CubeSat-Scale Hyperspectral Imager for Middle Atmosphere Investigations

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Scientific Solutions, Inc.
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Environment Canada

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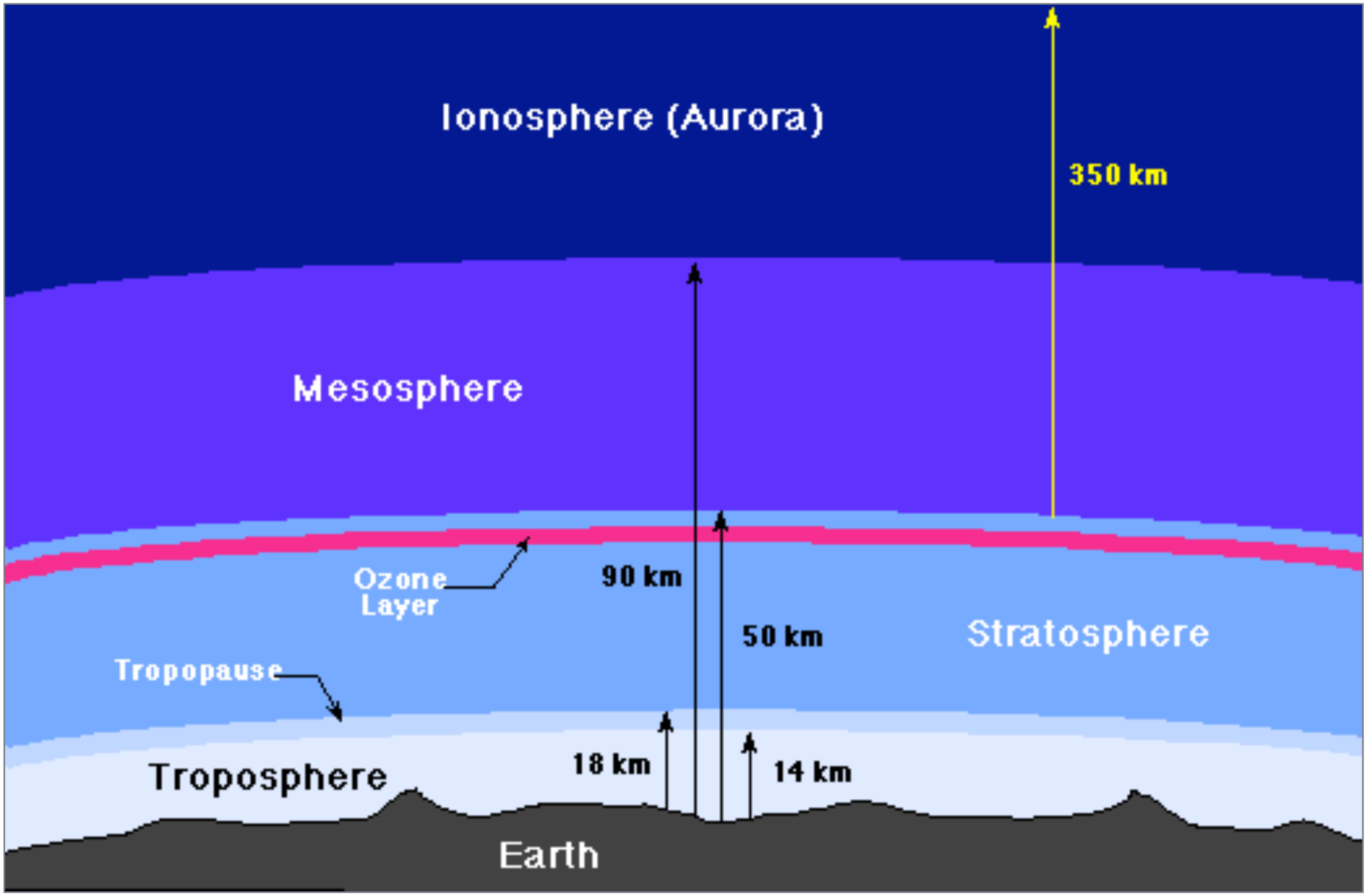
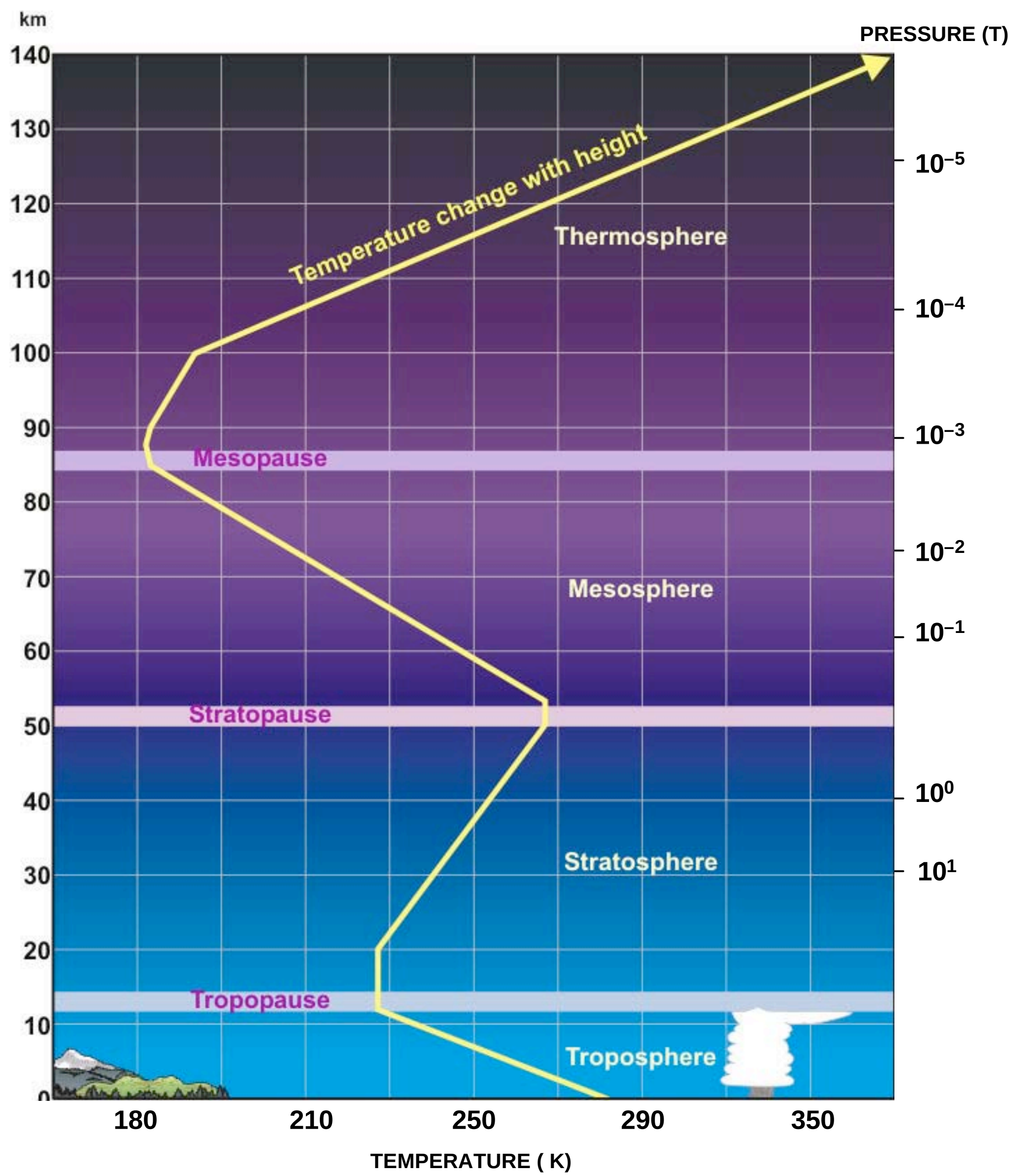
The Earth's Atmosphere



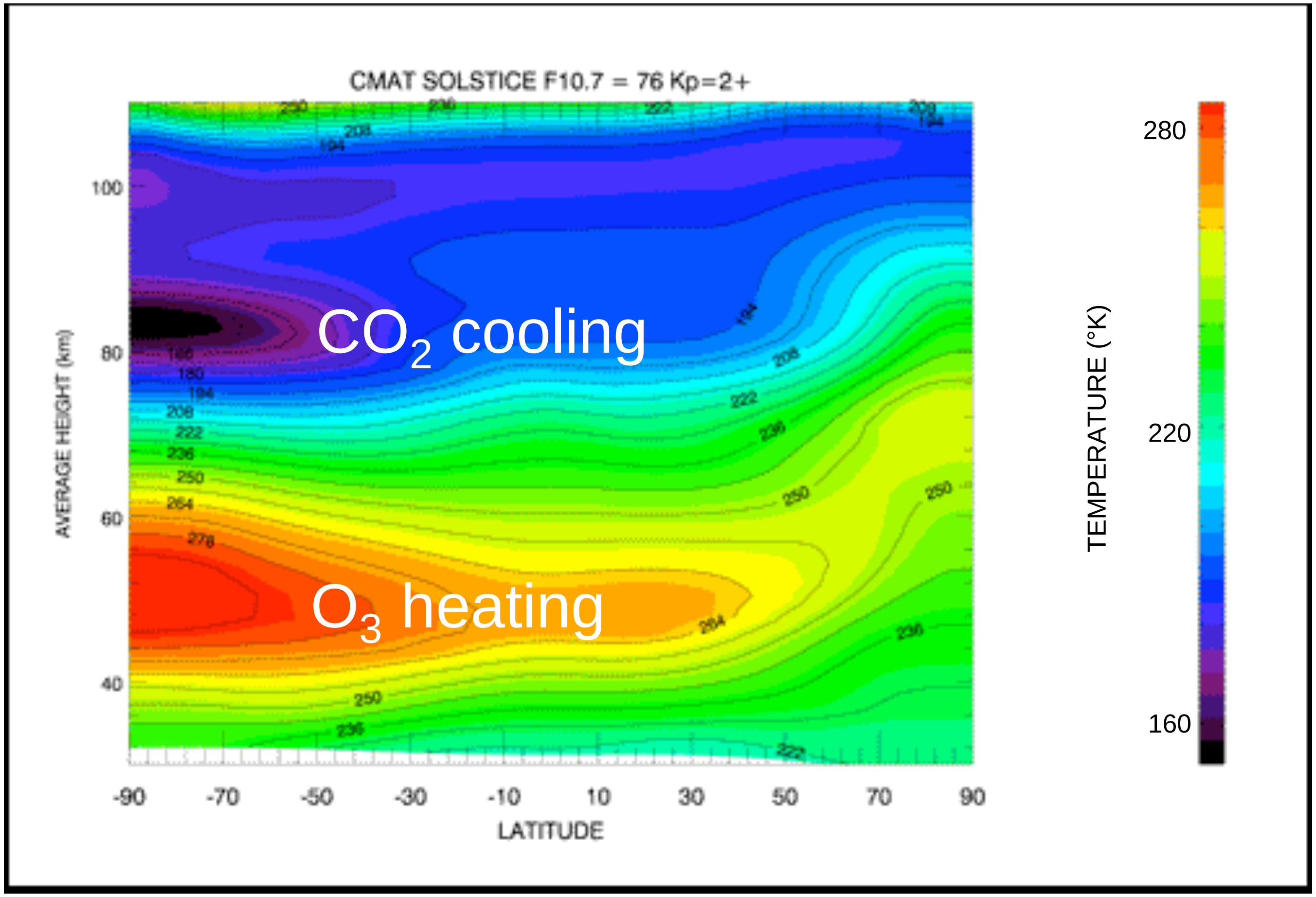
Characteristics of the Middle Atmosphere

