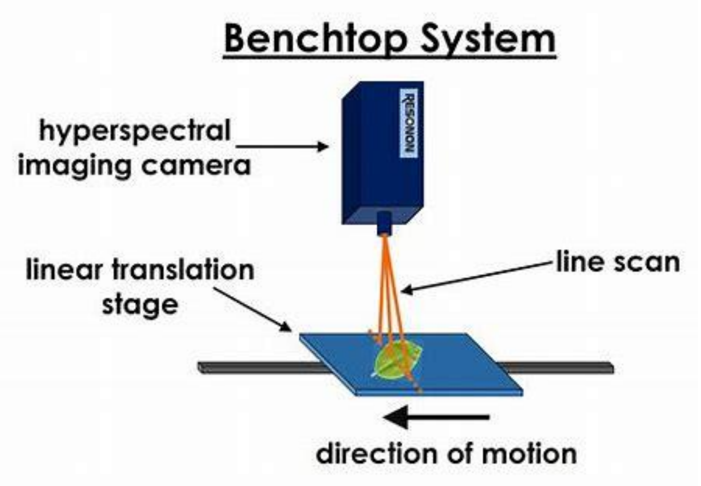

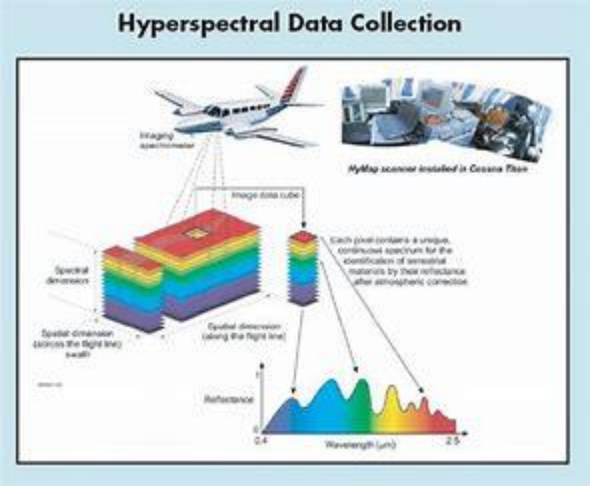

Hyperspectral Imaging Standard Workshop

Date: **Monday 16 April 2018**

Time: **1:00 PM - 3:00 PM**

Workshop Organizers:

Chris Durell, Labsphere, Inc. (USA)

David Allen, National Institute of Standards and Technology (USA)

Panel Moderator: **Chris Durell**, Labsphere, Inc. (USA)

SPIE.

Hyperspectral Imaging Standards (Why now?)

- Rapidly growing market of new hyperspectral imagers (compact, lower cost, innovative designs)
- Wide range of applications (too many to list). Some examples include agriculture, medical, environmental, manufacturing, and defense
- New platforms include benchtop, UAVs, and small satellites

Definition of a Standard (ISO/IEC 17000:2004)

Document, established by consensus and approved by a recognized body, that provides for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context. Note. Standards should be based on the consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits.

Hyperspectral Imaging Standards

- Few if any “Hyperspectral Imaging Standards”
- Based largely on input from the previous workshop:
  - Potential standards might include
    - Radiometric calibration
    - Validation
    - Instrument performance and characteristics
    - Methodology
    - File formats
    - Nomenclature
    - Spectral libraries
    - Algorithms

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Hyperspectral Imaging Standards Forecast

- Through community input, determine what standards are needed, what takes priority, and what if any standards can be cited?
- Work though standards development organization (SDO) to establish standards
- Long journey to develop formalize standards –requires persistence and long term vision
- How long this journey takes depends in part on how well the "community" can come together, come to a consensuses, and formalize
- Success depends on the community

Panel Discussion

Moderator - Chris Durell, Labsphere

Agenda

- Moderated Panel Format
  - Moderator – Chris Durell, Labsphere
- Overview of Current Status with activities and efforts
- HSI Topic of Interest for the IEEE P4001 Standard Efforts
  - 15-20 Minutes on each topic: 10 minutes of presentation / 5-10 minutes of Q&A
- 10-30 minutes will be Open Q&A at the end of the last presentation.
- Summary of IEEE & P4001 Options for Participation

Technical Focus of the Standard Effort

- Providing basic tools, test recommendations and procedures for absolute characterization of HSI instruments to ensure proper performance for the selected applications and standardization of data output

- Visible, Near-IR and SWIR Sensors (300-2500nm)
  - Silicon, InGaAs or MCT-based Focal Plane Arrays (FPAs)
  - Grating-based systems

- Passive Remote Sensing – Airborne, Handheld and Benchtop

- Pushbroom and Scanning configurations

- Establish a Foundation for future efforts to other spectral regions and instrument architectures.

Specific Topics = Possible Work Groups

- Terminology – **Chris Durell, Director of Business Development**
  - Labsphere - cdurell@labsphere.com
- Calibration Techniques – **Dr. David Allen, Research Chemist**
  - NIST - david.allen@nist.gov
- Classes of Instrumentation – **Dr. Kwok-Keung Wong, Technology Manager, Spectral Imaging**
  - Headwall Photonics - KWong@headwallphotonics.com
- Applications – **Dr. Miguel Velez-Reyes,**
  - Univ. of Texas, El Paso - mvelezreyes@utep.edu
- Current Standards and Conventions for HSI – **Dr. Siri-Jodha Singh Khalsa,**
  - National Snow and Ice Data Center - sjsk@nsidc.org

Terminology

Chris Durell, Labsphere

Why Terminology?

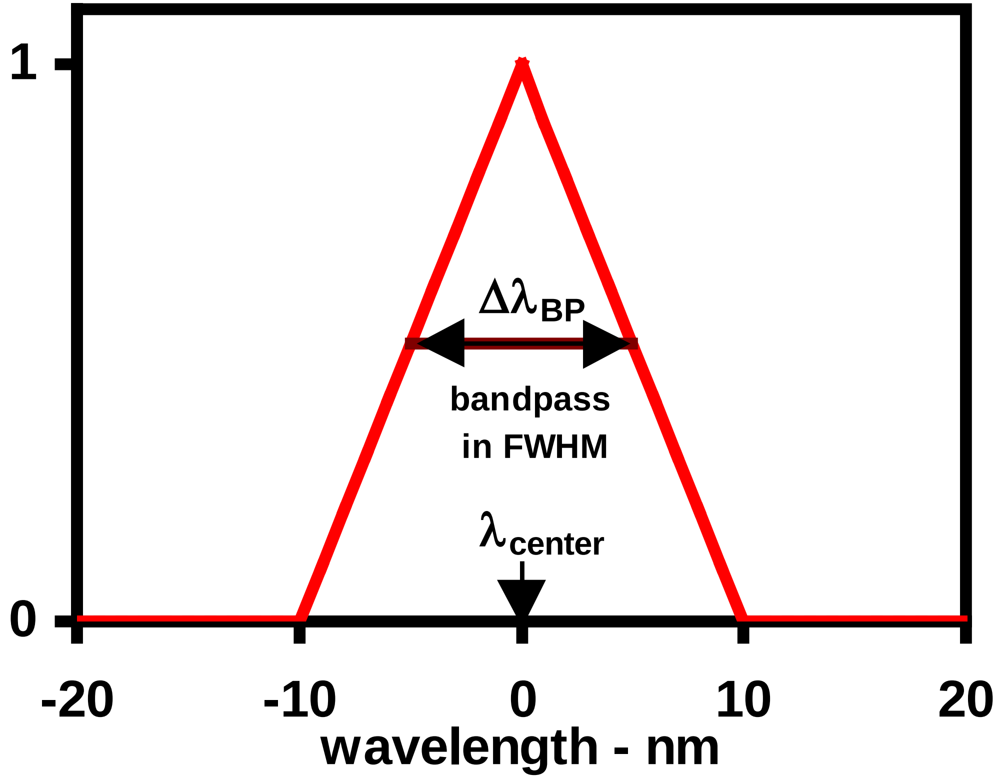
- English does not readily convey specific technical meanings
  - Example: Resolution, Stray Light, Bandpass

- Promote consistent use of terms across manufacturers and industries.

