Tunable Light-guide Image Processing Snapshot Spectrometer (TuLIPSS) for Earth and Moon Observations.

02-28-2018

T. S. Tkaczyk[1], D. Alexander[2], J. C. Luvall[3], Ye Wang[1], J. G.Dwight[1], M. E. Pawlowski[1], B. Howell[4] and P. Tatum[3], R.-I. Stoian[1], Shuna Cheng[1], Antoun Daou[2]

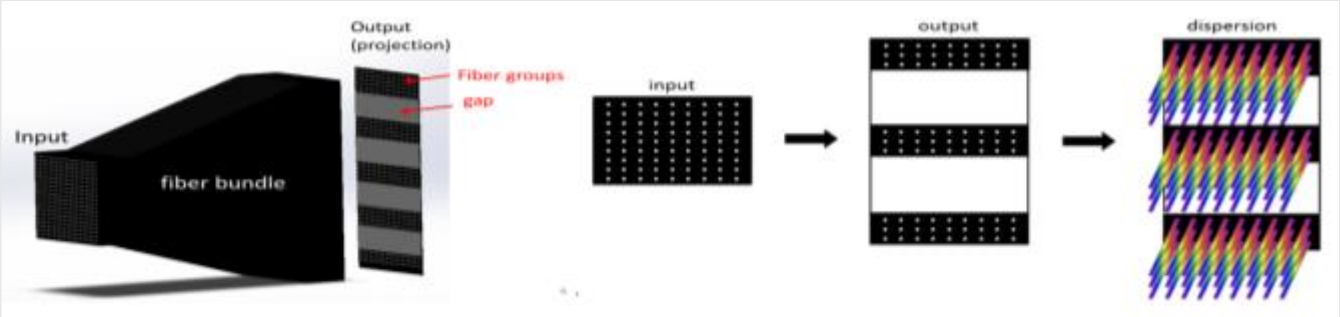
[1] Department of Bioengineering, Rice University 6100 Main Street, Houston, Texas 77005, tkaczyk@rice.edu.
[2] Department of Physics and Astronomy, Rice University 6100 Main Street, Houston, Texas 77005, dalex@rice.edu.
[3] NSSTC, NASA Marshall Space Flight Center, 320 Sparkman Dr., Huntsville, AL 35805. jluvall@nasa.gov
[4] USRA STI, 320 Sparkman Dr., Huntsville, AL 35805 @protonmail.com

Instrument Function Statement and Gateway Usage

STATEMENT	INSTRUMENT/CONCEPT DETAILS

FUNCTION STATEMENT

A tunable light-guide image processing snapshot spectrometer (TuLIPSS) for hyperspectral Earth Science Research and Observation - TuLIPSS will be capable of acquiring instantaneous images across the visible and near-IR, within a flexible spatial/spectral resolution trade space. Can be applied to Earth and Lunar Observation (EO and LO).



TuLIPSS is being developed through a NASA ESTO Instrument Incubator Program NNH16ZDA001N-IIP

WHY IS THE GATEWAY THE OPTIMAL FACILITY FOR THIS INSTRUMENT/RESEARCH?

The Gateway's primary advantages include "

- "whole earth" monitoring (lightning distribution and spectrum, atmospheric chemistry),
- hyperspectral lunar surface remote sensing (Lunar Impact Flash Monitoring, Exosphere Evolution – K, Na; surface mineral and water mapping),
- test platform for high capability, multi-functional, low resource instrument for Mars (both using external and internal platforms – allows changing applications in single instrument, station safety and performance – outgassing, plume etc. and crew health monitoring).

- Single instrument capable of multiple applications utilizing external platform for EO and LO and internal for monitoring crew health
- Tunability allows lower data content as it optimizes spectral-spatial acquisition for specific applications
  - tunable adjustment of spatial and spectral resolution, and flexible selection of target wavelengths and band passes (spatial dimensions at this point 100x100 through 400x400 while spectral sampling varies between 30 and 250)
- Improvement of quality of data / extending dynamic range through snapshot imaging of overlapping scenes and adjusting sensitivity of ROIs on FPA
  - processing of overlapping regions obtained in snapshot
  - adjustment of dynamic range within ROI
- Spectral coverage for 400nm – 1700nm

Basic Instrument Parameters

PARAMETER	INSTRUMENT ESTIMATE & ANY COMMENTS
MASS (KG)	Depends on implementation: for limited tuning hardware < 5 kg; for complete tuning functionality and dual spectral detection < 15kg
VOLUME (M)	Depends on implementation: for limited tuning hardware < 6U; for complete tuning functionality and dual spectral detection < 20U
POWER (W)	TBD
THERMAL REQUIREMENTS	TBD
DAILY DATA VOLUME	Application dependent. Current design provides cube in size of 10,000,000 values of 12bit data. The system is capable of acquiring up to 100 data-cubes / sec (this is though a capability rather than requirement)
CURRENT TRL	In transition from 3 to 4
WAG COST & BASIS	TBD – depending on tunability level, cost is currently driven by FPAs and tuning control
DURATION OF EXPERIMENT	The system is a snapshot modality enabling range of applications – duration will be application dependent
OTHER PARAMETERS	

Instrument Gateway Usage

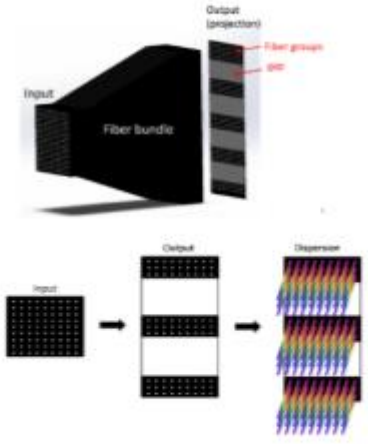
USAGE	INSTRUMENT REQUIREMENTS & COMMENTS
ORBIT CONSIDERATIONS	Application dependent
FIELD OF VIEW REQUIREMENTS	Application dependent
REQUIRES USE OF AIRLOCK	Application dependent
CREW INTERACTION REQUIRED?	Possible for in-station tests, not required. In case of crew health monitoring interaction will be necessary.
WILL ASTRONAUT PRESENCE BE DISRUPTIVE?	No
DOES THE INSTRUMENT PRESENT A RISK TO THE CREW	No
OTHER CONSUMABLES REQUIRED	NA
SPECIAL SAMPLE HANDLING REQUIREMENTS	NA
NEED FOR TELEROBOTICS?	The instrument will have internal tuning capability
OTHER REQUIREMNTS OF THE GATEWAY?	NA

