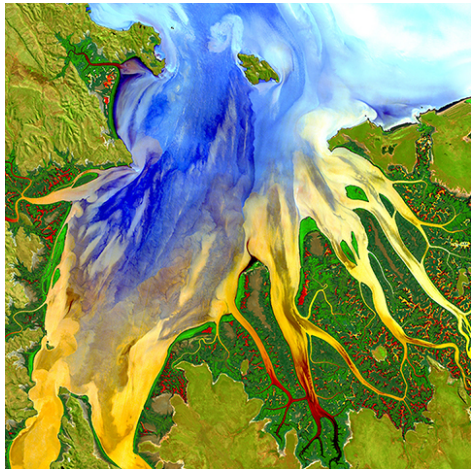
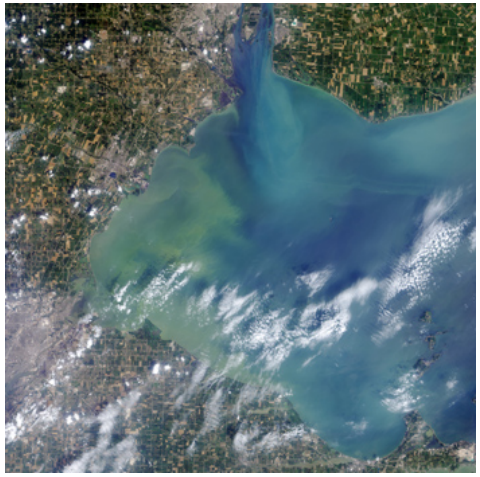




# CHPS: The Compact Hyperspectral Prism Spectrometer for Sustainable Land Imaging

Tom Kampe, Nathan Leisso
Ball Aerospace & Technologies

**S4P3**
Earth Science Technology Forum 2019
June 11, 2019

# Sustainable Land Imaging Program

***Sustainable Land Imaging-Technology Program***

- *Reduce the risk, cost, size, volume, mass, and development time for the next generation **Sustainable Land Imaging (SLI)** instruments while meeting or exceeding the current **Landsat** land imaging capabilities;*
- *Improve temporal, spatial, and spectral resolution of SLI measurements; and*
- *Enable new SLI measurements that can improve operational efficiency and reduce overall costs*
- ***Maintain continuity with heritage Landsat instrument to continue 40+ year data series***

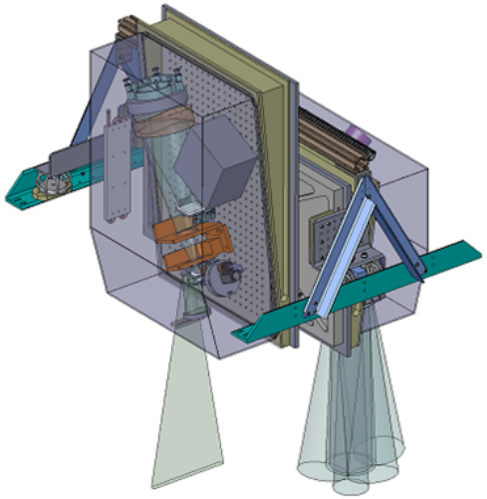
Ball Aerospace

OLI & OLI-2 developed by Ball

Ball Aerospace

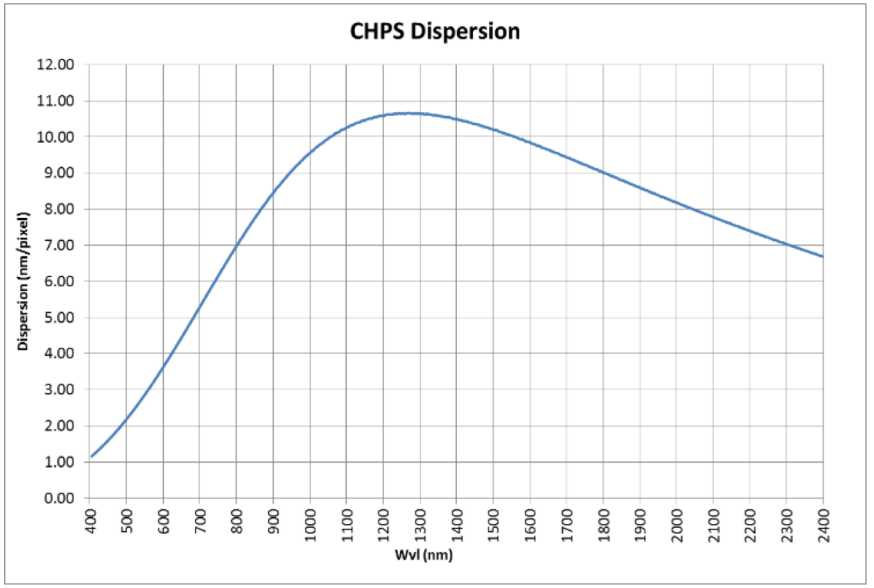
# SLI-T Compact Hyperspectral Prism Spectrometer (CHPS)

- Airborne instrument developed to demonstrate technology for potential insertion in spaceborne mission
- Prism-based pushbroom spectrometer
- Continuous VSWIR Spectral coverage (400-nm to 2500-nm)
- Maintain data continuity with heritage SLI bands of legacy Landsat instruments while enabling additional science from spectroscopic data



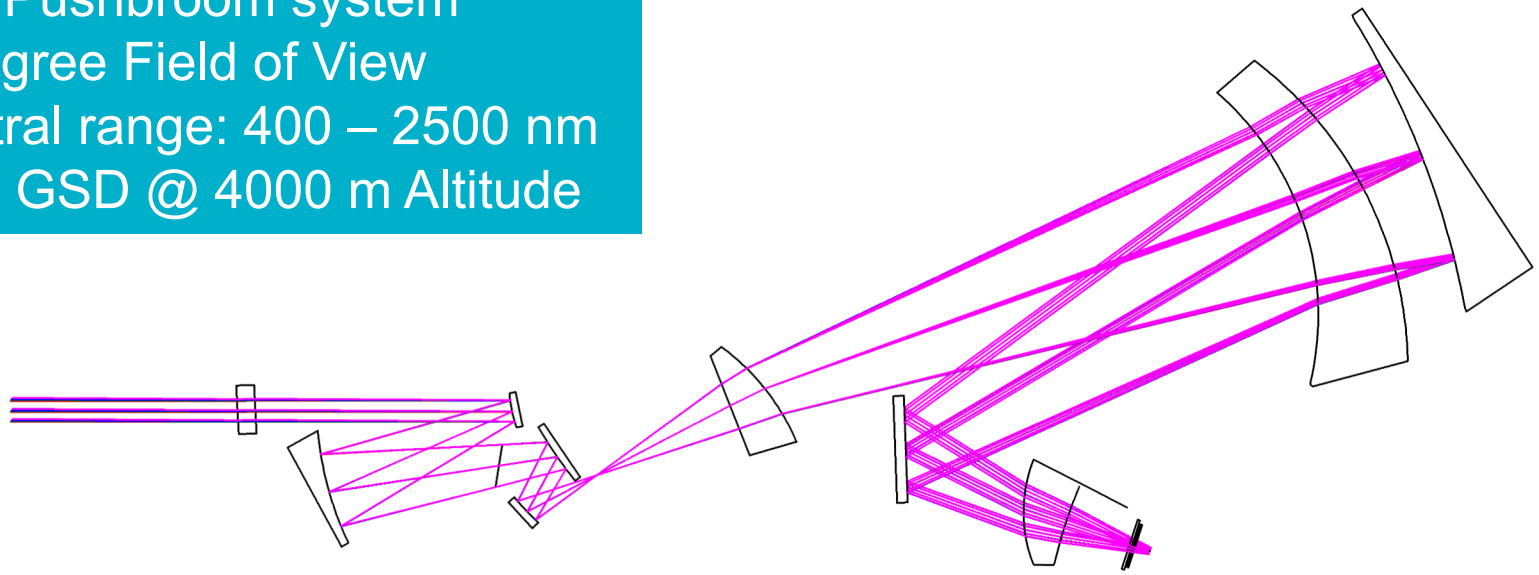
# SLI-T Compact Hyperspectral Prism Spectrometer (CHPS)