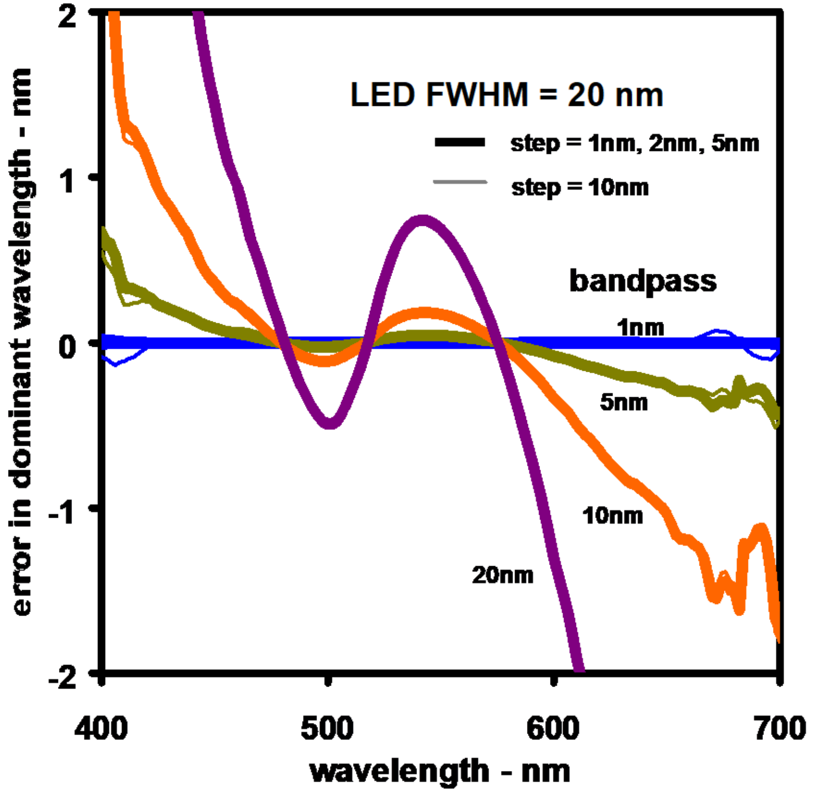
- There is some great work out there: but it needs an archive, an organizer and a lookup table.

Example – Bandpass effects on LEDs (and other signatures…)

- Spectrograph bandpass model



- Effect of Spectrometer Bandpass on measured LED Dominant Wavelength



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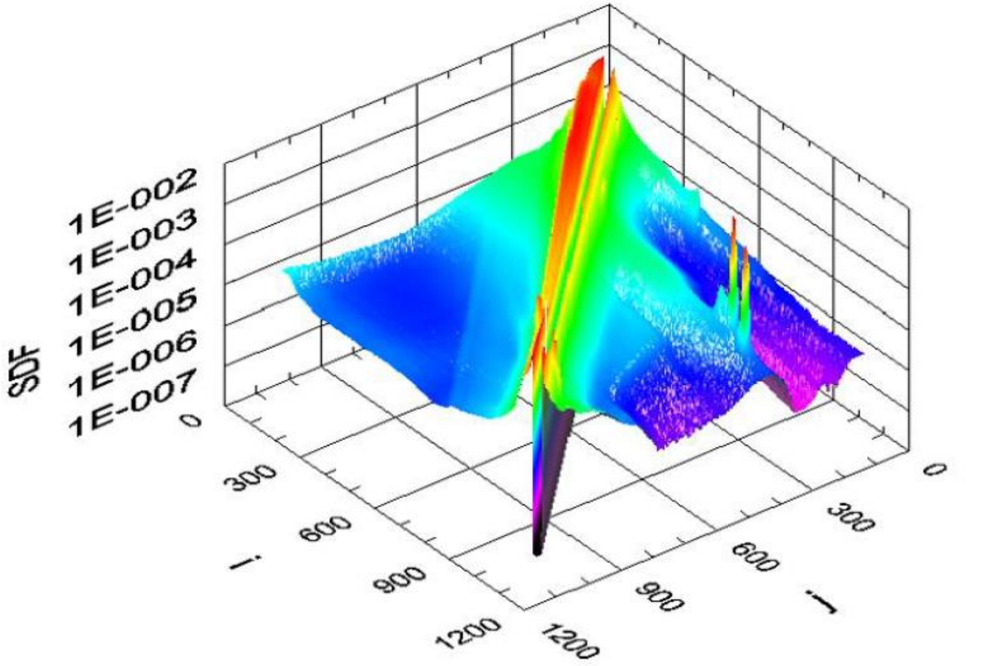
Example – Stray Light

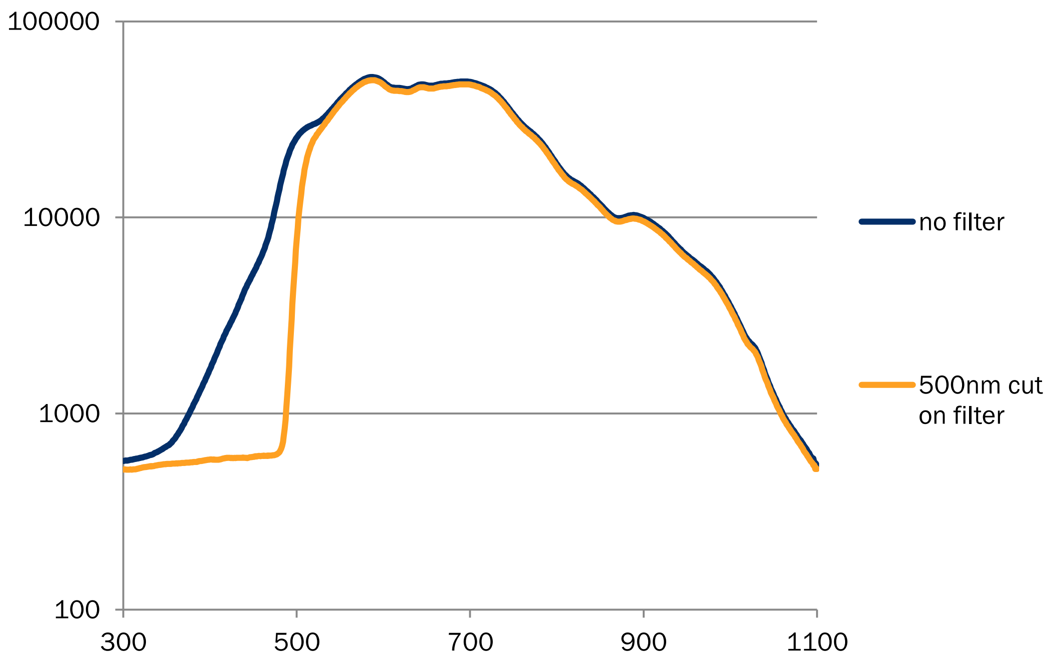
- Stray light is a function of the instrument and the observed target

3-D plot of the Stray Light Distribution (SDF) matrix, ***D***



[1] Zong, Y., Brown, S. W., Johnson, B. C., Lykke, K. R., Ohno, Y., "Simple spectral stray light correction method for array spectroradiometers", Applied Optics, Vol. 45, No. 6, 1111-1119 (2006)

Raw counts from spectrograph with QTH input



[24] Jablonski, J., Practical Implications of Standard Spectrograph Stray Light Specifications, International Symposium on Lighting 2011

Glossary of HSI Terms & References (A Start)

- EUFARs document:
  - https://www.eufar.net/cms/glossary-terms/

EUFAR GLOSSARY

EUFAR > EUFAR Glossary

- 2016 HSI Calibration Paper
  - (81) HSI Specific Terms Defined
  - (76) Citations
    - Categorized & Listed for Easy Reference

Best Practices in Passive Remote Sensing VNIR Hyperspectral System Hardware Calibrations

Joseph Jablonski[1], Christopher Durell[1], Terrence Slonecker[2], Kwok Wong[3]
Blair Simon[3], Andrew Eichelberger[4], Jacob Osterberg[4]
[1]*Labsphere, Inc., North Sutton, NH USA*
[2]*USGS, Reston, VA, USA*
[3]*Headwall Photonics, Fitchburg, MA USA*
[4]*Aeroptic, North Andover, MA USA*

