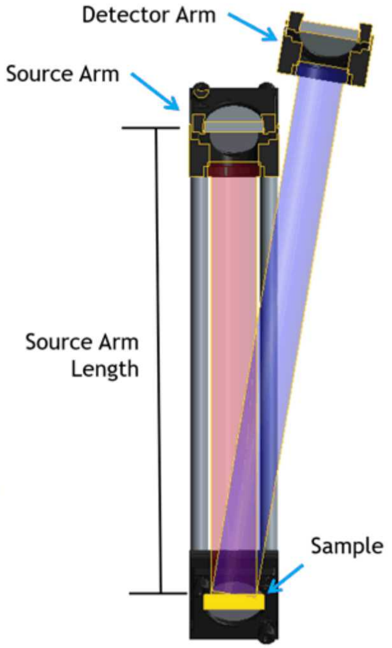
Design Challenges

- Radiometric modeling predicts this measurement is hard!
  - Broad band source, small solid angles, polarizer loss
  - 1% reflective samples -> 10 minutes integration
- Arm length determines occluded angles
- Polarizer optics are mounted at the base of the periscope
  - Retardance from proprietary protected gold mirror coatings is unknown, must be measured
- Polarization optics limit spectral band

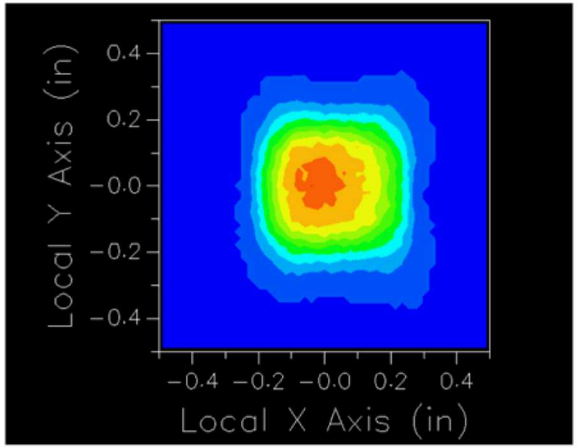


Bruker Model

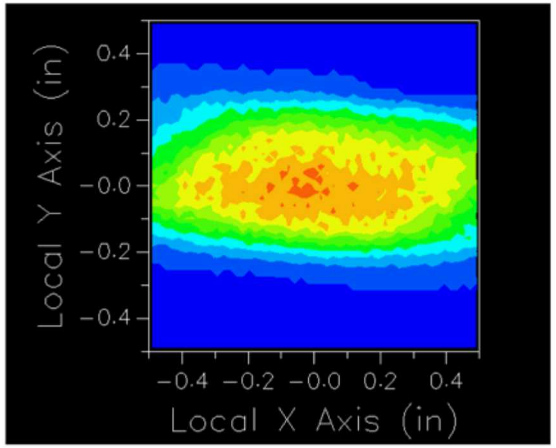




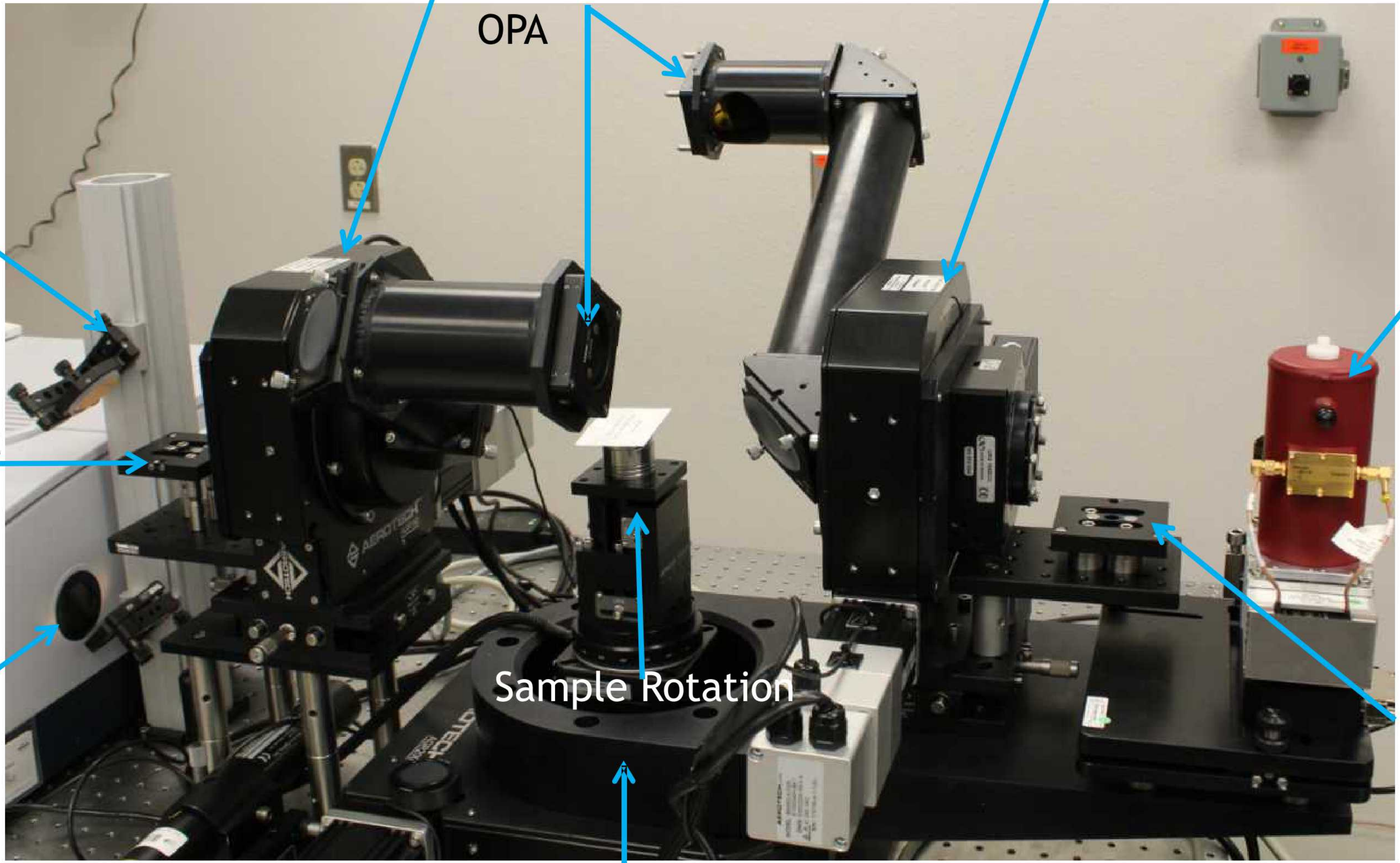
0° AOI



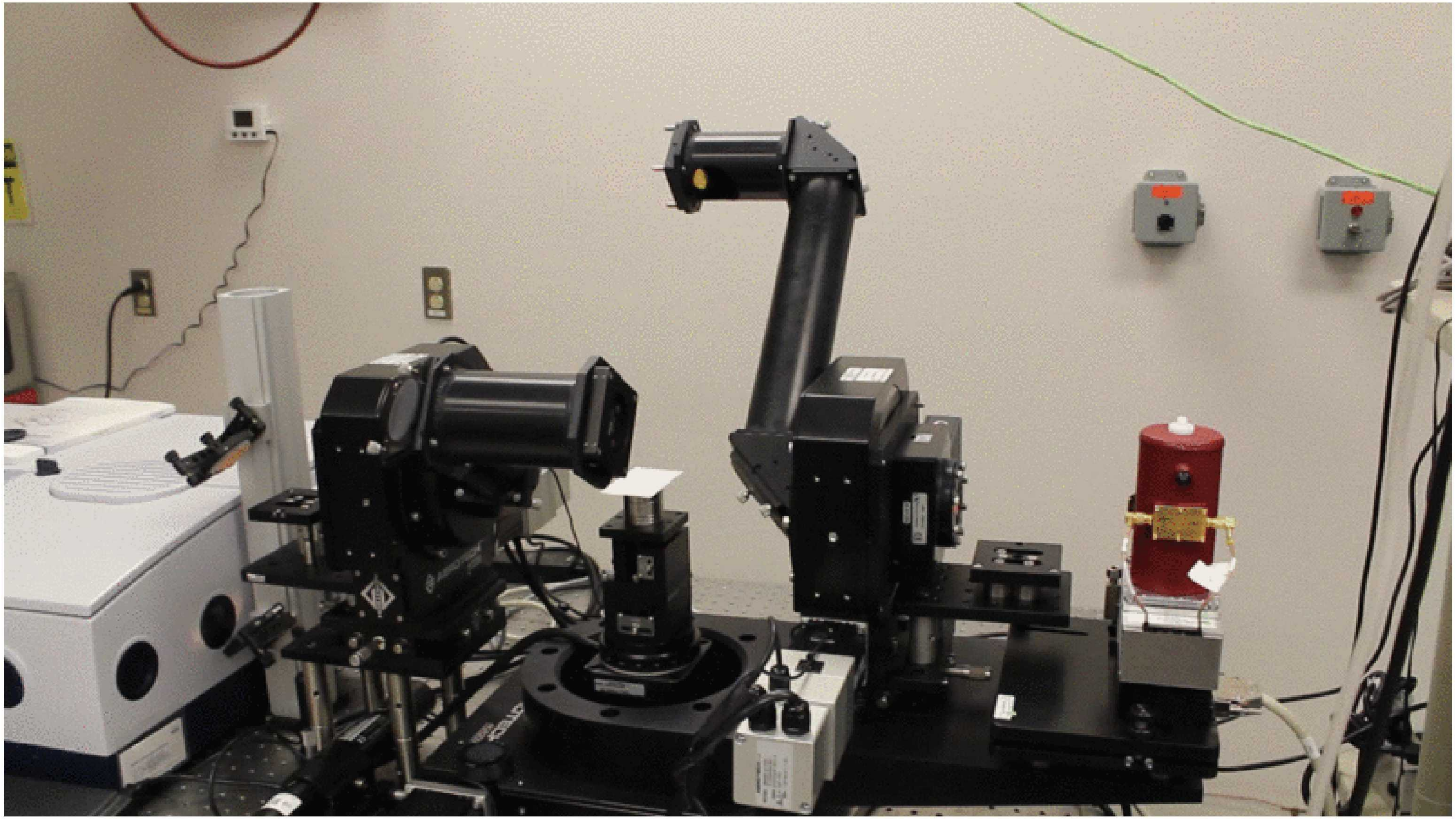
70° AOI



Instrument Realization



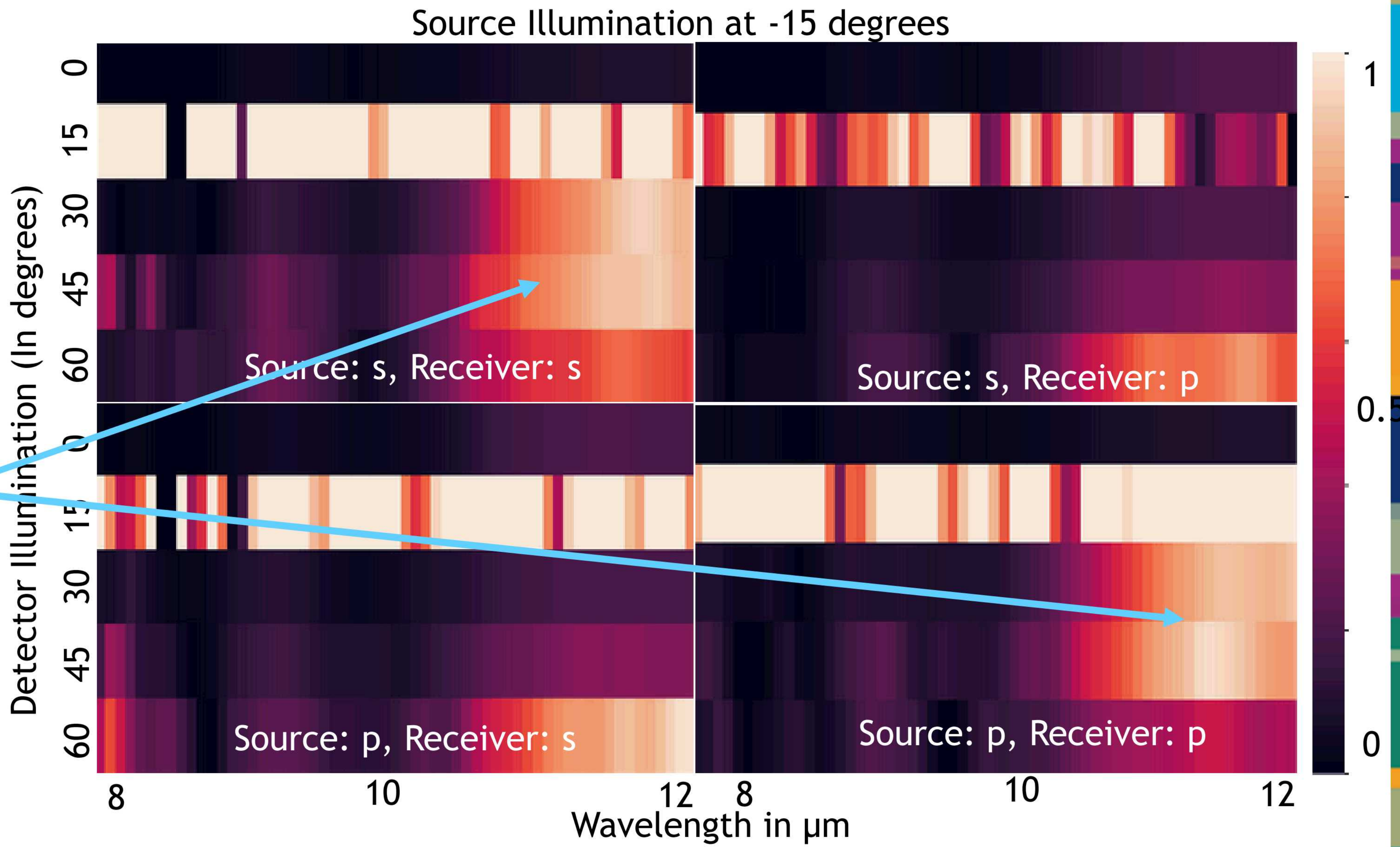
Polarimeter in action



Measured Data (Ammonium Nitrate powder)

