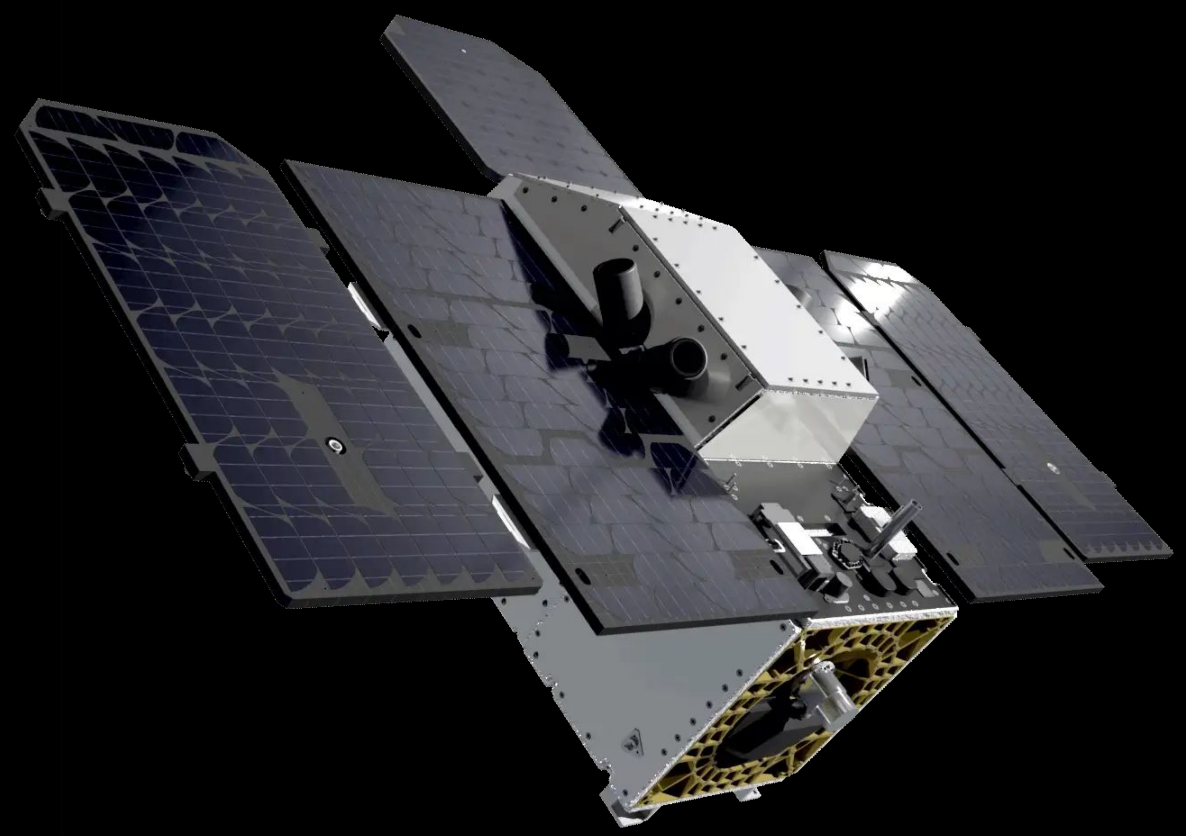


Planet's Hyperspectral Constellation: First Light Campaign and On-Orbit Calibration

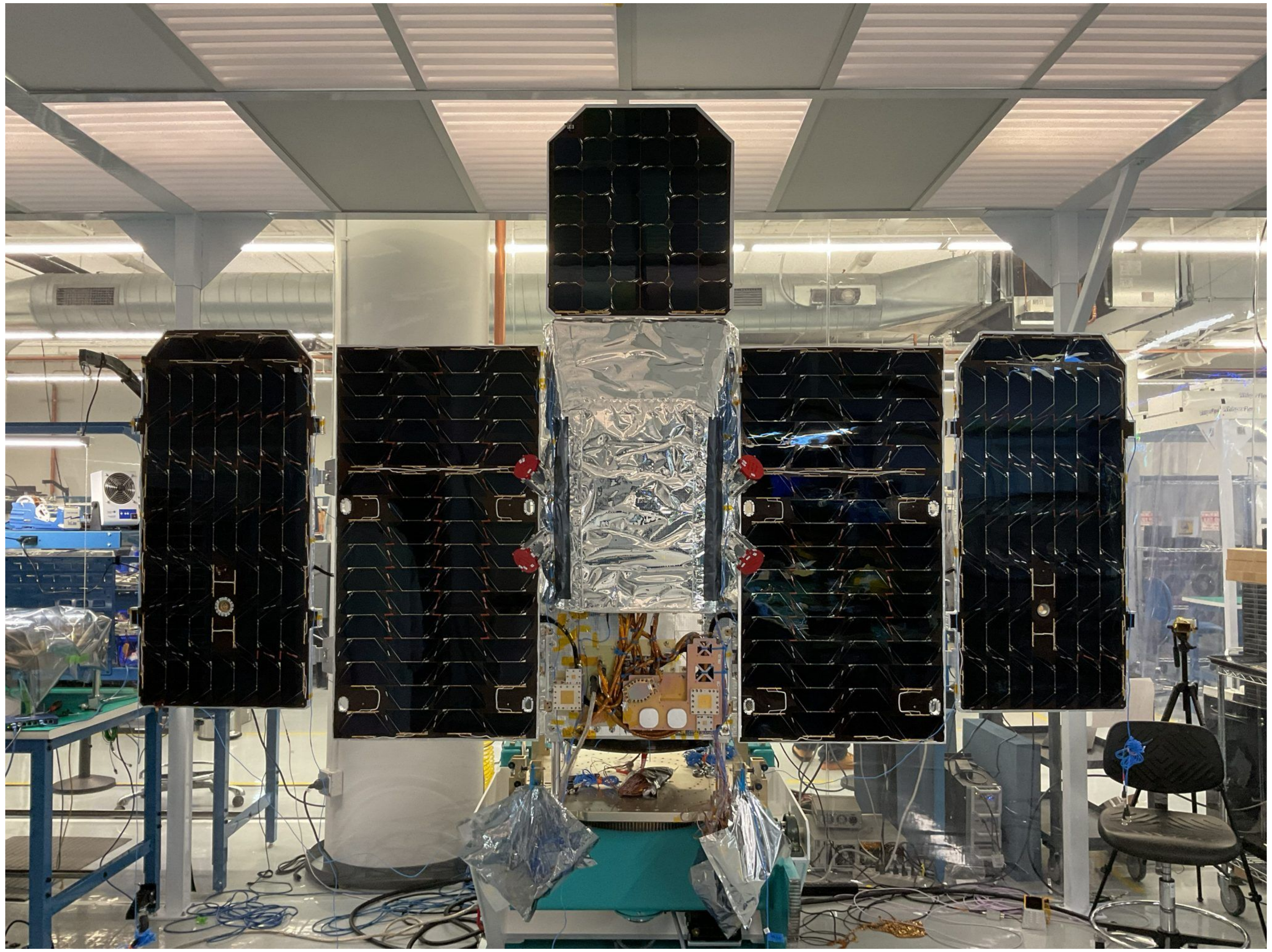
Geert Barentsen, Joseph Harris, Hannah Bourne, Justin Haag, Emily Martin, Caroline Pritchett, Paul Giuliano, Dominic LeDuc, Keely Roth, Alan Collison, Graham Mills, Arin Jumpasut, and the wider Tanager team

June 11, 2024 | CalCon 2024

Tanager-1 Is Ready For Launch: Planet's First Hyperspectral Satellite

Planet Labs PBC | June 6, 2024

NEWS We are proud to announce today that our first hyperspectral satellite, Tanager-1—made possible by the Carbon Mapper Coalition and its philanthropic partners—is ready for launch. The spacecraft arrived at Vandenberg Space Force Base on June 3rd in preparation for liftoff as early as July on board the Transporter-11 Rideshare mission with SpaceX. [...]



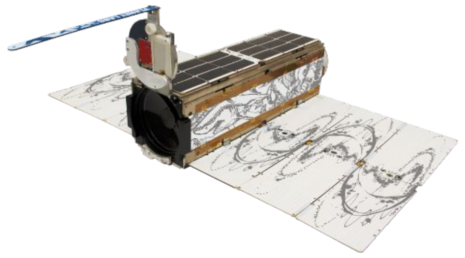
https://www.planet.com/pulse/tanager-1-is-ready-for-launch-planets-first-hyperspectral-satellite

Our mission

To image the whole world every day, making change **visible, accessible, and actionable**.

Planet's Agile Space Missions

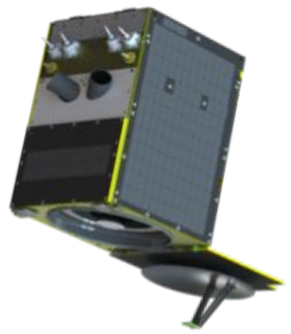
CURRENT CONSTELLATIONS



Dove

Always-on Monitoring

- ~180 satellites
- 3.7 m resolution
- 8-band
- Daily revisit



SkySat

High-Resolution Tasking

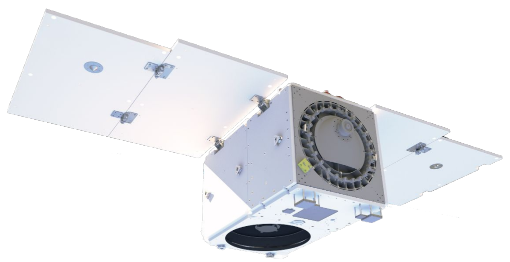
- ~20 satellites
- 50 cm resolution
- RGB, NIR, and Pan bands
- Sub-daily tasking