References and Status of Work in this Field

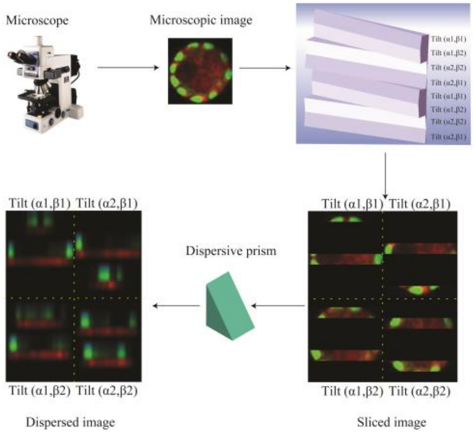
- **Christian, Hugh J, Richard J Blakeslee, and Steven J Goodman. 1989. “The Detection of Lightning From Geostationary Orbit.” Journal of Geophysical Research-Atmospheres 94 (D11): 13329–37.**
- **Salanave, L E, R E Orville, and C N Richards. 1962. “Slitless Spectra of Lightning in the Region From 3850 to 6900 Angstroms.” Journal of Geophysical Research-Atmospheres 67 (5): 1877–84.**
- **Suggs, Robert M, William J Cooke, Ronnie J Suggs, Wesley R Swift, and Nicholas Hollon. 2007. “The NASA Lunar Impact Monitoring Program.” Earth, Moon, and Planets 102 (1-4). Springer Netherlands: 293–98.**
- **Weidman, C, A Boye, and L Crowell. 1989. “Lightning Spectra in the 850- to 1400-Nm Near-Infrared Region.” Journal of Geophysical Research-Atmospheres 94 (D11).**
- **Whitley, R, R Martinez Aerospace Conference, 2016 IEEE, 2016. n.d. “Options for Staging Orbits in Cislunar Space.” Ieeexplore.Ieee.org**
- **Ortiz, Joseph D, Dulcinea Avouris, Stephen Schiller, Jeffrey C Luvall, John D Lekki, Roger P Tokars, Robert C Anderson, Robert Shuchman, Michael Sayers, and Richard Becker. 2017. “Intercomparison of Approaches to the Empirical Line Method for Vicarious Hyperspectral Reflectance Calibration.” *Frontiers in Marine Science* 4 (September): 1–21.**
- **Turpie, K et al. 2016. Global Observations of Coastal and Inland Aquatic Habitats. Response to Decadal Survey request for information #2. http://sites.nationalacademies.org/DEPS/esas2017/DEPS_170397**
- **Kameda, S., Ikezawa, S., Sato, M., Kuwabara, M., Osada, N., Murakami, G., Fujimoto, M. (2017). Ecliptic north-south symmetry of hydrogen geocorona. Geophysical Research Letters, 44, 11,706–11,712. https://doi.org/10.1002/2017GL075915**
- **Kagitani, M, M Taguchi, A Yamazaki, I Yoshikawa, G Murakami, K Yoshioka, S Kameda, and S Okano. 2010. “Variation in Lunar Sodium Exosphere Measured From Lunar Orbiter SELENE (Kaguya).” Planetary and Space Science 58 (12). Elsevier: 1660–64. doi:10.1016/j.pss.2010.07.025.**
- **Materials outgassing https://outgassing.nasa.gov**
- **NASA's Long Duration Exposure Facility, or LDEF. https://curator.jsc.nasa.gov/mic/ldef/index.cfm**
- **Hudson, M Keith, Robert B Shanks, Dallas H Snider, Diana M Lindquist, Chris Luchini, and Sterling Rooke. 1998. “UV, Visible, and Infrared Spectral Emissions in Hybrid Rocket Plumes.” International Journal of Turbo and Jet Engines 15 (1): 71–87.**

Snapshot Multi / Hyperspectral Systems based on Image Re-organization

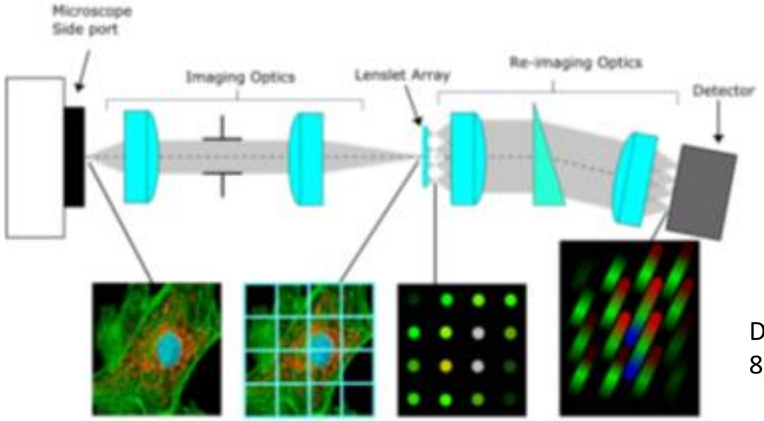
- Ye Wang et al, OPTICAL ENGINEERING, Volume: 56 Issue: 8. AUG 2017
- Biomed. Opt. Express 8, 1950-1964 (2017)
- Opt. Express 21, 13758-13772 (2013)
- Biomed. Opt. Express 4, 938-949 (2013)
- Journal of Cell Science, JOCES/2012/108258
- Journal of Biomedical Optics Letters, August 2012 • Vol. 17(8), p.080508-1
- Optical Engineering 51(11), (November 2012)
- Optical Engineering 51(4), 043203 (April 2012)
- JOURNAL OF MICROSCOPY Volume: 246 Issue: 2 Pages: 113-123, MAY 2012
- Biomed. Opt. Express 3, 48-54 (2012)
- Opt. Express 19, 17439-17452 (2011)
- Journal of Biomedical Optics, 16(05), 056005, May 2011
- Opt. Express 18, 14330-14344 (2010)
- Appl. Opt. 49, 1886-1899 (2010)
- Opt. Express 17, 12293-12308 (2009)