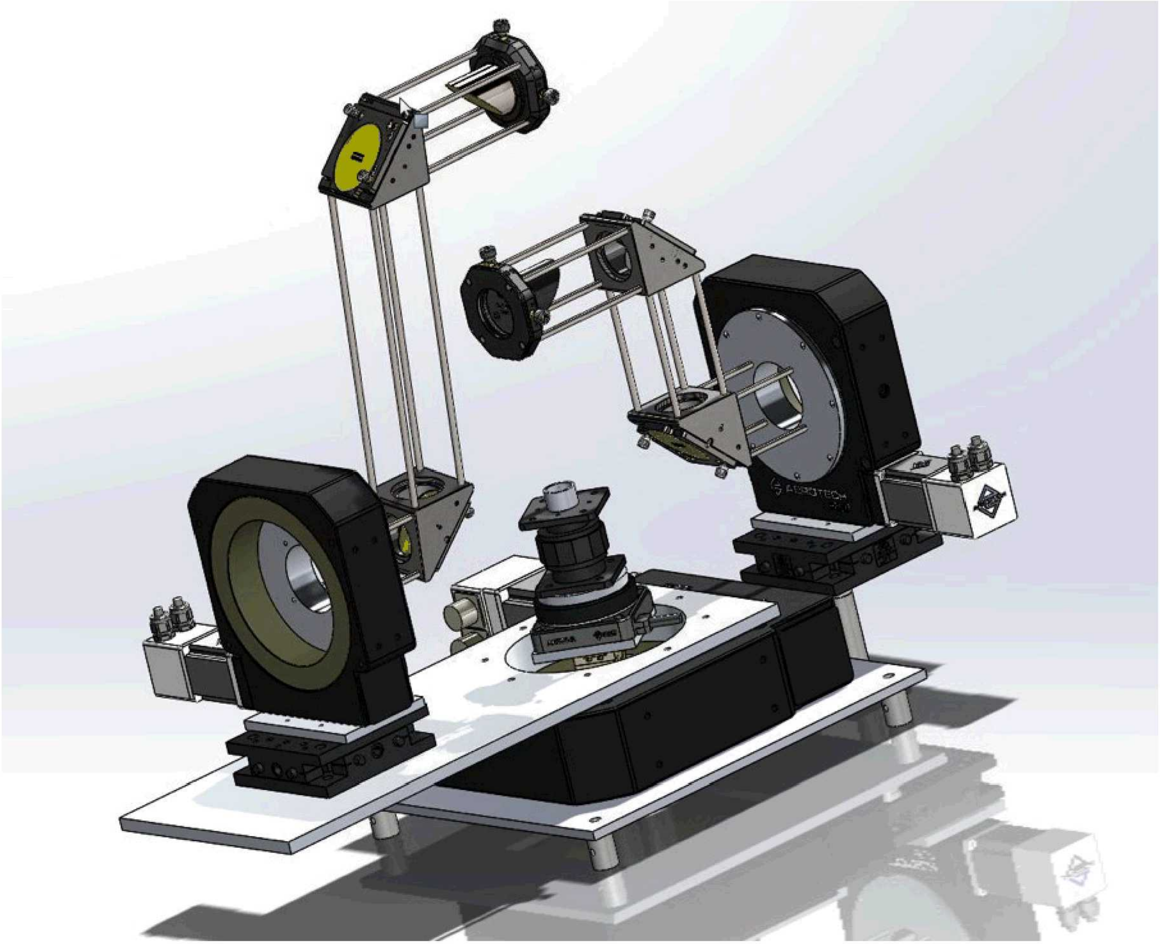
- Calibrated with Infragold reference

Off specular peaks expected for roughened surfaces
Torrance and Sparrow, 1967



Conclusions and Future Work

- LWIR pBRDF System is realized and initial measurements have been collected.
- Calibration procedure needs refinement
  - Need to move to multi-reference method
  - Validation against Surface Optics SOC100 reflectometer



C. Polarimetry for Hazardous Chemical Detection

Julia Craven[1], Leah Appelhans[1], Eric Couphos[1], Todd Embree[1], Patrick Finnegan[1], Dennis Goldstein[2], David Karelitz[1], Charles LaCasse[1], Ting S. Luk[1], Adoum Mahamat[3], Lee Massey[1], Anthony Tanbakuchi[1], Cody Washburn[1], Steven Vigil[1]