PLANNED FUTURE CONSTELLATIONS

Tanager

Hyperspectral Tasking

- 400 - 2500 nm
- ~400 5 nm bands
- 30 m resolution
- Industry leading SNR



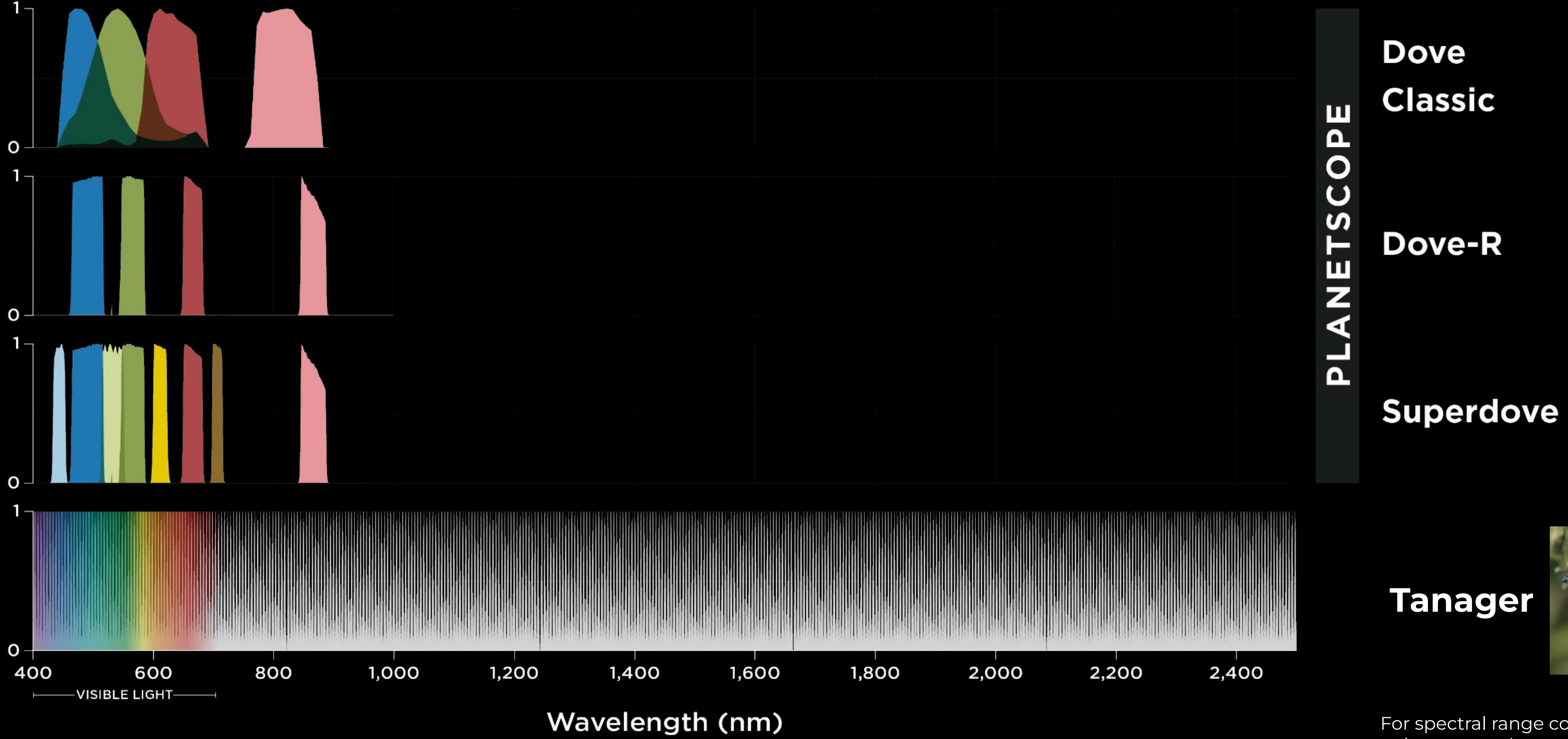
Pelican

Very High Resolution Tasking

- Initial fleet of up to 30 satellites[1]
- Up to 30 cm resolution
- Pan + 6 RGB+NIR bands
- Up to 30 revisits/day

[1] Does not include initial demonstration satellites.

Imaging spectrometers can significantly enhance Planet's spectral capabilities

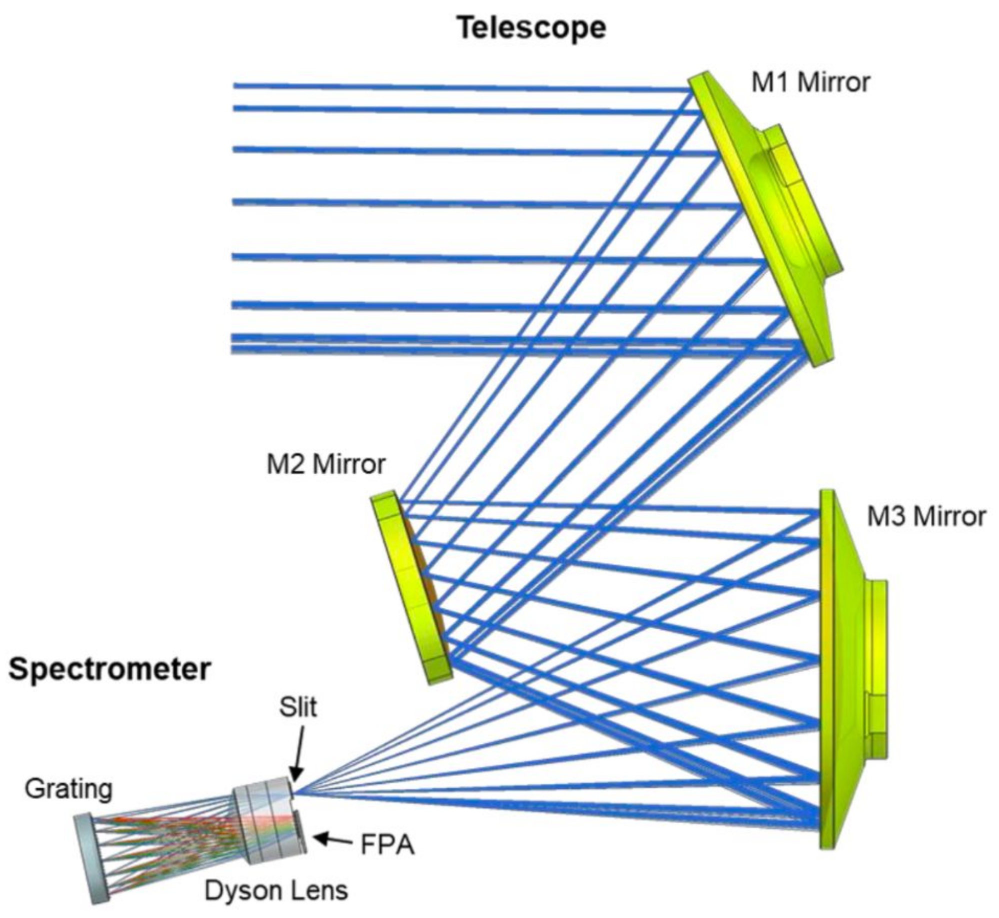


For spectral range comparison purposes only – sensor does not provide uniform response across spectrum.

Tanager is a high-precision Dyson imaging spectrometer

Telescope	3-Mirror Anastigmat (F/1.8)
Swath Width	18 km at 406 km (SSO)
Spatial Sampling	30 - 35 m
Spectral Range	400 - 2500 nm
Spectral Sampling	5 nm
SNR	300-600 at 2300 nm

Table adapted from Carbon Mapper & Keremedjiev et al. 2022



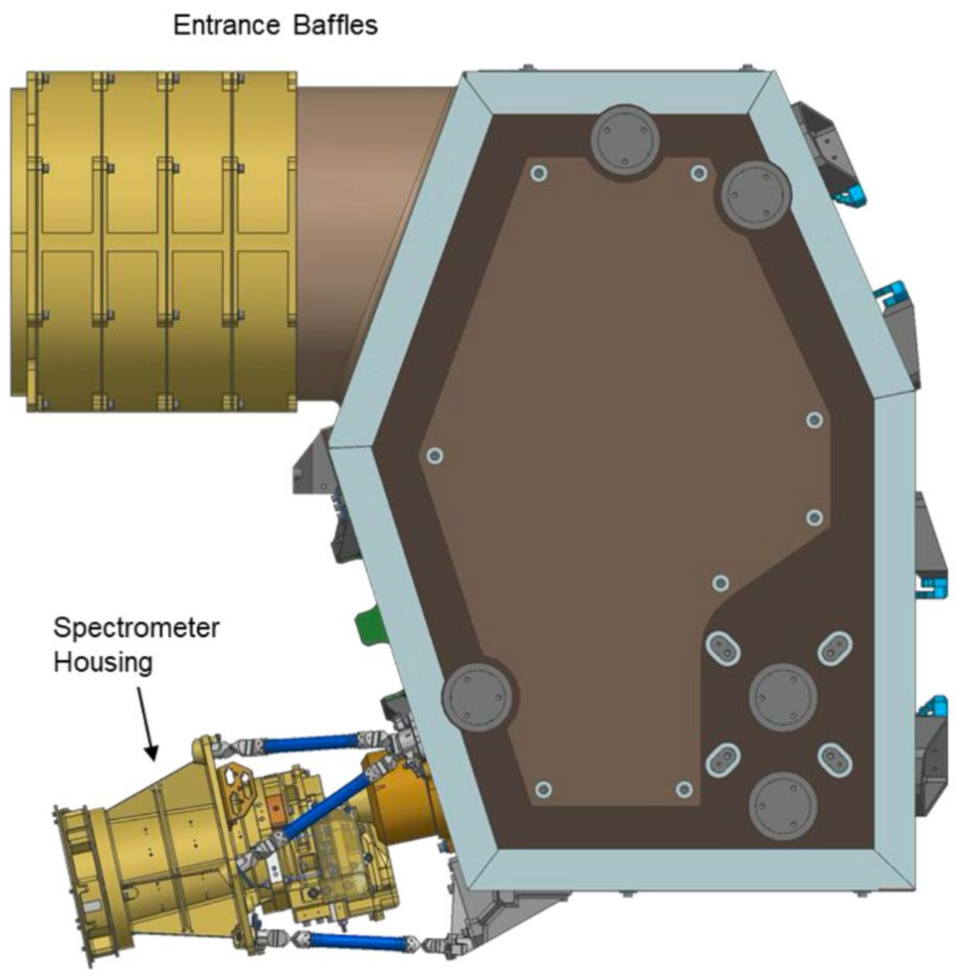


Figure citation: Zandbergen et al. 2022

Methane detection drives the requirements

Methane requires high SNR in SWIR

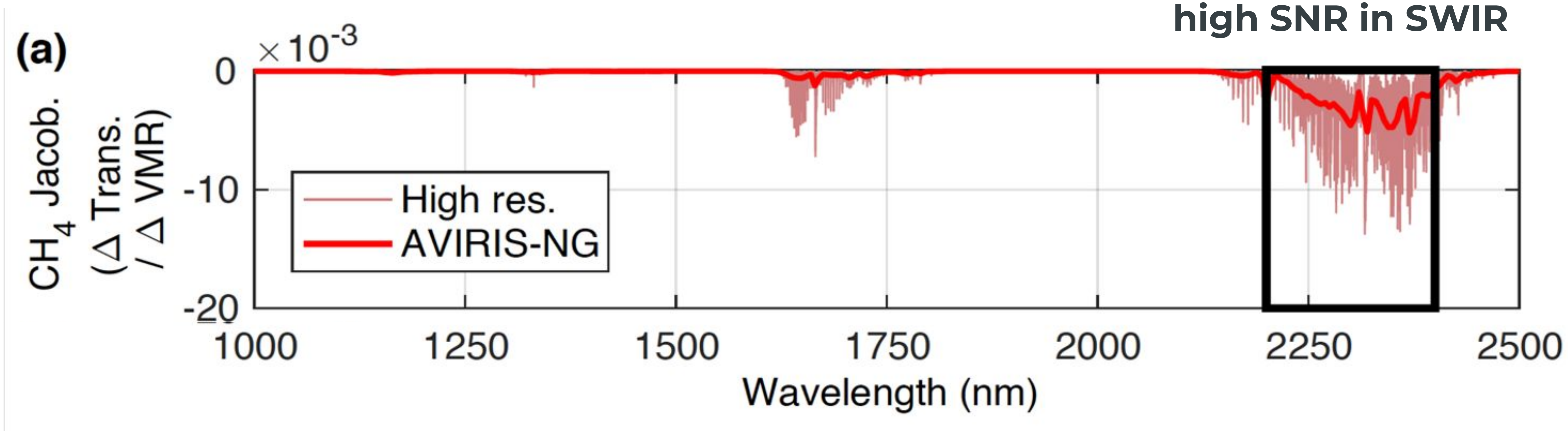


Figure adapted from https://avirisng.jpl.nasa.gov/greenhouse_gas_mapping.html

Planet is part of the Carbon Mapper Coalition

- Carbon Mapper aims to pinpoint and track up to 90% of high-emitting CH_4 and CO_2 point sources globally.
  - Public-private partnership which brings together philanthropy orgs, regulatory boards, Planet, JPL, and universities.
  - Planet's role is to build, launch, and operate the constellation of VSWIR imaging spectrometers we call Tanager.
- Tanager also enables a wide range of applications across agriculture, biodiversity, water quality, forest health, mineral mapping, ...