- **Continuous high spectral resolution from 400 to 2500 nm provides spectroscopic information to support wide range of emerging land science products:**
  - *Plant functional types and distribution*
  - *Intelligent agriculture (crop selection, water use practices, drought mitigation, etc.)*
  - *Ecological disturbances (invasive species, wild fires, forest thinning and dieback, insect infestation, etc.)*
  - *Near-shore Coastal Water Science (chlorophyll concentrations, algae blooms, water pollution)*



# Airborne CHPS Optical Subsystem

- F/3.0 Pushbroom system
- 20 degree Field of View
- Spectral range: 400 – 2500 nm
- 2.5 m GSD @ 4000 m Altitude

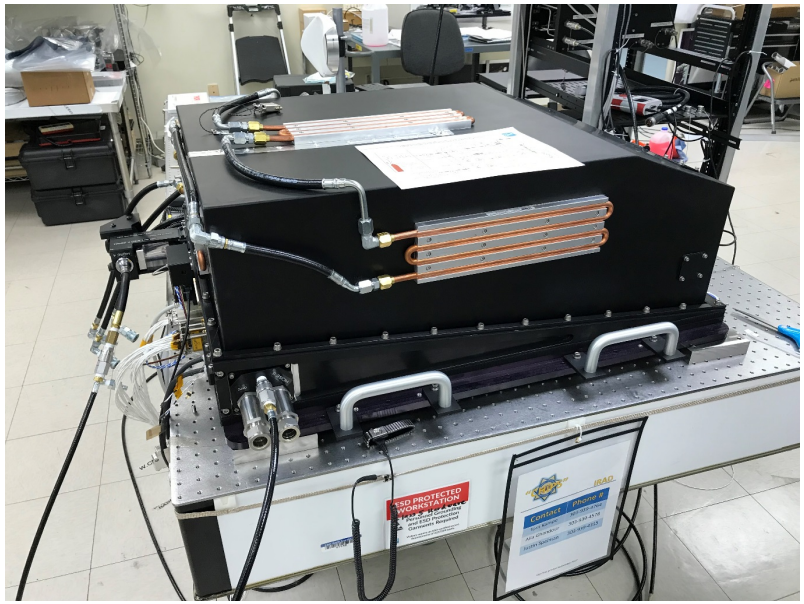


- 4-Mirror Telescope coupled with prism spectrometer
- Fused Silica refractive elements
- Protected silver coated mirrors
- Each major optical subsystem assembled and tested independently and then brought together to form full system

# CHPS offers advantages for SLI

- ***Small Size/Cost:*** Compact form factor utilizing dual purpose optical elements for efficient space-saving design
- ***Low stray-light:*** prism-based design eliminating multiple orders and scattering common in grating based instruments
- ***High SNR:*** capability for spectral binning to match Landsat bands while also providing additional bands
- ***Low polarization:*** increased utility for inland and coastal water studies