- Coldest temperatures on Earth
- Convectively unstable
- Breaking gravity waves drive planetary wind circulation
- Competition between eddy and molecular diffusion
- Meteoric deposition of trace metals (Na, Fe, K)
- Inaccessible to satellites and balloons

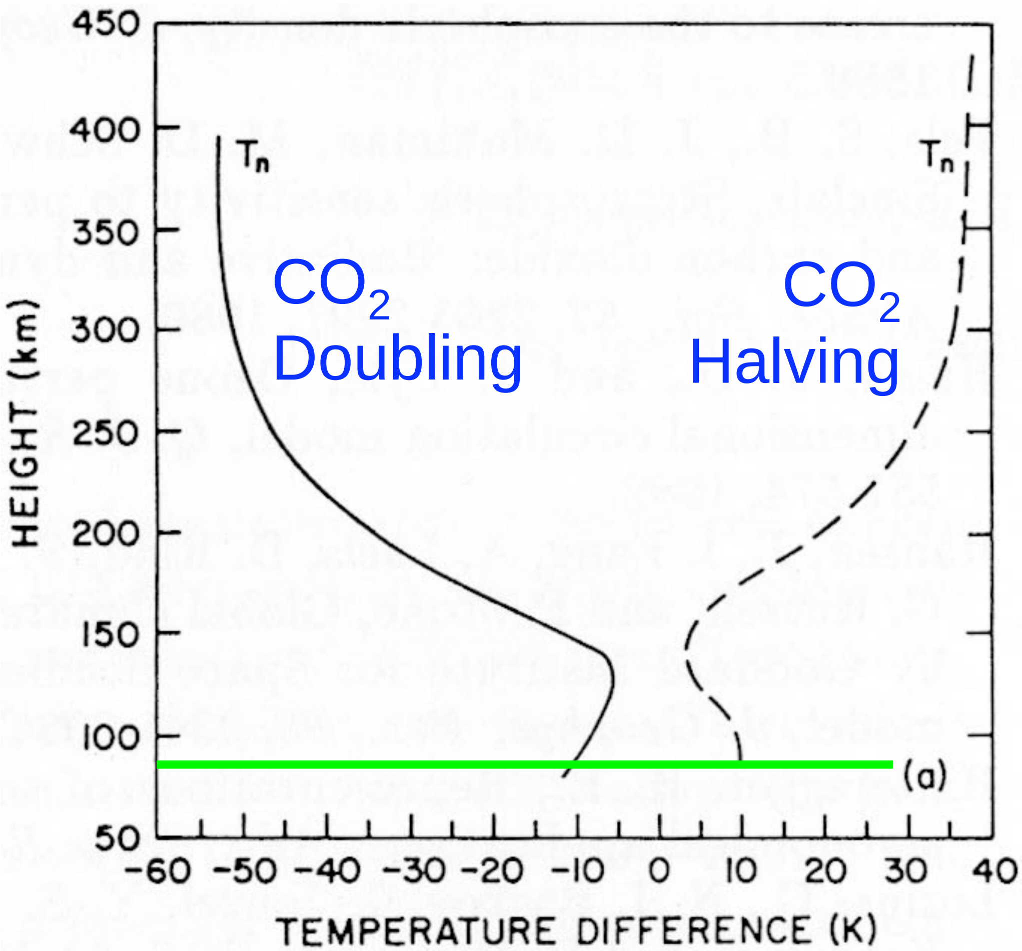
Coldest Temperature in the Atmosphere



Mesospheric Temperature Minimum is Controlled by CO_2 IR Radiation

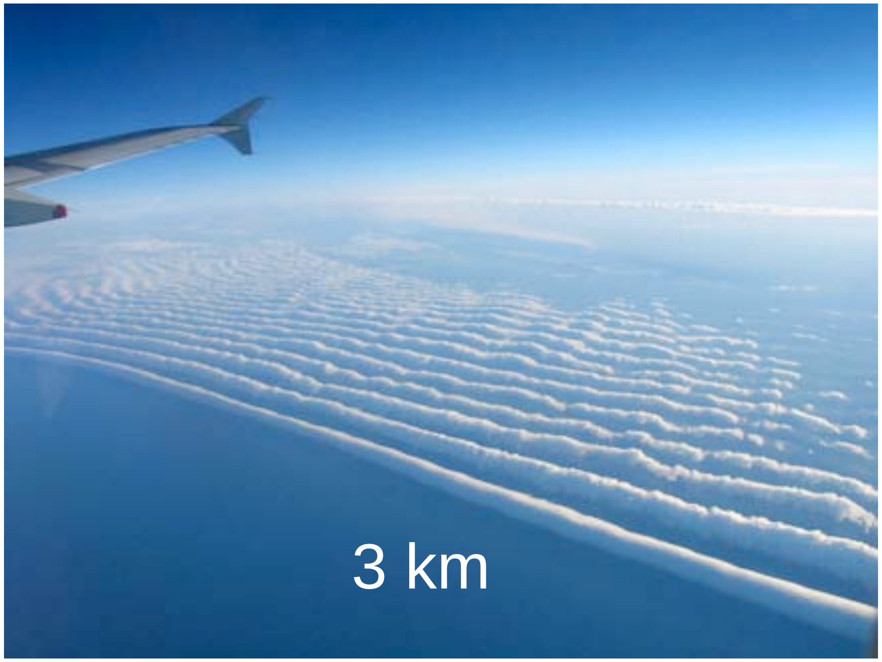


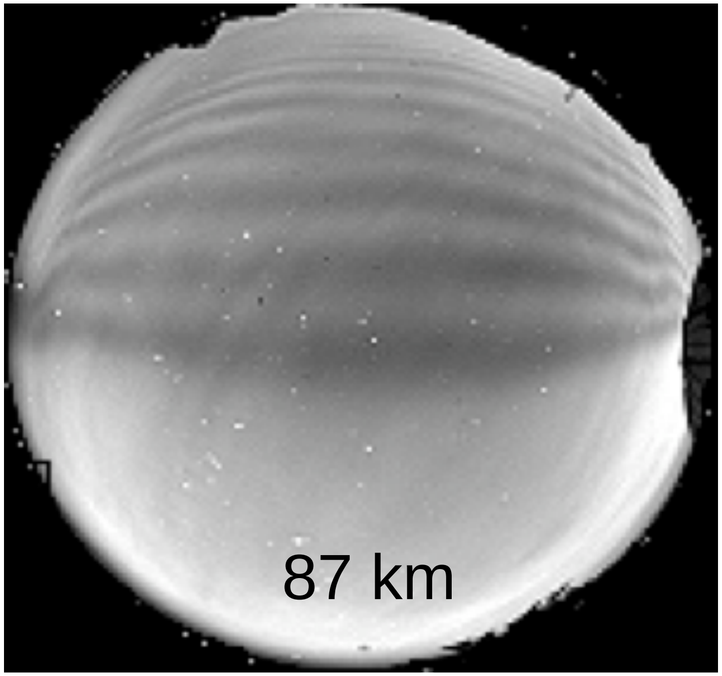
Mesopause Temperature Minimum is a Harbinger of Climate Change



Roble and Dickinson, *GRL*, *16*, 12, 1441-1444, 1989.

Gravity Waves in the Middle Atmosphere



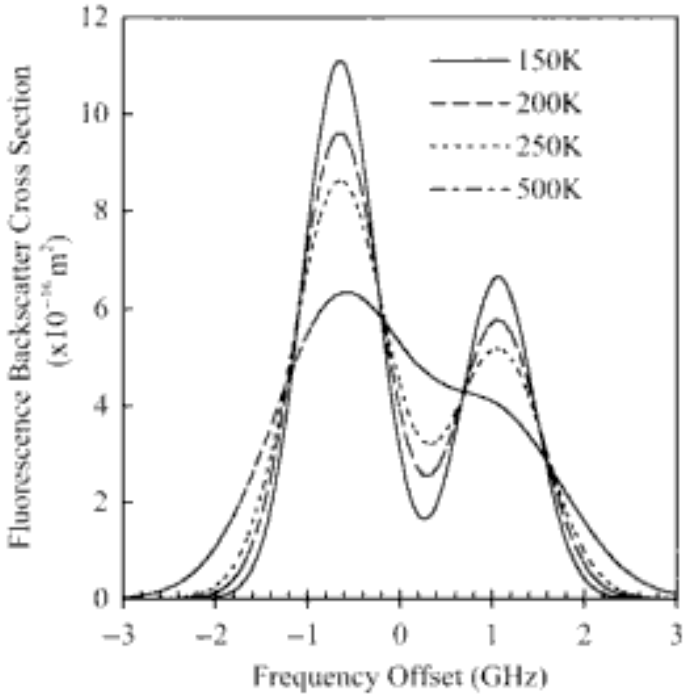


- Middle atmosphere gravity waves couple energy and momentum fluxes from the troposphere to the thermosphere
- GW climatology helps improves our understanding of mean wind flow and tides, turbulence, heat and chemical transport, and higher altitude gravity waves (100–500 km)

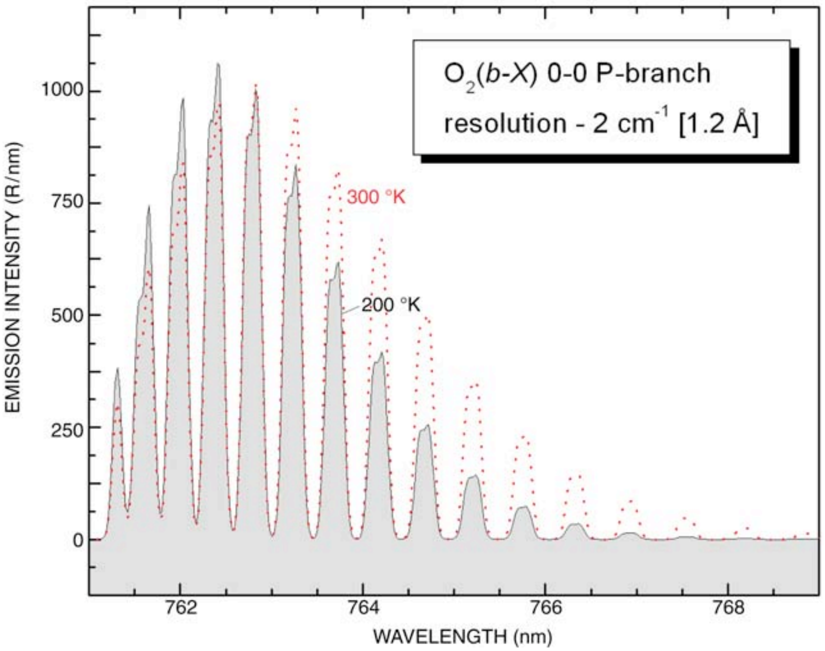
Target Species for Middle Atmosphere Remote Sensing