Methane plume near Salt Lake City's landfill, detected by CarbonMapper/GAO:

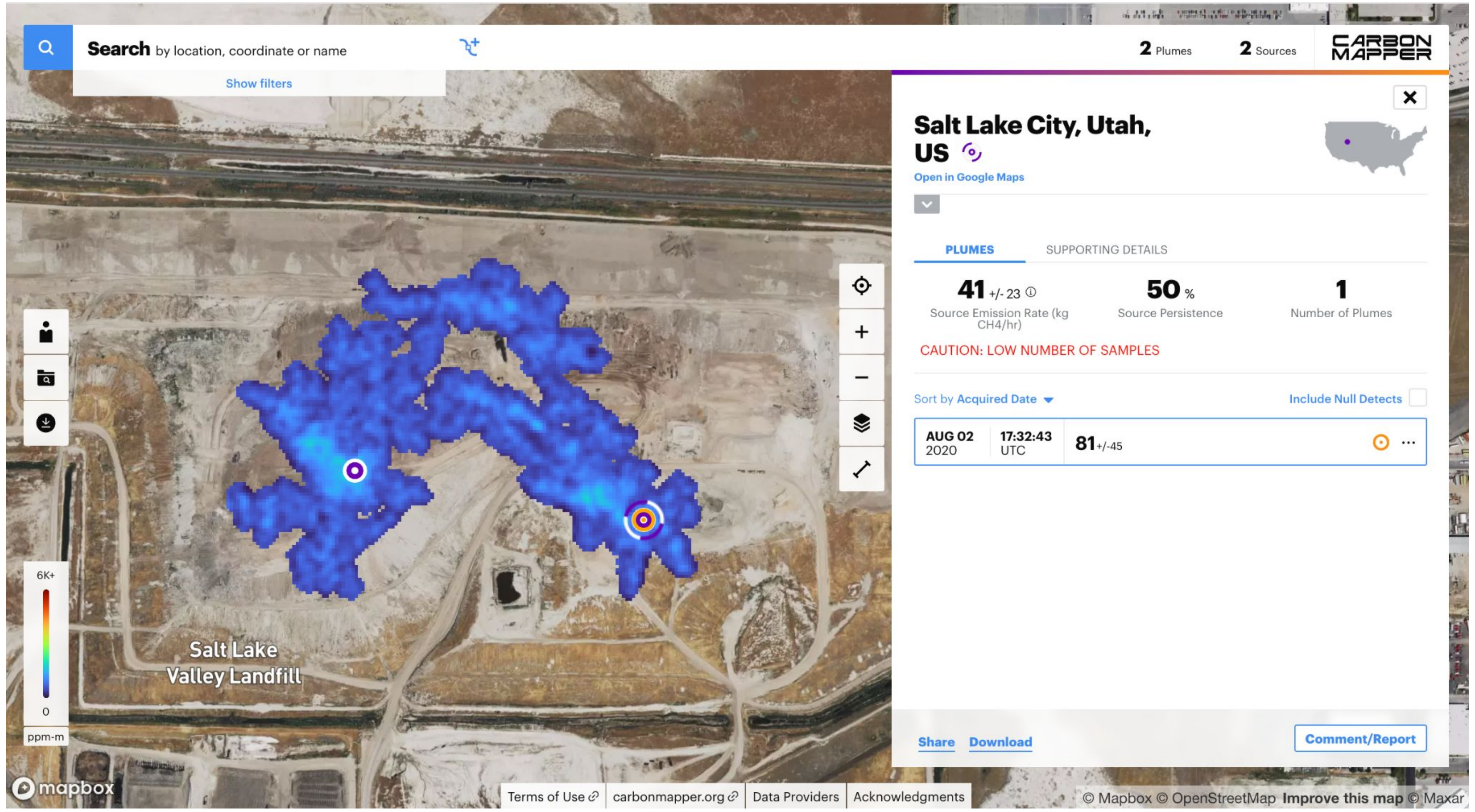
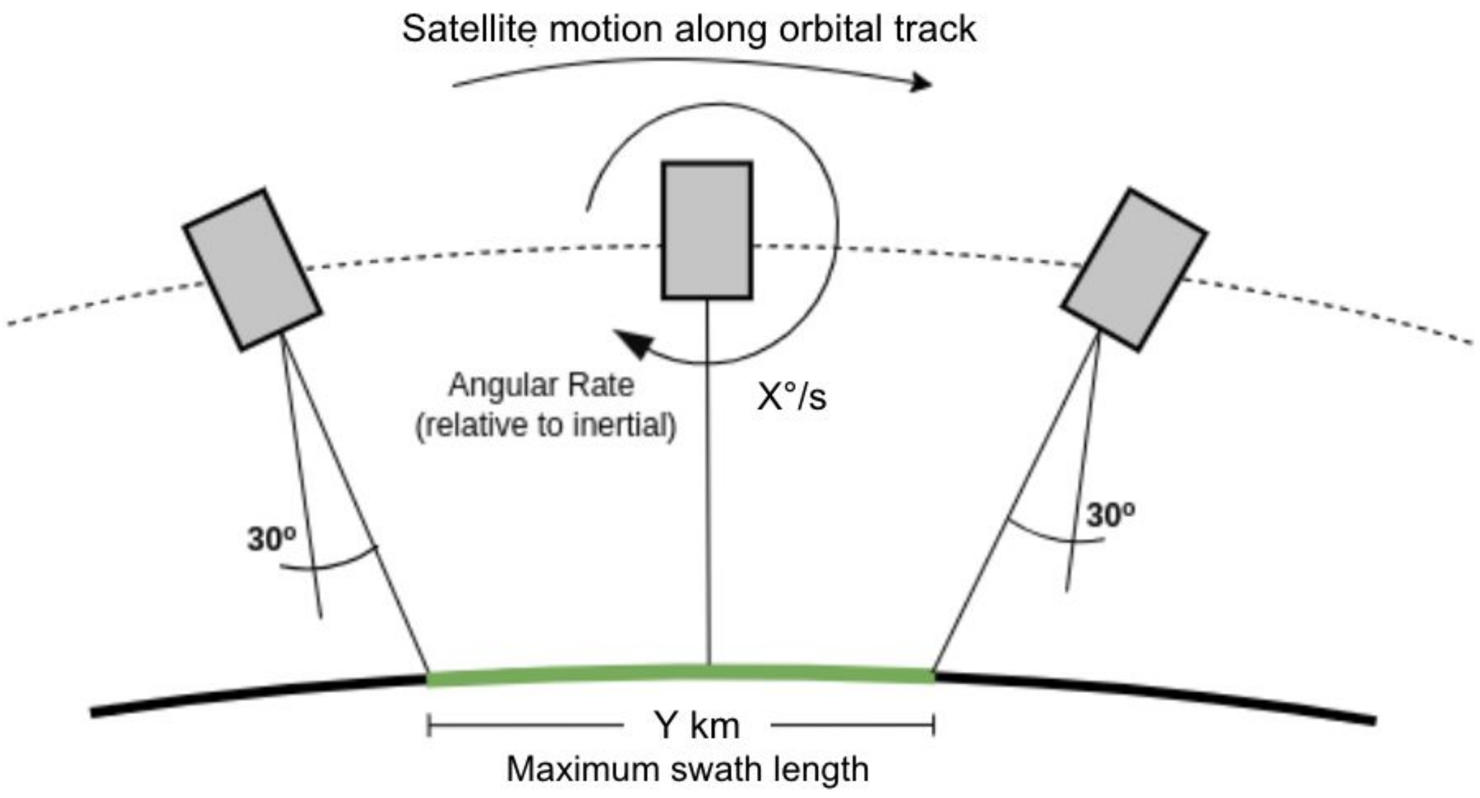


Figure: https://data.carbonmapper.org

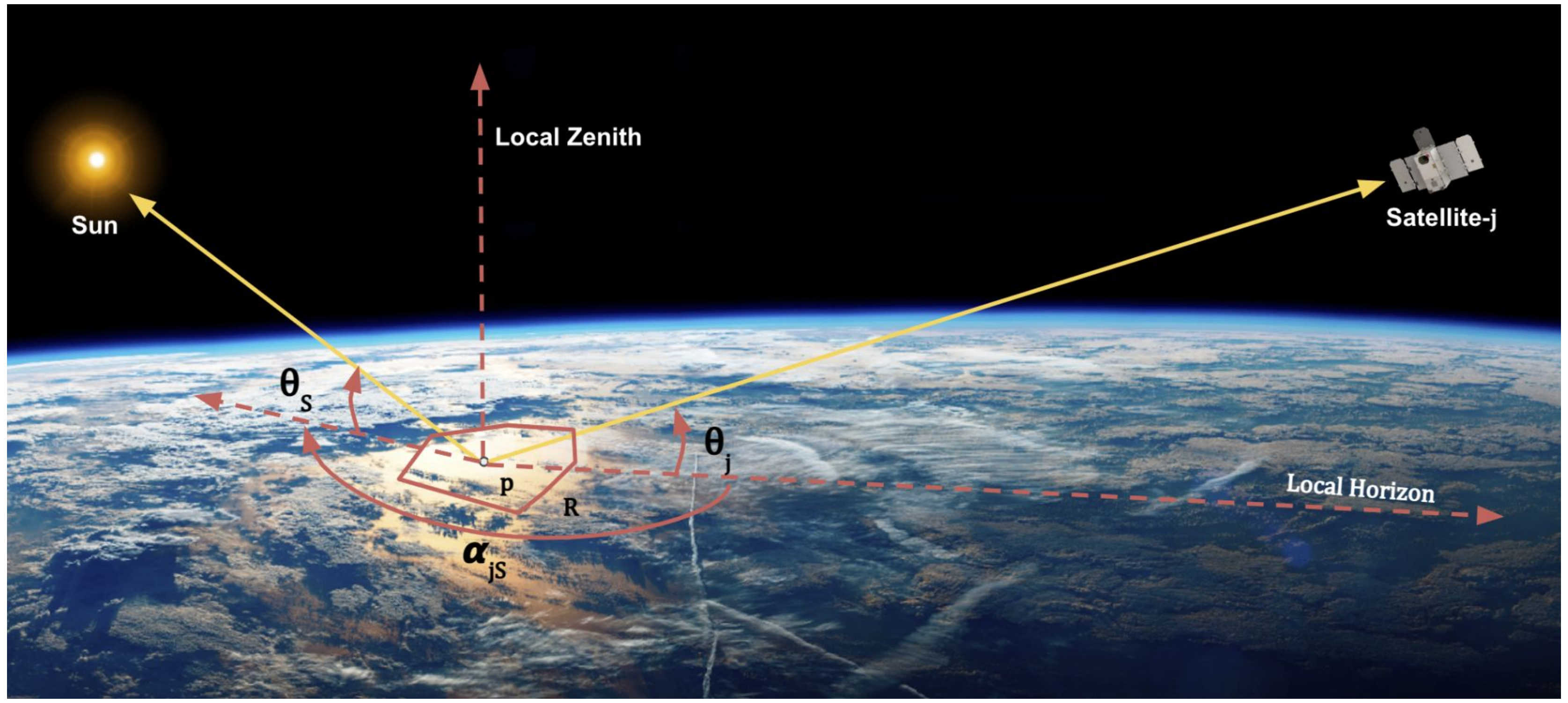
Intelligent operation modes contribute to the high SNR

1. Back-nodding mode



Attitude maneuvering is used to observe a target up to 8 times longer compared to what a simple pushbroom scan would allow.

2. Glint mode



Glint mode enables methane plumes to be detected over dark water. In this strategy, the satellite points towards the Sun's specular reflection point to increase the photon count.

Planet's tasking system can autonomously predict and schedule glint observations. (Nallapu et al. 2023)

Tanager leverages NASA JPL expertise

JPL's expertise in imaging spectrometers goes back 40+ years, including multiple iterations of AVIRIS.

Tanager leverages JPL expertise in three ways:

1. **Hardware**: The spectrometer design is based on EMIT, a JPL-built instrument installed on the ISS. (Green et al. 2020, Thompson et al. 2024)
2. **Software**: Data processing is based on the open source EMIT pipeline and the ISOFIT atmospheric correction package. See github.com/emit-sds.
3. **Calibration**: We adopt EMIT's calibration procedures and will receive JPL support during First Light.