# Current CHPS Hardware Status

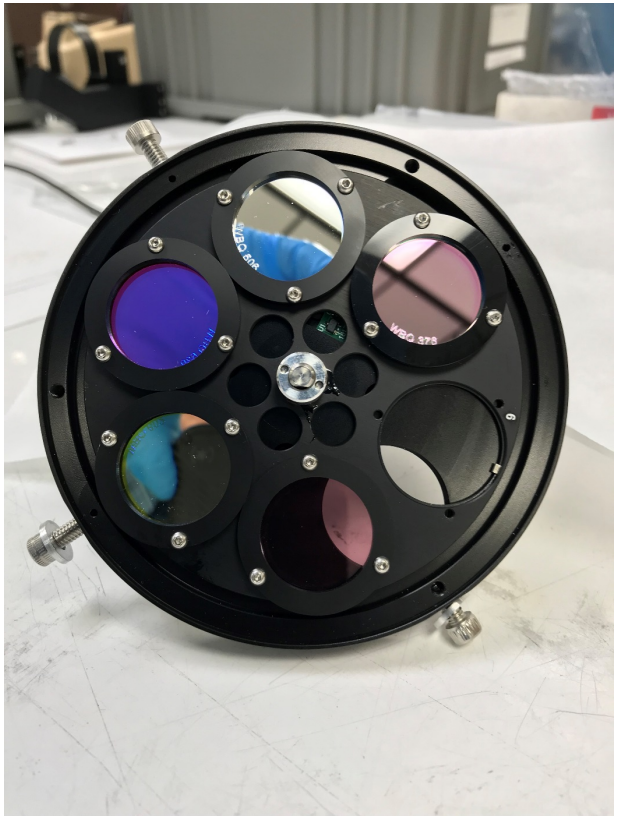


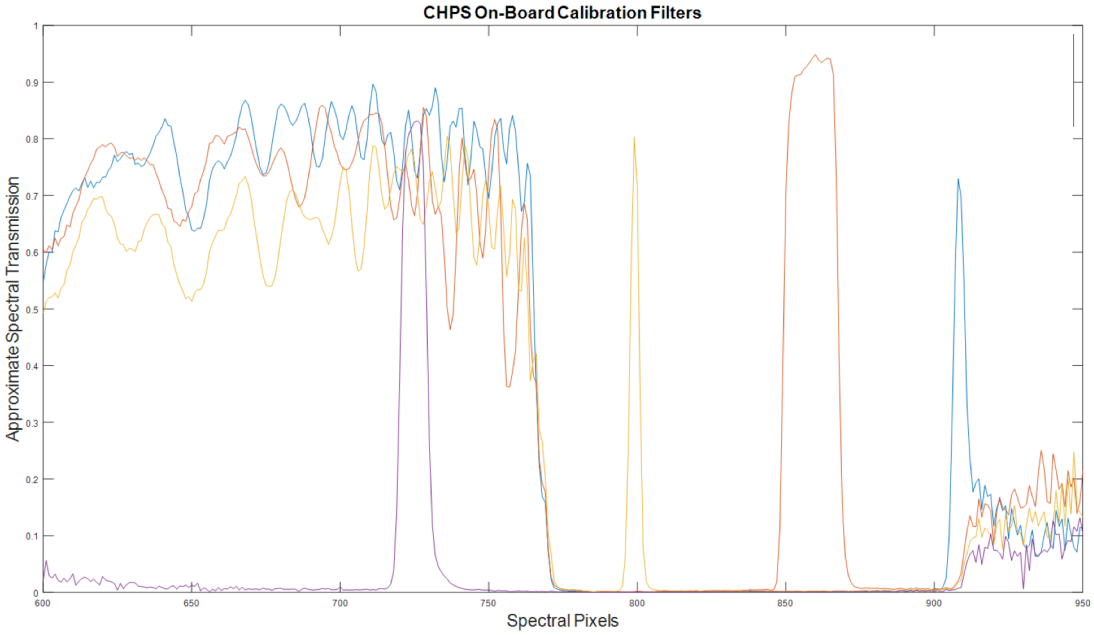
Integrated CHPS Sensor

CHPS and REMI Integrated on Flight Mount

# CHPS On Board Calibration Sequence

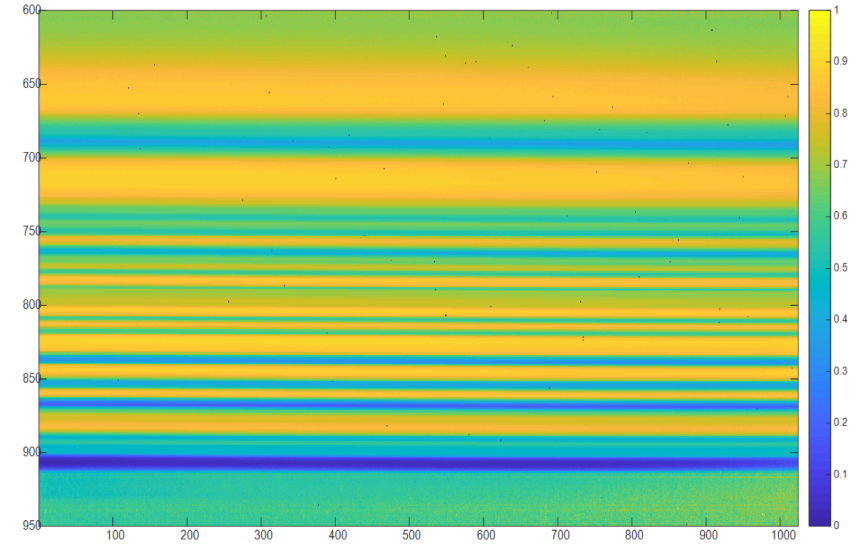
- CHPS performance during flight is monitored using:
  - Broad-band Source
  - Shutter for dark collects
  - OLI filters
  - NIST 2035b Wavelength standard
- Calibration collects conducted for each flight line for sensor trending

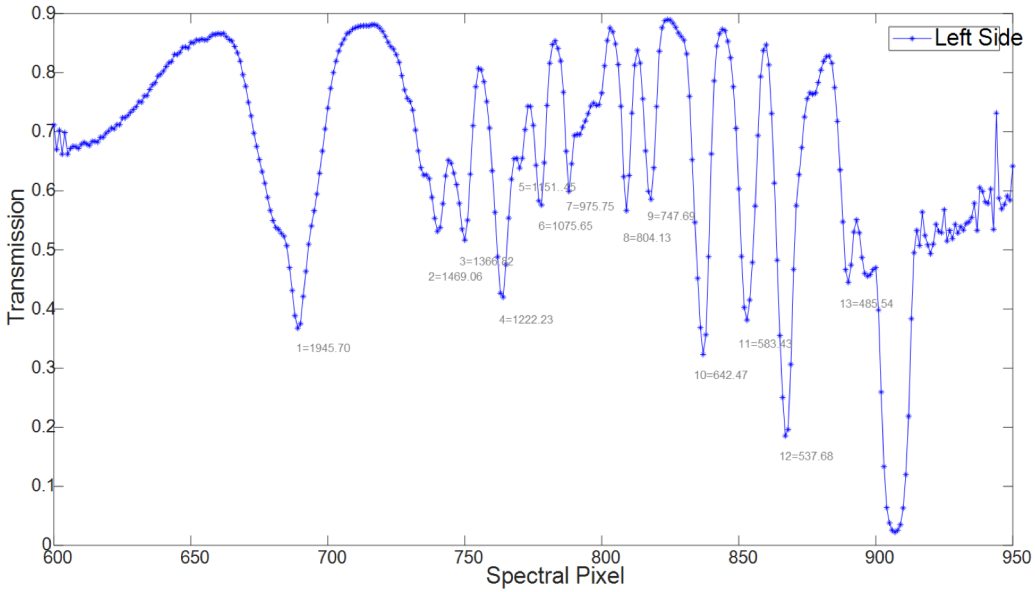




# Spectral Calibration of CHPS

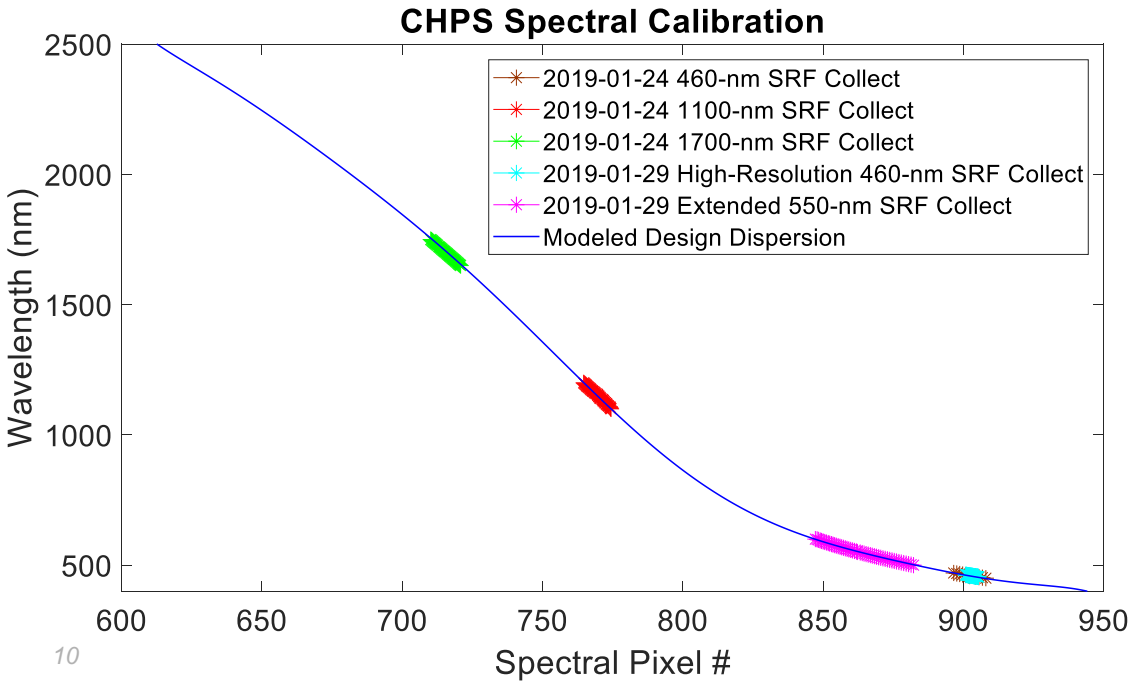
- NIST 2035b Wavelength Standard included in On-Board Calibration system
- Utilized to verify CHPS Spectral calibration for every collect