Ye Wang et al, OPTICAL ENGINEERING, Volume: 56 Issue: 8. AUG 2017

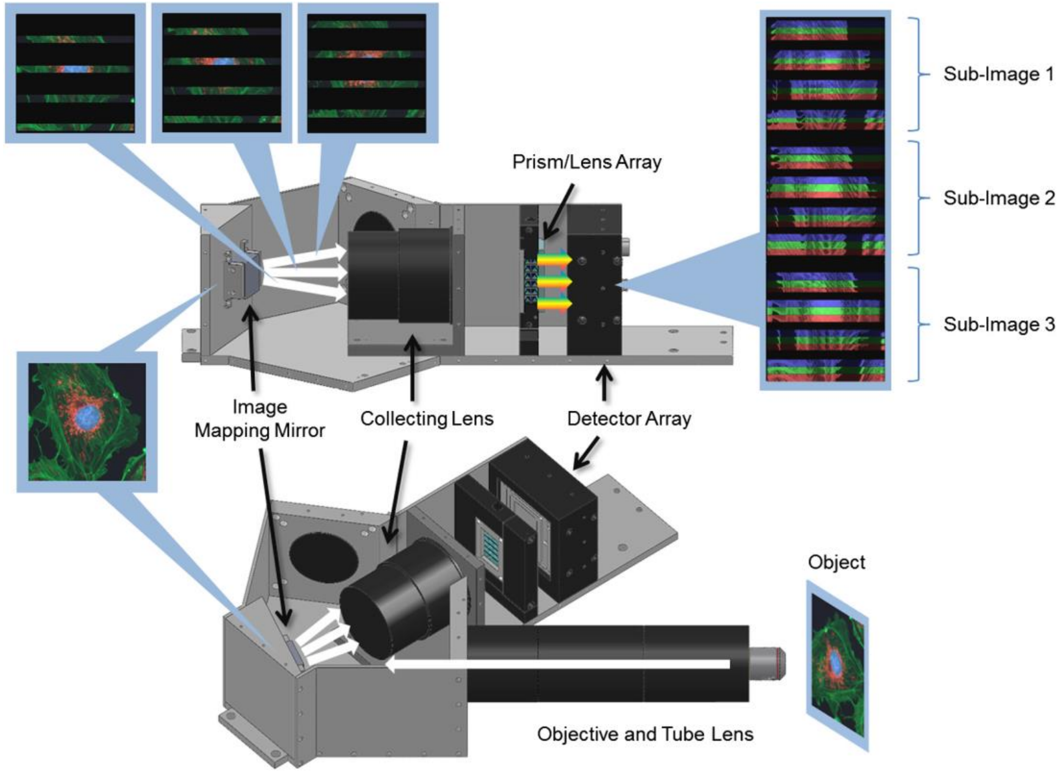


Liang Gao at al 20 July 2009 / Vol. 17, No. 15 / OPTICS EXPRESS

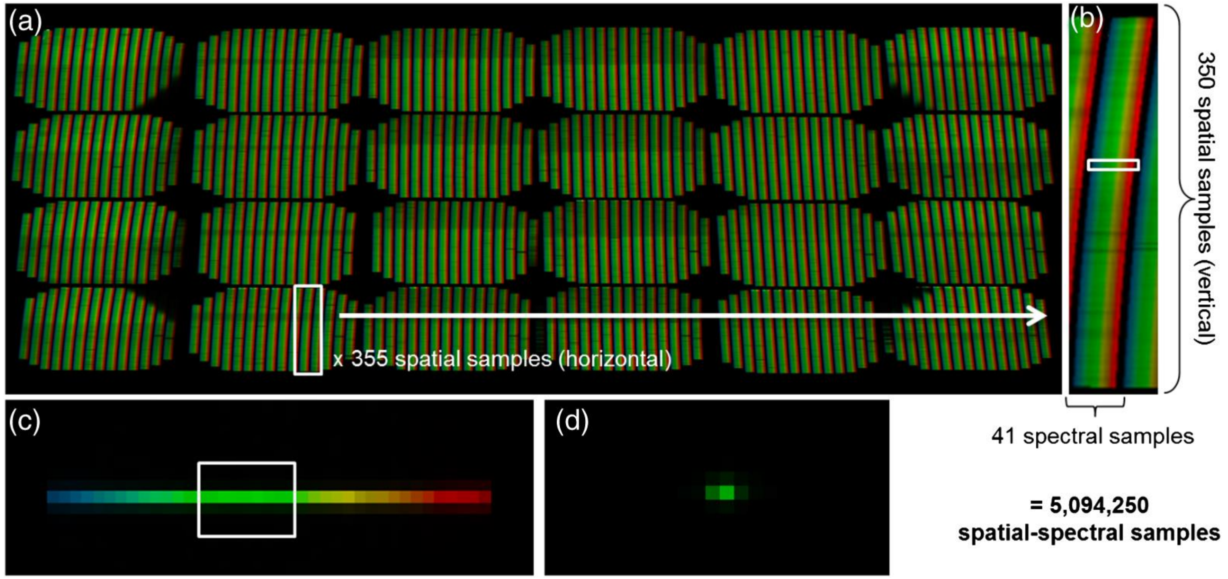


Dwight et al Biomed. Opt. Express 8, 1950-1964 (2017)

Mirror Based – compact image slicing/mapping system



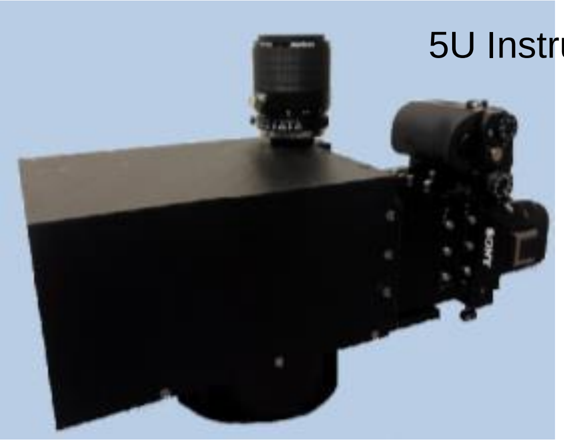
Bedard et al, Opt. Eng. Nov 2012



Bedard et al, Opt. Eng. Nov 2012

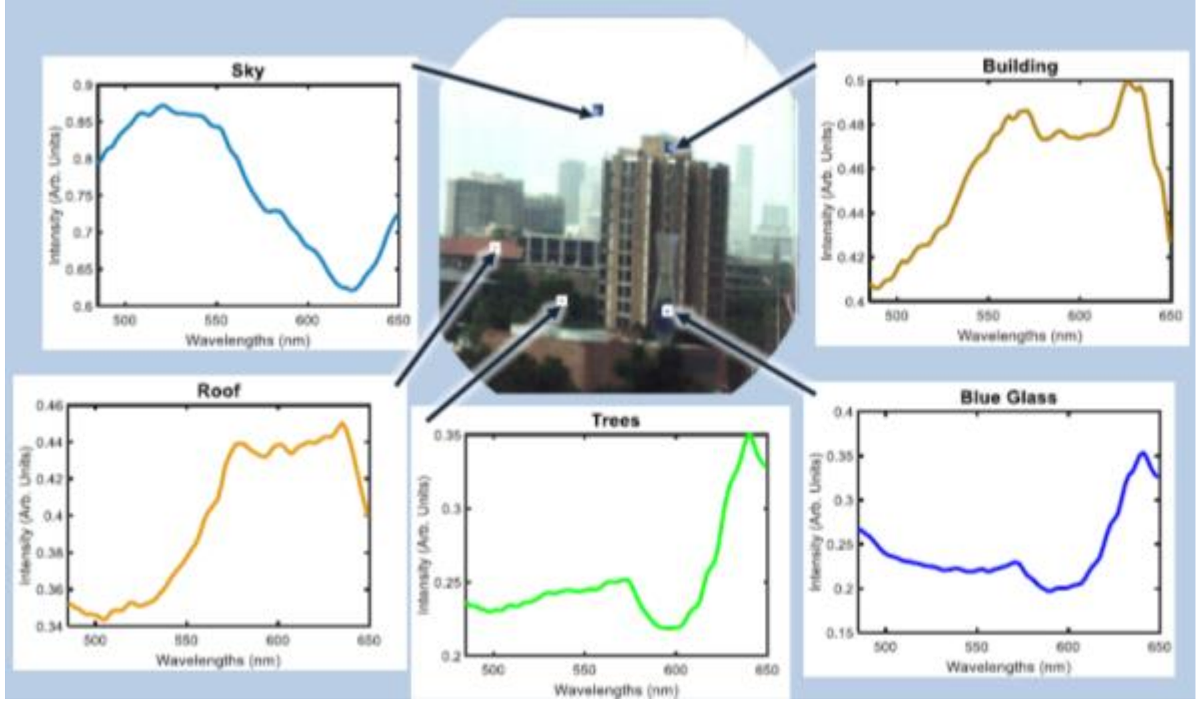
Mirror Based – compact image slicing/mapping system – cont.

5U Instrument



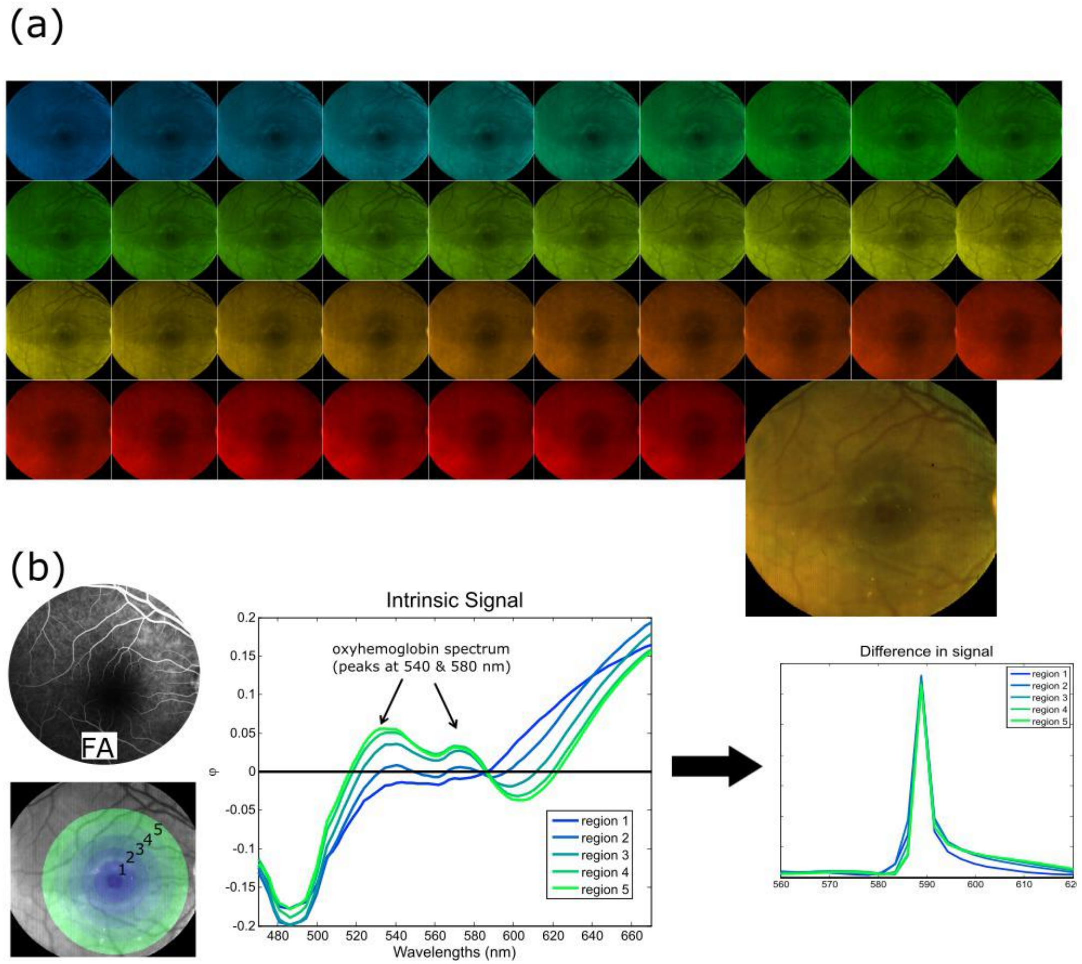
J.Dwight et. al, poster presentation at Hyspiri Workshop, Caltech, October 2017