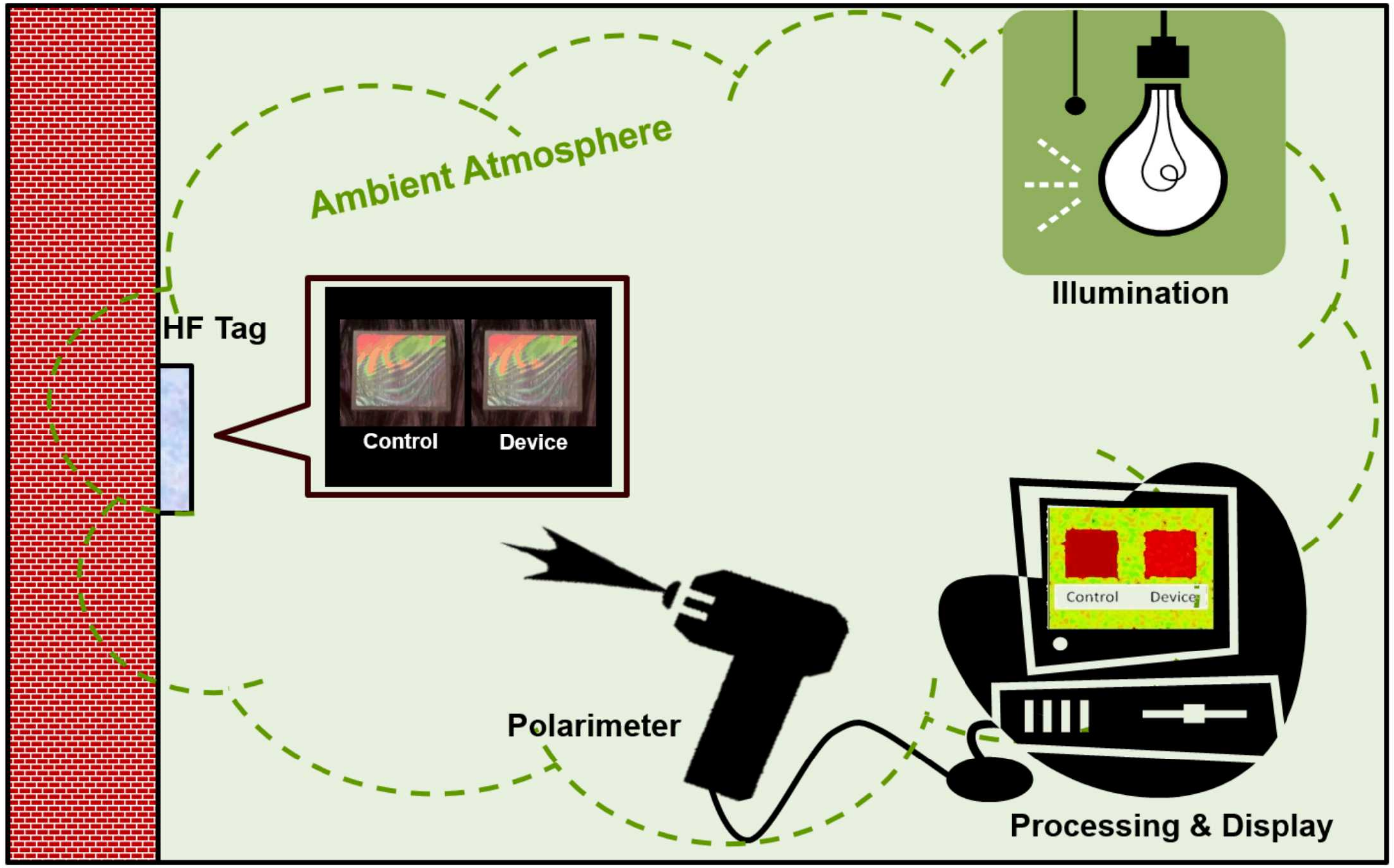
[1]Sandia National Laboratories

[2]Polaris Sensor Technologies

[3]College of Optical Sciences, The University of Arizona

Objective

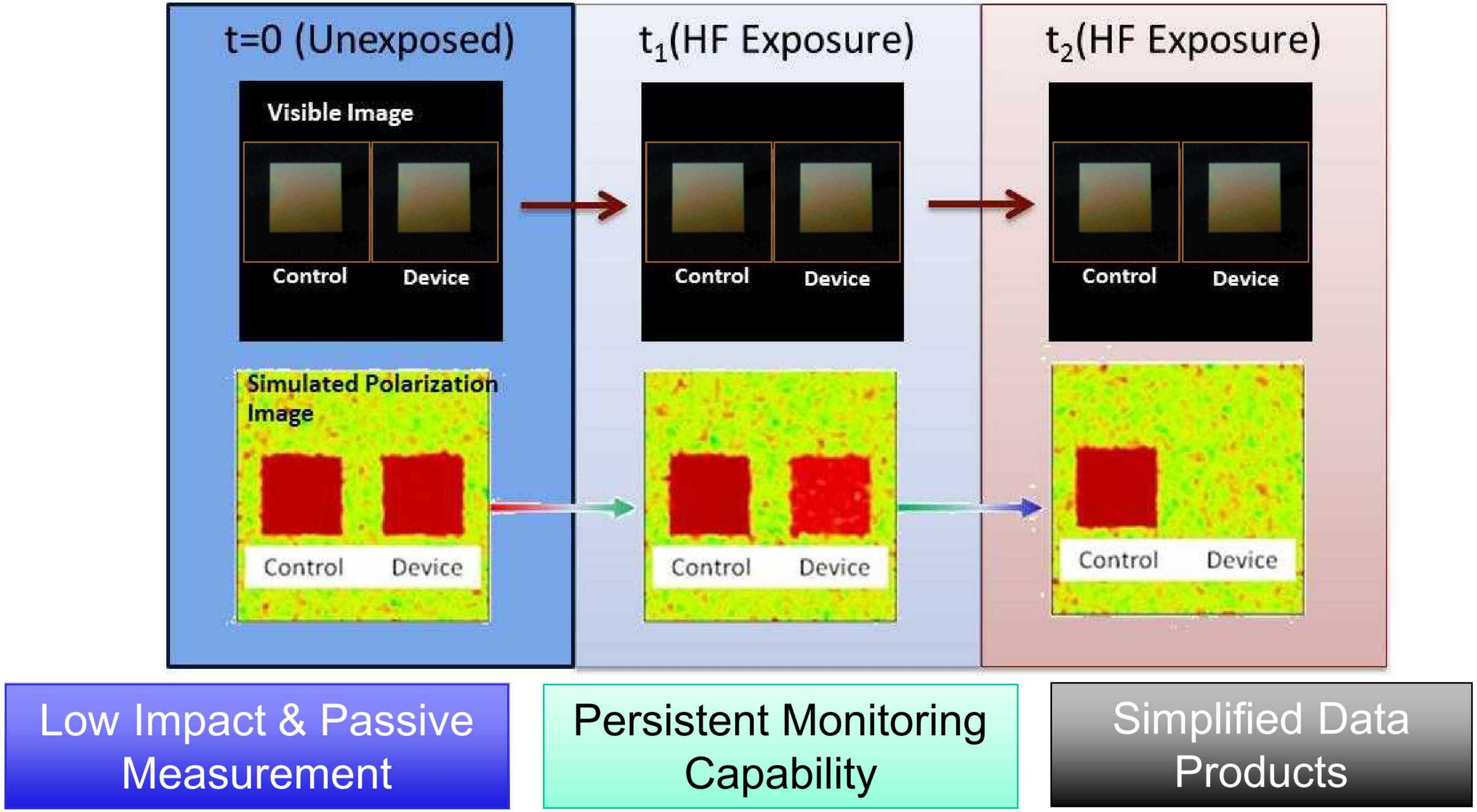
- Develop a low concentration hazardous chemical detection system that can be used to monitor an area for a period of weeks to months.



- Hydrogen fluoride (HF) gas was selected as the chemical to detect in this proof-of-concept work.
  - HF is highly toxic but the principal industrial source of fluorine.

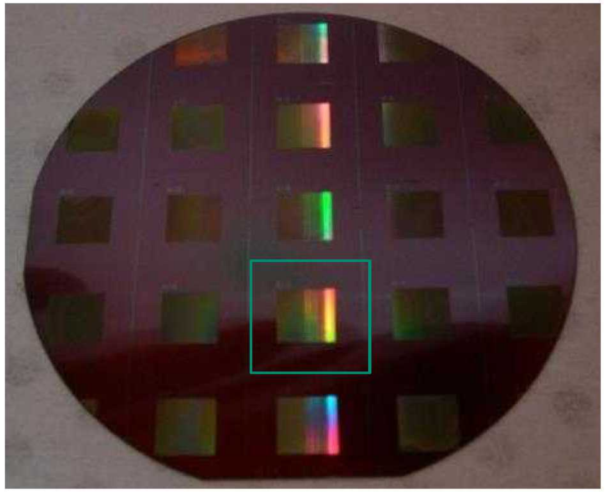
Monitoring Approach

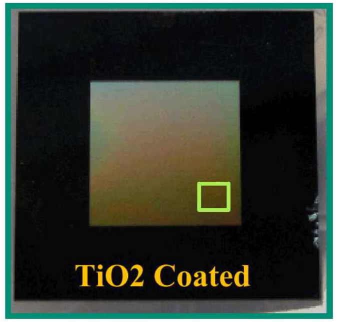
- Design tags that experience a change in optical polarization properties when exposed to a chemical of interest (HF gas, ~1-3 ppm, 30+ days).
- Measure the polarization of light reflected from the tags using a passive polarimeter and a broadband low power light source.

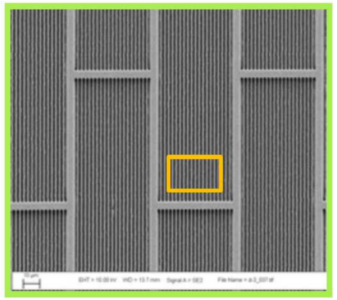


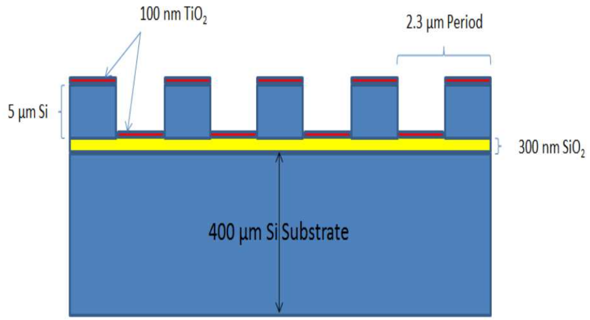
Tag Production

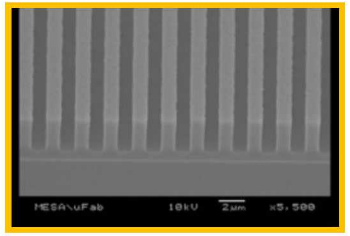
- Standard lithographic approach used for tag production.
  - 2.3 μm periodic structure etched in silicon provides polarimetric response.
  - Overarching ‘brick’ structure included to improve tag robustness.
  - Active area of 1 – 2.54 cm square.
- Substrate is coated with HF-sensitive TiO_2 amorphous film.
  - Many fabrication approaches were studied and tested.
  - Electron beam evaporative deposition selected.