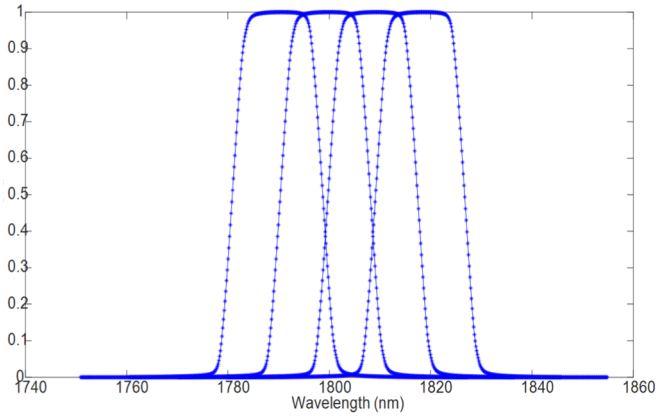



# Spectral Calibration of CHPS

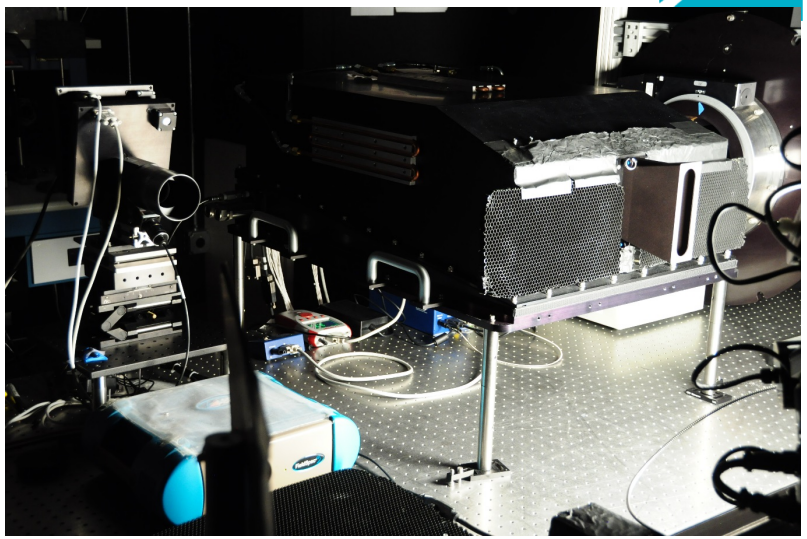
- Tunable Laser utilized to illuminate CHPS at select wavelengths
  - Spectral Mapping
  - Instrument Line Shape and Spectral Response Function
- Excellent correlation between measured Spectral Mapping and the designed Dispersion Model

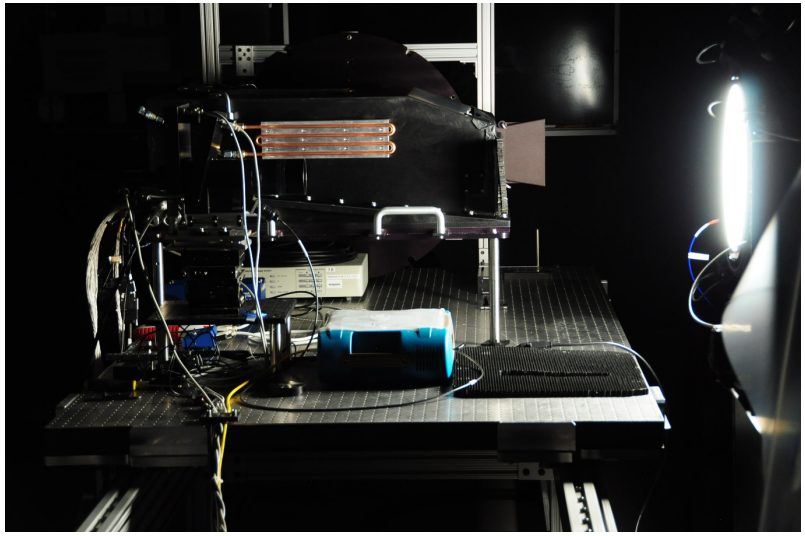


# Radiometric Calibration of CHPS

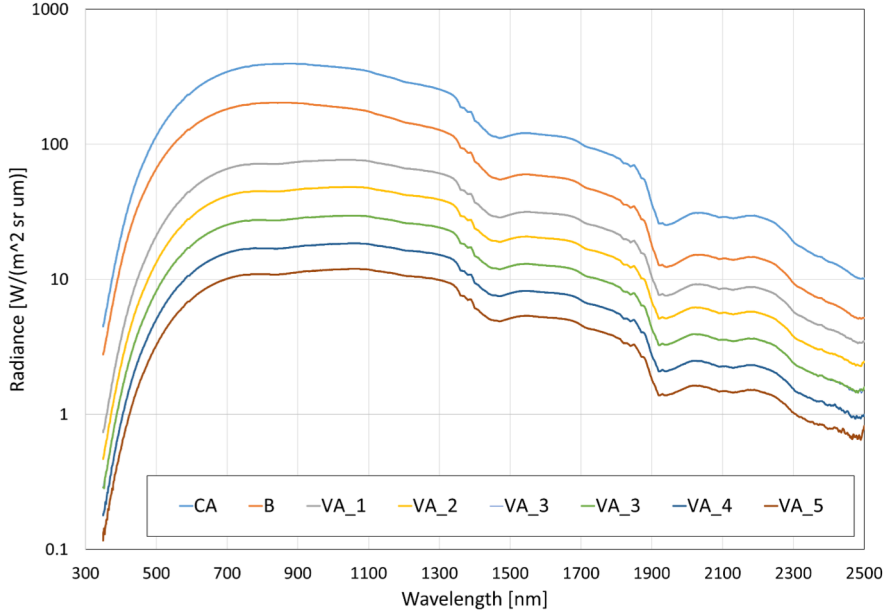
- CHPS radiometrically calibrated in the Ball Radiometric Calibration Laboratory
- Utilized the “Death Star Source” (DSS) used in the OLI and OLI-2 radiometric calibration
- Ball Custom Transfer Radiometer (CXR) used to transfer calibration to DSS
- CXR is traceable to NIST and was also used for OLI and OLI-2