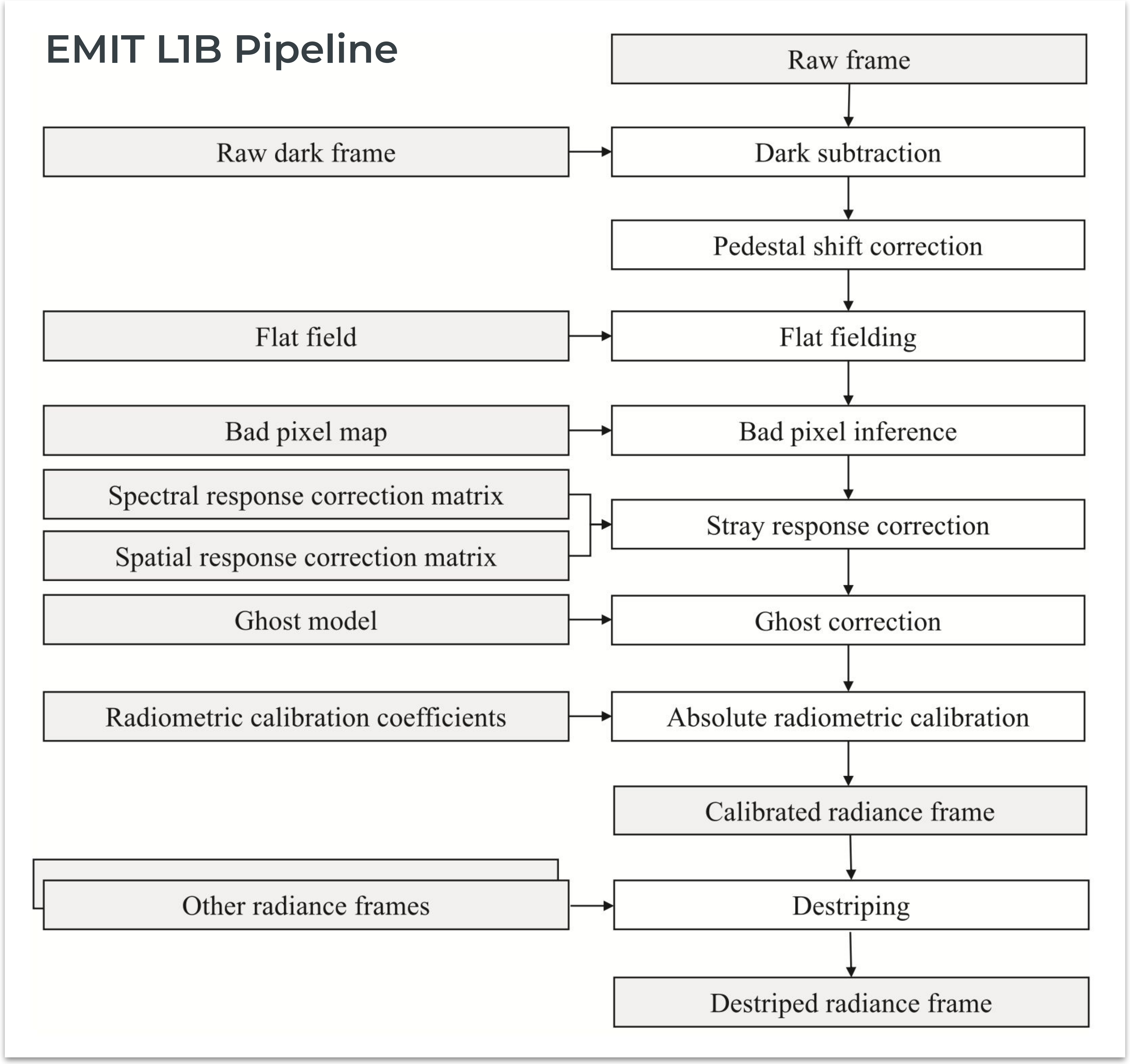
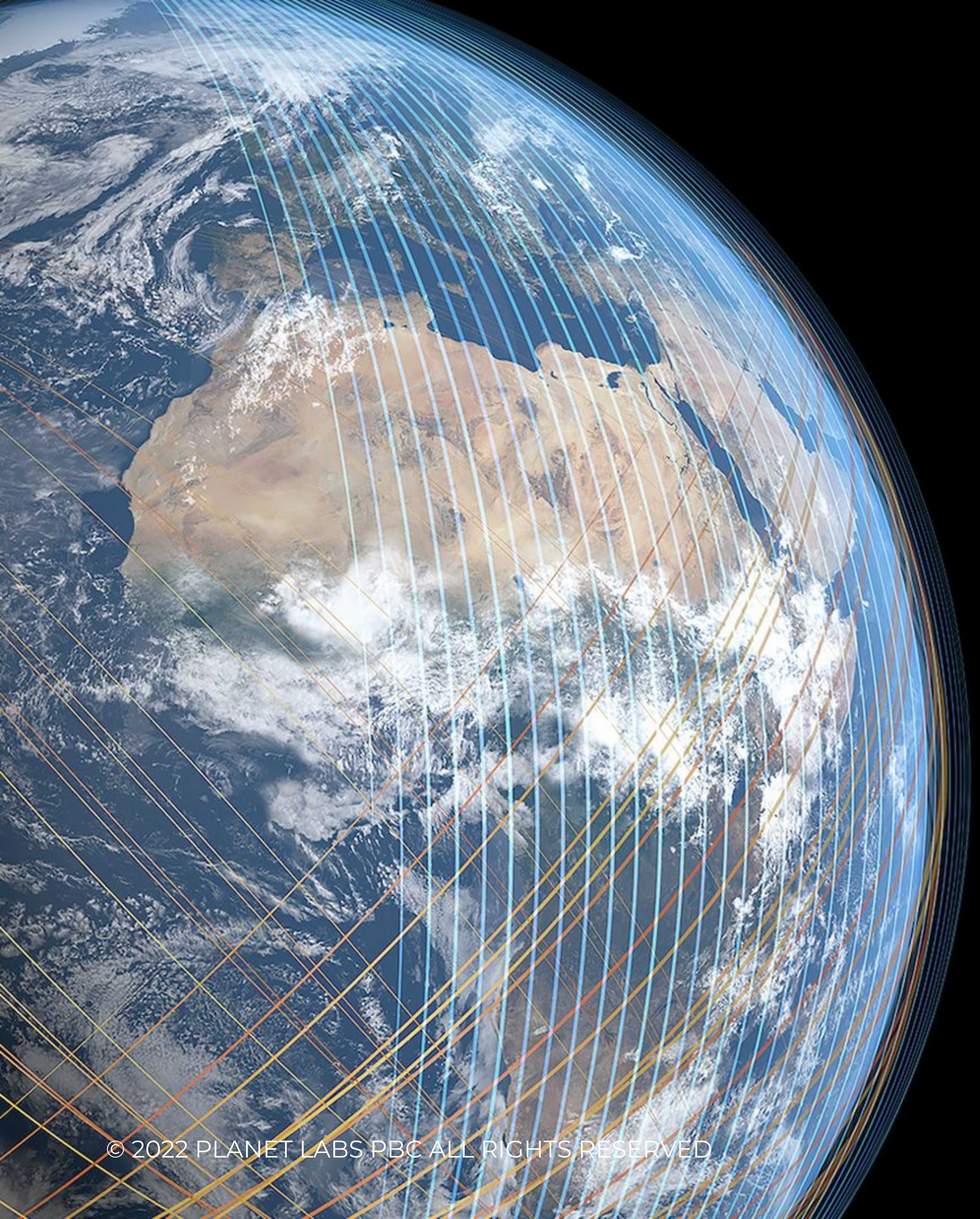


Figure citation: Thompson et al. 2024.



Calibration strategy

Calibration strategy

Tanager's simple design emphasizes the uniformity and stability required to enable on-orbit vicarious calibration:

1. Spectral calibration
   a. Lab: laser & monochromator measurements.
   b. On-orbit: fitting atmospheric absorption features.
2. Radiometric calibration
   a. Lab: calibration lamp measurements.
   b. On-orbit: vicarious calibration + frequent dark/flat updates.
3. Spatial/Geometric calibration
   a. Lab: broadband source measurements
   b. On-orbit: ground control point analysis.

A validation campaign will test these calibrations.

See Thompson et al. 2024 for details:

On-orbit calibration and performance of the EMIT imaging spectrometer

David R. Thompson [a], Robert O. Green [a], Christine Bradley [a],
Philip G. Brodrick [a], Natalie Mahowald [c], Eyal Ben Dor [b], Matthew Bennett [a],

Center wavelengths of the 400+ spectral bands are measured pre-launch by observing lasers of known wavelengths

The lasers are known to σ_λ < 0.01 nm and are observed in TVAC conditions. The laser stimulus is translated across all spatial columns to characterize spectral uniformity (i.e., smile).

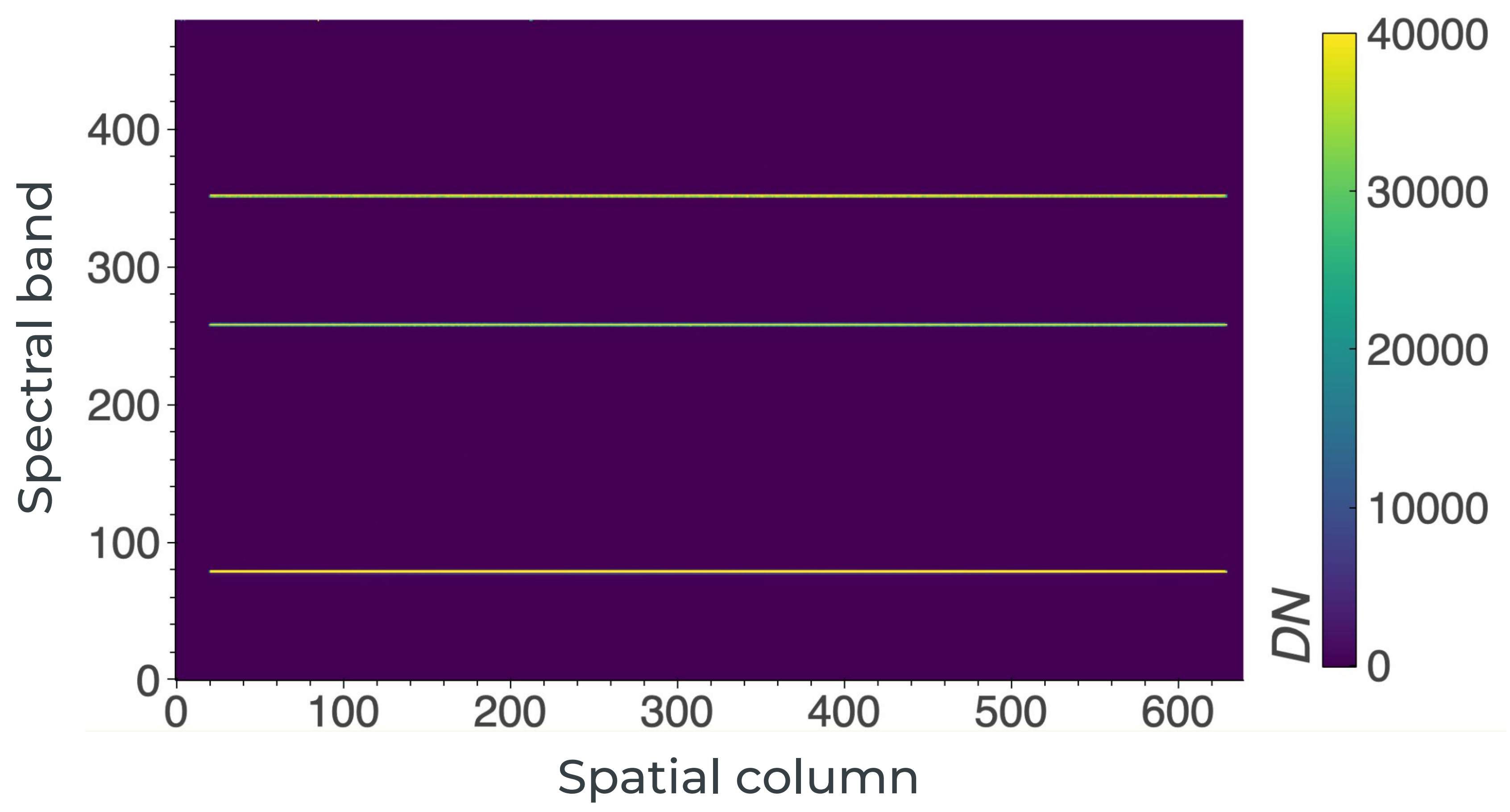


Figure: sum of integrations obtained by observing an integrating sphere fed with three lasers. A hexapod system translates the stimulus across spatial positions.