OH, Atomic Metals (Na & K), O, and O_2

Spectral Signatures are Sensitive to Mesopause Temperature



Sodium (80 - 105 km)

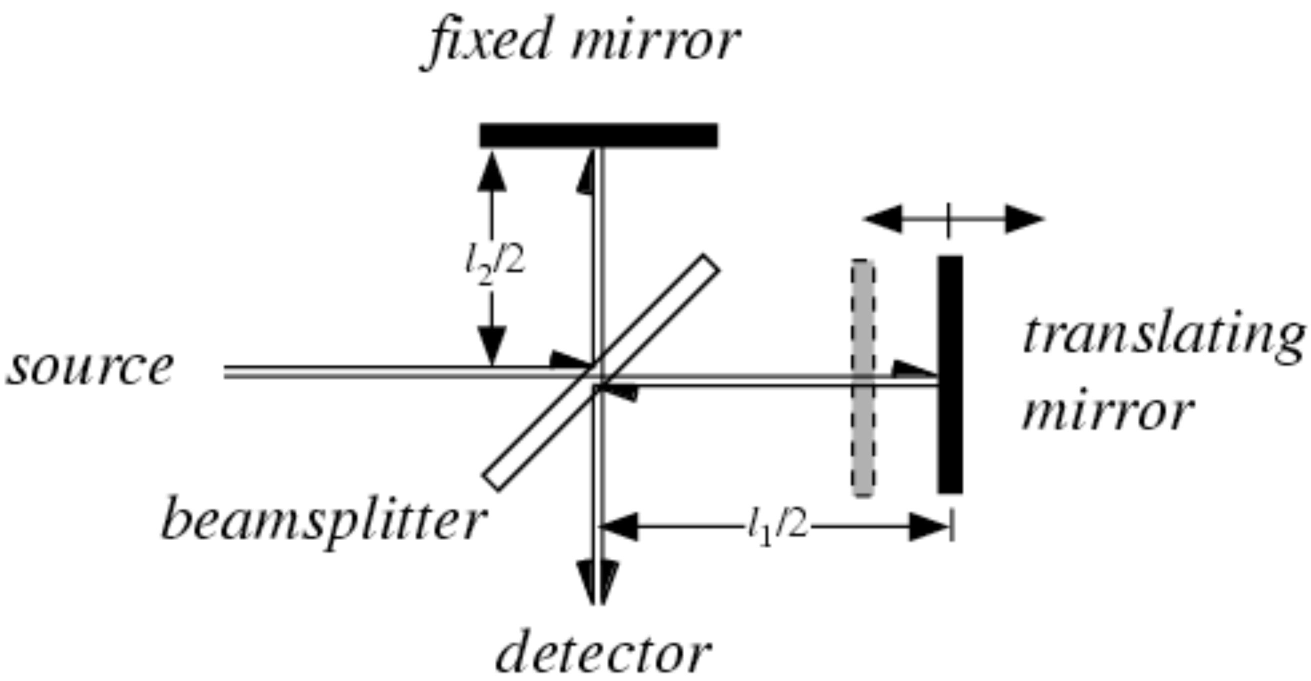


Molecular Oxygen (97 km)

Candidate Techniques for CubeSat-Based Middle Atmospheric Studies

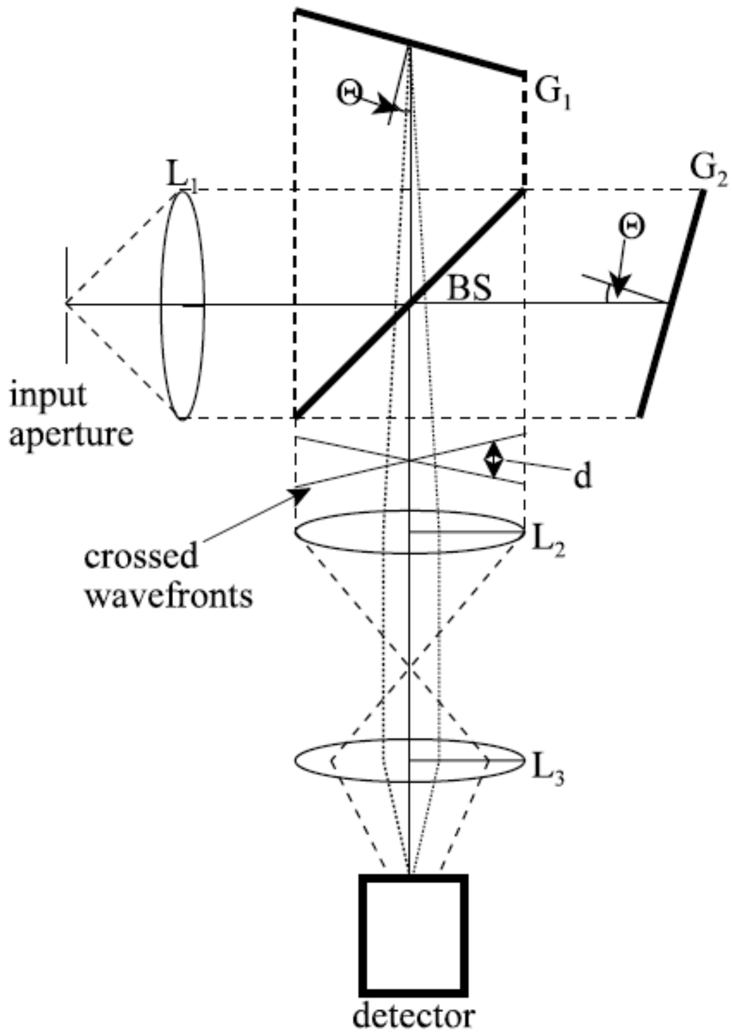
- Imagers (limited spectral information)
- Traditional Slit Grating Spectrograph (large)
- Interferometer (luminosity advantage)

Classic Michelson Interferometer



- Peaks and Nulls in Fringe Pattern Probed by Moving Mirror
- Recovered Spectra is Fourier Transform of Fringe Pattern
- Moving Parts !

SHS Interferometer - No Scanning Required

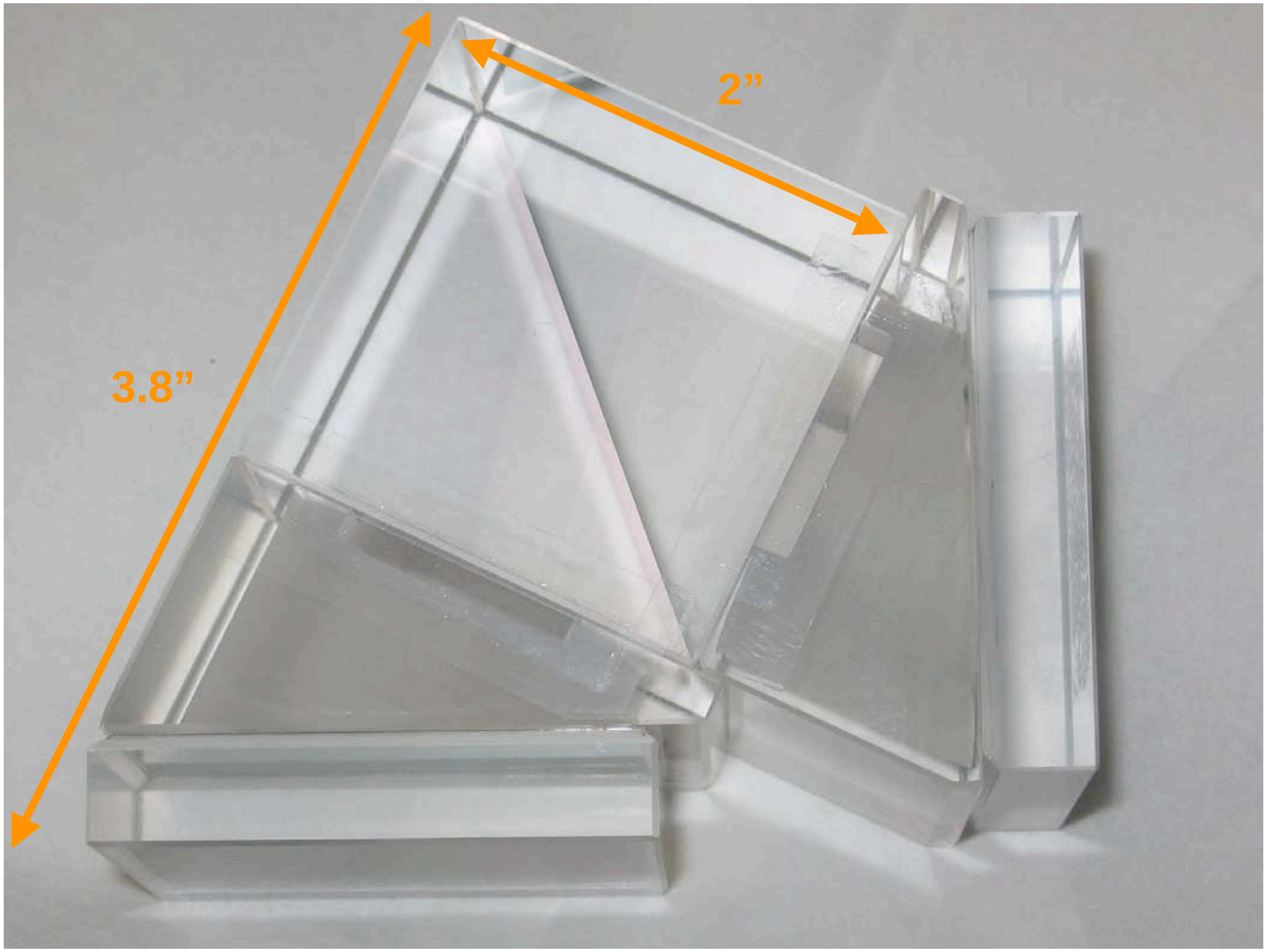


- Tilted gratings replace mirrors to provide crossed wavefronts at exit aperture
- Wedge angle, grating density, and optical path adjusted to tune SHS to desired wavelength, resolution, and coverage
- Fringe pattern (Fourier Transform of Spectra) acquired without scanning
- Robust design