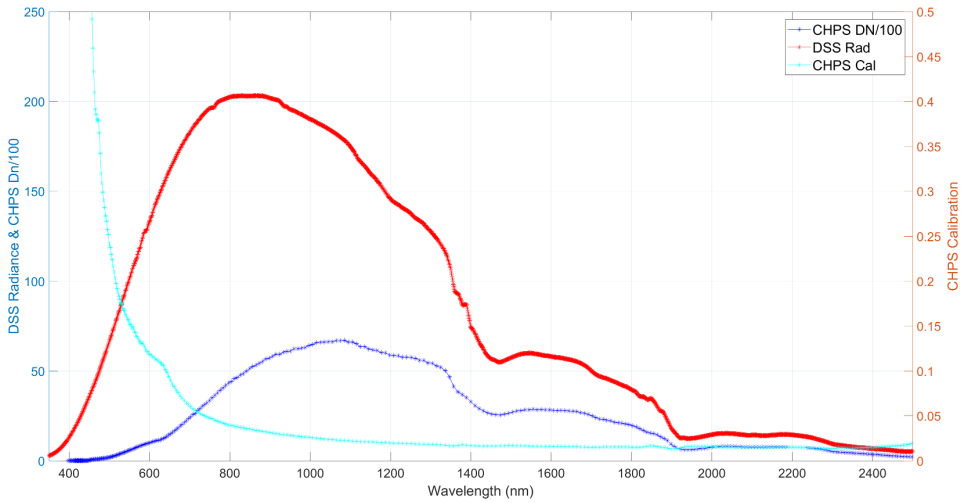


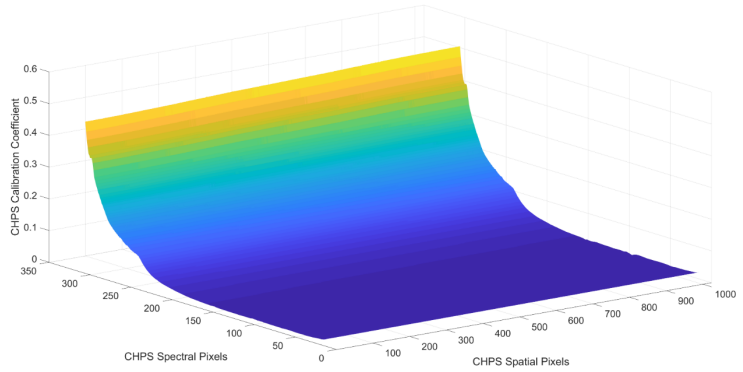


# Radiometric Calibration of CHPS

- DSS Radiance levels selected to span expected dynamic range
- DSS includes feedback loop for stable operation