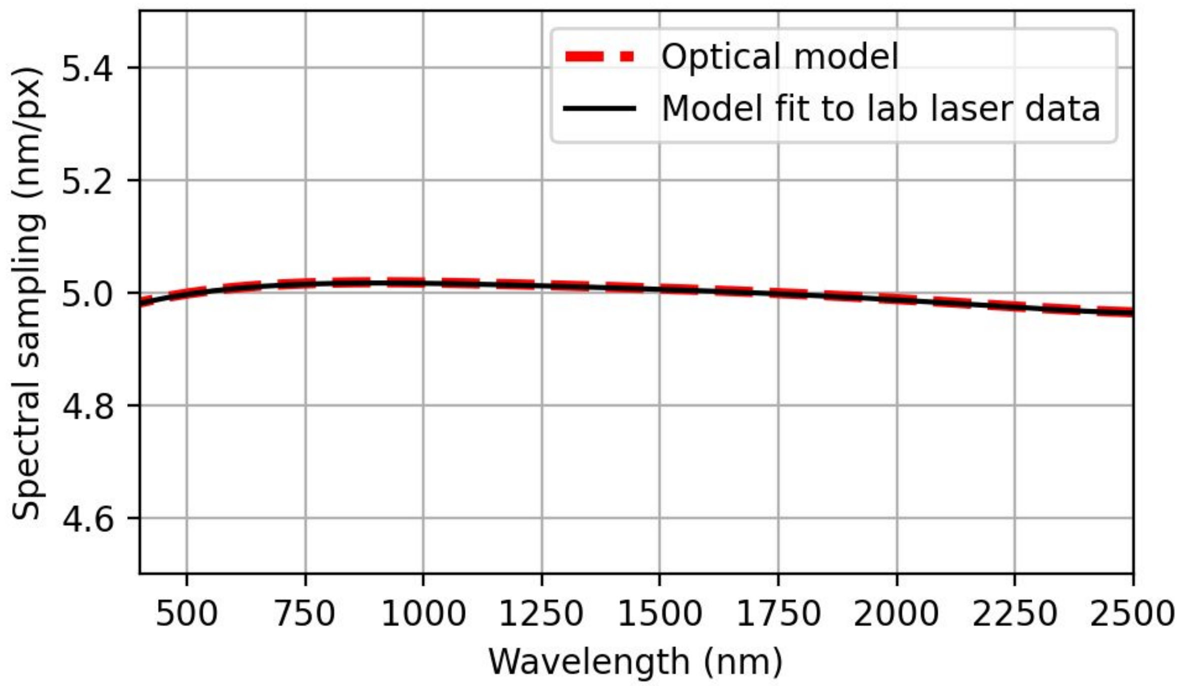


Figure: a dispersion curve is fit to the laser data, initialized by optical models.

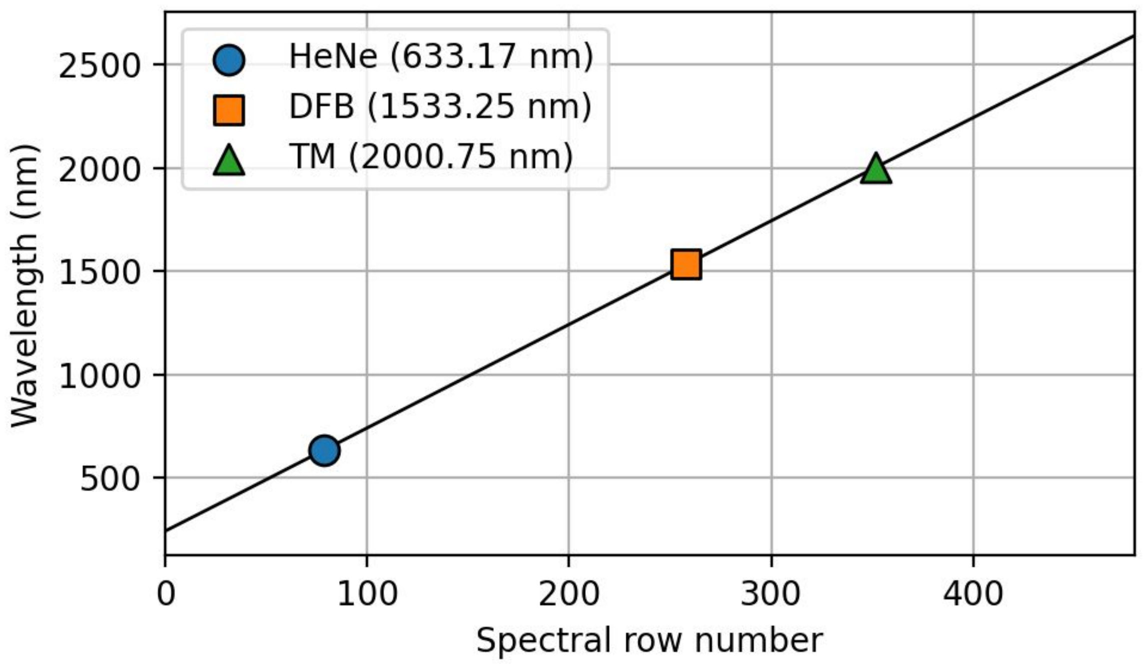


Figure: the dispersion model fit yields center wavelengths for each spectral band.

Spectral Response Functions (SRFs) are measured pre-launch using a scanning monochromator

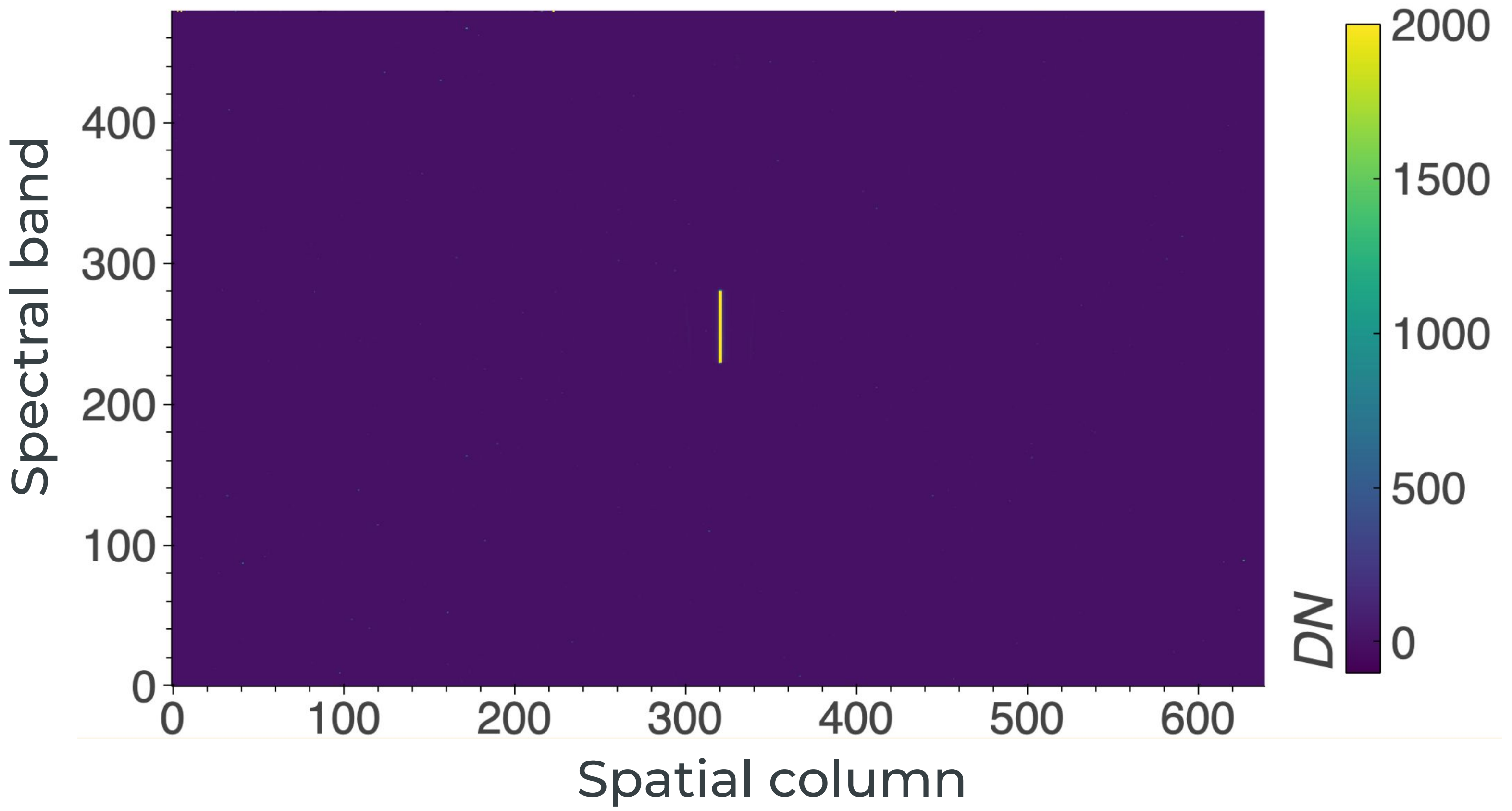


Figure: sum of integrations obtained while a monochromator sweeps a spectrally-narrow stimulus from 1400 to 1650 nm in column 320.

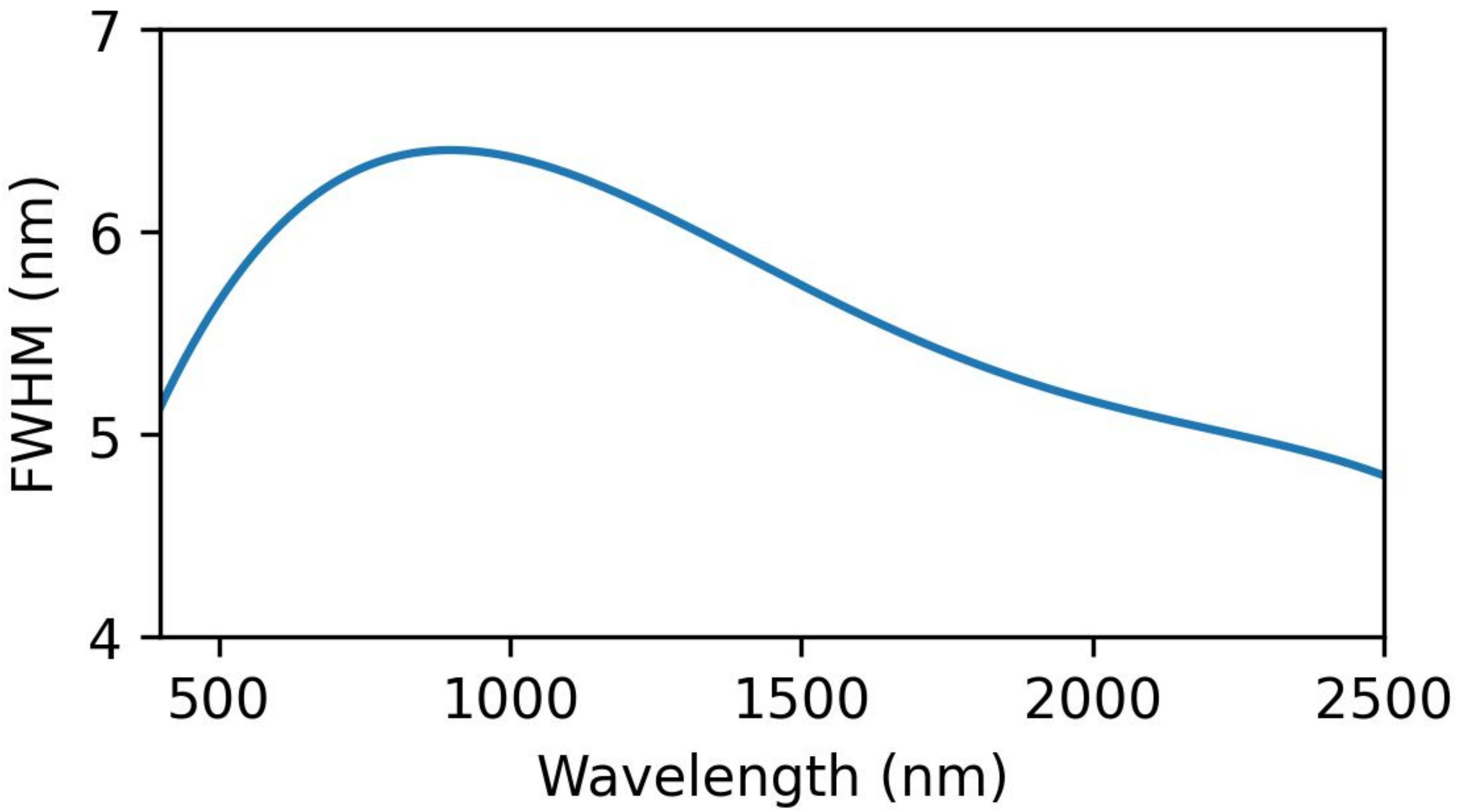


Figure: Example Full Width at Half Maximum (FWHM) curve derived from the monochromator measurements.