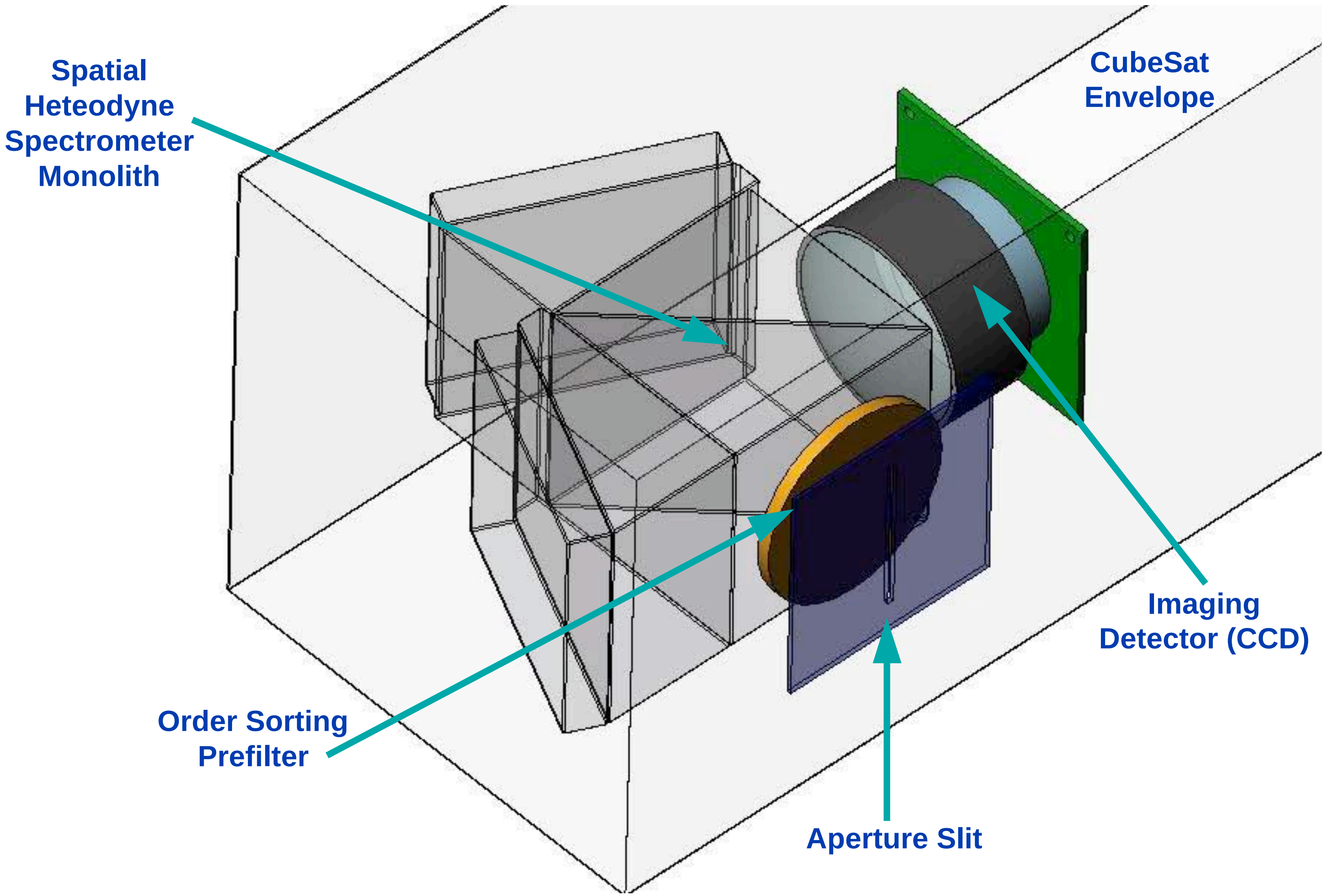
Spatial Heterodyne Spectrometer (SHS)

- Monolithic design can be locked down with no alignment issues or moving parts
- Fused silica design first created for space-based limb imaging of OH by NASA, U Wisconsin, and NRL
- SHS Instrument Operating on STPSat-1 since March 2007