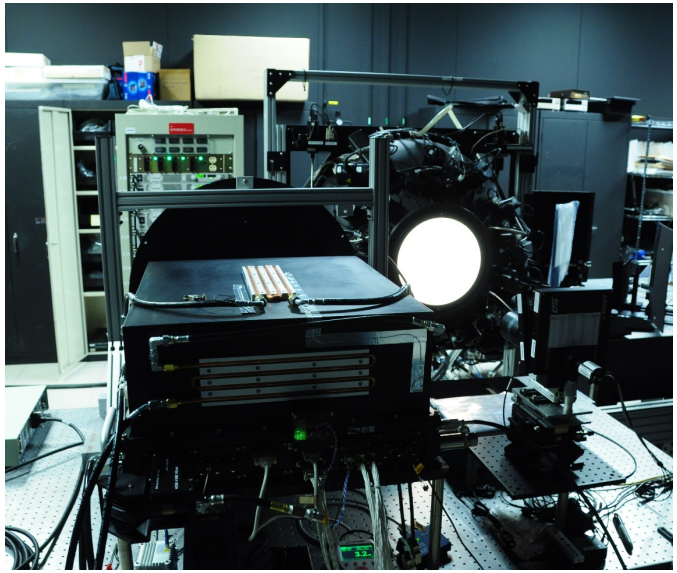


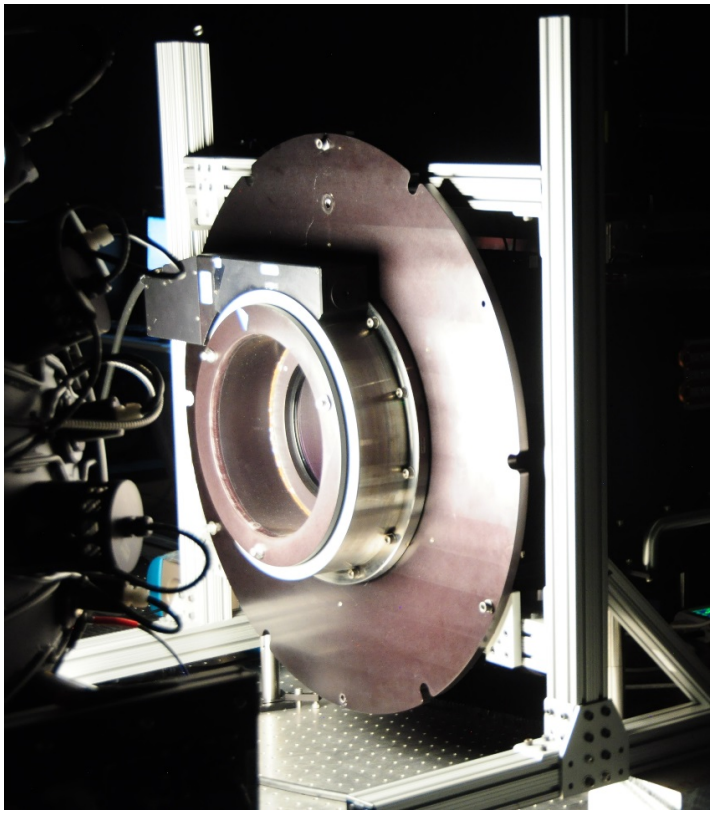



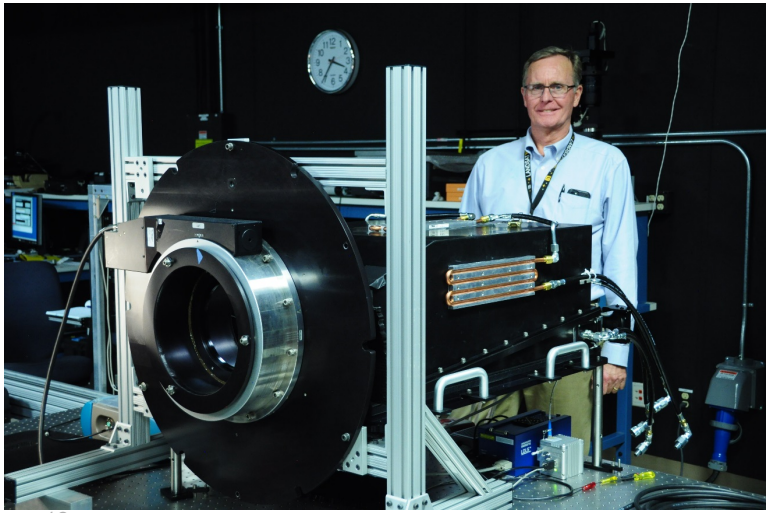




Radiometric Calibration across FPA

# Polarization Characterization of CHPS

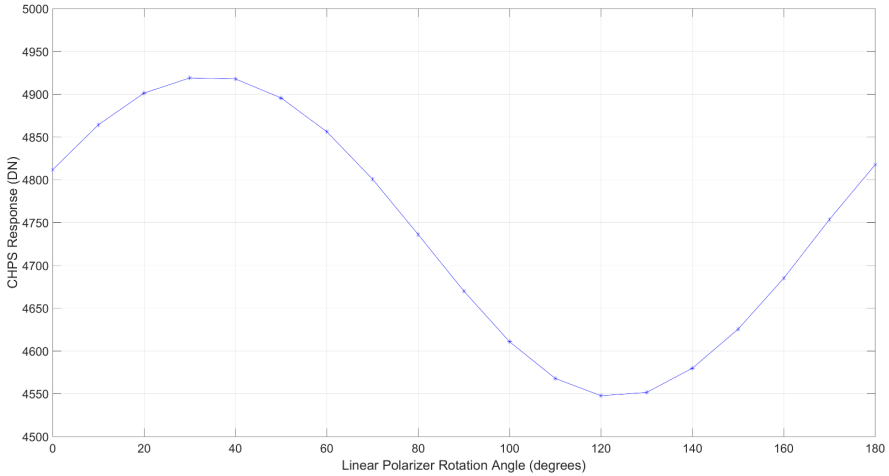


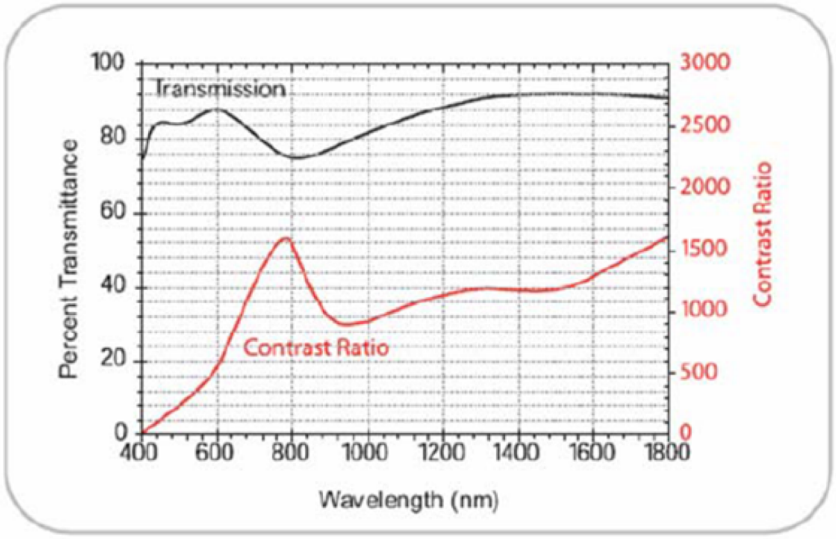




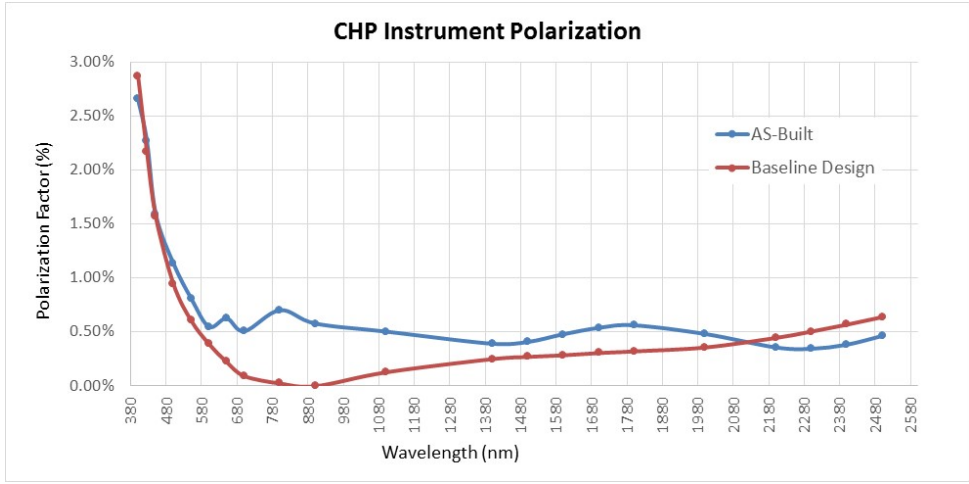
# Polarization Characterization of CHPS

- Generally low Polarization sensitivity (<3%)
- Polarizer had a decreasing contrast ratio at short wavelengths