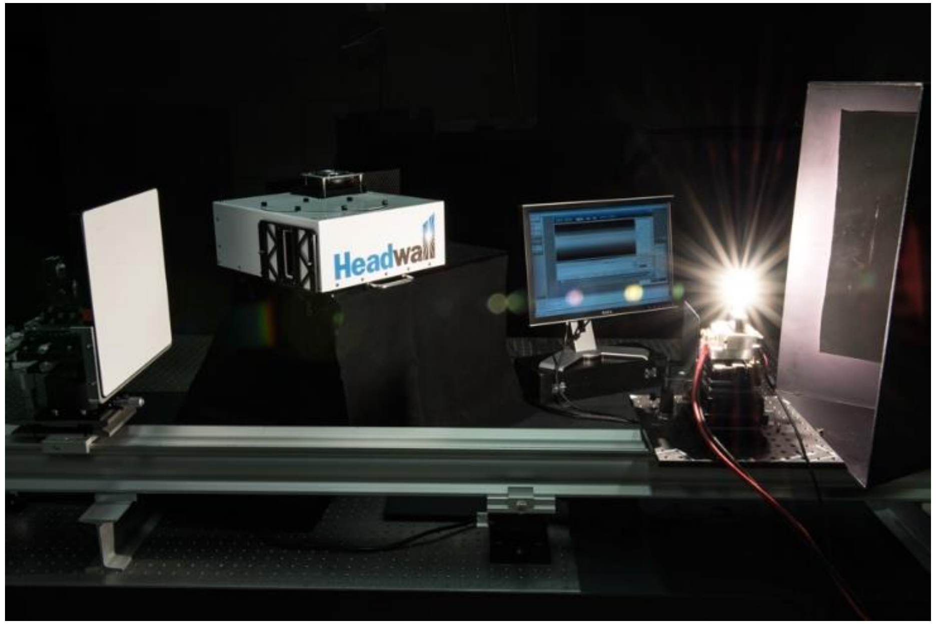
- Submissions of Terms & Definitions by Industry for consideration…

Calibration and Testing of HSI Instruments

Dr. David Allen, NIST

Calibration and Characterization of HSI Instruments

- Calibration standards provide a means of comparison to recognized scales and units (SI). Traceability provides an unbroken chain of comparisons with stated uncertainties
  - https://www.nist.gov/nist-policy-traceability
- The use of standards facilitates the ability to compare results from different instruments, at different physical locations and times.
- National Metrology Institutes (NMIs), such as NIST play a key role in establishing and or disseminating these scales



Disclaimer
Certain commercial products are identified to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products identified are necessarily the best available for the purpose

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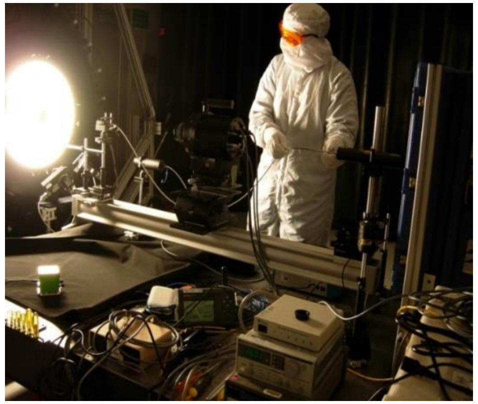
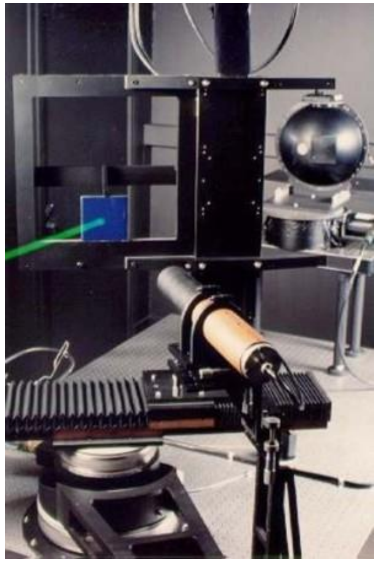
Basic Radiometric Standards (what we have now)

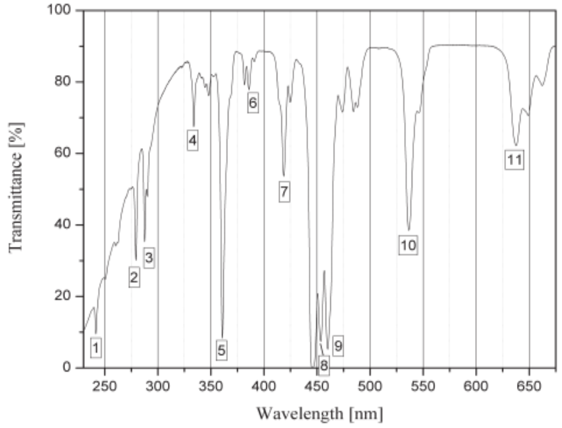
- A search for “hyperspectral imaging standards” will likely result no HSI specific calibration standards
- The well established scales of radiance, reflectance and wavelength serve as the foundation
- Best practices for HSI still need to be refined in the application of these



Radiance



Reflectance



Wavelength

"Standardized" Characterization & Specification of HSI Instruments

- Characterization helps in evaluating design performance and specifying instruments based on requirements
- Suggested specification that each imager should aspire to give the user:
  - Architecture of the spectrometer: Diffraction, Prism, etc.
  - Number of Pixels / Spatial Resolution (columns and rows)
  - Spectral Range (ex: 400 to 1100 nm) – usable range
  - Signal-to-Noise over the Spectral Range
  - Spectral Sampling / Number of bands (ex: 5 nm/140 bands)
  - Spectral Resolution / Spectral Bandwidth
  - Radiance Responsivity (W/sr-m2-nm)/(counts/sec)
  - Radiometric / Wavelength Accuracy over full range
  - Smile & Keystone, PSF

How are each of these determined?

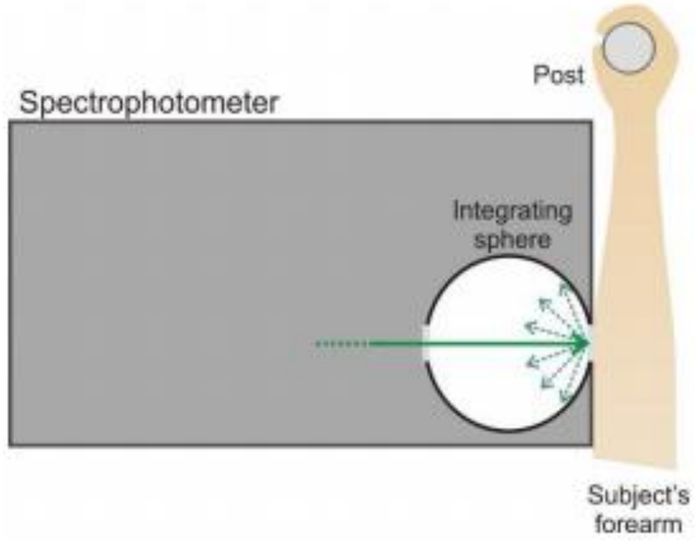
Wide Range of Applications May Require Multiple Standards