On orbit, the spectral calibration will be revised by fitting atmospheric features

The best spectral calibration standards available to us on orbit are the well-studied absorption features in the atmosphere (e.g., Oxygen A near 760 nm).

We will use MODTRAN to forward-model atmospheric features and fit spectral calibration parameters using non-linear optimization.

Using this technique, we have been able to reproduce EMIT's spectral calibration to within ~0.03 nm.

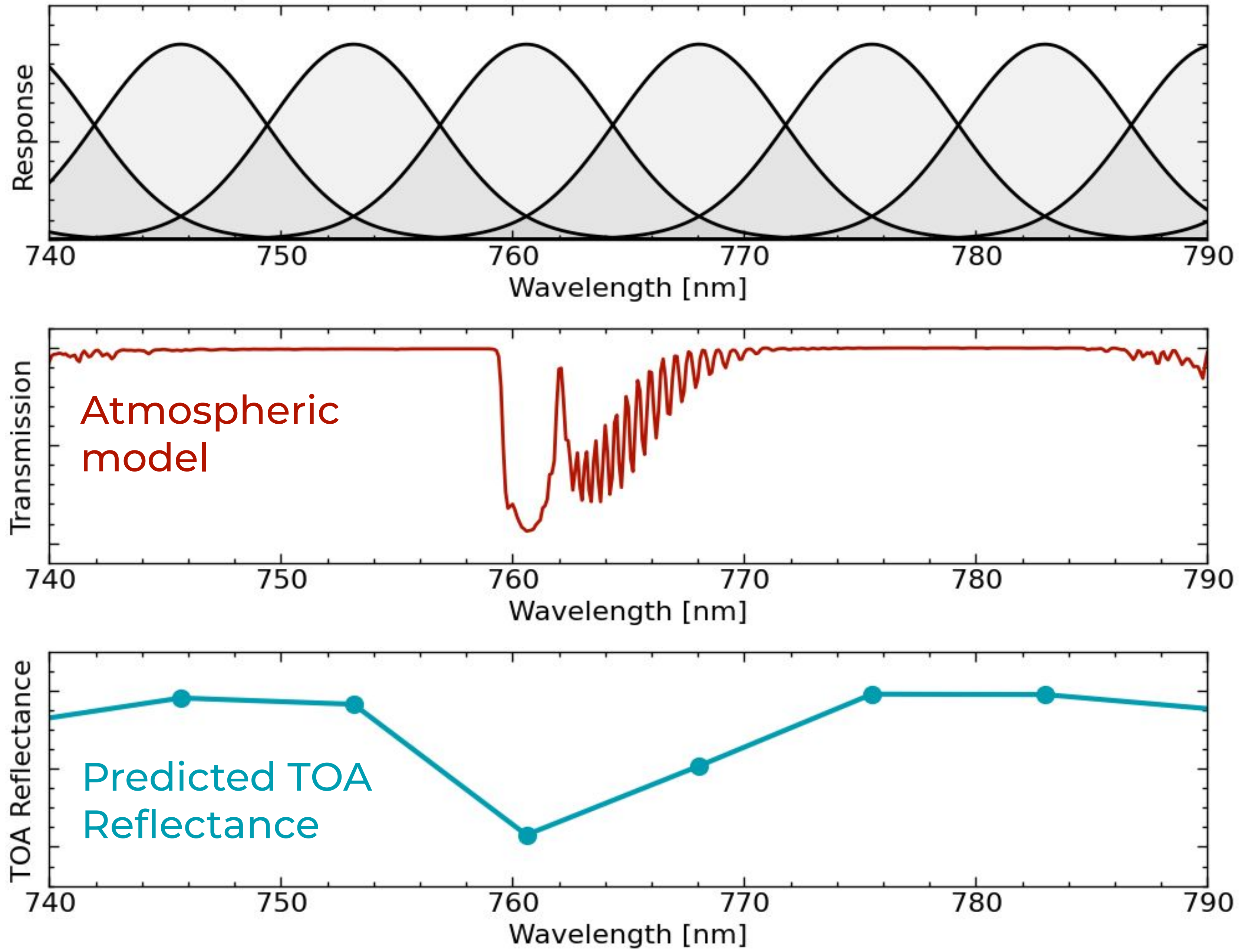
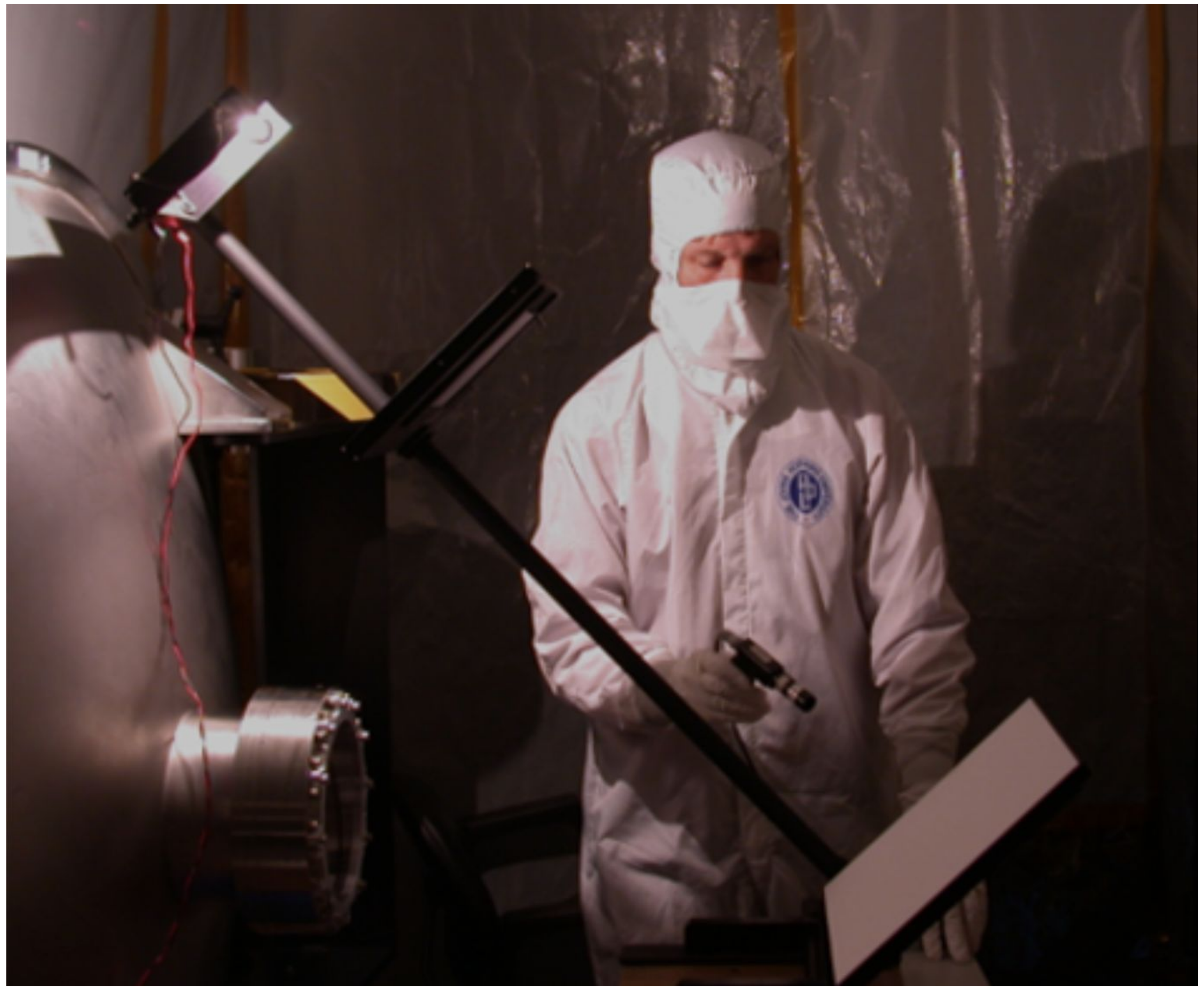


Illustration of a forward-model in which EMIT's SRFs (top panel) and an atmospheric model (middle panel) are used to predict the observed shape of the Oxygen A absorption band.

Radiometry is calibrated pre-launch using a NIST-traceable lamp & panel

Radiometric calibration coefficients are measured to translate instrument DNs into physical units of radiance (W/m^2/sr/μm). We use a NIST-traceable Quartz Tungsten Halogen (QTH) Lamp and Spectralon Panel.

Additional lab measurements include dark frames, flat fields, bad pixels, stray light, optical ghost model, and SNR characterization.