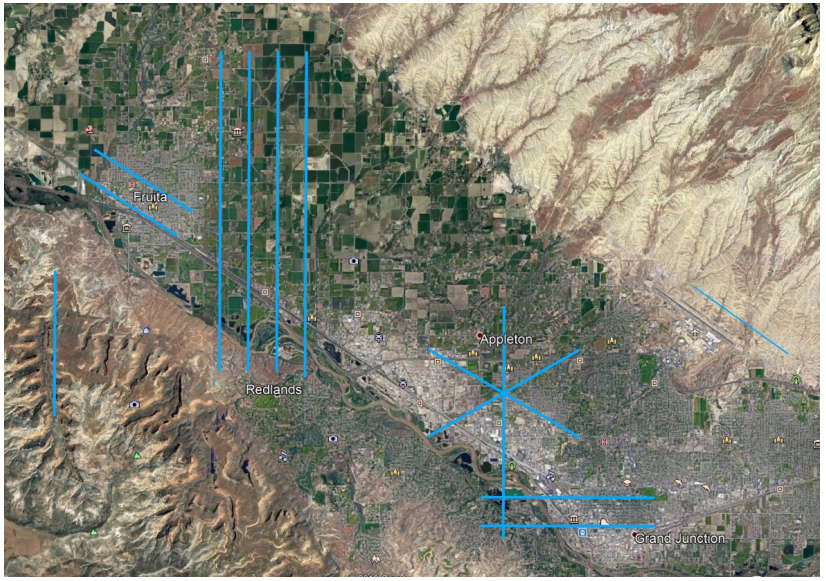




*IR VersaLight Polarizer performance*



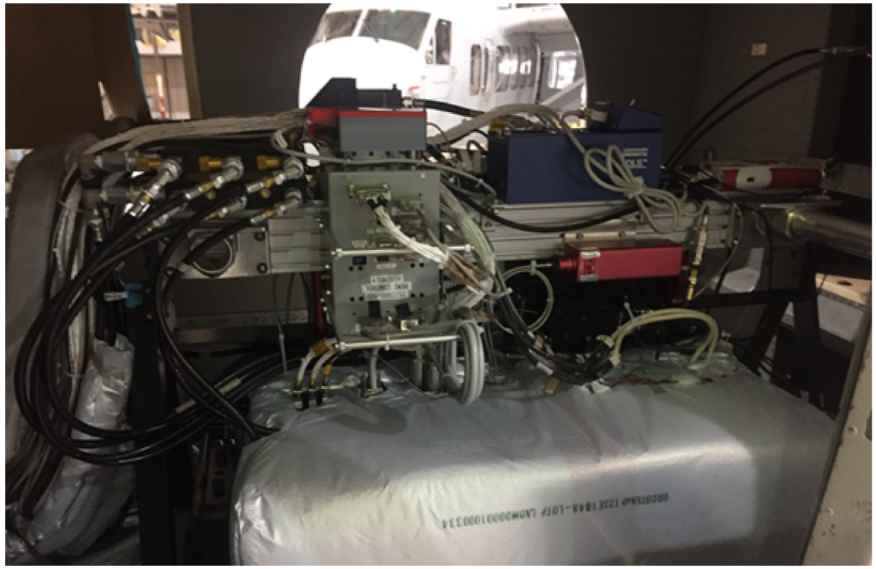
# CHPS Engineering Flights

- Engineering flights conducted in March of 2019
- CHPS and REMI integrated into leased Twin Otter DHC-6 in Grand Junction, CO
- Flight plans were designed to test the instrumentation
  - Instrumentation Checkout
  - Geolocation
    - Timing
    - Pixel Pointing
    - Edge-shear
  - Sensor Comparison
    - CHPS
    - REMI
    - OLI
  - Heterogenous scenes



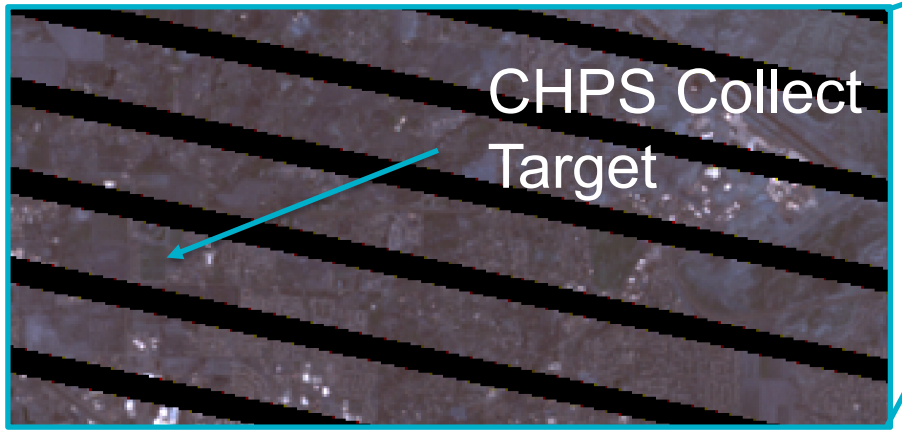

| Priority | Collect Name | Required Weather Conditions | Flight Line # | Entry Point | Exit Point | Flight Altitude | Ground Elevation | *Ground Height (m) | *Desired Flight Altitude (m) | *Desired Flight Altitude (ft) | Actual Flight Altitude (ft) | Actual Flight Altitude (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Functional Checkout | No Precipitation, partially cloudy is acceptable | 1 | 39.075269, -108.612540 (West) | 39.075256, -108.556747, (East) | 17,500 ft | 4600 ft | 1,380 | 5,380 | 17,652 | 17,500 | 5,334 |
| | | | 2 | 39.082394, -108.556741 (East) | 39.082407, -108.612540 (West) | 17,500 ft | 4600 ft | 1,380 | 5,380 | 17,652 | 17,500 | 5,334 |
| 2 | Wiggle Test | No Precipitation, Light cirrus clouds or better desired to aid in feature identification | 1 | 39.118287, -108.513960 (East) | 39.135051, -108.544498 (West) | 17,500 ft | 4800 ft | 1,477 | 5,477 | 17,970 | 17,500 | 5,334 |
| 3 | Geolocation | No Precipitation, Light cirrus clouds or better desired to aid in feature identification | 1 | 39.153206, -108.705509 (East) | 39.168521, -108.737130 (West) | 17,500 ft | 4500 ft | 1,375 | 5,375 | 17,635 | 17,500 | 5,334 |
| | | | 2 | 39.162474. -108.741999 (West) | 39.147159, -108.710381 (East) | 17,500 ft | 4500 ft | 1,375 | 5,375 | 17,635 | 17,500 | 5,334 |
| 4 | OLI Cross-Comparison and/or Radiometric Calibration | Clear, no clouds except on horizon desired but we'll take what we can get for the OLI cross-calibration. Radiometric calibration will be dependent on weather and ground crew (Probably Nathan and Tom). | 1 (Nominal) | 39.130045, -108.605279 (North) | 39.072060, -108.605279 (South) | 17,500 ft | 4600 ft | 1,394 | 5,394 | 17,698 | 17,500 | 5,334 |
| | | | 2 (60/240 degree Alternate) | 39.119138, -108.581080 (NE) | 39.097459, -108.629479 (SW) | 17,500 ft | 4600 ft | 1,394 | 5,394 | 17,698 | 17,500 | 5,334 |
| | | | 3 (120/300 degree Alternate) | 39.119138, -108.629478 (NW) | 39.097459, -108.581088 (SE) | 17,500 ft | 4600 ft | 1,394 | 5,394 | 17,698 | 17,500 | 5,334 |
| 5 | Waterbody | Clear, no clouds except on horizon | 1 | 38.988311, -108.281919 (North) | 38.933948, -108.281919 (South) | 17,500 ft | 5700 ft | 1,755 | 5,755 | 18,882 | 17,500 | 5,334 |
| 6 | Edge Shear | No Precipitation, Light cirrus clouds or better desired to aid in feature identification | 1 | 39.138325, -108.749540 (North) | 29.102084, -108.749540 (South) | 17,500 ft | 4500 ft to 6000 ft | 1,700 | 5,700 | 18,702 | 17,500 | 5,334 |
| 7 | Area Mapping Test | Clear, no clouds except on horizon | 1 | 39.112020, -108.669120 (South) | 39.193249, -108.669072 (North) | 17,500 ft | 4600 ft | 1,400 | 5,400 | 17,717 | 17,500 | 5,334 |
| | | | 2 | 39.193249, -108.678245 (North) | 39.113520, -108.678245 (South) | 17,500 ft | 4600 ft | 1,400 | 5,400 | 17,717 | 17,500 | 5,334 |
| | | | 3 | 39.113519, -108.687419 (South) | 39.193248, -108.687419 (North) | 17,500 ft | 4600 ft | 1,400 | 5,400 | 17,717 | 17,500 | 5,334 |
| | | | 4 | 39.193246, -108.696592 (North) | 39.113517, -108.696592 (South) | 17,500 ft | 4600 ft | 1,400 | 5,400 | 17,717 | 17,500 | 5,334 |