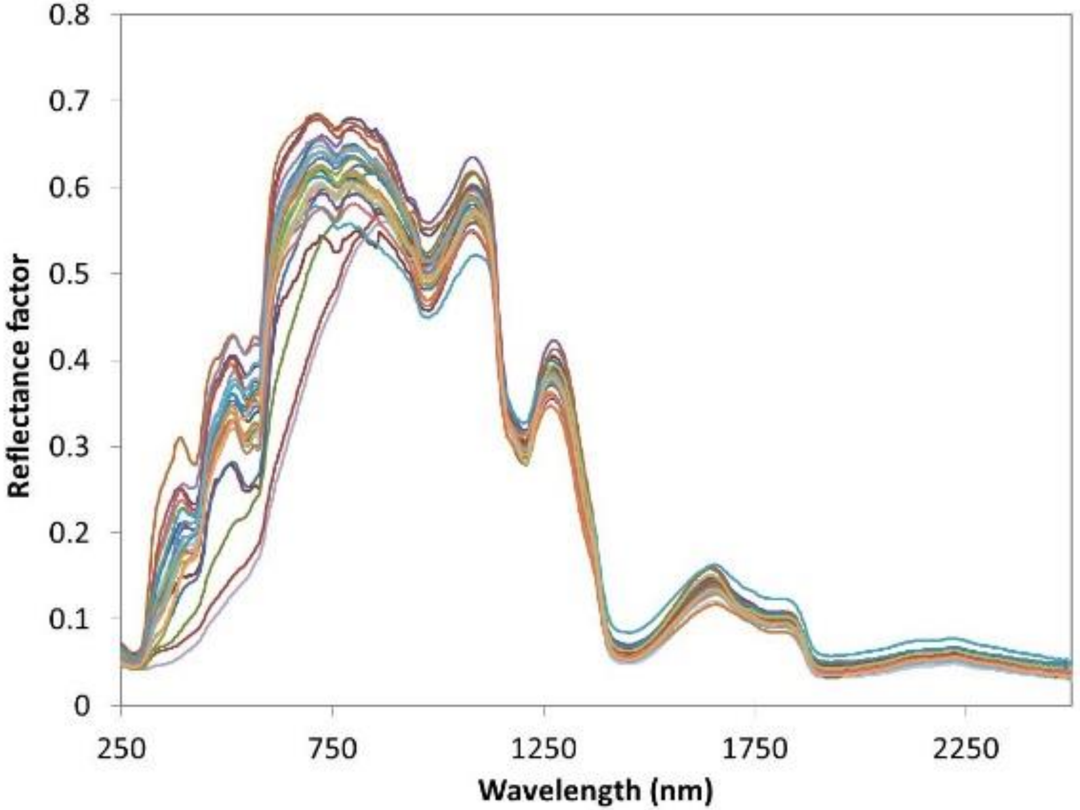
- However, basic radiometric standards may be insufficient providing the information required in predicting performance (e.g., medical, agriculture, manufacturing, etc.)
- The required performance is highly dependent on the application
- “Is the device suitable for the application?”, may be a better question

Example: Human Skin Reflectance

- Beyond basic radiometric calibration and characterization, application specific standards and best practices should be considered

Volume 122, Article No. 26 (2017) https://doi.org/10.6028/jres.122.026
Journal of Research of the National Institute of Standards and Technology





Classes of Instrumentation

Dr. Kwok-Keung Wong, Headwall Photonics

Classes of Instrumentation

- Hyperspectral imaging instruments can be broadly categorized into a number of classes depending on the intended applications, operating environments, and usage modes of the instruments
- Each class of instruments has a number of specification parameters that are particularly important for its applications
- The categorization of these instruments help guide manufacturers to specify and publish these key parameters so instruments can be more effectively and consistently evaluated for end use applications
- Note: the focus of this standards effort is on pushbroom and scanning configurations only
- List of suggested classes of instrumentation for hyperspectral imagers:
  - Benchtop / research
  - Industrial machine vision
  - Field
  - Airborne
  - Handheld
- The following slides help define each of these suggested classes of instrumentation

Classes of Instrumentation – Benchtop / Research

- Benchtop / research hyperspectral imagers are used indoors for scanning small to medium sized objects (< ~2m long) typically in a laboratory or office environment where the ambient temperature is stable
- They can be mounted on a stationary or moving platform depending on the scanning configuration of the hyperspectral imager
- Example applications include: Microscopy, sample scanning on a motorized stage
- Example key parameters/specifications: Spatial and spectral resolution, FOV, keystone and smile distortion, dynamic range
- Typical operating parameters:

Operating Parameter	Description / Typical ranges, Examples
Working distance	> Contact (e.g. microscope), < ~2m (e.g. benchtop scanner)
Illumination	Artificial broadband source, e.g. quartz tungsten halogen lamp
Operating environment	Indoors, temperature ~17°C - ~30°C, stable Humidity: non condensing E.g. typical laboratory/office environment
Speed / frame rate	Sub-Hz to < ~200Hz for line (1D spatial x spectral) scanners, up to minutes for full 2D scan Sub-Hz to < ~10Hz for area (2D spatial x spectral) scanners, up to minutes for full 2D scan
IP rating, shock	Typically none

Classes of Instrumentation – Industrial Machine Vision

- Industrial machine vision hyperspectral imagers are used indoors typically in an industrial production environment where the operating environment can be somewhat harsh (temperature, humidity, water, dust)
- They are usually mounted on a stationary platform, in an IP rated enclosure and may require air conditioning within the enclosure if the room environment is too hot
- Example applications include: Product evaluation/sorting on a conveyor belt
- Example key parameters/specifications: frame rate, spatial resolution & FOV, keystone and smile distortion, MTF, SNR (at specific wavelengths, radiance levels and integration times), dynamic range, sensor drift/stability, operating environment (temperature range and stability), IP rating, vibration/shock
- Typical operating parameters:

Operating Parameter	Description / Typical ranges, Examples
Working distance	> ~15cm, < ~4m (e.g. product sorting/evaluation on conveyor belt)
Illumination	Artificial broadband source, e.g. quartz tungsten halogen lamp
Operating environment	Indoors, can be harsh, temperature may not be well controlled, <40°C Humidity: can be harsh Can be very dusty, may endure periodic hot water sprays
Speed / frame rate	~50Hz to > ~300Hz for line (1D spatial x spectral) scanners ~1Hz to > ~50Hz for area (2D spatial x spectral) scanners
IP rating	Protection highly recommended

Classes of Instrumentation – Field

- Field hyperspectral imagers are typically used outdoors, e.g. for ground truth measurements/spot checks or for repetitive monitoring of an ongoing process. The operating environment can be somewhat harsh (temperature, humidity, water, dust).
- They can either be portable with the sensor on a pan-tilt stage on a tripod, or can be fixed mounted in an IP rated enclosure for repetitive scanning.
- Example applications include: portable instrument for ground truth/surveying measurements; fixed mounted instrument on a large gantry over a field of plants
- Example key parameters/specifications: angular spatial resolution & FOV, keystone and smile distortion, radiometric calibration, SNR (at specific wavelengths, radiance levels and integration times), dynamic range, sensor drift/stability, operating temperature range and stability, IP rating

- Typical operating parameters:

Operating Parameter	Description / Typical ranges, Examples
Working distance	> ~15cm to ~infinity (e.g. scanning a field of crops with sensor on a tripod)
Illumination	Solar
Operating environment	Outdoors, can be very cold or hot (below freezing to > 40°C Humidity: can be harsh Can be very dusty, rain, snow
Speed / frame rate	Sub-Hz to ~200Hz for line (1D spatial x spectral) scanners, up to minutes for full 2D scan Sub-Hz to ~10Hz for area (2D spatial x spectral) scanners, up to minutes for full 2D scan
IP rating, shock	Protection highly recommended

Classes of Instrumentation – Airborne

- Airborne hyperspectral imagers are used on drones or manned aircrafts. The operating environment can be somewhat harsh and temperature can change drastically.
- They may be mounted on a gimbal or hard mounted onto the aircraft.
- Example applications include: sensor on a drone scanning a field of crops, sensor on a manned aircraft scanning large area conservation land, forests, etc.
- Example key parameters/specifications: size, weight, power, data storage capacity, angular spatial resolution & FOV, keystone and smile distortion, radiometric calibration, SNR (at specific wavelengths, radiance levels and integration times), dynamic range, sensor drift/stability, operating environment (temperature range and stability)
- Typical operating parameters:

Operating Parameter	Description / Typical ranges, Examples
Working distance	> 10m to ~infinity (e.g. sensor on a drone scanning a field of crops)
Illumination	Solar
Operating environment	Outdoors, can be very cold or hot (below freezing to > 40°C Humidity: can be high Can be dusty
Speed / frame rate	> ~100Hz for line (1D spatial x spectral) scanners > ~10Hz for area (2D spatial x spectral) scanners
IP rating	Protection recommended but may not be possible due to payload capacity of aircraft

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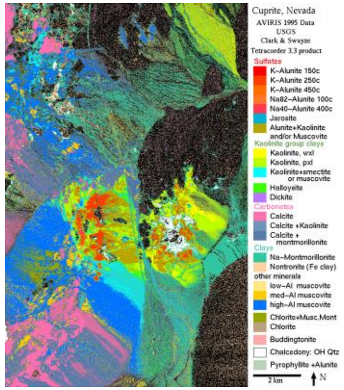
Classes of Instrumentation – Handheld