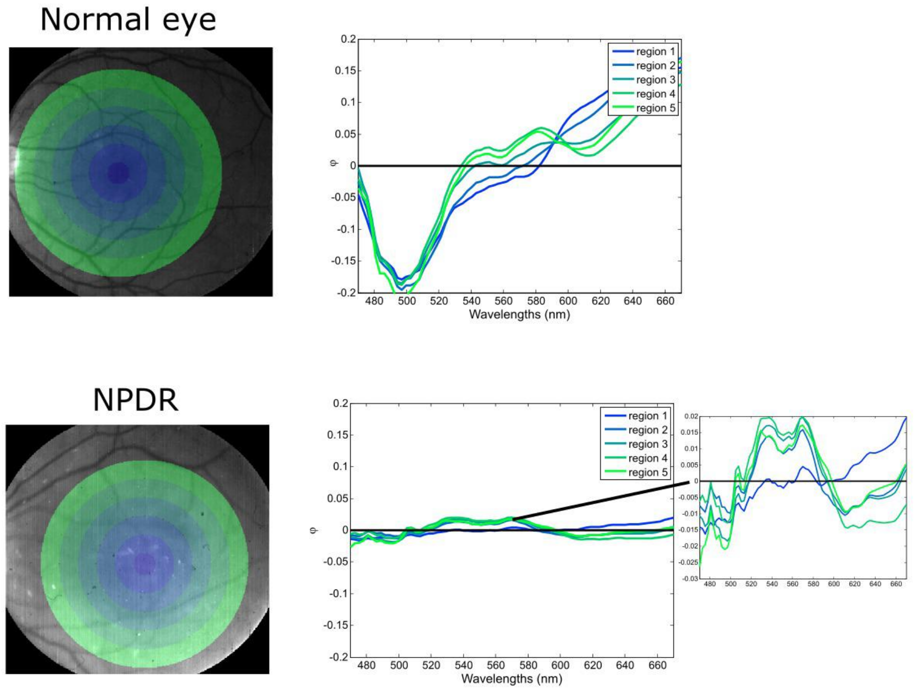
- A cost effective platform for environmental sensing applications that include monitoring water quality, land use, air pollution, vegetation and agriculture.
- Small size, power, and weight of payloads allows for a wider range of applications, incorporation of additional instrumentation or the augmentation of flight parameters such as altitude, distance and duration.
- System demonstrates high light-throughput.
- Hyperspectral datacubes can be acquired at 1/500 sec to 1/100 sec, eliminating motion artifacts
- Applications include monitoring plant pigmentation, vegetation state, leak detection at petrochemical plants, and urban sustainability, lightning etc.



J.Dwight et. al, poster presentation at Hyspiri Workshop, Caltech, October 2017

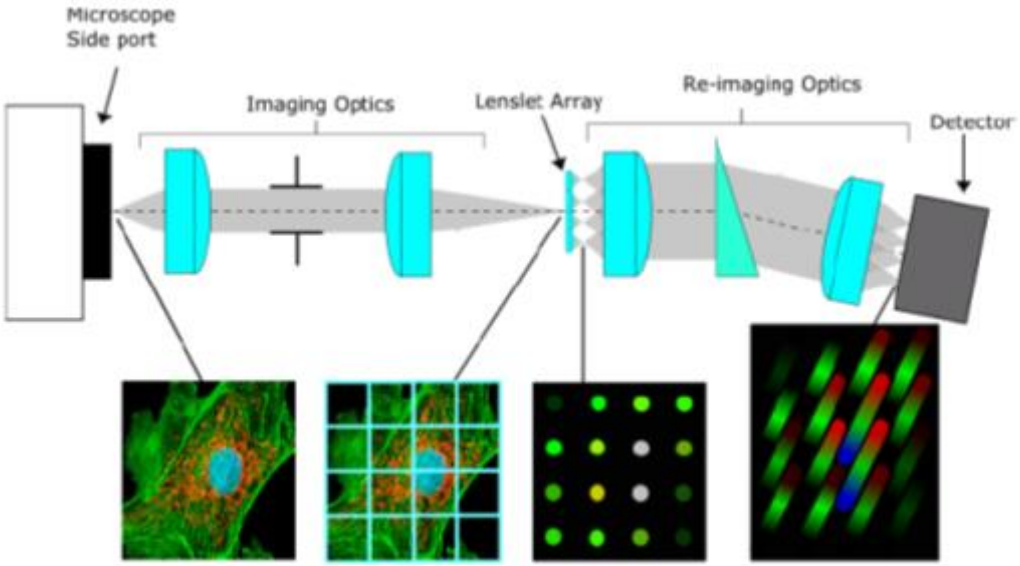
Mirror Based – compact image slicing/mapping system – cont.