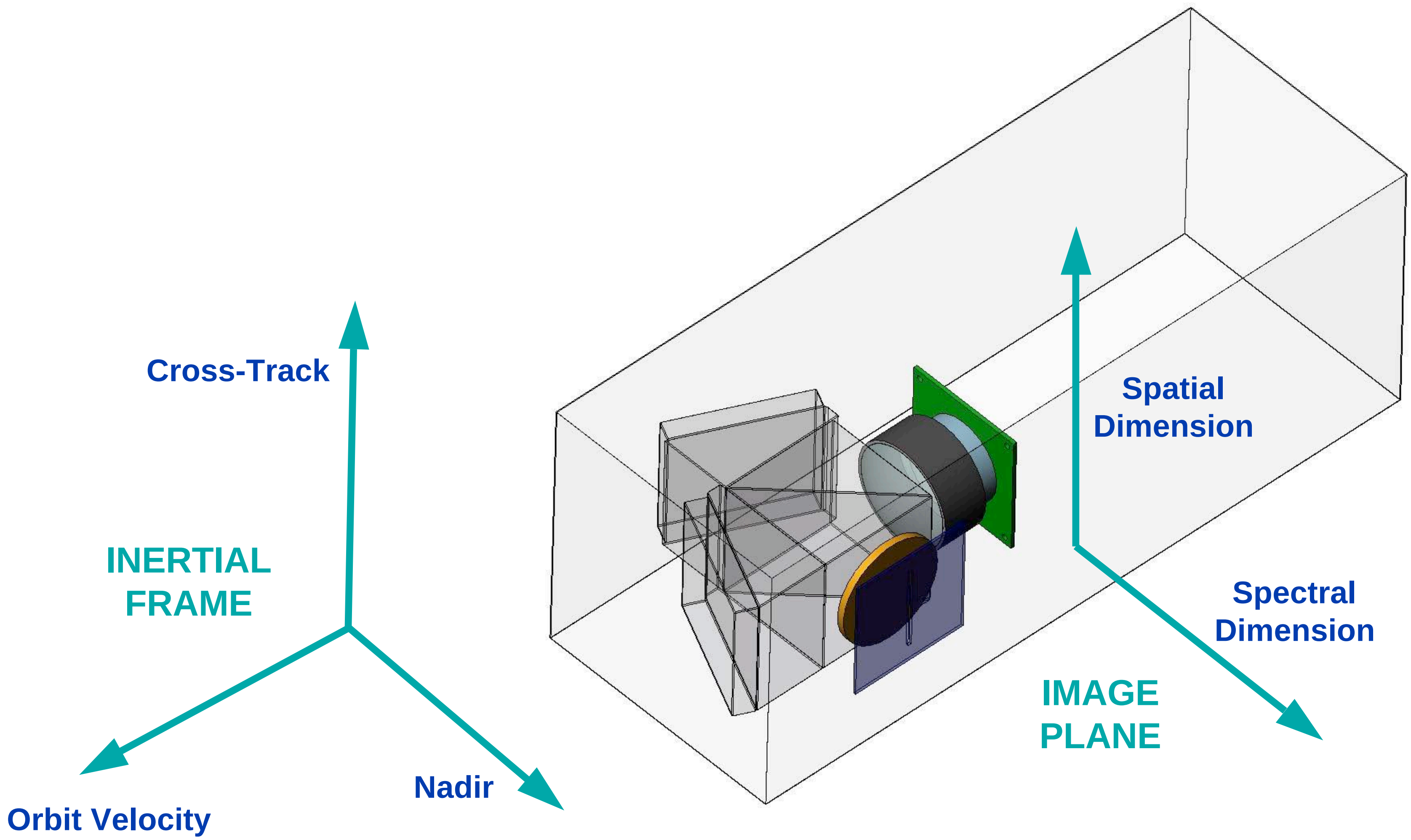
In Hand Na-Optimized SHS Monolith



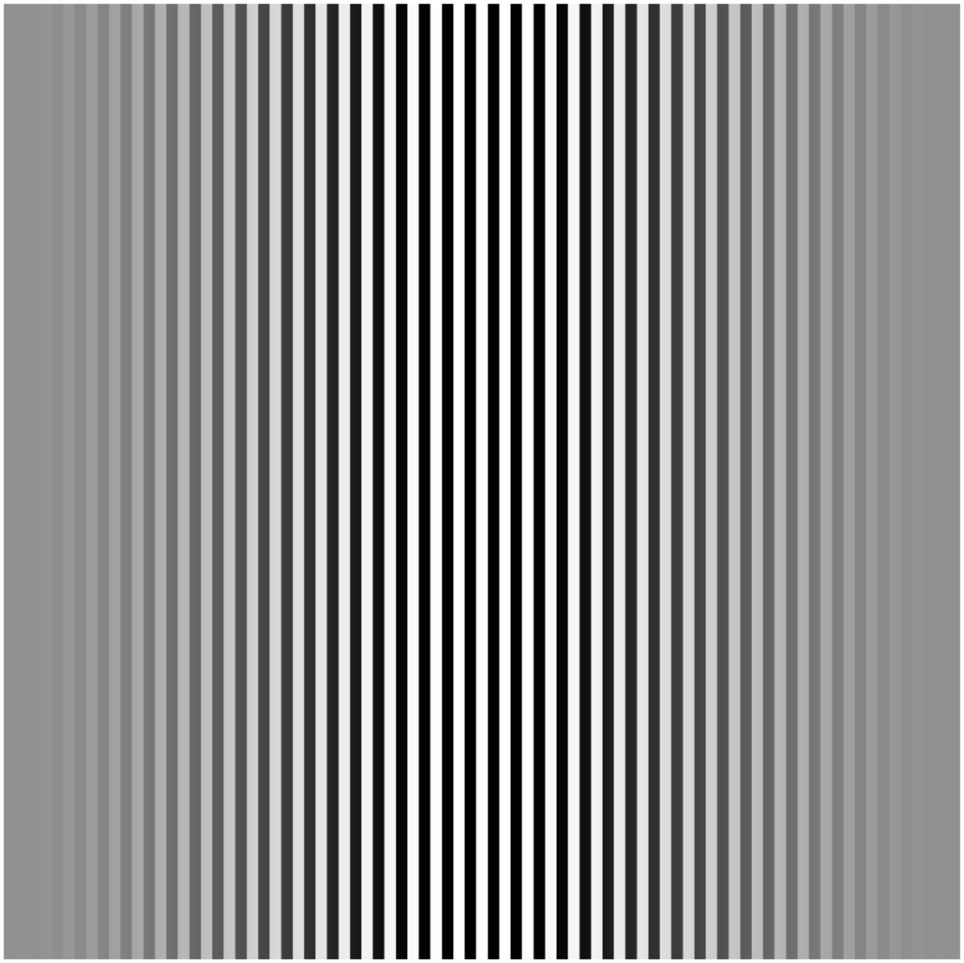
Notional CubeSat HSI (CHSI) Layout



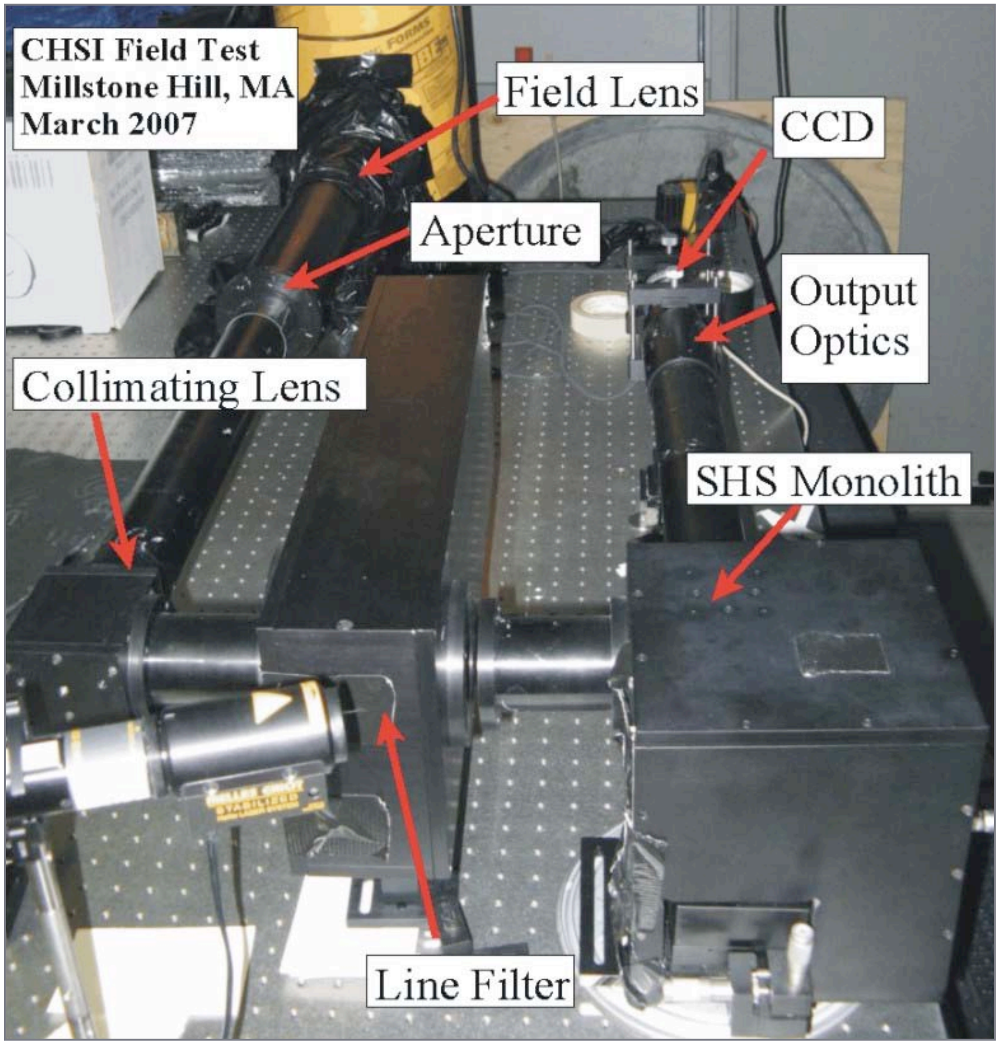
CubeSat HSI Orientation



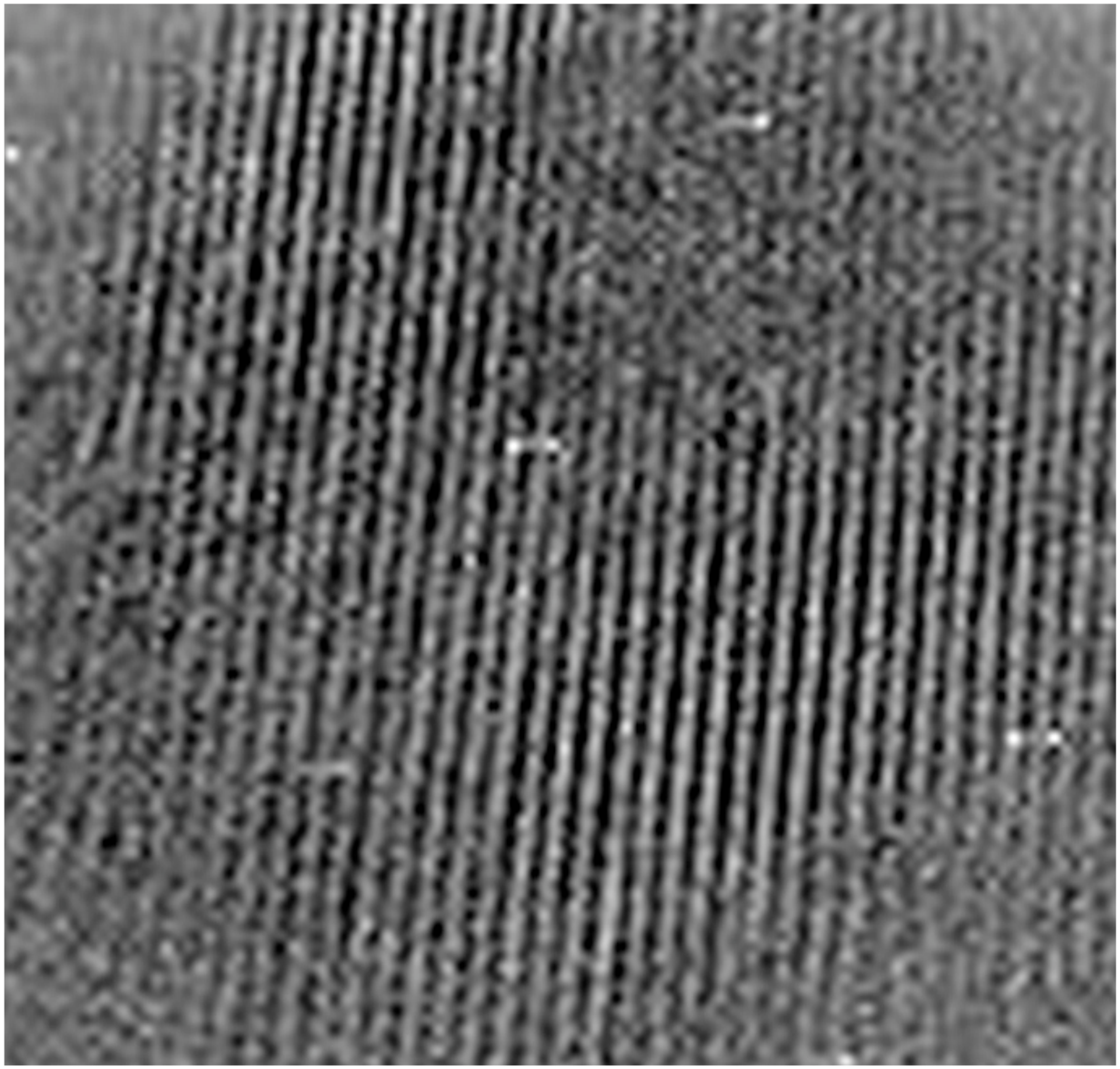
Ideal SHS Fringe Pattern for Imaging Spectroscopy