- Handheld hyperspectral imagers are used for spot check measurements and may be mounted on a fixed platform for repetitive scanning applications.
  - Snapsnot imagers and new emerging technology need to be considered
- They are lightweight, battery operated and should operate fast enough to avoid motion blur or image distortion and usually include a touch screen user interface
- Example applications include: Color analysis, artwork analysis, field measurements
- Example key parameters/specifications: Spatial and spectral resolution, FOV in X and Y, spectral range, keystone and smile distortion, dynamic range, battery life, radiometric calibration
- Typical operating parameters:

Operating Parameter	Description / Typical ranges, Examples
Working distance	> ~3cm to ~infinity
Illumination	Artificial broadband source, or solar
Operating environment	Indoors and outdoors, temperature ~0°C - ~30°C Humidity: non condensing
Speed / frame rate	Sub-Hz to < ~50Hz for full 2D image (slower operation would require tripod or fixed mounting)
IP rating, shock	Recommended



Hyperspectral Imaging Applications

Dr. Miguel Velez-Reyes, F-SPIE
Professor an Chair
Sensor and Signal Analytics Laboratory
Electrical and Computer Engineering Department
The University of Texas at El Paso

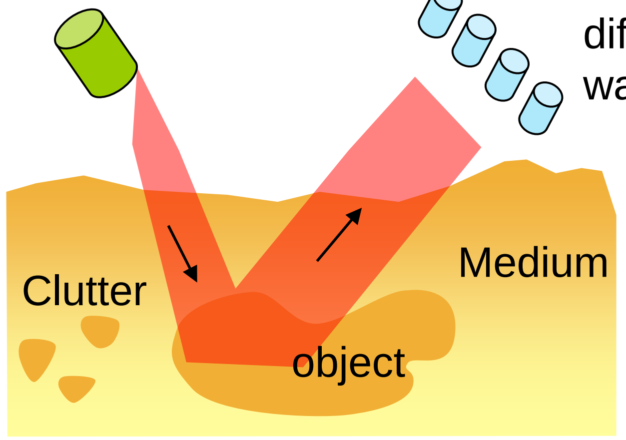
SenSAL
SENSOR AND SIGNAL ANALYTICS LABORATORY

UTEP

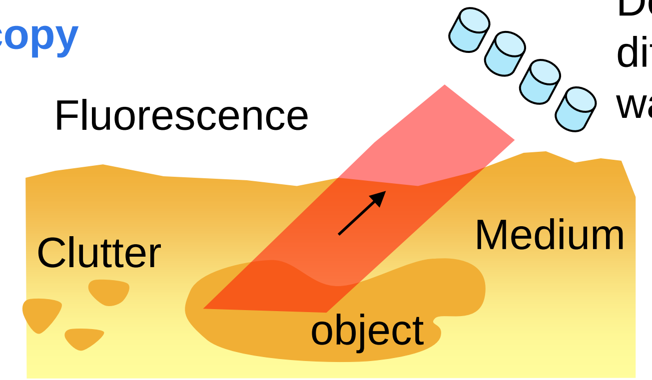
Spectral Sensing and Imaging

Remote Sensing

Broadband
Probe, P

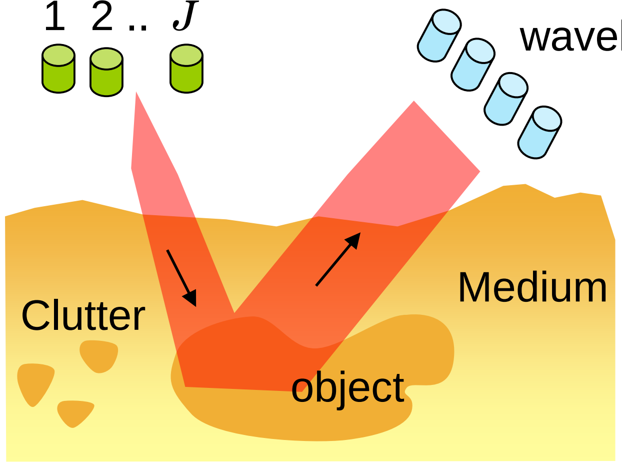


Microscopy

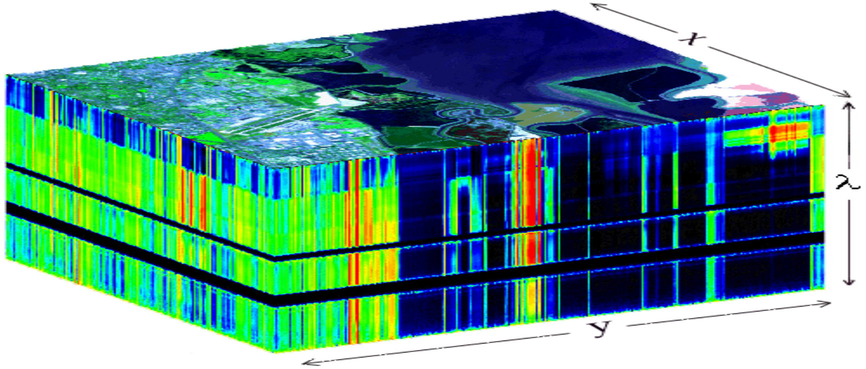


Multispectral DOT

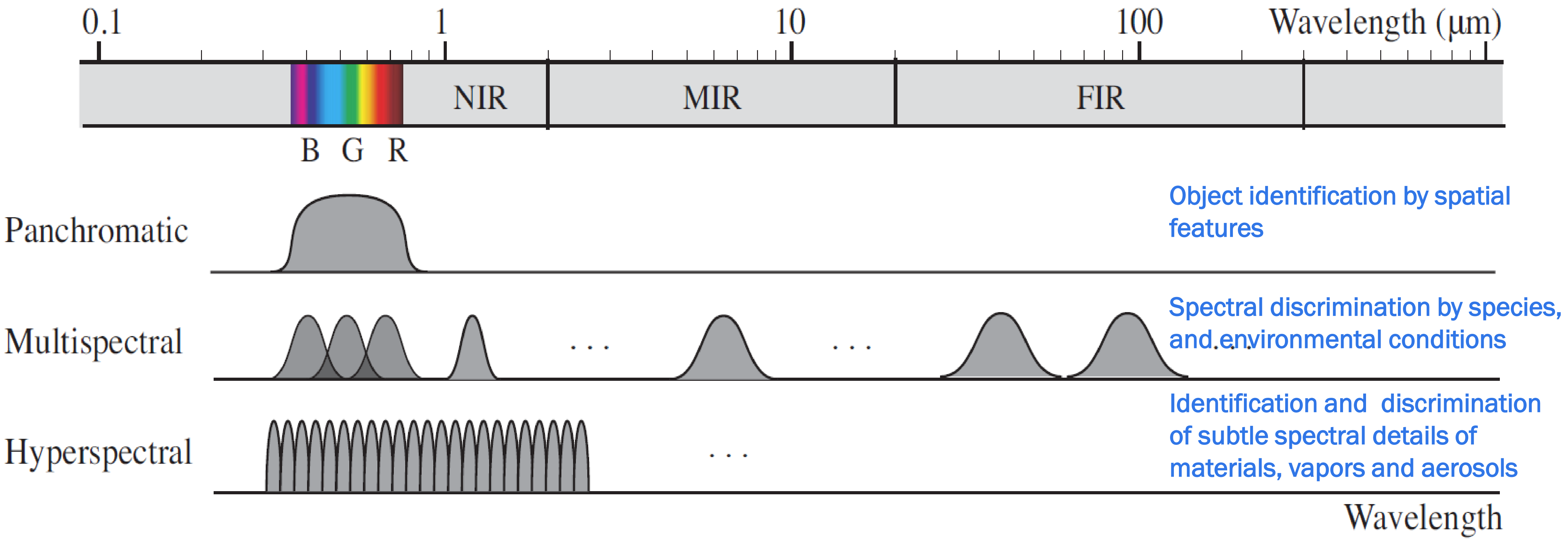
Probes at different wavelengths, P_i



$$Y(\mathbf{r},\lambda_i) = T(\mathbf{r},\alpha(\beta(\lambda_i)), S_i, \gamma_i) + w(\mathbf{r},\lambda_i)$$