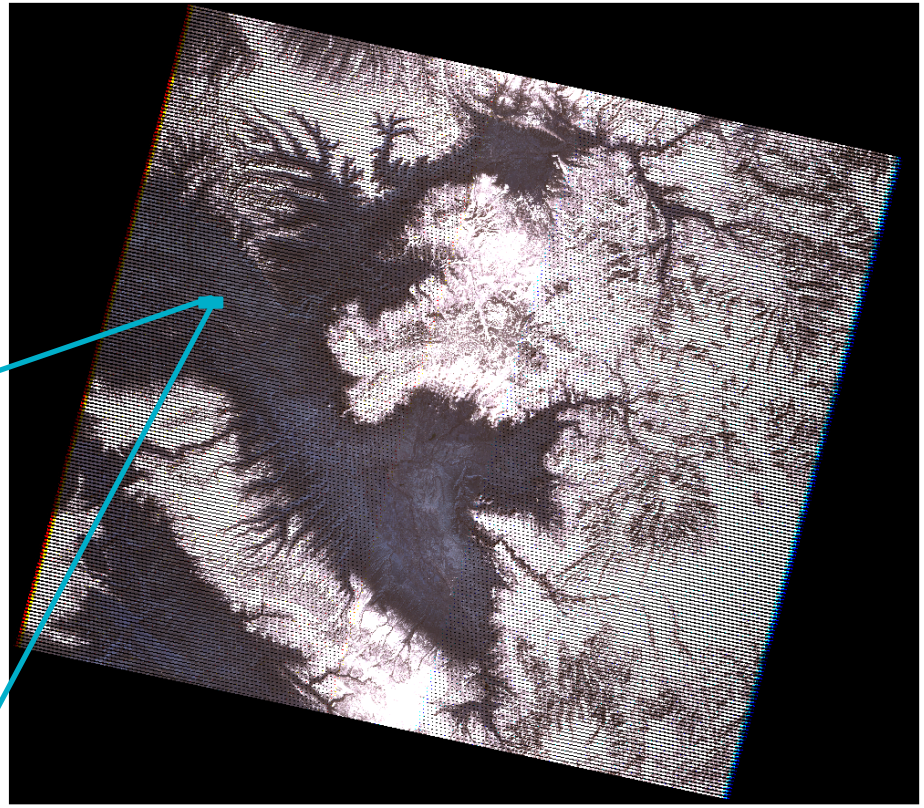
# CHPS Engineering Flights



# CHPS Engineering Flights

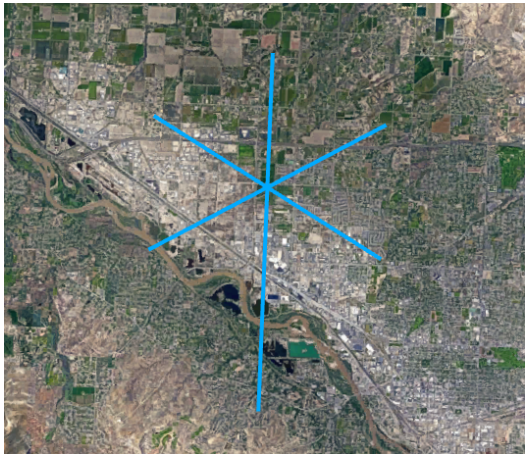
- Weather prevented co-incident CHPS and Landsat 8 OLI collect
- Co-incident collect with off-nadir Landsat-7 collect
- CHPS collect conducted over vegetated community park in Grand Junction



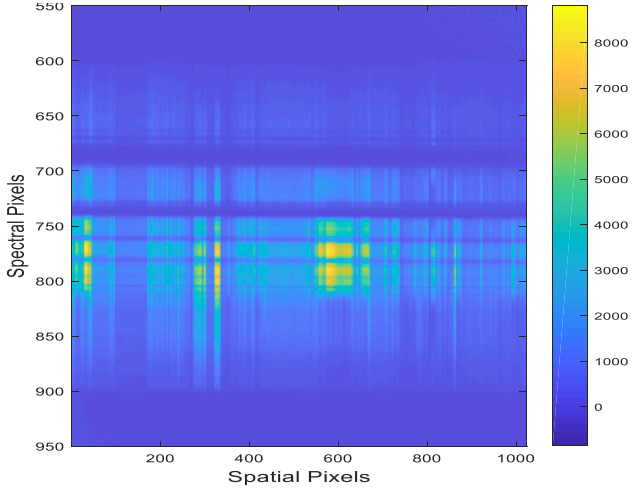



# CHPS Engineering Flights

- CHPS Laboratory Calibration being applied to Engineering flight data
- CHPS Spectral Calibration trended using NIST 2035b wavelength standard
- Development of CHPS Radiance data enables comparison to Landsat data

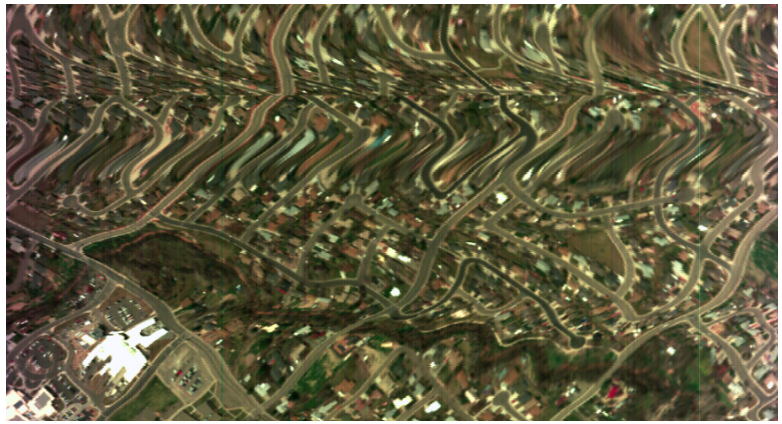



CHPS FPA Frame from Flight



# CHPS Geolocation

- Geolocation Flights
  - "Wiggle" Test over Grand Junction Airport to verify system timing
  - Series of flight lines over Fruita, CO for geolocation
  - Initial CHPS "Camera Model" is in development



# Remaining Activities

- Preparations for Science flights
  - Further Laboratory verification
  - Minor Software enhancements
  - Additional Radiometric and Spectral Calibration
  - Further analysis of sensor performance
- 2019 Science flights
- Produce sample L1 data from engineering or science flights
- Spaceborne Instrument Concept underway

# 2019 CHPS Science Flights

- Science flight are expected to occur in late summer 2019 due to aircraft availability
- Calibration Flights
  - Landsat/Sentinel-2 under flight
  - Table Mountain – vicarious calibration collect
- NEON Sites
  - Niwot Ridge – Alpine ecology site west of Boulder
  - Central Plains Experimental Range – managed Prairie site
- Other potential Science sites
  - High Park burn scar subset - Previously burned area undergoing regeneration
  - Horsetooth Reservoir – Inland open water

# Acknowledgements


- This project funded by the NASA Earth Science Technology Office, Grant NNX16AP61G

- Thanks to all of CHPS Team: Paul Kaptchen, Nathan Showalter, Jonathan Fox, Lyle Ruppert, Jerold Cole, Bob Slusher, Rusty Schweickart, Bob Warden, Bill Good, and Jim Howell