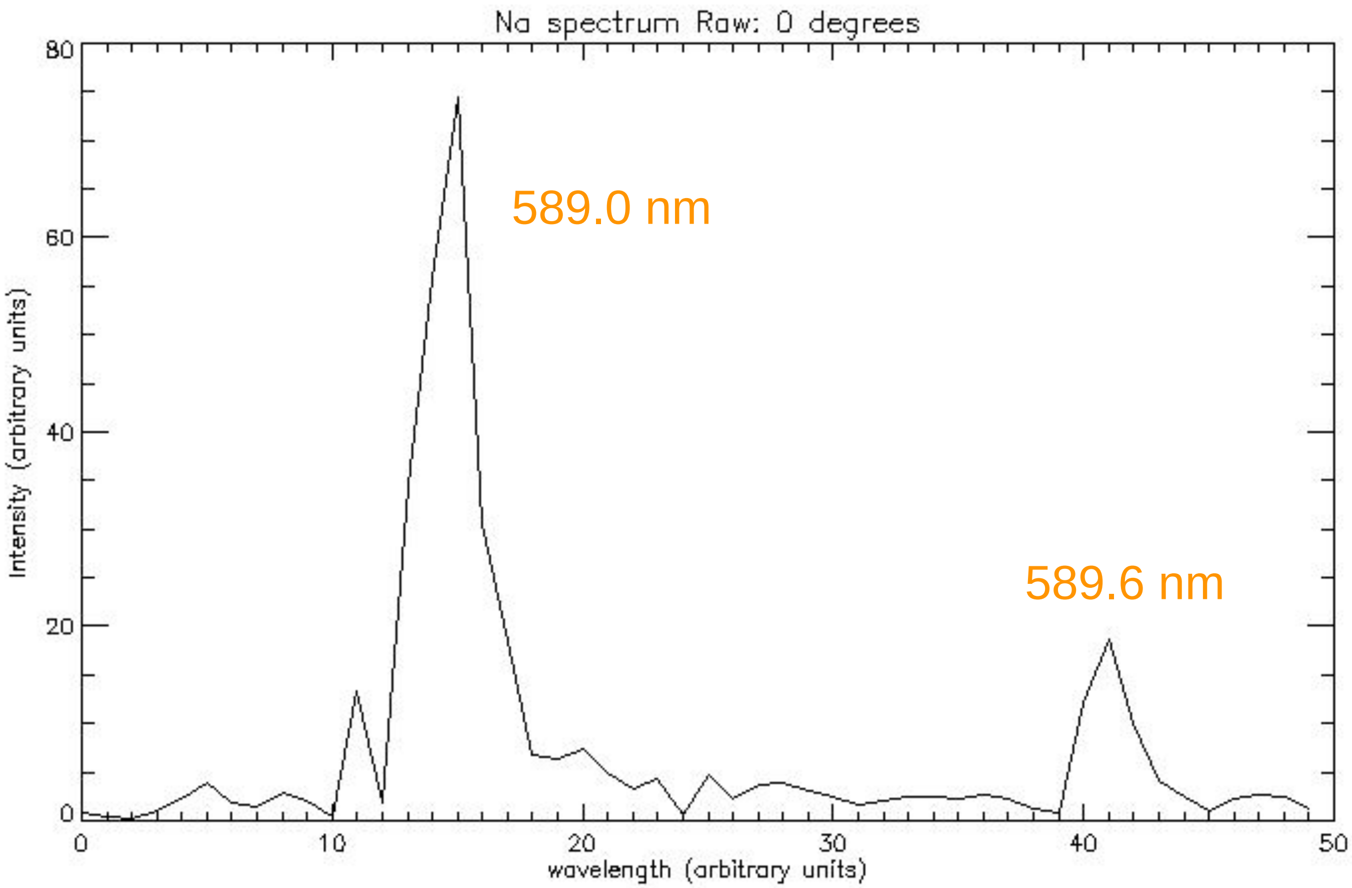
Prototype Sodium CHSI Field Test



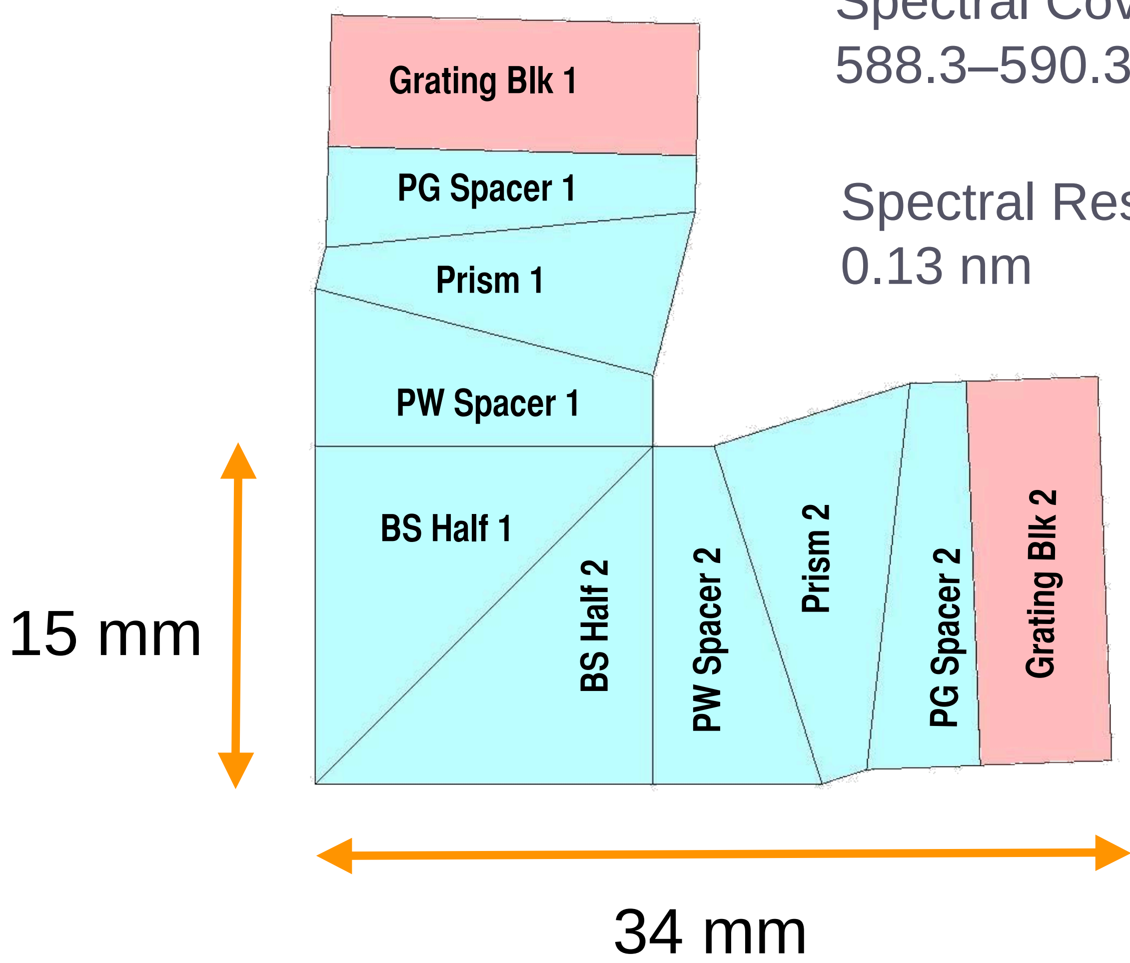
Raw Fringe Pattern from Prototype of Sodium CHSI