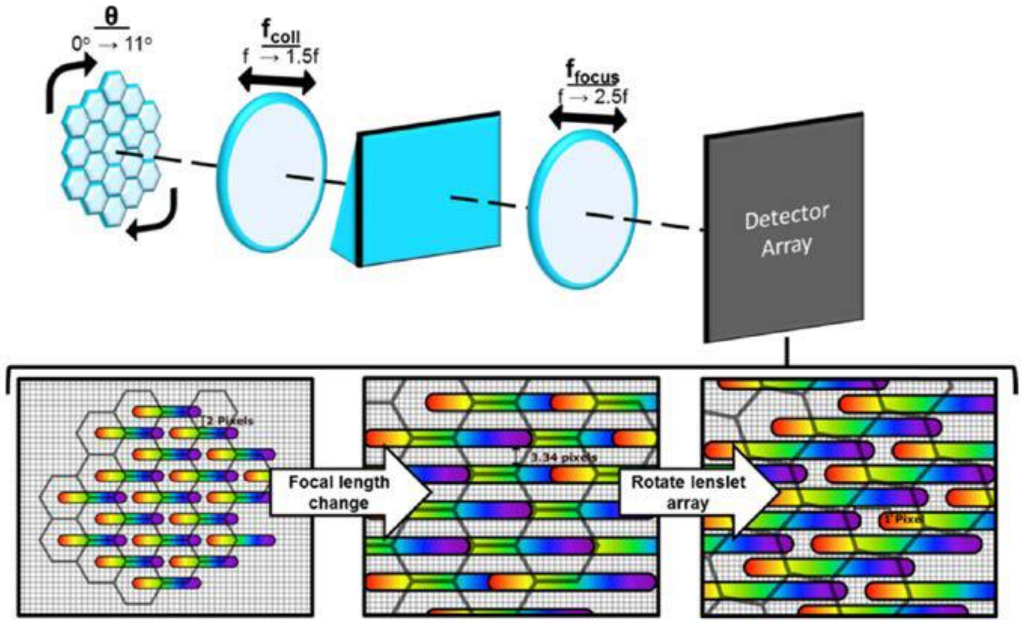


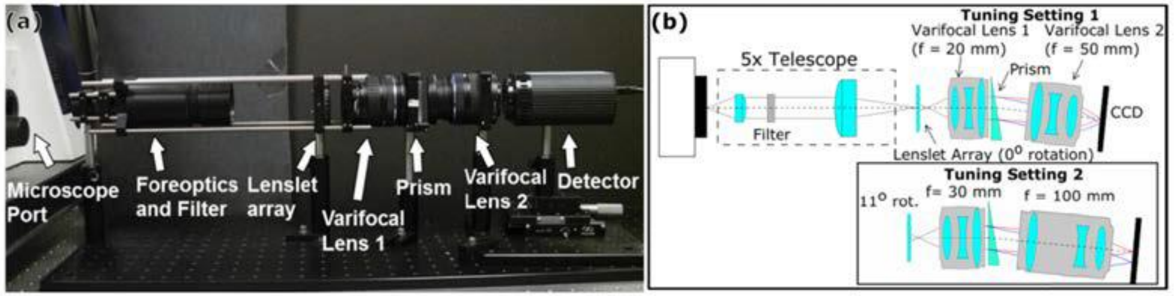


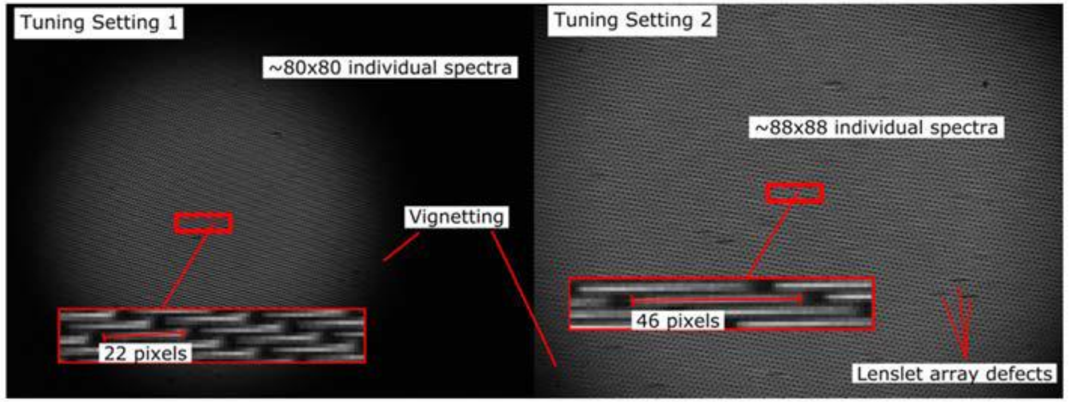
Dwight et al: Oxygen Signal Extraction from Bulk Retinal Tissue using Hyperspectral Image Mapping Spectrometry, ARVO 2017

Lenslet array tunable snapshot imaging spectrometer (LATIS)



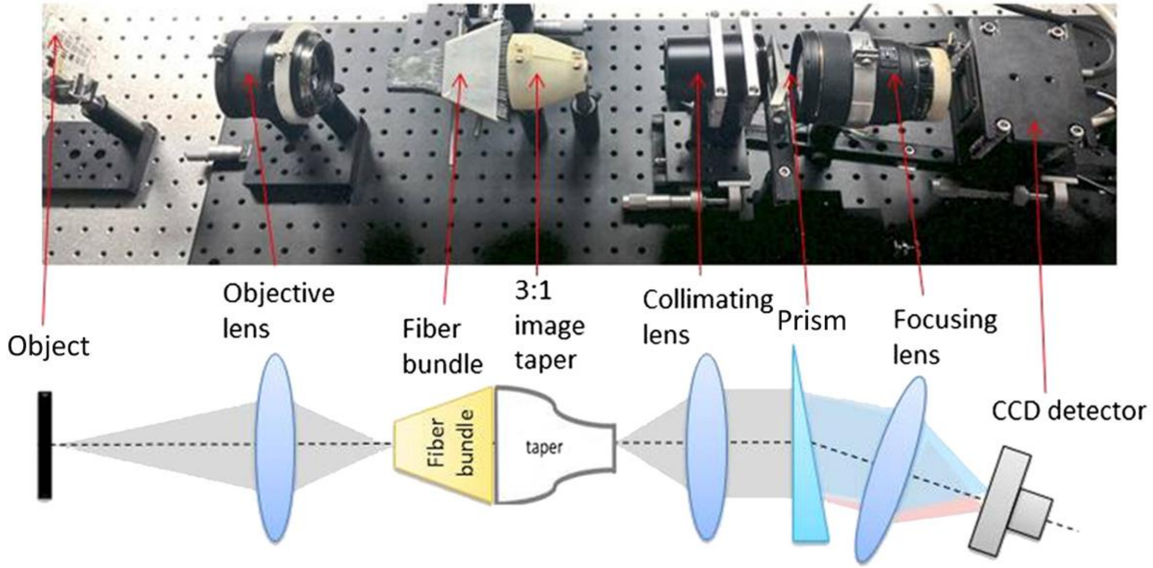


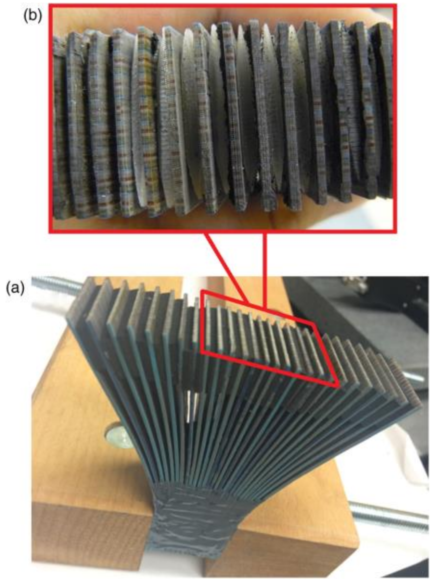


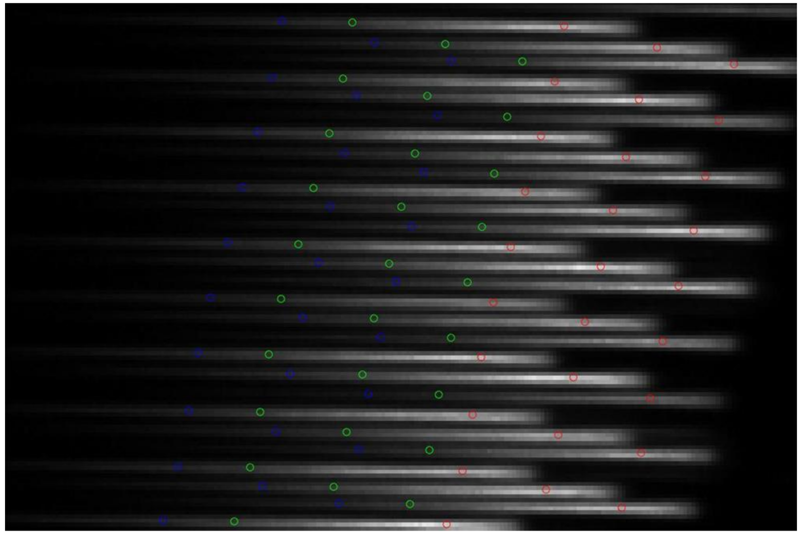


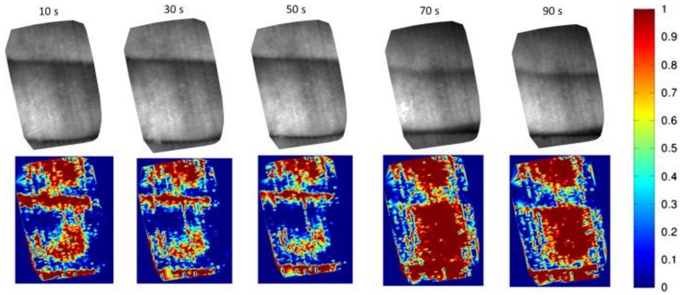
J.Dwight and T.Tkaczyk, Biomed. Opt. Express 8, 1950-1964 (2017)