Example lab setup in which a QTH lamp illuminates a Spectralon Panel in front of the TVAC window. (Image Credit: R. Green, JPL)

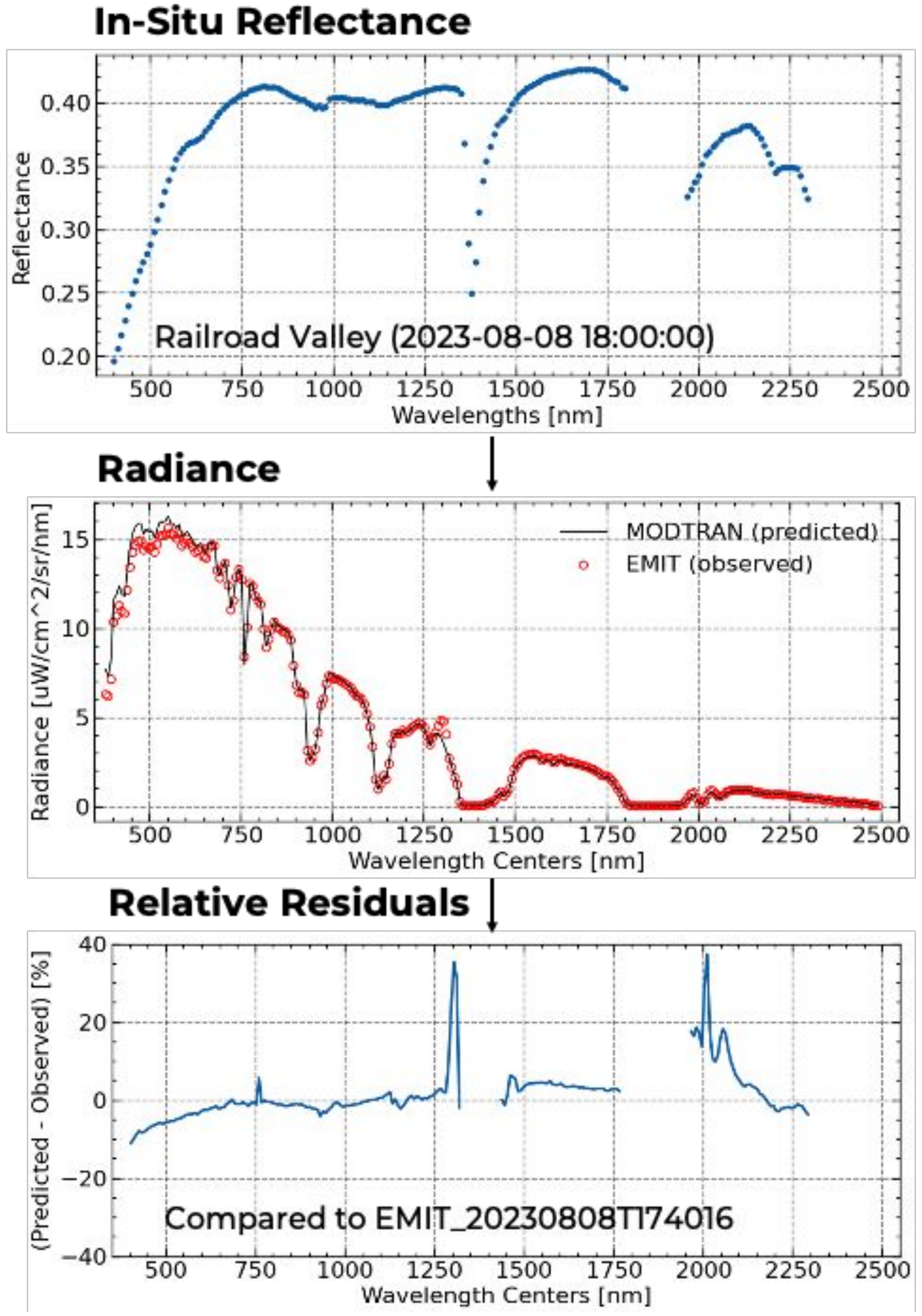
On orbit, the radiometric calibration will be revised using vicarious calibration

Plan:

1. Obtain in-situ surface reflectance data at a high-elevation playa.
2. Predict at-sensor radiance using the approach outlined in Bruegge+ (2021).
3. Derive updated calibration coefficients
4. Validate against other locations with available ground reflectance data

Large high-elevation playas will be preferred, e.g.:

- Black Rock Playa, NV
- Ivanpah Playa, CA
- Railroad Valley, NV



The figures on the left demonstrate the vicarious calibration method applied using the automated RadCalNet station at Railroad Valley as reference.

In this exercise, we are able to recover EMIT's calibration to <5% across most wavelengths.

Spatial response functions and field angles are measured pre-launch

A white light source illuminates a test slit placed at the focus of a collimator. The slit is then scanned in the along-track or cross-track direction to obtain the corresponding response function. (Zandbergen et al. 2023)

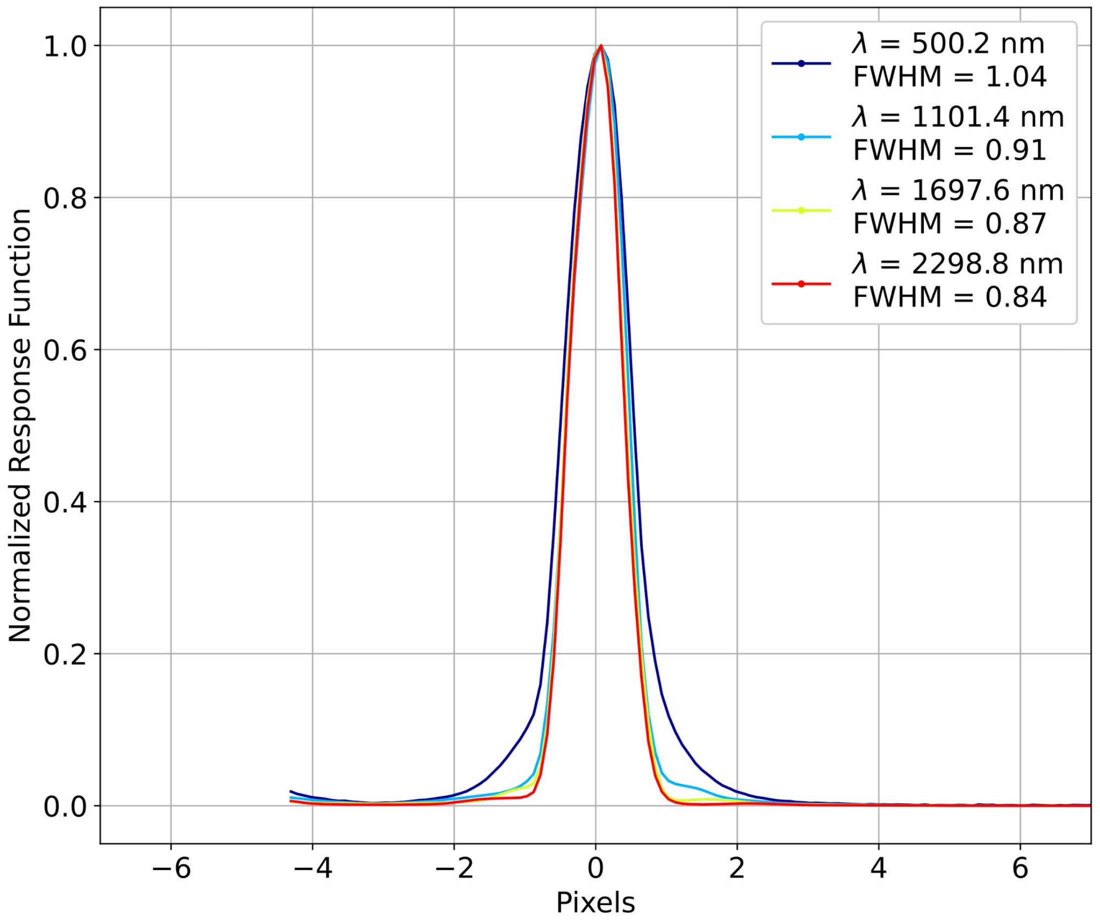


Figure: Example Along-track Response Functions (ARFs).

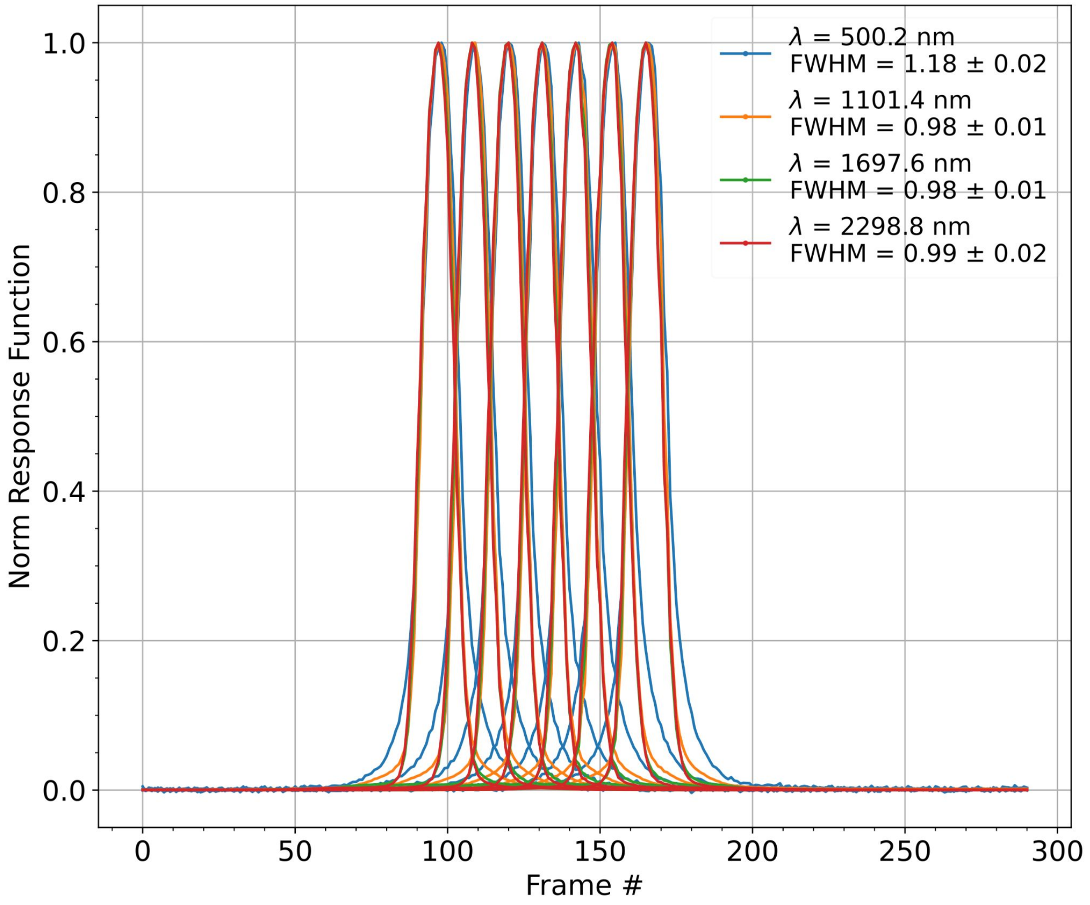


Figure: Example Cross-track Response Functions (CRFs).

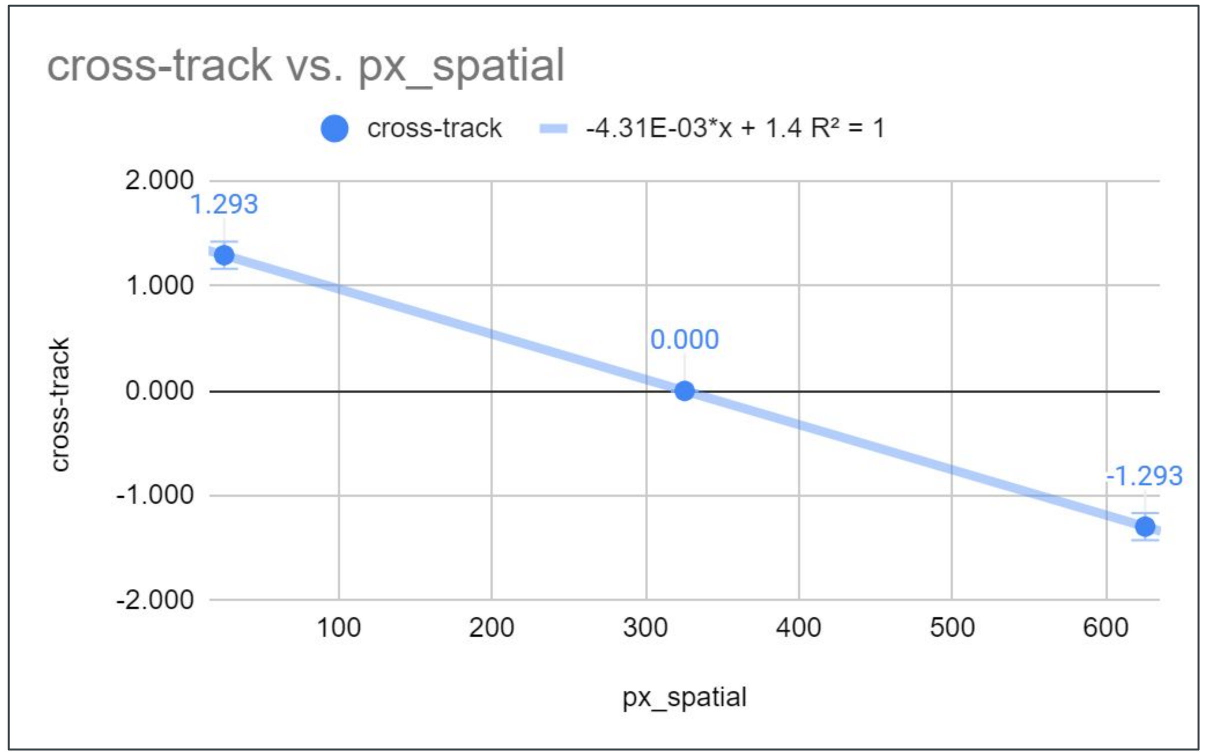


Figure: Example model cross-track field angles.