Recovered Na Spectra from CHSI Prototype



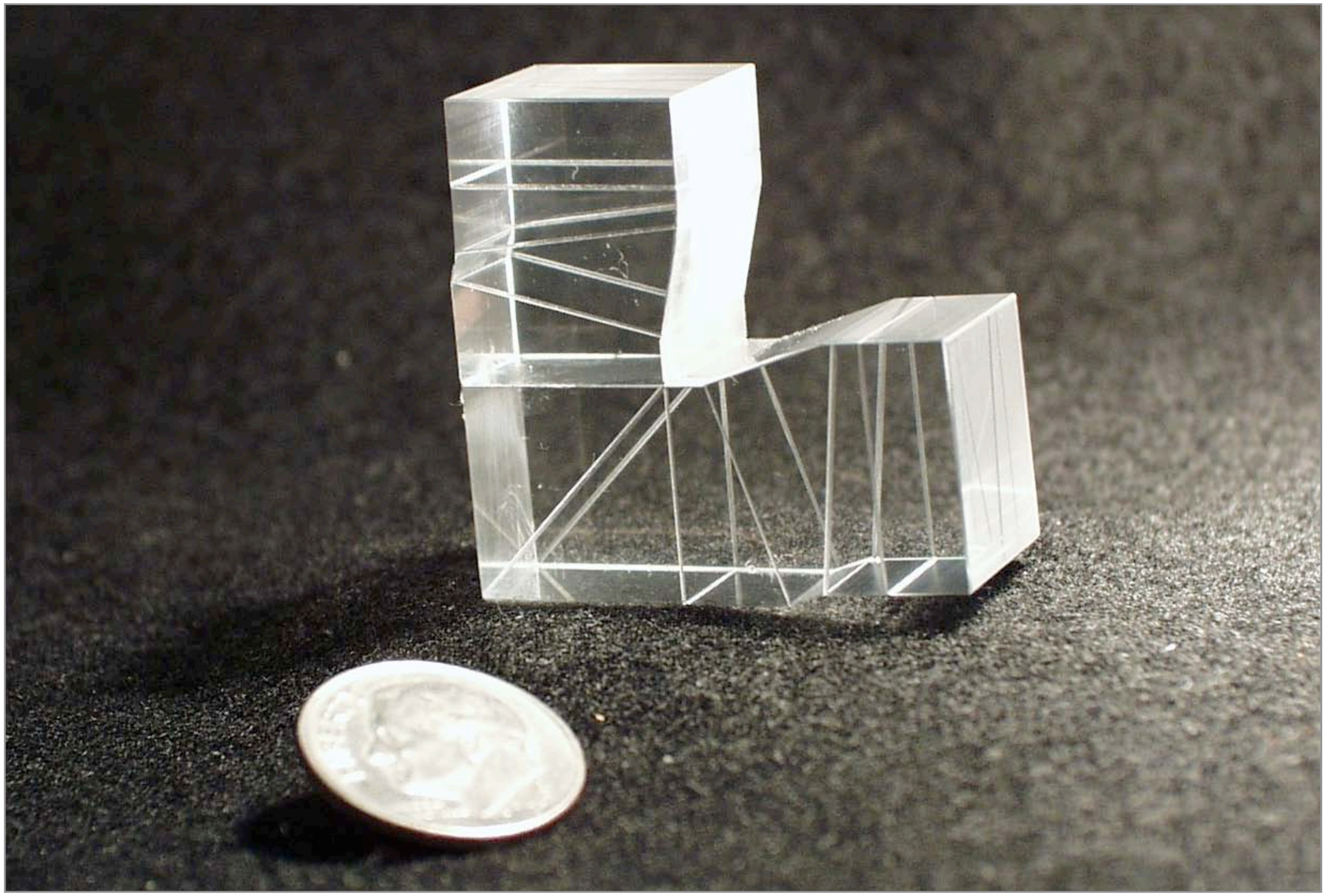
CubeSat-Optimized Na Monolith Design



Spectral Coverage:
588.3–590.3 nm

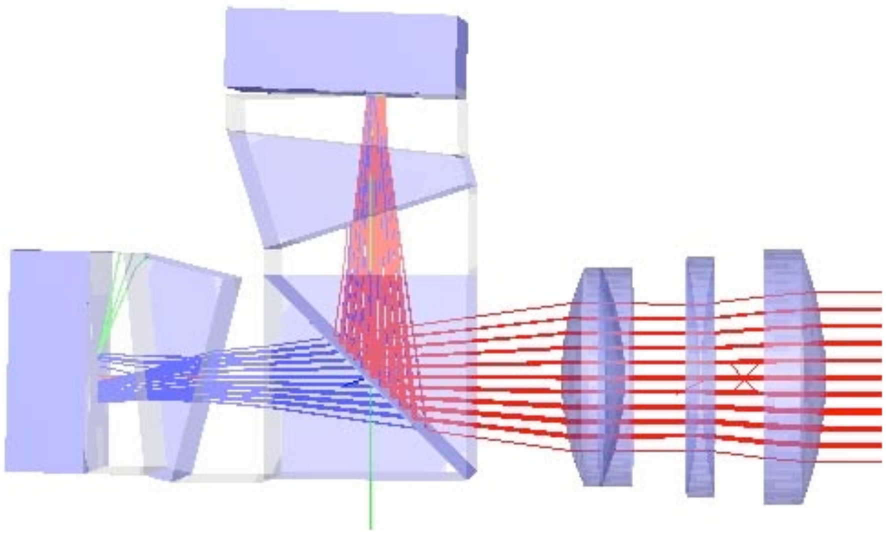
Spectral Resolution:
0.13 nm

CubeSat-Optimized Monolith Mass Model

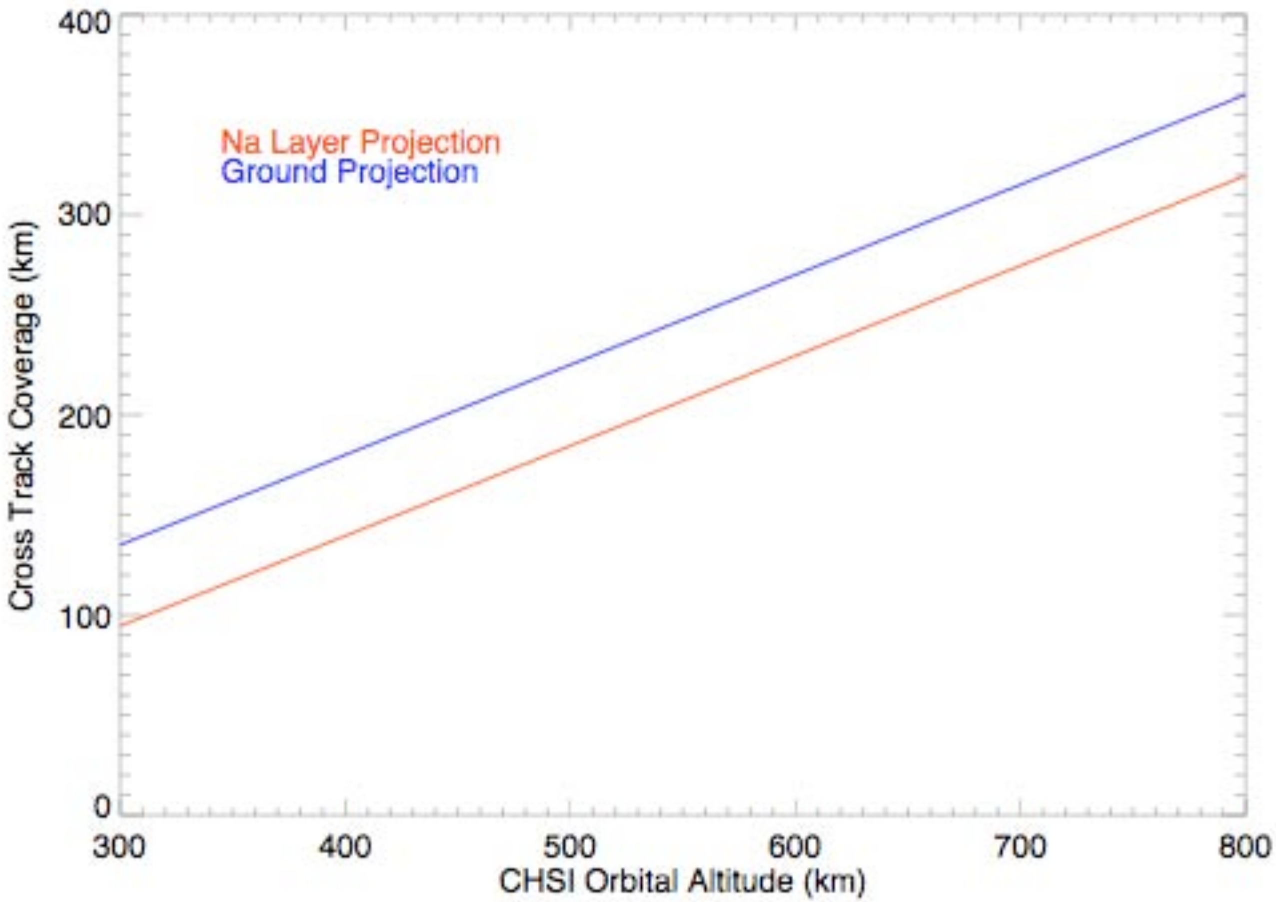


Front Optic Selection

- 50 mm FL for 10° spatial field of view on grating
- Low-distortion Leica rangefinder lens
- 28 mm back focus distance sufficient to illuminate grating

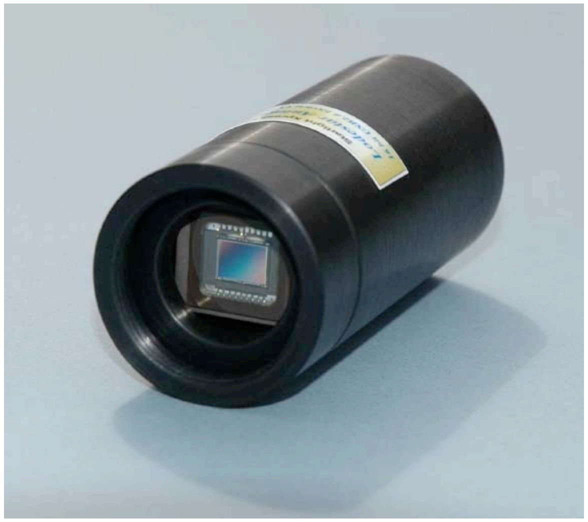


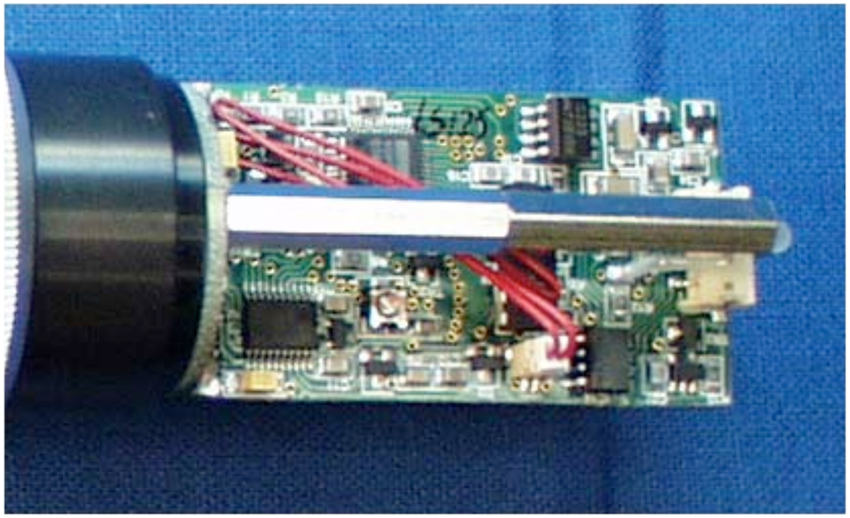
Spatial Coverage



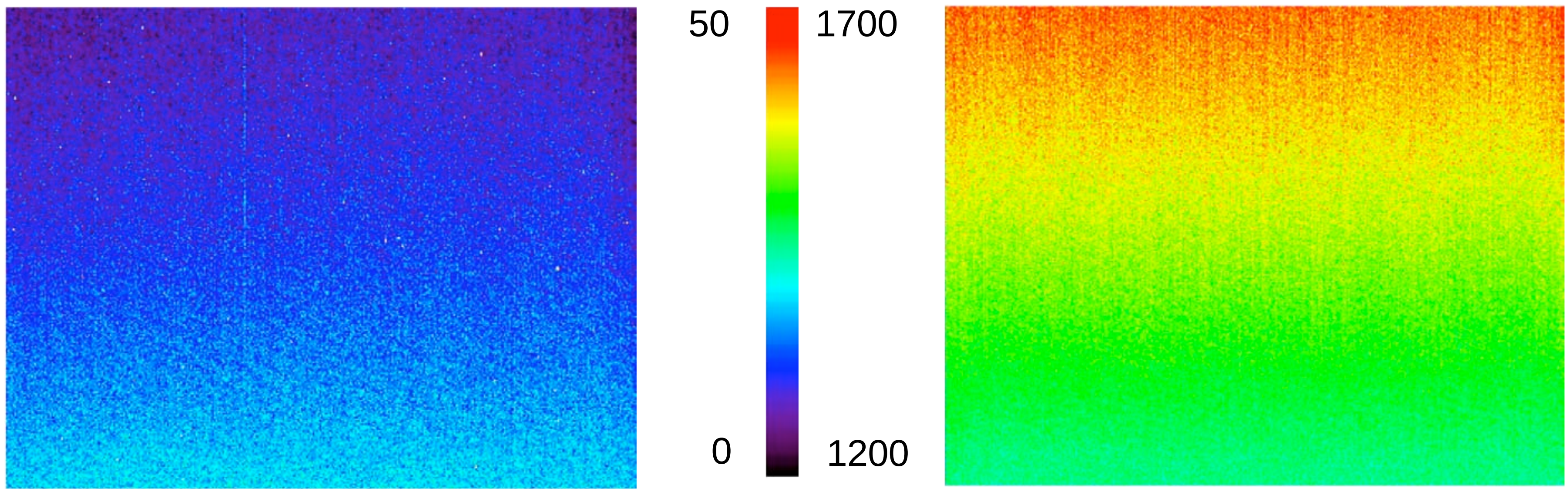
Starlight Xpress Lodestar CCD Camera

- Astronomy grade 752 X 580 pixel Sony ICX429AL CCD
- Low noise, 16-bit dynamic range, 10 Hz max sampling
- On-chip binning to enhance SNR and minimize telemetry
- Extensive Linux libraries for image processing





CCD Camera Performance



Dark Noise, 50º C

1 s Integration

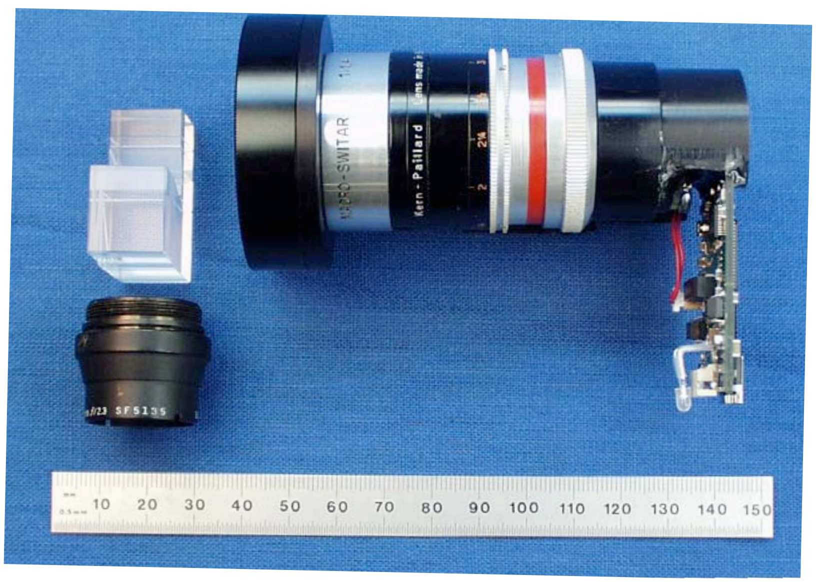
Read Noise, 50º C

1 ms Integration

Reimaging Optics Selection

- Transfers SHS fringe pattern to CCD focal plane
- Large aperture (F/1.4) to maximize sensitivity
- Close-up diopter added to decrease standoff distance
- Bolex 36-mm macro lens with +10 diopter adapter