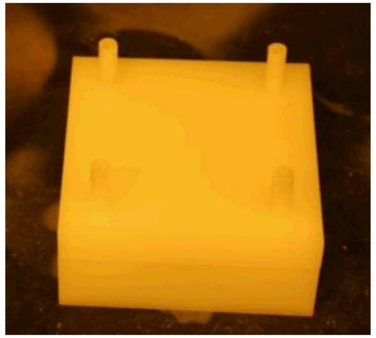




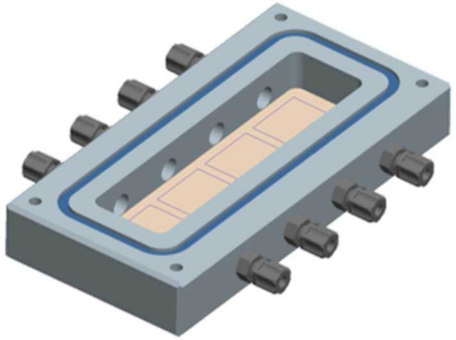


Simulating Tag Exposure

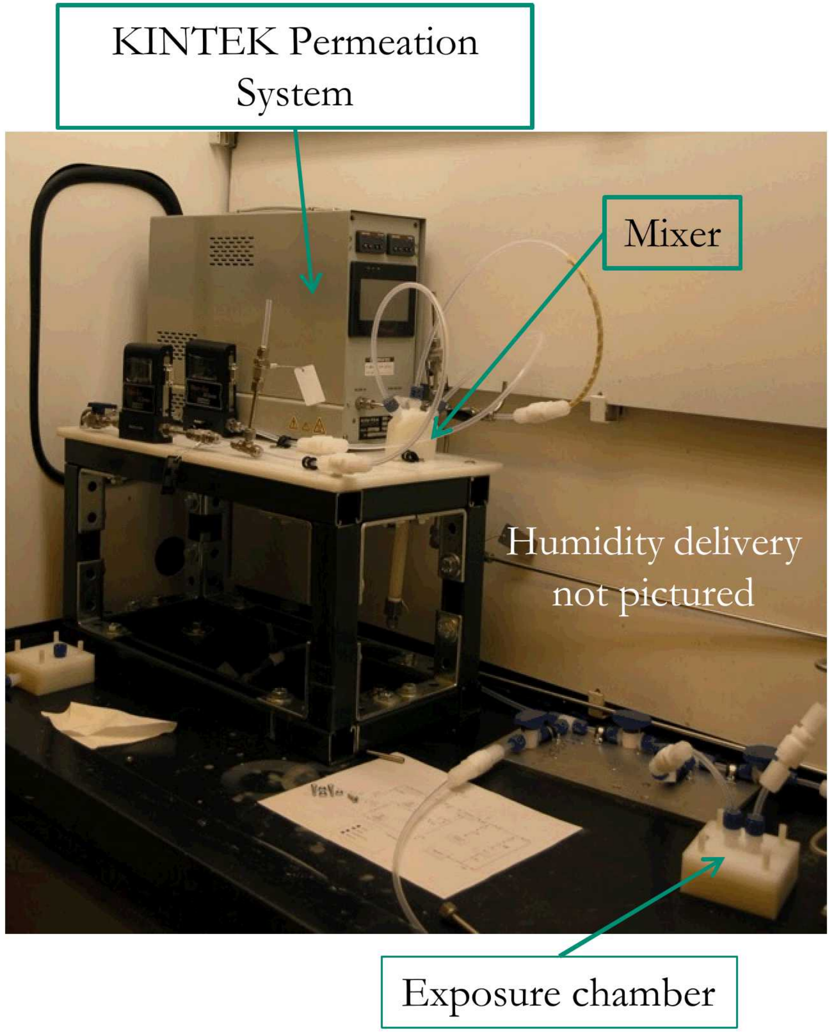
- Developed low concentration HF exposure system to provide realistic exposure conditions.
  - HF vapor exposure, 1-30 ppm.
  - Lab room temperature (~22 C).
  - Variable humidity (0-50%)
- 1-8 samples per exposure



Single Sample Exposure

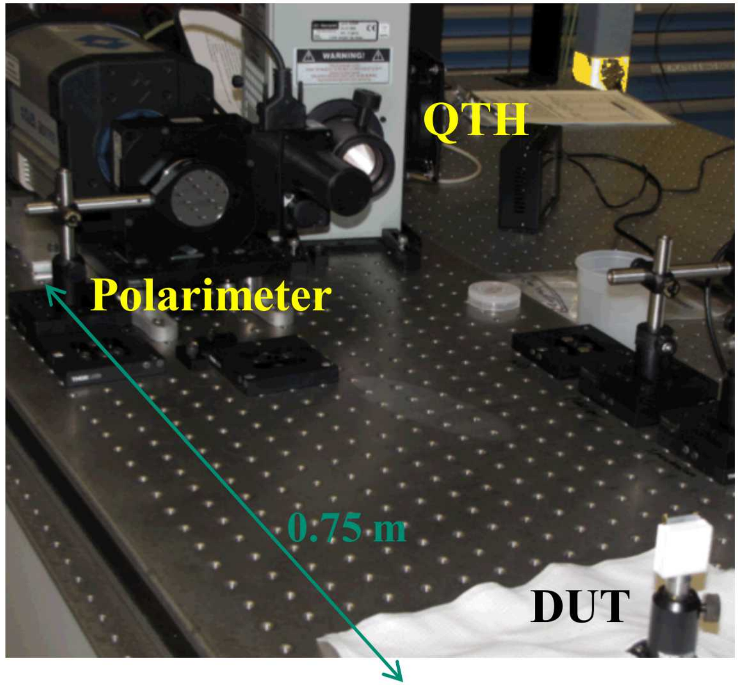


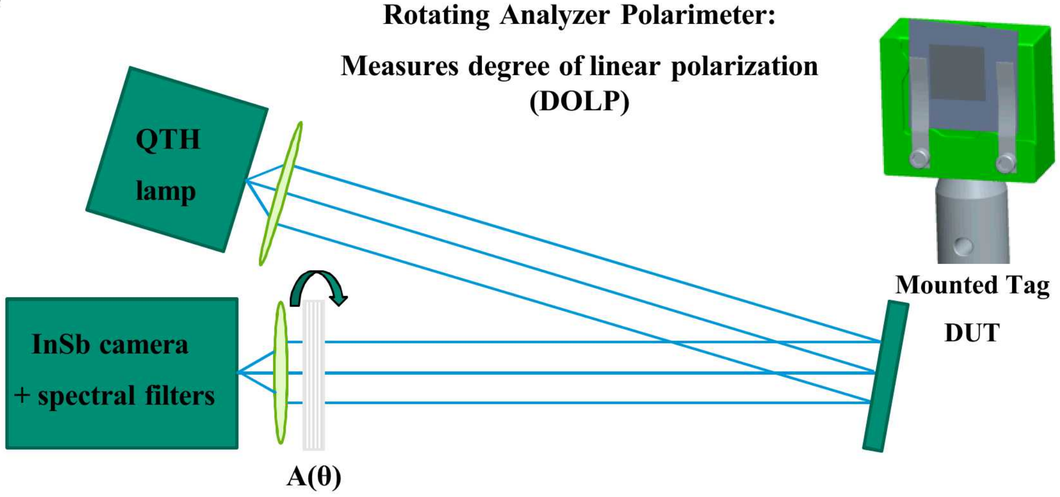
Multi-Sample Exposure



SWIR Tag Characterization

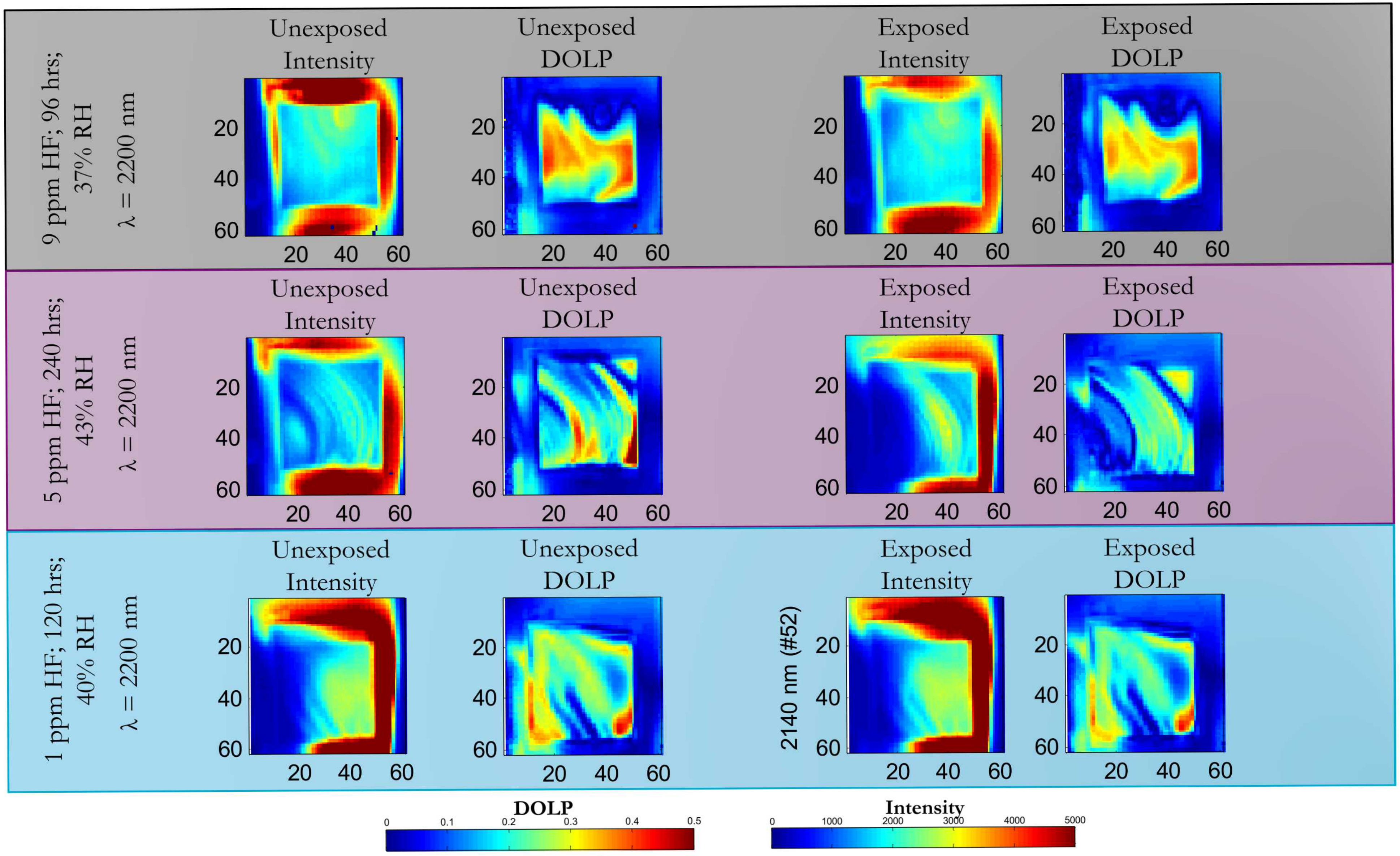
- Rotating polarizer polarimeter characterizes the degree of linear polarization (DOLP) reflected off the tags in the SWIR.
  - QTH 50 W collimated light source.
  - 100 nm spectral filters centered at λ = 2.14, 2.20, and 2.36 μm.
  - FLIR InSb imaging camera with 50 mm objective.