On orbit, Ground Control Points (GCPs) are used to fine-tune the camera model and evaluate geolocation performance

Images over locations with identifiable spatial structure and dense, pre-existing Ground Control Points (GCPs) allow us to:

- Verify swath width and spatial sampling
- Correct for line-of-sight error
- Update the camera/slit model
- Provide a full state model needed for orthorectification
- Characterize geolocation performance

Tanager's geolocation builds upon existing Planet expertise. See talks by Matthias Kolbe and Graham Mills today.

Figure: Example GCP matching between EMIT and Landsat-8.

Campaigns are being planned to validate our calibrations

Goals:

1. Validate surface reflectance retrievals with ground data and well-characterized calibration sites
   - RadCalNet, Hypernets, PICS, MOBY Buoy.
   - Field team at South Dakota State University.
2. Validate methane retrievals
   - Controlled release experiments led by CarbonMapper/Stanford.
3. Execute cross-sensor comparisons
   - Potential partners include EMIT, EnMAP, PRISMA, NEON, AVIRIS, PACE-PAX, ...

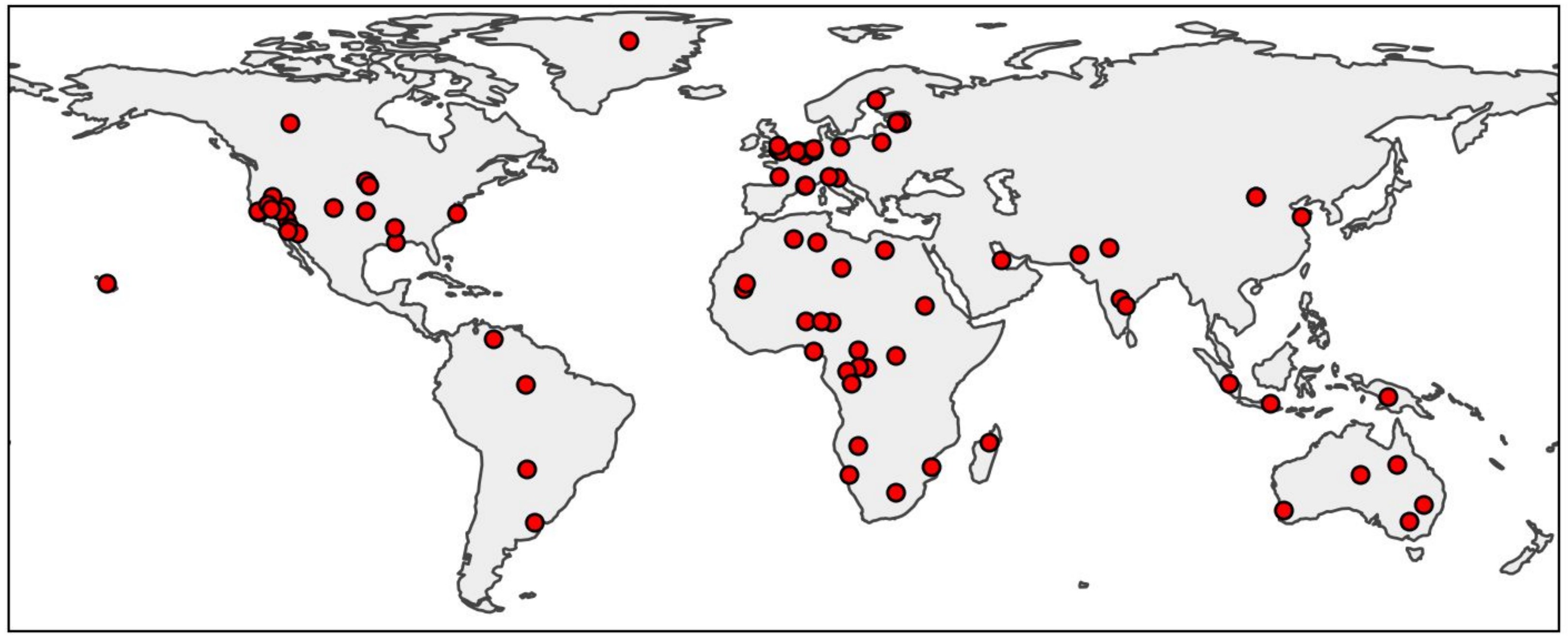


Figure: First Light CalVal targets.

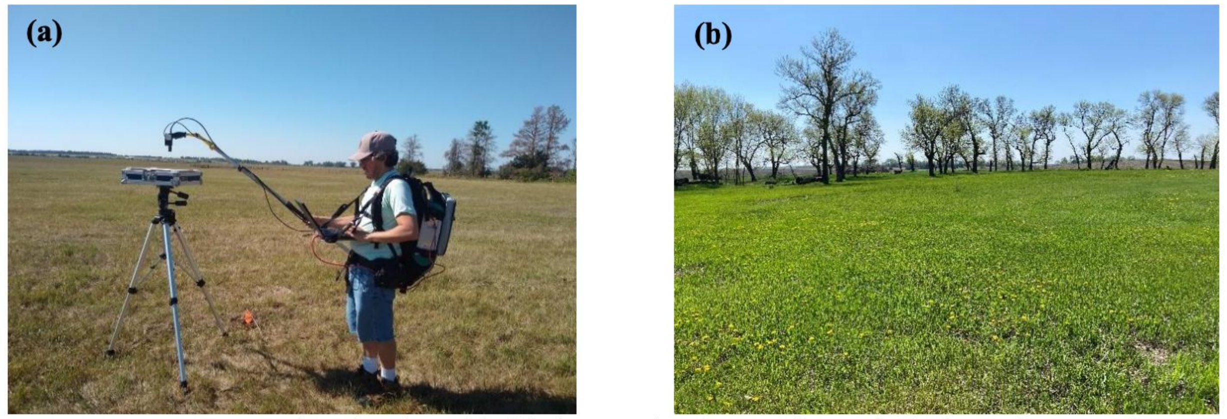
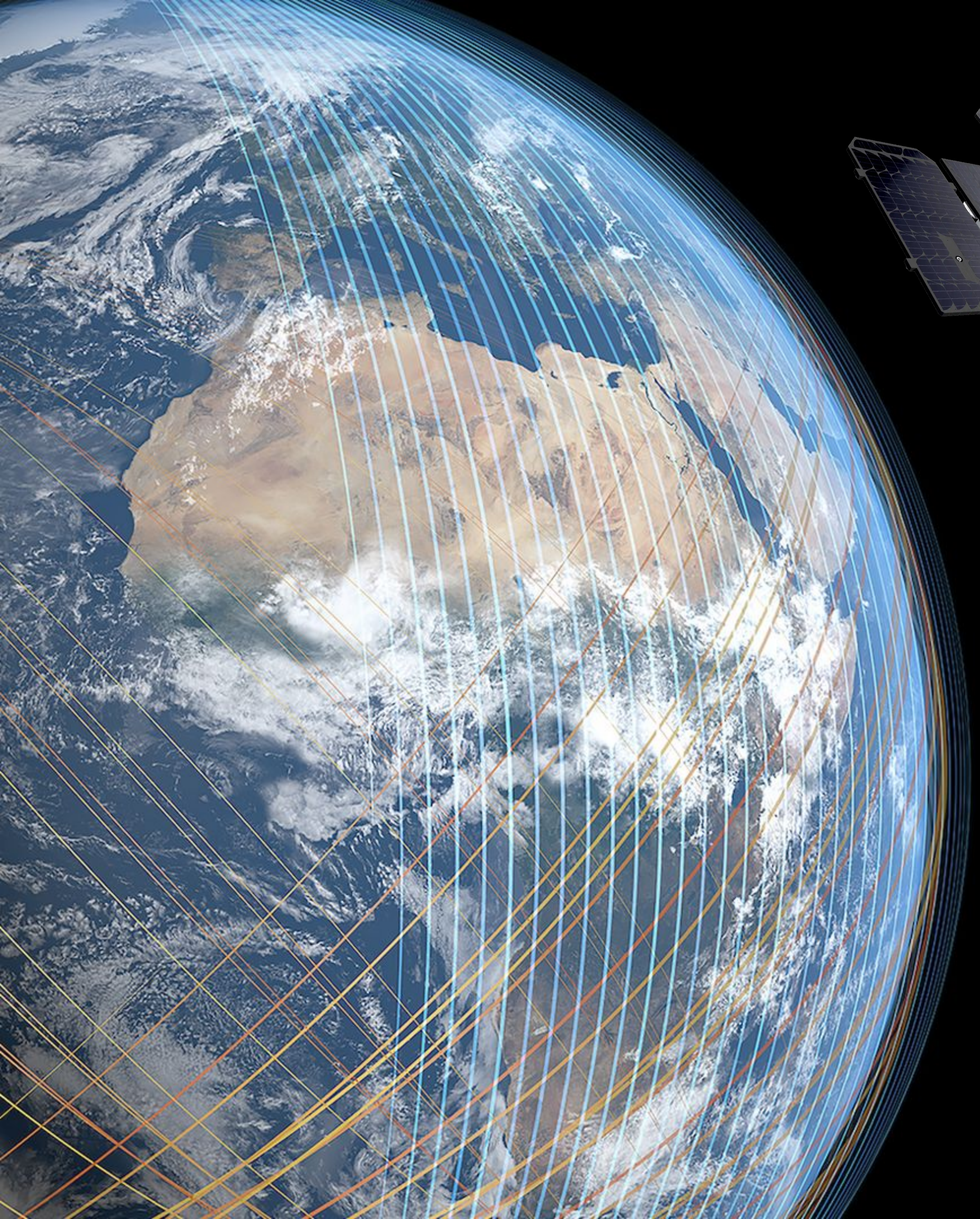
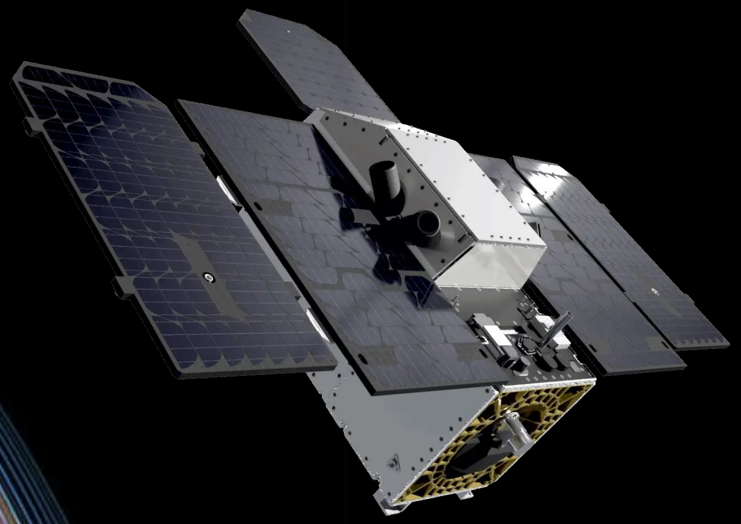


Figure 2. Presents on-site visuals, with (a) the North Airport Site and (d) the Arlington Site.

We expect to publish results in the scientific literature and quarterly data quality reports.

Please get in touch if you'd like to partner with us!





Thank You.

Connect with us at
hyperspectral@planet.com

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