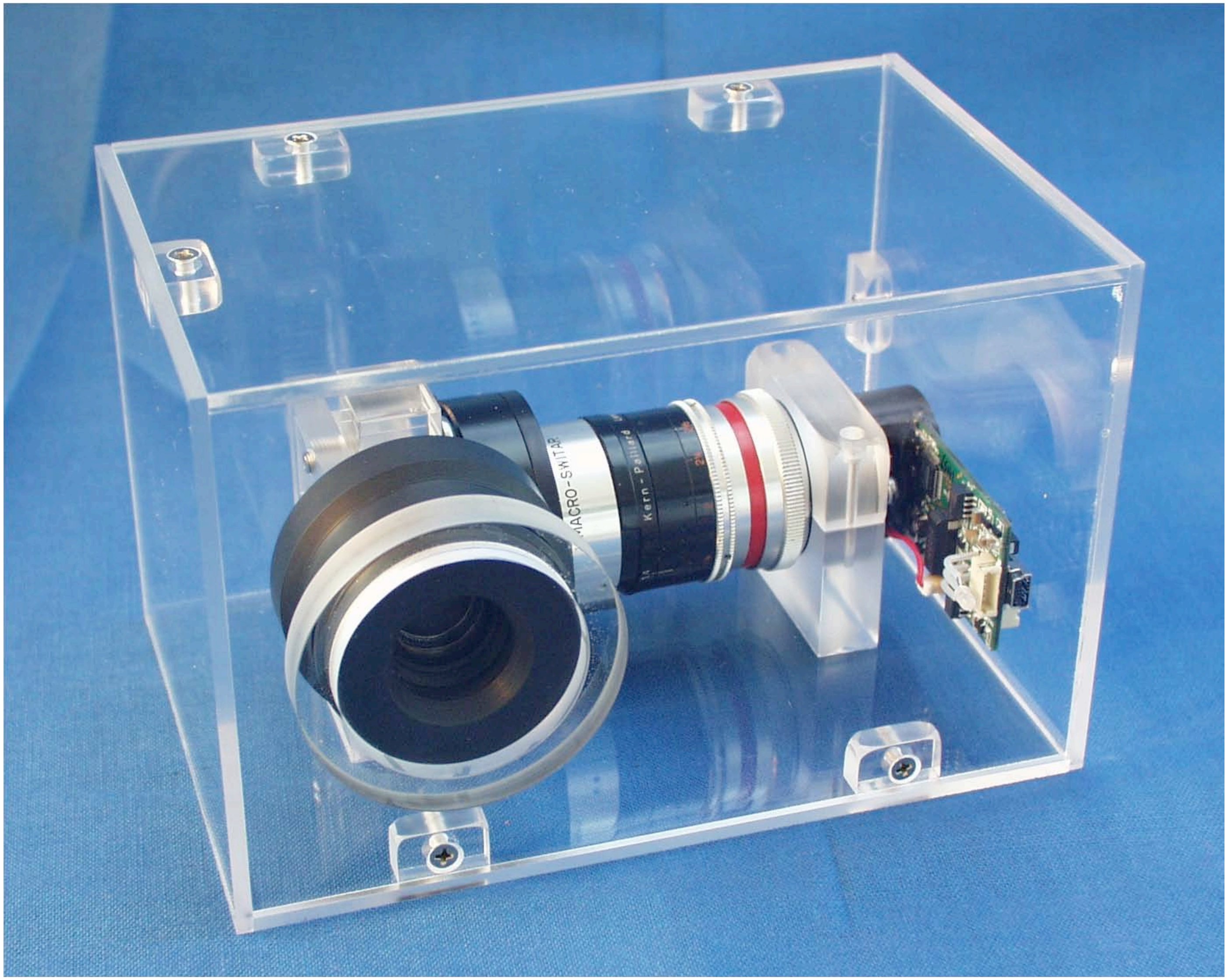
Payload Miniaturization for 1.5 U Form Factor



Miniaturized with

- Folding mirrors
- Folded electronics
- Repackaged lens

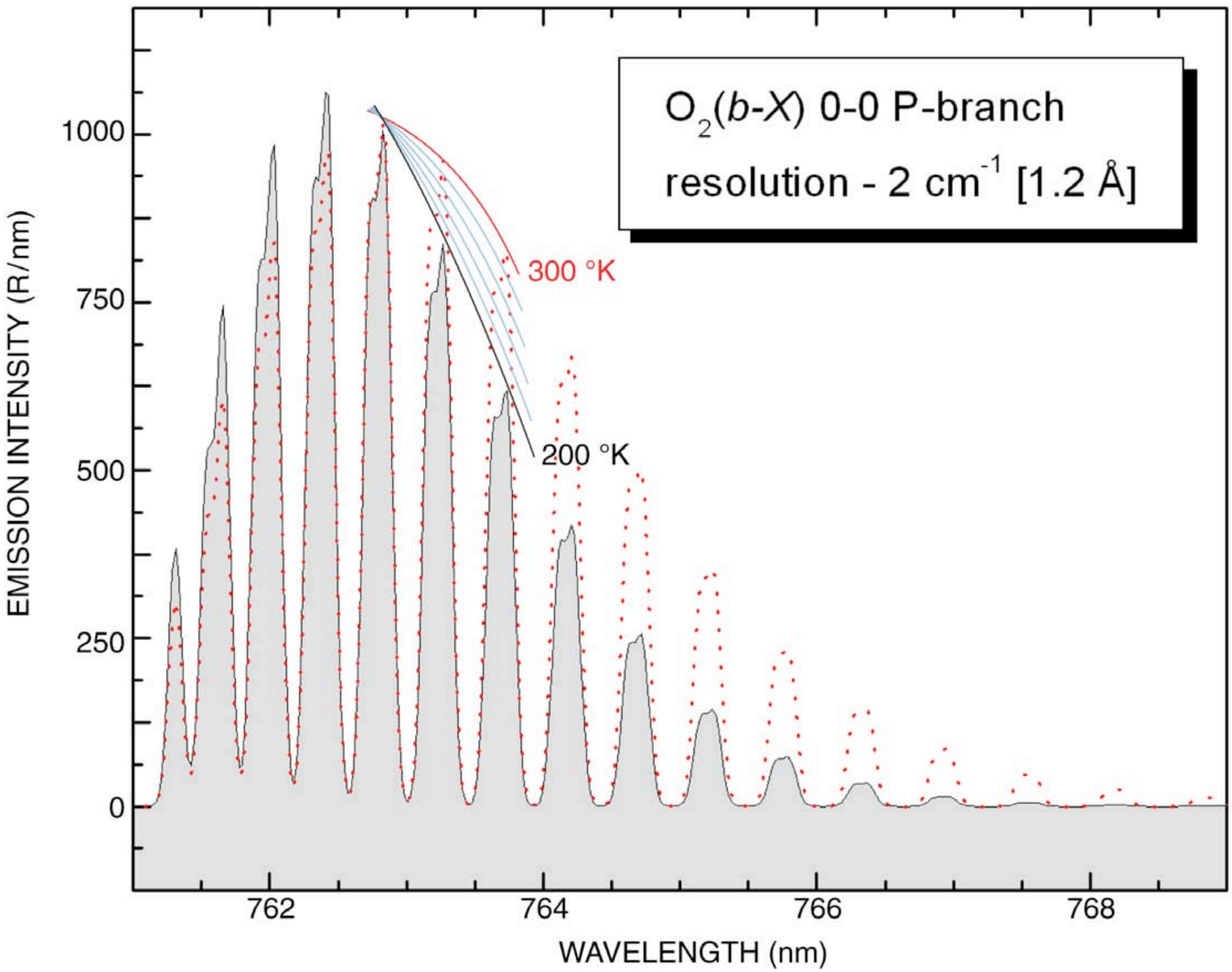
1.5 U CHSI Payload Model



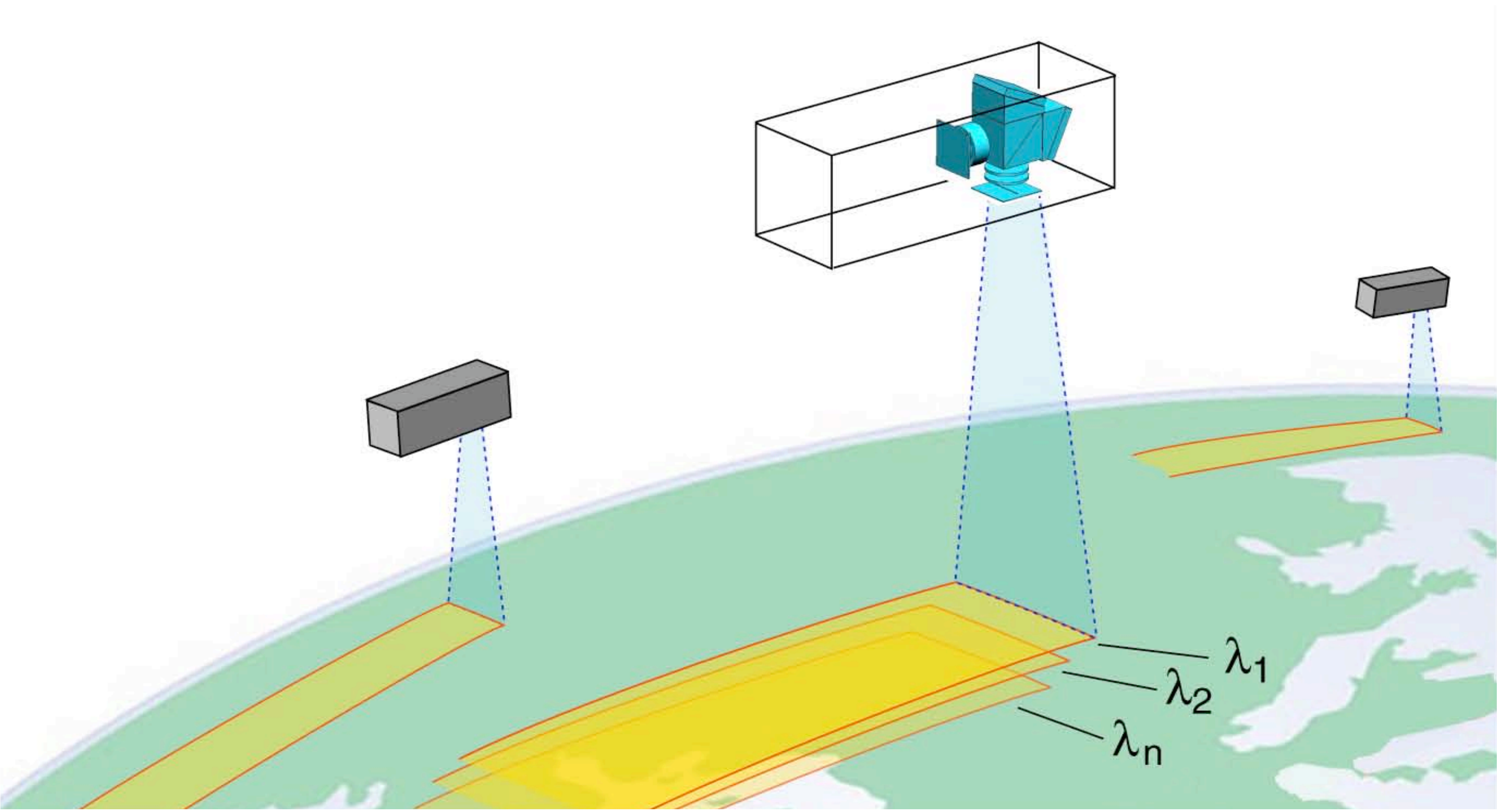
Flight Processing Goals

- Optimize spectral and spatial binning for best science at acceptable telemetry and power loads
- Investigate on-orbit photometric correction (flat fields, dewarping)
- Perform on-orbit FFTs to extract band feature intensity
- Analyze recovered bands to extract temperature

Temperature Extraction from O_2 Spectra



CHSI Requires Nadir Orientation with CCD Spatial Axis Perpendicular to Ram Direction



Path Forward

- Design Integrated Cruciform
- Optimize foreoptic mechanical support
- Assess processing power associated with image manipulation
- Build vibration and thermal test unit