$$\vec{S} = \begin{pmatrix} S_0 \\ S_1 \\ S_2 \\ S_3 \end{pmatrix} = \begin{pmatrix} I_H + I_V \\ I_H - I_V \\ I_{45} - I_V \\ I_R - I_L \end{pmatrix} \qquad DOLP = \frac{\sqrt{S_1^2 + S_2^2}}{S_0}$$

Exposure Results



Exposure Results

- Tags have been exposed to a large range of exposure conditions.
- Results indicate that at 40% RH, the current tag design approach is sensitive to:
  - 5 ppm over 10 days consistently
  - As little as 1 ppm HF over 5 days
- Tag sensitivity improves with increase in humidity.
- Tags are not sensitive to other acid vapors (HCl, H2SO4, HNO3) or ethanol.

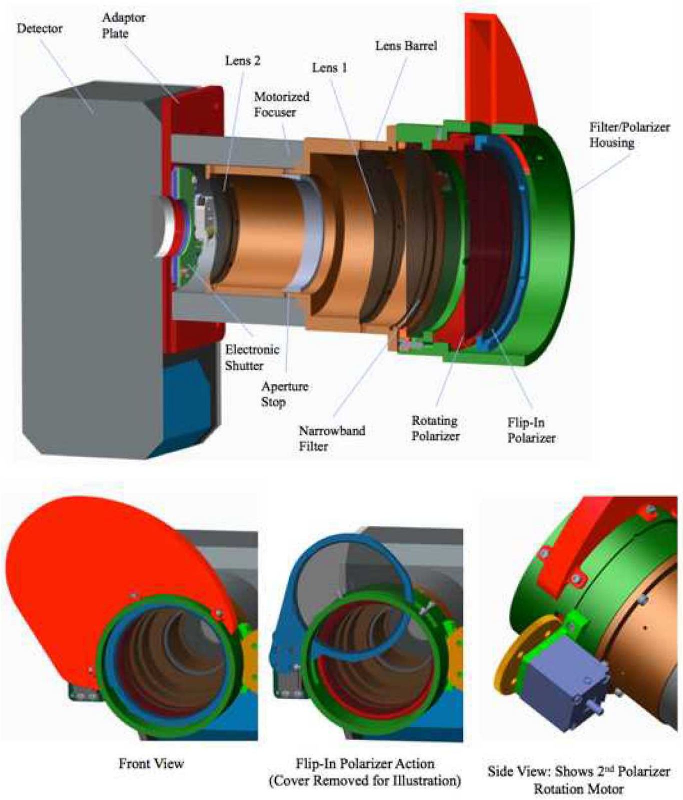
Summary of HF exposure results

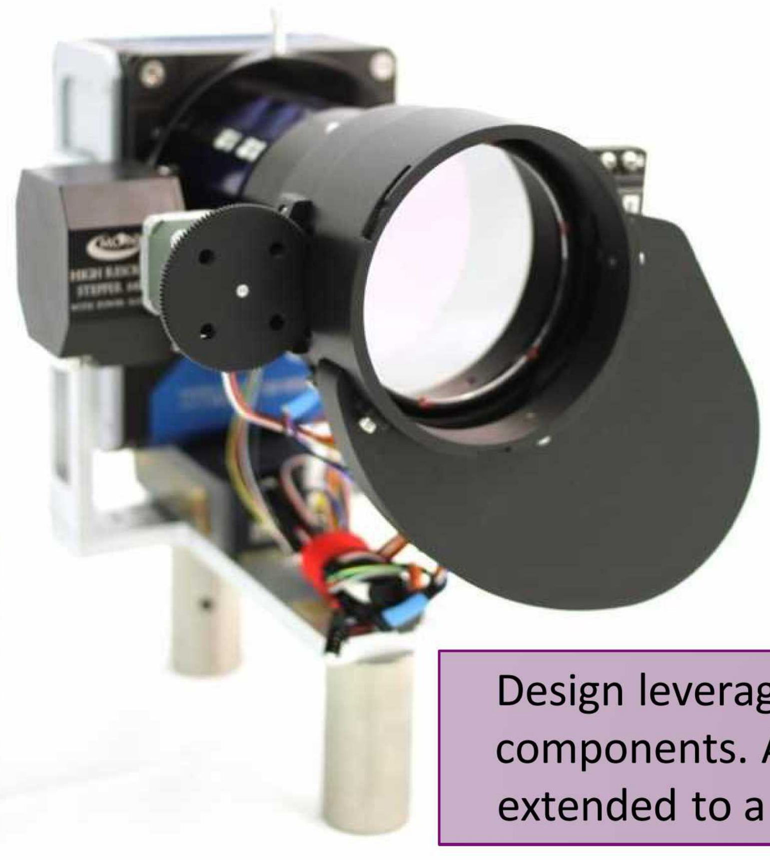
humidity (%RH) \ ppm	1	3	5		7		10	20			30
0	-	-	-		-		-	-			720
10	-	-	-		-		-	-			720, 2880
17-23	720	-	-		-		-	120, 480	720	1440	720
28-33	-	406	-		672		-	120, 480			-
35-43	120	-	600	1200	336	372	960	120, 480			-

No detectable change	Some detectable change	Consistent detectable change

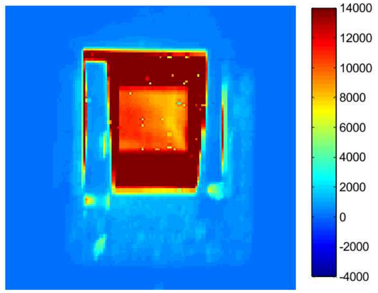
Polarimeter Prototype

- SWIR (λ=2.1 – 2.4 μm) imaging polarimeter designed for measuring the polarization of light reflected off of the tags.
  - Straightforward data products and processing; field portable; simple and automated operation.
  - Polarimeter was assembled, tested and validated at SNL.

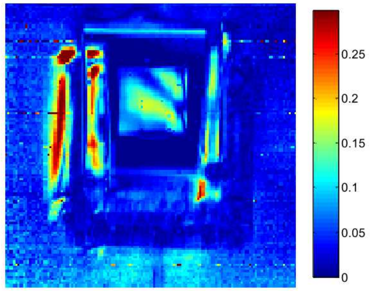




Intensity for mounted tag



DOLP for mounted tag



Design leveraged primarily COTS components. Approach could be extended to a hand-held design.

Conclusions

- We have demonstrated a polarimetric approach to monitoring for hazardous gases.
  - Passive and persistent monitoring using an unconventional approach.
  - Tags are simple and small and could be installed nearly anywhere.
  - Monitoring approach could be extended to other hazardous chemicals.
- Current implementation is sensitive to HF concentrations as low as 1 ppm.