Fiber based spectrometer – proof of concept









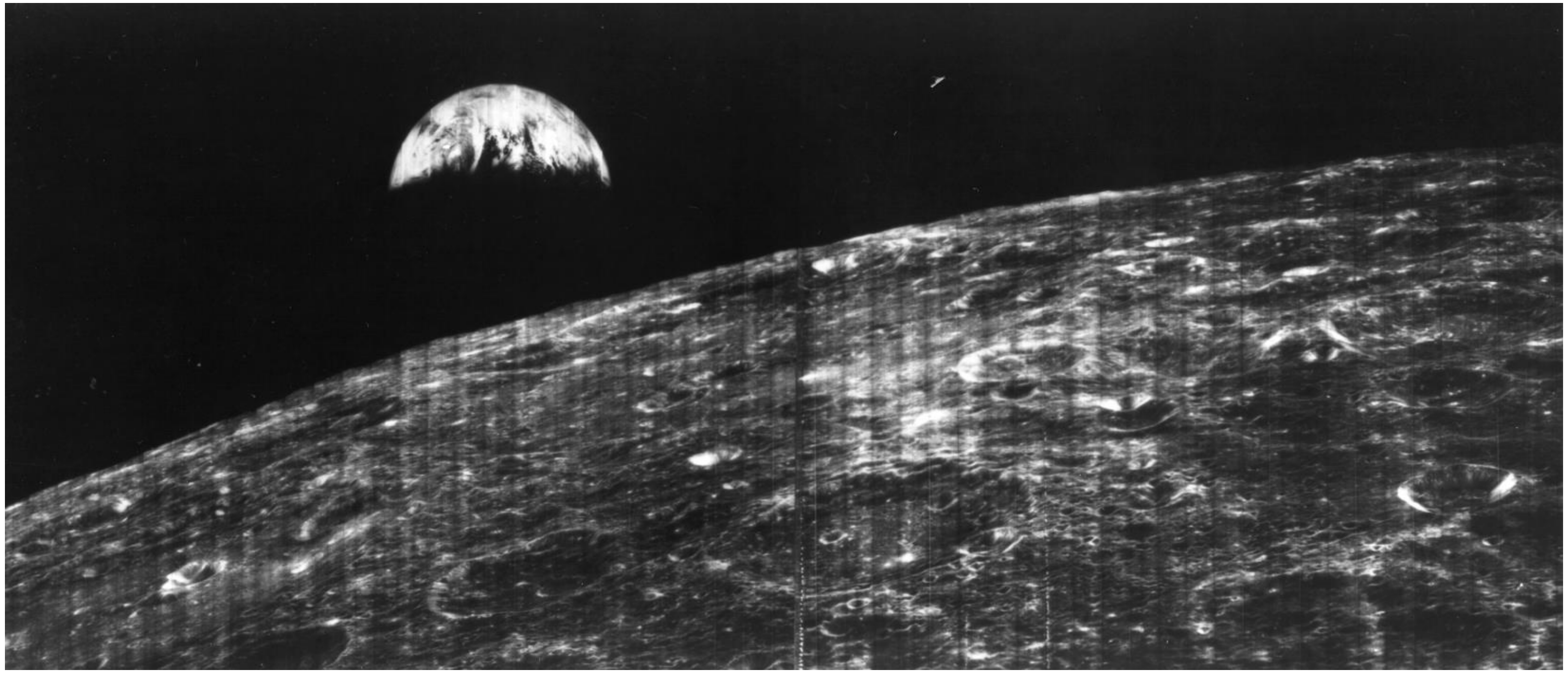
Ye Wang, Michal E. Pawlowski, **Tomasz S. Tkaczyk**, “High spatial sampling light-guide snapshot spectrometer”, OPTICAL ENGINEERING, Volume: 56 Issue: 8. AUG 2017

Current TuLIPSS Activities/Improvements

- **Decreasing bundle dimensions (below 1 inch input) – smaller individual fiber diameter (10 microns and below)**
- **Optimizing throughput – fiber NA and coupling (lenslet array)**
- **Increasing spatial sampling (targeted 400x400)**
- **Elastic tuning (1-2 second mode switching) of fiber distance**
  - Mechanical actuators
  - Magnetic
  - Pneumatic
- **Dispersion and bandwidth tuning (selection of sub-bands and spectral sampling)**
- **ROI dynamic range tuning**

First view of Earth Taken by a Spacecraft

Lunar Orbiter I, 16th orbit, Aug. 23, 1966



Deep Space Gateway

TuLIPSS Observations

- ✓ Earth
- ✓ Lunar
- ✓ Station
- ✓ Earth-Lunar

Earth Observations

Apollo 8, the first manned mission to the moon, entered lunar orbit on Christmas Eve, Dec. 24, 1968.

The image is composite made from a series of images taken by the Lunar Reconnaissance Orbiter Camera (LROC) on October 12, 2015. “Earthrise”

Near Rectilinear Orbit (NRO)
6-8 days
2,000 to 75,000 km Roughly polar
Earth ~ 10x geo distance

L1 and Distant Retrograde Orbit better suited for earth obs.

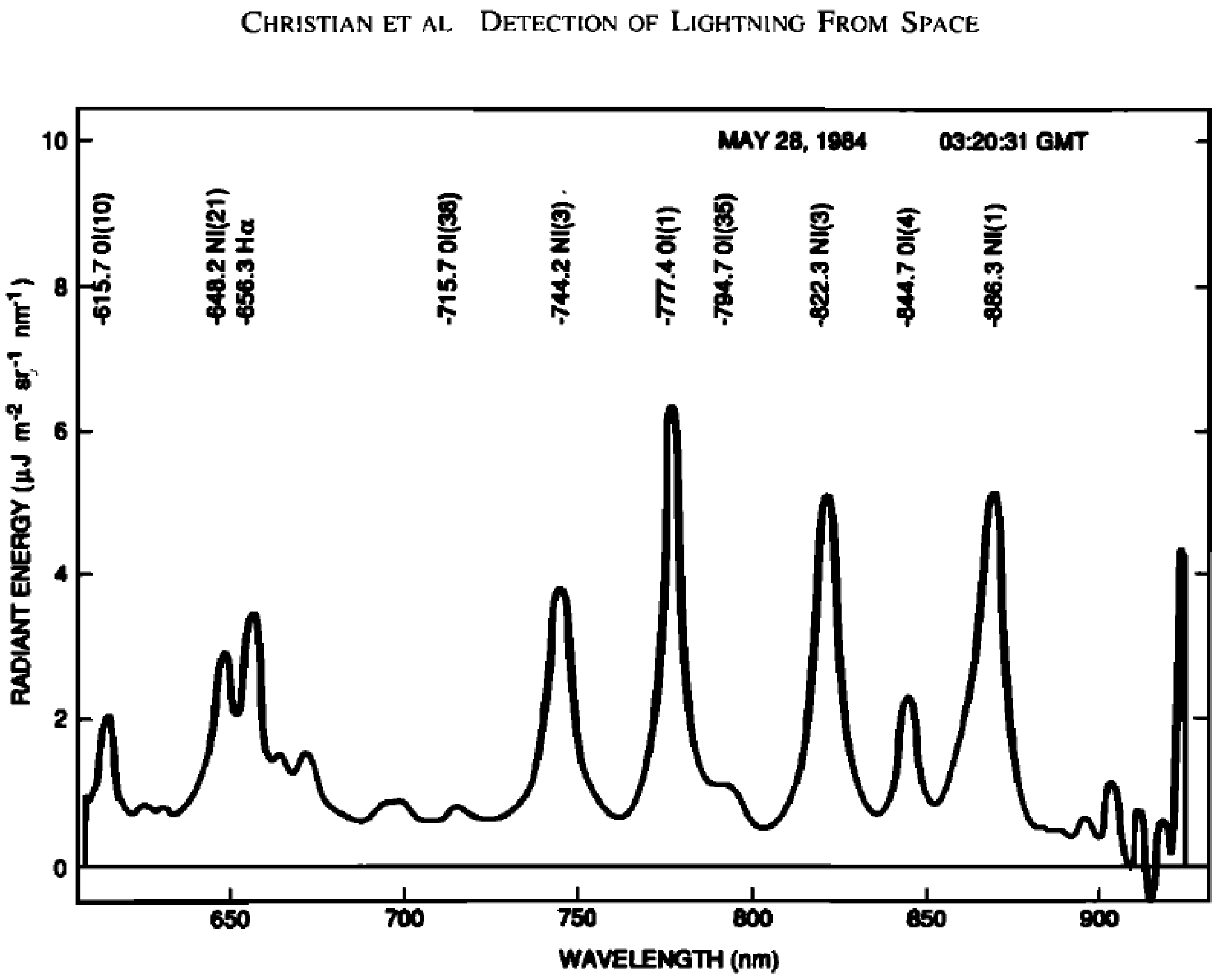
Ability to change orbits impacts types of possible observations, ie spectral, temporal & spatial domains