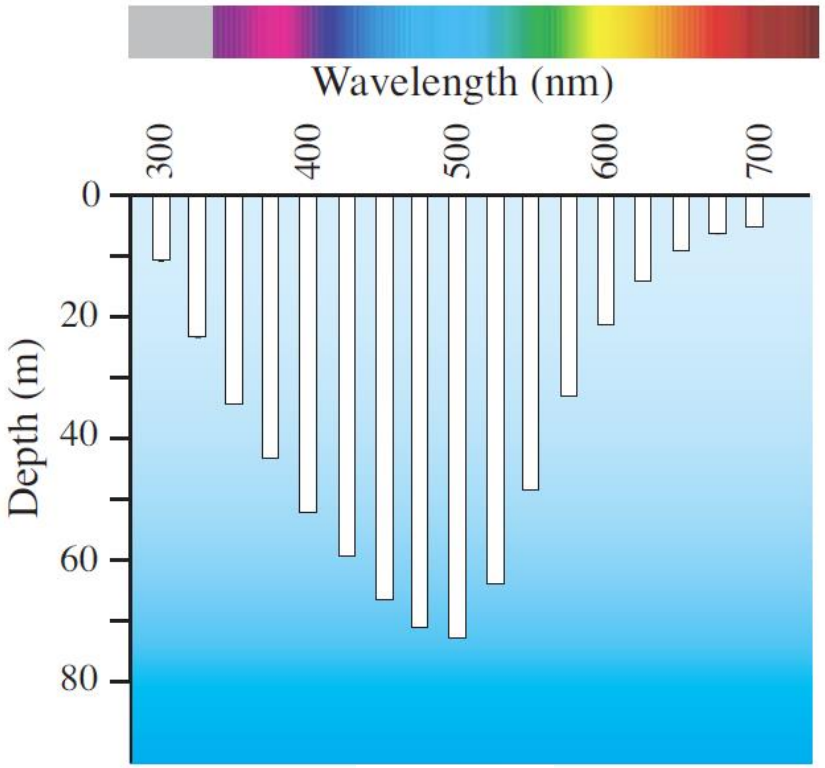
Spectral Sensing and Imaging



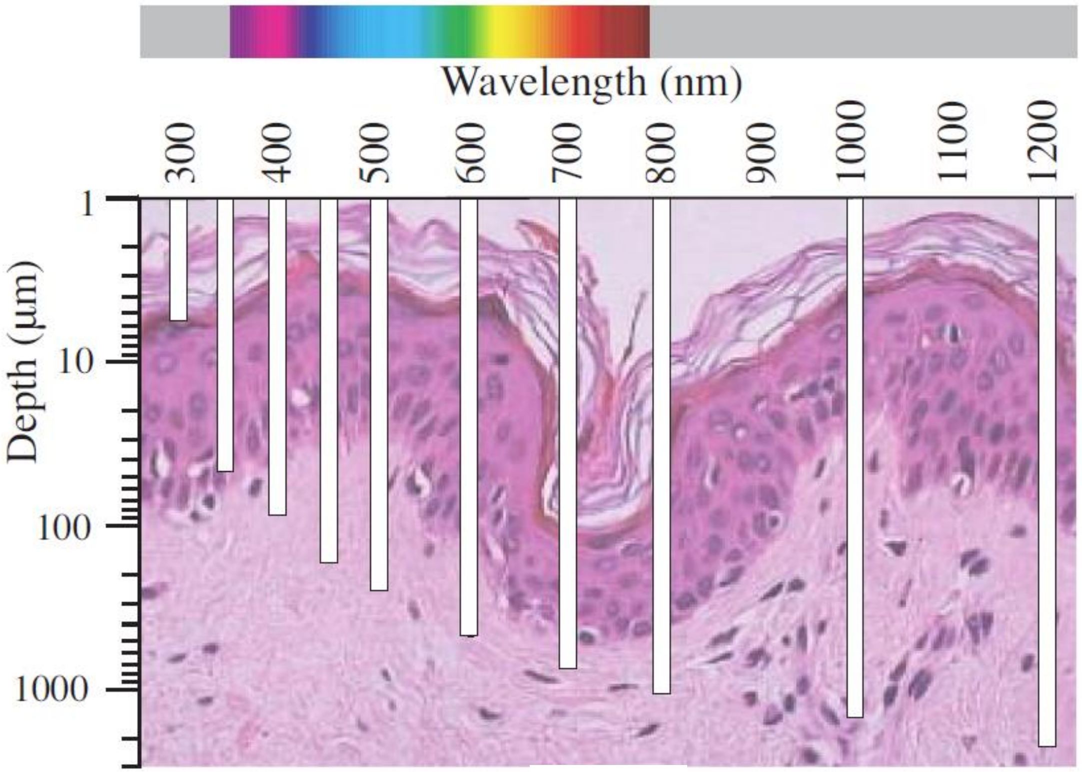
Source: M. Velez-Reyes, J. A. Goodman, and B.E. Saleh, "Chapter 6: Spectral Imaging." In B.E. Saleh, ed., *Introduction to Subsurface Imaging*, Cambridge University Press, 2011.

Adapted from
From 1993 MUG

Spectral Dependency: Light Penetration Water vs Skin



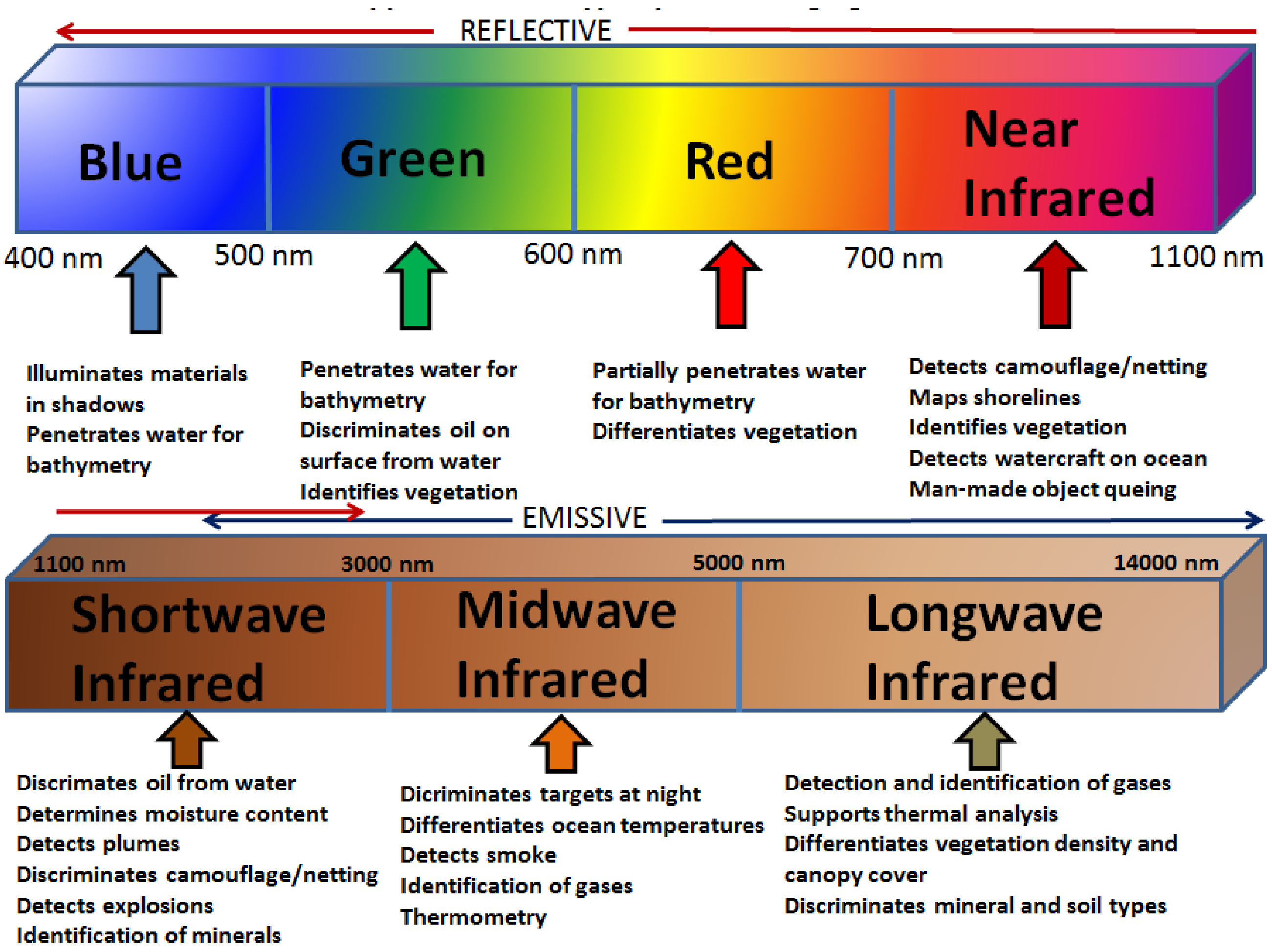
Water



Skin

Source: M. Velez-Reyes, J. A. Goodman, and B.E. Saleh, “Chapter 6: Spectral Imaging.” In B.E. Saleh, ed., *Introduction to Subsurface Imaging*, Cambridge University Press, 2011.