Summary

- This work overviewed several independent research efforts focused on developing and leveraging spectral and polarimetric sensing techniques for CBRNE applications, including system development efforts, field deployment campaigns, and data exploitation and analysis results.
- While this body of work has primarily focused on the application spaces of chemical and underground nuclear explosion detection and characterization, the developed tools and techniques may have applicability to the broader CBRNE domain

Acknowledgements

The authors would like to thank:

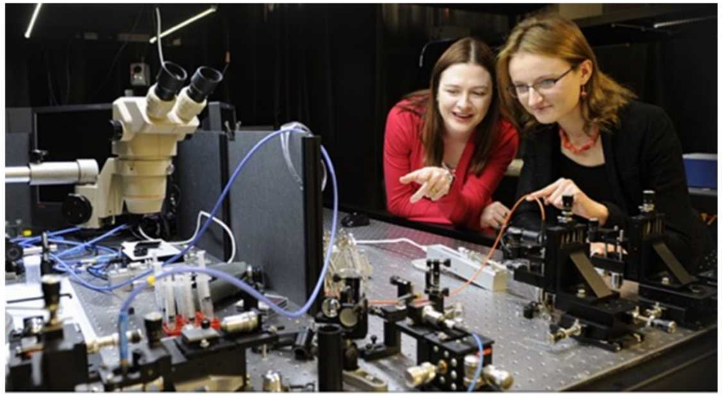
- National Nuclear Security Administration, Defense Nuclear Nonproliferation Research and Development.
- The Underground Nuclear Explosion Signatures Experiment team, a multi-institutional and interdisciplinary group of scientists and engineers, for its technical contributions and support at the NNSS. In particular, we wish to acknowledge the indispensable field support of Michael Floyd, Robert Ziehm, Christian Melchor, and Veraun Chipman; all were with National Security Technologies LLC at the time of our field collections.

Some of the NNSS photos and figures in this talk are courtesy of NNSS Geologist Dr. Lance Prothro

SPIE.

THE INTERNATIONAL SOCIETY
FOR OPTICS AND PHOTONICS

SPIE Equity, Diversity & Inclusion – Results from the Gender Equity Task Force



Julia Craven[1], Katie Schwertz[2], Krisinda Plenkovich[3] – *with contributions from many others*

[1]*Sandia National Laboratories*, [2]*Edmund Optics*, [3]*SPIE*

Context: SPIE Equity, Diversity & Inclusion

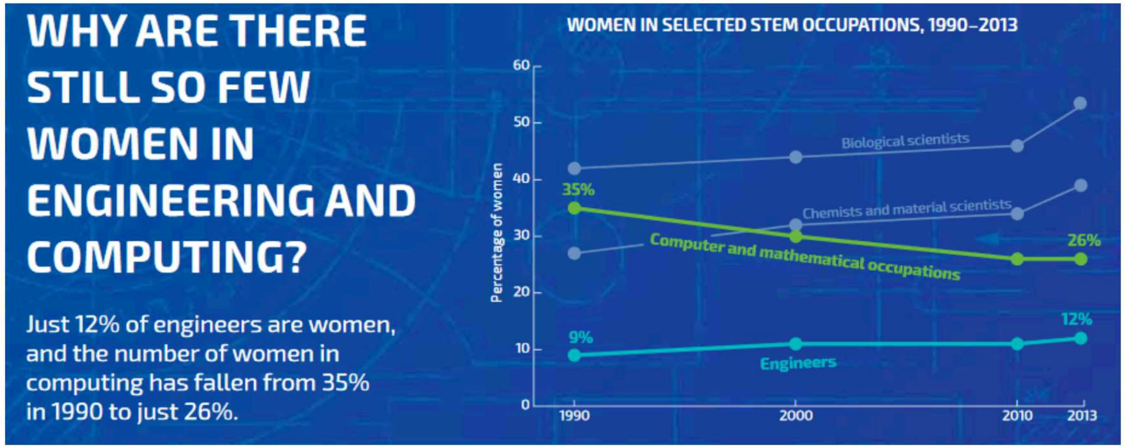
- SPIE recognizes the importance of Equity, Diversity and Inclusion and initiated several independent efforts to engage the community, identify areas for improvement and make recommendations:
  - Women in Optics
  - D&I Ad-Hoc Committee
  - **Gender Equity Task Force**
- In 2019, these efforts are being consolidated into a single SPIE Equity, Diversity and Inclusion (ED&I) program.

SPIE. EQUITY DIVERSITY INCLUSION

SPIE, its volunteers, and staff work to encourage and promote diversity at our events and within our profession. We believe that bringing together people from different backgrounds, experiences, and perspectives will support innovation through a diversity of ideas, and solve challenges faced by our world. We also believe in the development of collaborative environments that value participation from individuals with different ideas and perspectives, that ultimately have a positive impact on the science of light. It is our aim that our programs reflect these core values.

Why Gender Equity and Why Now?

- Sweeping popular attention to gender equity & reducing sexual harassment in the workplace.
- Women remain the minority gender in STEM – why?



VS

In a Catalyst study of Fortune 500 companies with the **highest representation of women** on the board of directors, they found that companies see **higher financial performance in return on equity, return on sales, and return on invested capital** when compared to companies with low female representation on their board.

SCIENTIFIC AMERICAN. Article: "How Diversity Makes us Smarter"

Why Gender Equity and Why Now?

- Sweeping popular attention to gender equity & reducing sexual harassment in the workplace.
- Women remain the minority gender in STEM – why?

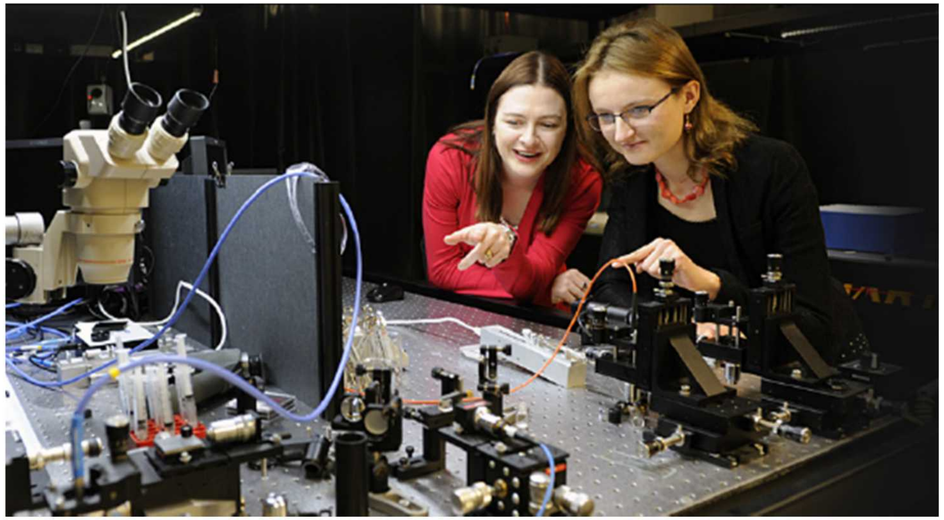
Vision: Optics & Photonics as an industry apart

In a Catalyst study of Fortune 500 companies with the **highest representation of women** on the board of directors, they found that companies see **higher financial performance in return on equity, return on sales, and return on invested capital** when compared to companies with low female representation on their board.

SCIENTIFIC AMERICAN Article: “How Diversity Makes us Smarter”

Gender Equity Task Force Mission

- The SPIE Gender Equity Task Force was formed in 2015 to *identify how the optics and photonics workplace can better enable opportunities, rewards, and recognition for its members, independent of gender*.
- The Task Force focused on recommending specific steps O+P can take to:
  - Improve ongoing advocacy and career assistance for women
  - Attract more women to pursue optics and photonics careers.