Whitley and Martinez 2015

Earth Observations

Lightning
Harmful Algal Blooms/Water quality
Volcanic activity
Terrestrial Ecosystems (400-2400 nm)
Agriculture
Atmospheric Chemistry/Air Quality

Earth Observations - Lightning



Lightning Observation

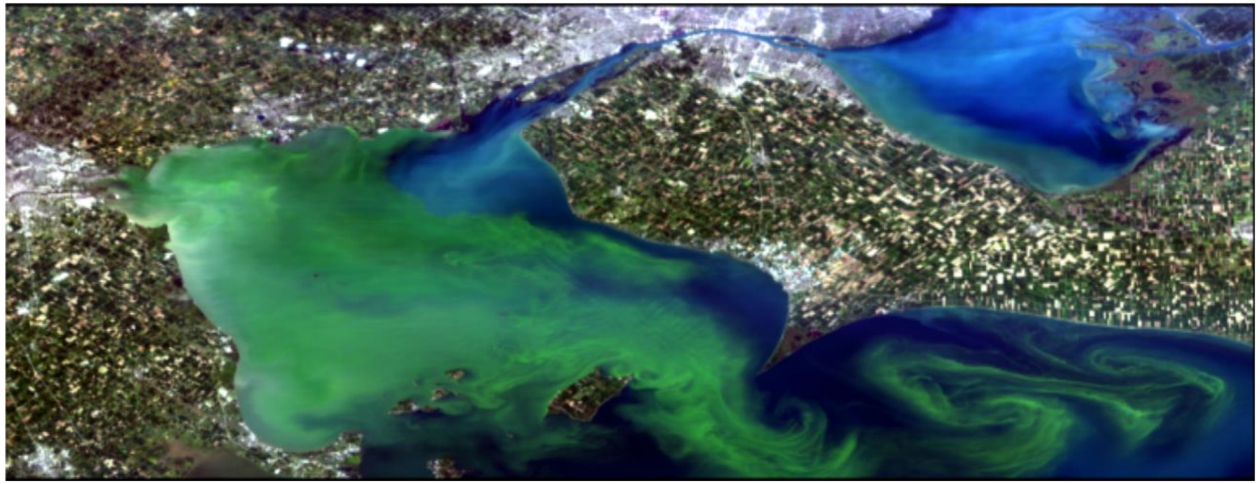
600-950 nm
Detection ~ 500 frames/sec
10 km resolution
5-10 nm Spectral bandwidth