Applications of Spectral Imaging



Enablers
- Instrument design,
- Signal processing,
- Data management,
- Computing

Making HSI viable in applications ranging from food inspection to pathogen detection to airport security and more.

Source: https://gis.stackexchange.com/questions/195015/hyperspectral-imaging-material-spectral-signature

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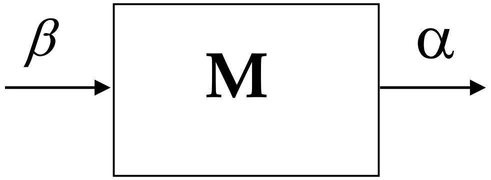
Goals of Hyperspectral Sensing & Imaging

Estimation, Detection, Classification, or Understanding

Estimate: probed spectral signature $\{\alpha(x, y, \lambda)\}$
parameter to be estimated $\{\beta(x, y, \lambda)\}$



Examples of β

- Crop health
- Chemical composition, pH, CO_2
- Metabolic information
- Ion concentration
- Physiological changes (e.g., oxygenation)
- Extrinsic markers (dyes, chemical tags)

Detect: presence of a target characterized by its spectral features $\alpha(x, y, \lambda)$ or $\beta(x, y, \lambda)$

Classify: objects based on features exhibited in $\alpha(x, y, \lambda)$ or $\beta(x, y, \lambda)$

Understand: object information, e.g., spectral signature, shape or other features based on $\alpha(x, y, \lambda)$ or $\beta(x, y, \lambda)$

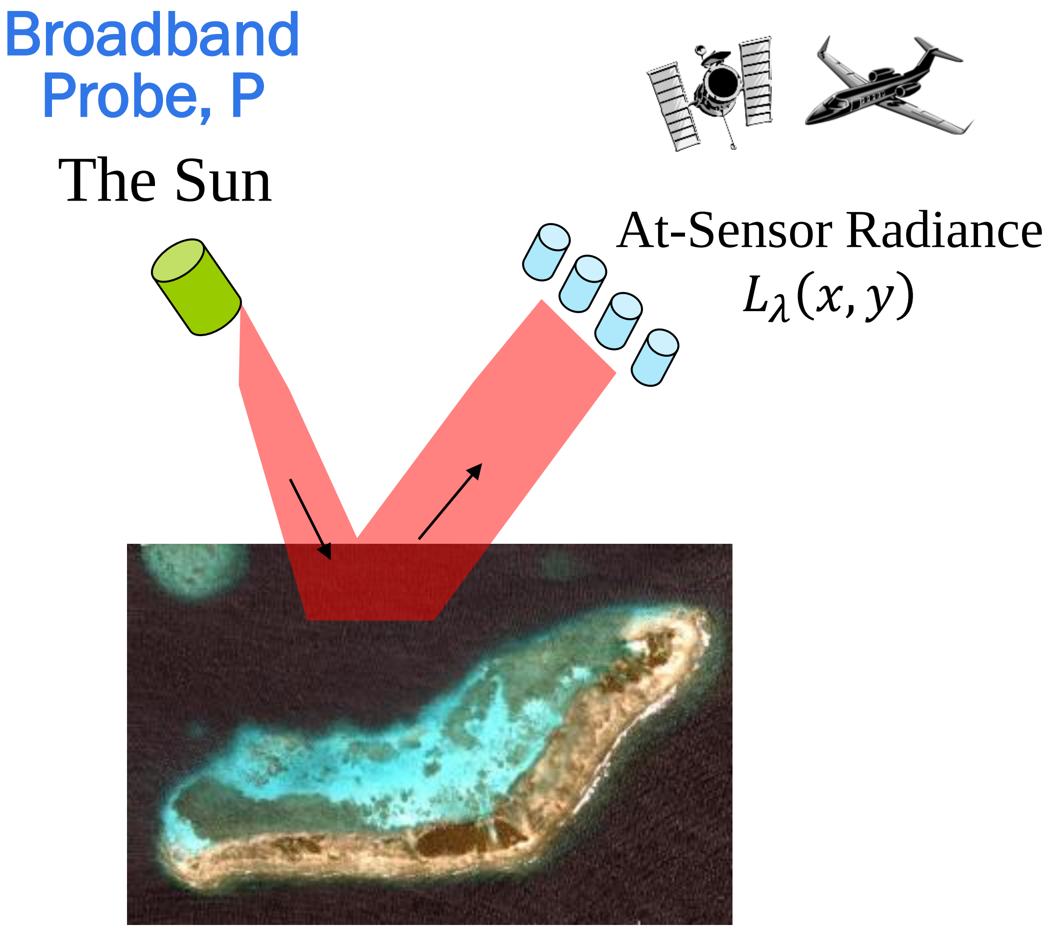
Application Example:
Benthic Habitat Monitoring and Mapping

Estimate:
- Atmospheric constituents
- Water optical properties
- Benthic composition
- Bathymetry (water depth)

Detect:
- Healthy/unhealthy coral
- Unexploded ordinance
- Human induced changes

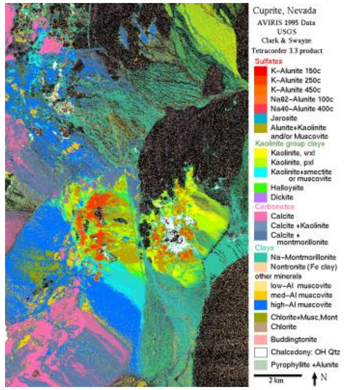
Classify:
- Coral distribution
- Seagrass density
- Benthic habitat maps

Understand:
- Environmental stressors
- Seasonal/annual changes
- System productivity



2020 Global Market for Hyperspectral Imaging

- Military ($42.7M)
- Healthcare ($30.8M)
- Mineralogy ($22.3M)
- Research ($19.5M)
- Agriculture ($11.8M)
- Food processing ($16.0M)
- Others ($7.3M)



Total: $152.9 M by 2020

Source: BCC Research, May 2016

Standards Relevance to Applications

- Calibration
  - Relative vs. Absolute (Physics-based signal processing)
  - Data sets across scales and platforms
  - Close range imaging
- Performance
  - Is the device suitable to the application
- Metadata
  - Understand data characteristics
- Standardized reference data
  - Accessibility to multiple users
  - Testing and validation
  - Comparison of different approaches

http://dailycommercenews.com/tag/medical-hyperspectral-imaging/

https://www.hypersurvey.com/

Coffey, 2015

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SPIE. DCS DEFENSE+ SECURITY

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Conference 10644

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Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XXIV

Tuesday - Thursday 17 - 19 April 2018

Conference Sessions At A Glance

SHOW | HIDE

1: Target and Anomaly Detection
2: Dimensionality Reduction and Feature Extraction
3: Image Fusion
4: Machine Learning in Spectral Sensing
Posters-Tuesday
5: Performance Evaluation of Sensors and Systems
6: Atmospheric Modeling and Compensation
7: LWIR and MWIR Spectral Sensing
8: Change Detection and Image Registration
9: Applications
10: Sensor, Design, Development, and Characterization
11: Keynote Session

Important Dates

SHOW | HIDE

Abstract Due:
9 October 2017

Author Notification:
11 December 2017
Notifications will be sent no later than 12/15/17

Manuscript Due Date:
21 March 2018

Location
Ballroom Level, Osceola 2

Current Standards and Conventions for HSI & The IEEE Standards Development Process

Dr. Siri-Jodha Singh Khalsa
National Snow and Ice Data Center

Where to Start?