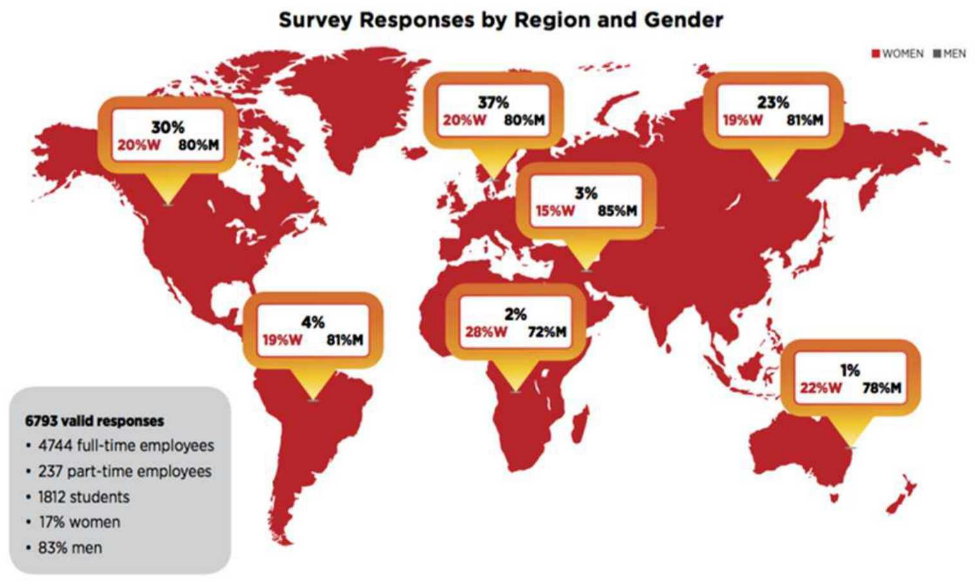


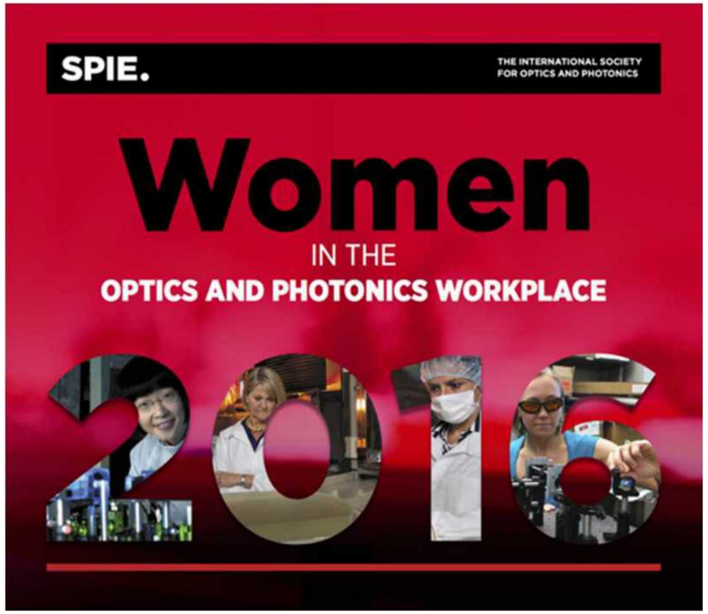
"Science and research need both genders to cooperate because men and women think differently…Only the combination of different attitudes and ideas can lead to outstanding results"

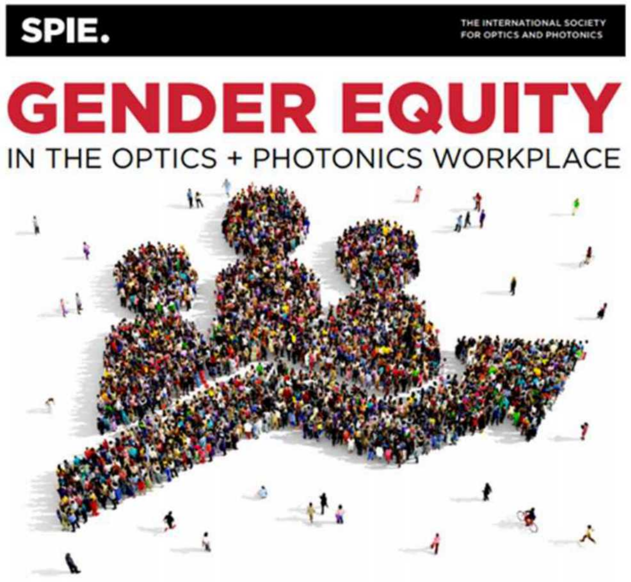
– **Marketa Zikova,** PhD Student in Physical Engineering, Czech Technical University

Data Collection: Global Salary Surveys

- Questions were integrated into 2016-2017 SPIE Global Salary Surveys to gather data that would help define gender equality issues in the O+P community.
  - Personal interviews were also conducted
- Results were used to produce:
  - *2016 Women in the Optics & Photonics Workplace Booklet*
  - *2017 Gender Equity in the Optics and Photonics Workplace Booklet*







Survey Findings and Insights

- Female representation in the workplace declines over time (21% to 10% from entry level to 30+ years)
- Median salaries are 37% higher overall for men than women
- Fewer women than men think that they are paid fairly (69% vs 76%) or promotions are handled fairly (59% vs 65%) at their organizations
- At nearly all career stages, higher percentages of men are in management and senior academic positions than women
- Women take mid-career breaks more often than men (27% vs 14%)
    - Childcare cited as primary motivation for 69% of women and 9% of men

Results to Recommendations

- GETF used survey results to produce
  - Initiative recommendations in a *SPIE GETF Strategic Plan*
  - Proposed execution strategy in *Feasibility Study Report*
- Strategic Plan focused on 3 initiatives:

Initiative 1: Develop passive tools to engage and educate SPIE Constituents and Community Members

Initiative 2: Develop active tools to enable managers, leaders, HR representatives, and other influencers to actively improve the gender equity culture of their teams and work environment

Initiative 3: Engage corporate partners to provide a path towards gender equity accountability at the corporate level

Results to Recommendations

- GETF used survey results to produce
  - Initiative recommendations in a *SPIE GETF Strategic Plan*
  - Proposed execution strategy in *Feasibility Study Report*
- Feasibility study gathered data to solidify the 'how' behind the 'what'. Produced 3 principal recommendations for implementation of a Gender Equity Program:

1. **Pursue a Scientific Society Led Gender Equity in Photonics Initiative (Umbrella)**
2. **Prioritize Engagement of Corporate and Institutional Leadership (Initiatives 2 & 3)**
3. **Enhance Content for Individuals (Initiative 1)**

GENDER EQUITY
IN THE OPTICS + PHOTONICS WORKPLACE

Recommendations

1. **Pursue a Scientific Society Led Gender Equity in Photonics Initiative**
   - *Bring broad attention to optics and photonics as "an industry apart" from the broader STEM community by being GE proactive*
   - *Change the community level perspective*
   - *Responds to recent NAS Study on Sexual Harassment*
2. **Prioritize Engagement of Corporate and Institutional Leadership**
   - *Offer meaningful tools for corporate & institutional leadership for ensuring equitable workplaces*
   - *Impact many members by engaging corporate leadership*
3. **Enhance Content for Individuals**
   - *Enhance content focused on engaging and empowering <u>all</u> individual members.*
   - *Increases impact of existing operational program.*

Moving Forward

- Feasibility Study recommendations were approved by the SPIE Board in Oct 2018.
- Work is incorporated into new SPIE ED&I umbrella program.
- Several actions already taken:
  - Company highlights in SPIE Pro Magazine
  - Childcare grants at PW2019
  - Anti - Harassment Policy

Edmund optics | worldwide

SPIE joins other professional societies to discuss harassment in STEMM fields

Some 70 professional societies came together to work on making science, technology, education, math, and medicine fields harassment free.

08 October 2018

SPIE joined leaders from some 70 professional societies in Washington, D.C., on 1 October to discuss the issue of harassment in the science, technology, engineering, mathematics, and medical (STEMM) fields. The meeting was hosted by the American Association for the Advancement of Science (AAAS), the American Geophysical Union (AGU), and EducationCounsel (EC).

Zemax

Optical design business promotes gender equity

Zemax has a work culture that supports women and families

The engineering team at SPIE corporate member Zemax has an equal number of men and women, a rarity at technology companies. In addition to this gender balance, women engineers at Zemax earn pay equal to their male counterparts. *SPIE Professional* asked Alison Yates, director of virtual prototyping, and Isis Peguero, an optomechanical engineer, how the optical design software company achieved gender balance and what advice they could offer other organizations.

What Can I Do?

- ED&I needs advocacy from ***<u>all</u>*** community members - effect your circle of influence (which is larger than you think!)
  - Communicate your values
  - Be the change you wish to see – small changes can make a big impact!
  - Commit to education