Christian et al., 1989

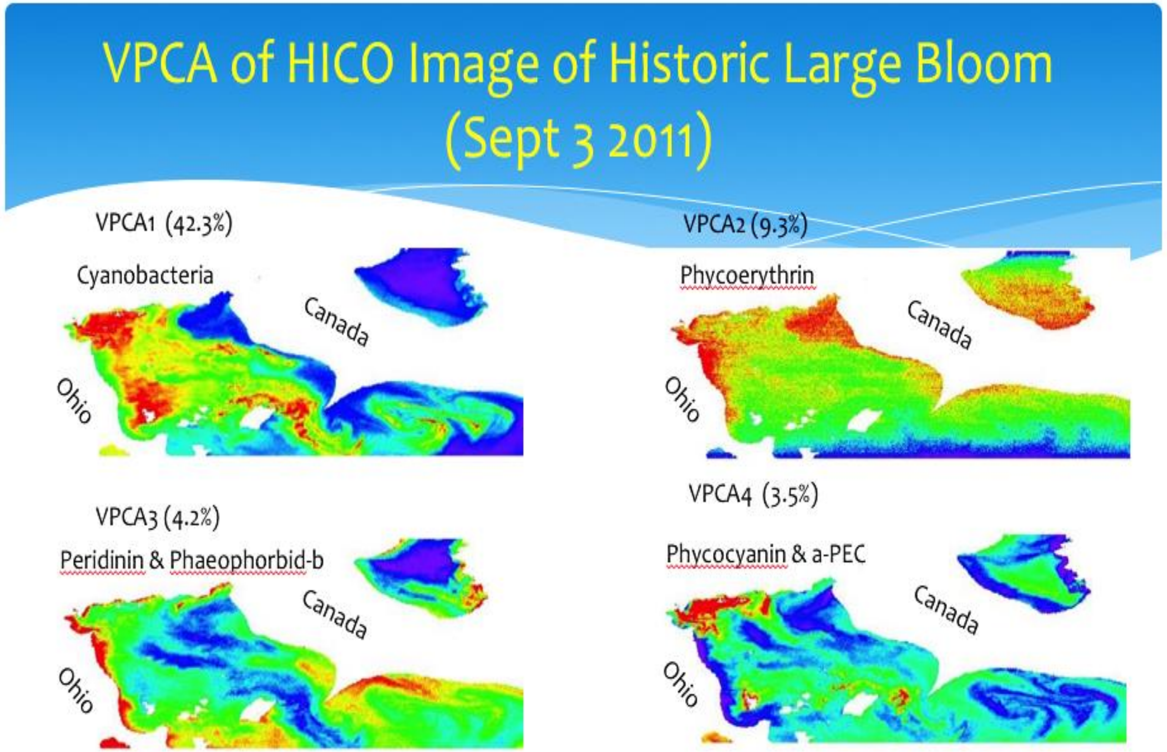
Earth Observations – Water Quality

400-700 nm
Imaged 1x per day
100m spatial resolution
5 nm bandwidth

HICO Image of Lake Erie 2nd largest bloom year



True Color (OSU, not reprojecte



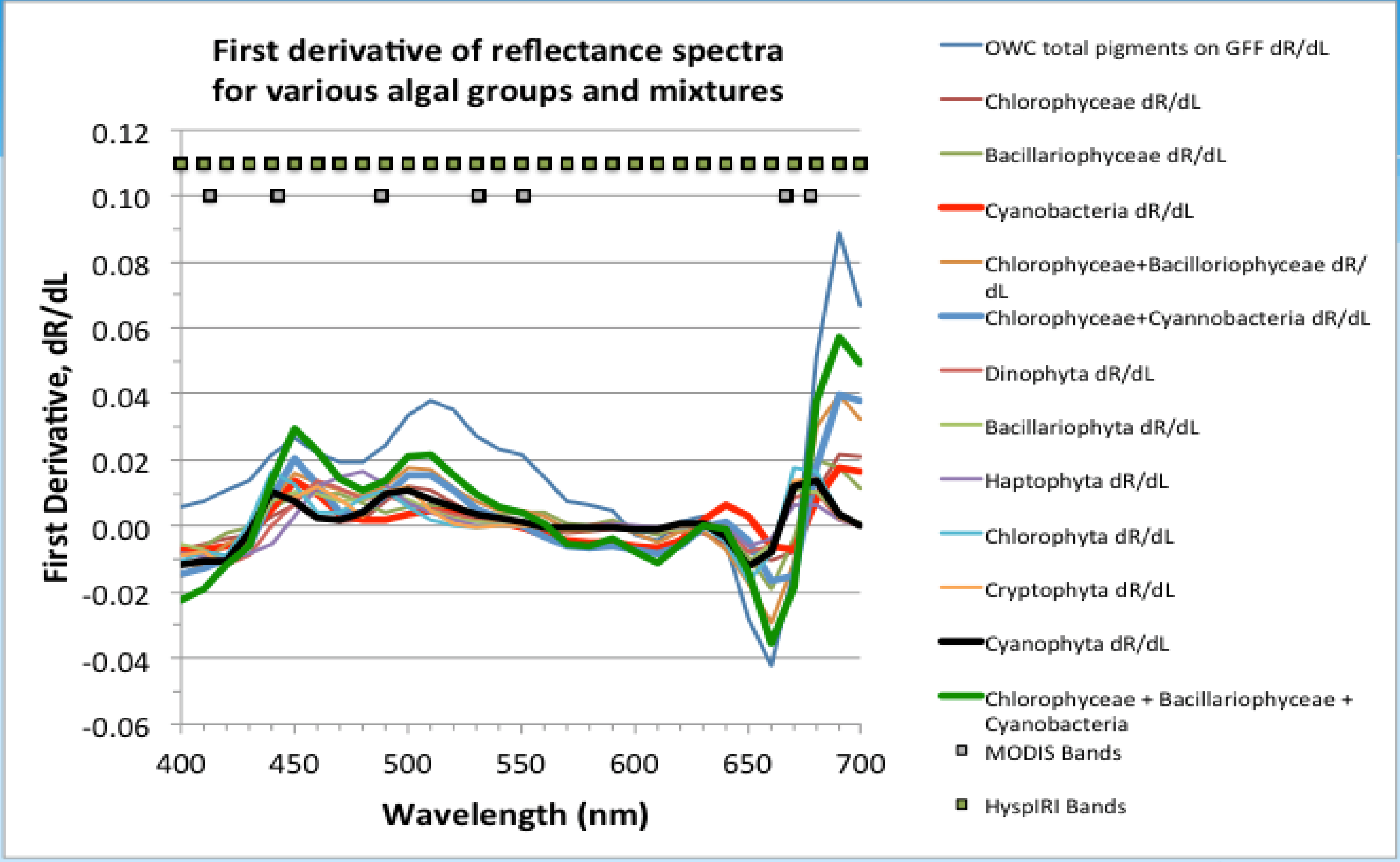
HyspIRI measurements - Designated 2017 Decadal Survey

Ortiz et al., 2017

Reflectance Spectra from Various Algal Groups

1st derivative

Provides information on different pigments and thus algal and cyanophyte composition



Ortiz et al., (HyspIRI 2015)

Lunar Observations

Lunar Impact Flash Monitoring – 400-900 nm
Continuous monitoring 10 km res ~ 5-10 nm bandwidth

Suggs et al, 2007

Surface Mineral Mapping

500-1000 nm, 900-1700 nm, 1700-2600 nm
Specific targets of interest
15 nm bandwidth
80 m Spatial Res

Lunar Exosphere Evolution
(Na & K) (SELENE)

Periodic imaging
589.3 nm, 3.5 nm BW
630 nm, 2 nm BW
Lunar Disk
Kagitani et al., 2010

This false-color image composed of 15 images taken through three color filters by NASA's Galileo spacecraft, as it passed through the Earth-Moon system on Dec. 8, 1992

On “Station”

The International Space Station, with a crew of six onboard, is seen in silhouette as it transits the moon at roughly five miles per second on Tuesday, Jan. 3

Materials Exposure Monitoring (LADEE)

230 to 1700 nm
Imaged as needed
Macro to microscopic
1 nm bandwidth
https://curator.jsc.nasa.gov/mic/ldef/index.cfm

Material Out Gassing

230 to1700 nm
Imaged as needed
Macro to microscopic
1 nm bandwidth
https://outgassing.nasa.gov

Rocket Plume Emission Analysis

400 to 1700 nm
Imaged as needed
TBD
5 nm bandwidth
Hudson et al., 1998

Earth - Lunar

Geocorona Monitoring

300 - 400 nm & 10 -121 nm
Periodic Monitoring
Earth Disk & surrounding space ~ 600,000 km
10 nm

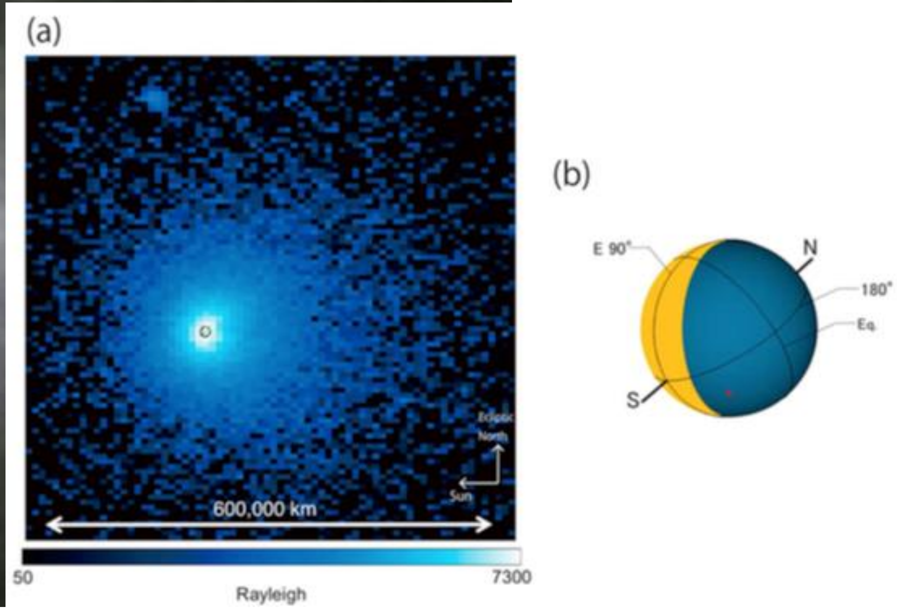


Fig. 1, Kameda et al., 2017

SUMMARY on TuLIPSS for Gateway usage and benefits

System main features

- **Snapshot operation**
- **Capable of multiple applications for external platform for EO and IO and internal for monitoring crew health**
- **Tunability to lower data content – system optimizes spectral-spatial acquisition for specific applications**
- **Improvement of quality of data / extending dynamic range through snapshot imaging of overlapping scenes and adjusting sensitivity of ROIs on FPA**
- **Spectral coverage for 400nm – 1700nm and its subsets**

TuLIPSS in context of Gateway

- **“whole earth" monitoring (lightning distribution and spectrum, atmospheric chemistry),**
- **hyperspectral lunar surface remote sensing**
- **test platform for high capability, multi-functional, low resource instrument for Mars (both using external and internal platforms – allows changing applications in single instrument, station safety and performance – outgassing, plume etc. and crew health monitoring).**

Additional Information

Acknowledgment:

Tunable Light-guide Image Processing Snapshot Spectrometer - TuLIPSS system is being developed through a **NASA ESTO Instrument Incubator Program NNH16ZDA001N-IIP** at Rice University (Tkaczyk, PI; Alexander Science-PI) with support of Marshall Space Flight Center and USRA