- While it is true that there are few, if any, widely recognized standards for hyperspectral data…
  - Hyperspectral sensors share many characteristics with other optical sensors
  - Starting point should be an examination of existing related standards

Relevant ISO/TC211 Standards

- ISO 19115 – Metadata
  - 19115:2003 Widely used in the science and applications community
  - 19115-1:2014 Major revision and update (not fully backwards compatible)
  - 19115-2:2009 remote sensing specific, revised (2018) to "Extensions for acquisition and processing"

- ISO 19130 - Imagery sensor models for geo-positioning
  - 19130:2010 for EOIR (undergoing revision, will be 19130-1)
  - 19130-2:2014 for SAR, InSAR, lidar and sonar

Relevant ISO/TC211 Standards – Continued

- ISO 19159-1:2014 - Calibration and validation of remote sensing imagery sensors and data -- Part 1: Optical sensors
  - Applies to airborne and space-borne imagery sensors
  - Refers to geometric, radiometric, and spectral calibration
  - In laboratory as well as in situ calibration methods

- ISO 19159-2:2016 - Calibration and validation of remote sensing imagery sensors and data -- Part 2: Lidar
  - Also addresses data capture methods and relationships between the coordinate reference systems

Encoding of ISO/TC211 Standards

- ISO 19139:2007 defines an XML implementation of 19115
- ISO 19139-2:2012 defines an XML implementation of ISO 19115-2
- ISO 19115-3 (under development) XML implementation of 19115-1
- ISO 19130-3 XML implementation of 19130-1 and -2
- ISO 19139-1 (under development) XML implementation -- Encoding rules

De Facto Standards for encoding HSI data

- Binary with ENVI header
  - AVIRIS distributed in this format
  - The ENVI header has been proposed as a standard
- Hierarchical Data Format (HDF)
  - Can contain all relevant data and metadata in a single file
- TIFF widely used
- Tool-specific formats (e.g. Matlab)
- Vendor specific formats

- How can standardization support innovation and provide choice in what tools can be used?
  - Without some standardization there will be increasing chaos

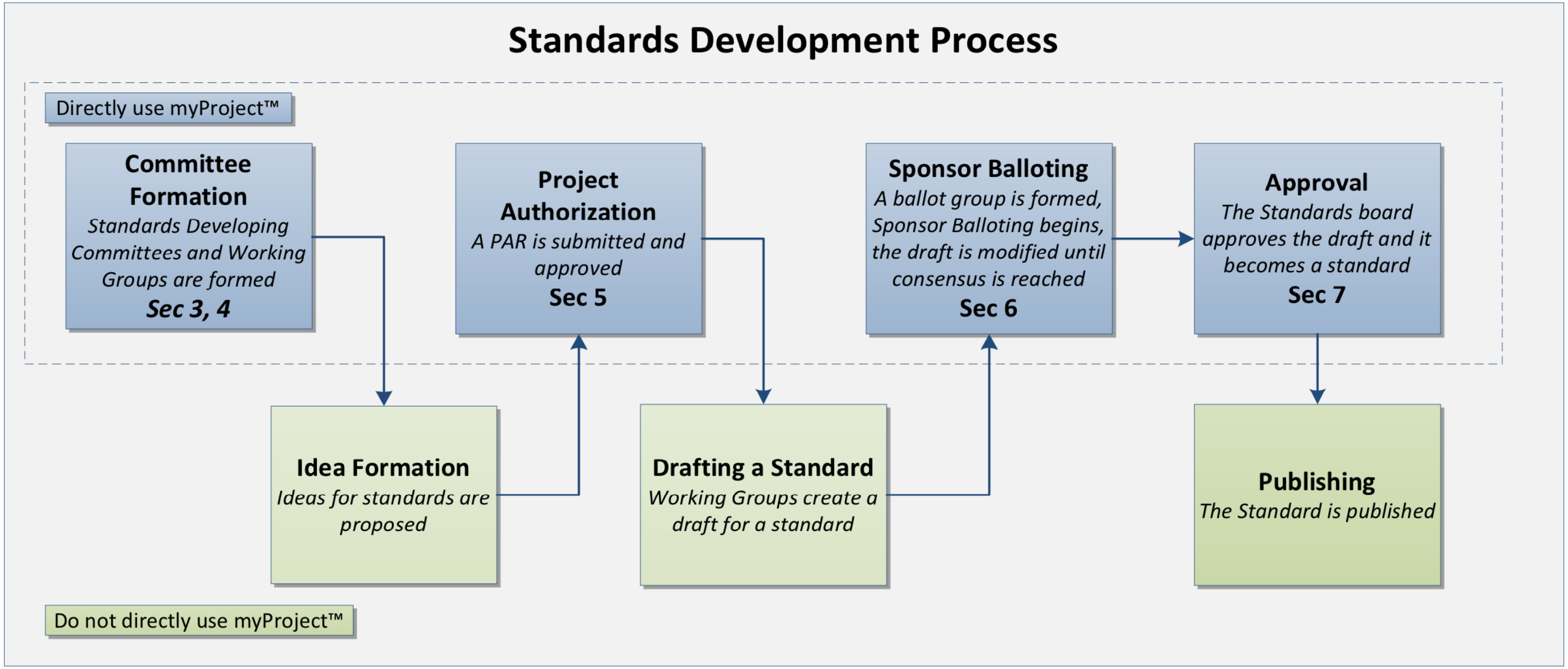
Open Question Session

Participation in IEEE Standards Development Activities

IEEE Standards Development Process

- The GRSS Standards Committee
  - Operates under the IEEE Standards Association Policies and Procedures
  - Closely aligned with the GRSS Standards for Earth Observations (GSEO) TC
- Development is carried out in Projects initiated by Working Groups
  - WGs operate under a Policy and Procedures document
  - Openness and fairness is paramount
- Membership
  - Anyone can participate
  - Join the group to have your voice heard
  - Voting members need to register in IEEE myProjects (no cost)
  - Must join IEEE Standard Association (SA) to be an officer

IEEE myProject™



GRSS & IEEE-SA P4001 Participation

- myProject™ is a web based tool used by everyone participating in the standards development process
  - Requires a free IEEE web account (does not require IEEE membership)
  - After creating an account you can register interest in a Working Group
- Levels of Participation
  - Observer (Participant)
    - May attend meetings but shall not participate in discussions or voting.
  - Member
    - Participant can become a non-voting member by attending one meeting and requesting membership from the Chair.
    - Becomes non-member by missing 4 consecutive meetings (meetings held electronically count)
  - Voting Member
    - Granted to all those in attendance at an inaugural meeting of a Working Group
    - Or by attending 2 of last 4 meetings and requesting voting membership from the Chair.
    - Becomes non-voting member by missing 2 of the last 4 meetings.
    - Voting membership can be regained by attending two consecutive meetings.

Officers of P4001

- Siri-Jodha Singh Khalsa – Chair GRSS Standards Committee
- Chris Durell, Labsphere – (Pending PAR approval) Chair P4001
- David Allen, NIST – (Pending PAR approval) Co-Chair P4001
- (TBD) - Secretary
- Each Working Group with also need Officers

IEEE P4001: Standards for Characterization and Calibration of UV-SWIR Hyperspectral Imaging Devices

- Unlimited to group of voting members.
  - Officer positions initially appointed by GRSS
  - Elections for officer positions within 6 months

- People interested in participating or becoming officers should contact the group chair, Chris Durell:
  - cdurell@labsphere.com, Cell 858-414-1885
  - Provide a business card at the end of this meeting

- (1-2) P4001 Working Group On-line meetings following this SPIE event

- IGARSS 2018, Valencia Spain July 23-27
  - Working Group (WG) meeting – July 24, 18:30-20:00 (Location TBD)
  - Technology Industry Education (TIE) Forum during Conference – July 25, 08:30-10:10