# Design of a Pushbroom Imaging Spectrometer that Exceeds AVIRIS Performance

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# Overview

- Objective
- Critical Characteristics
- Design and Components
- Expected Performance
- Summary

# Objective

- Design a pushbroom imaging spectrometer that exceeds the performance of AVIRIS
- Why?
  - Smaller, lighter, lower power
  - More flexible
  - Easier to maintain
  - Higher SNR spectra
  - Multiple copies could be produced
  - Other….
- Not more uniform, Not simpler to calibrate

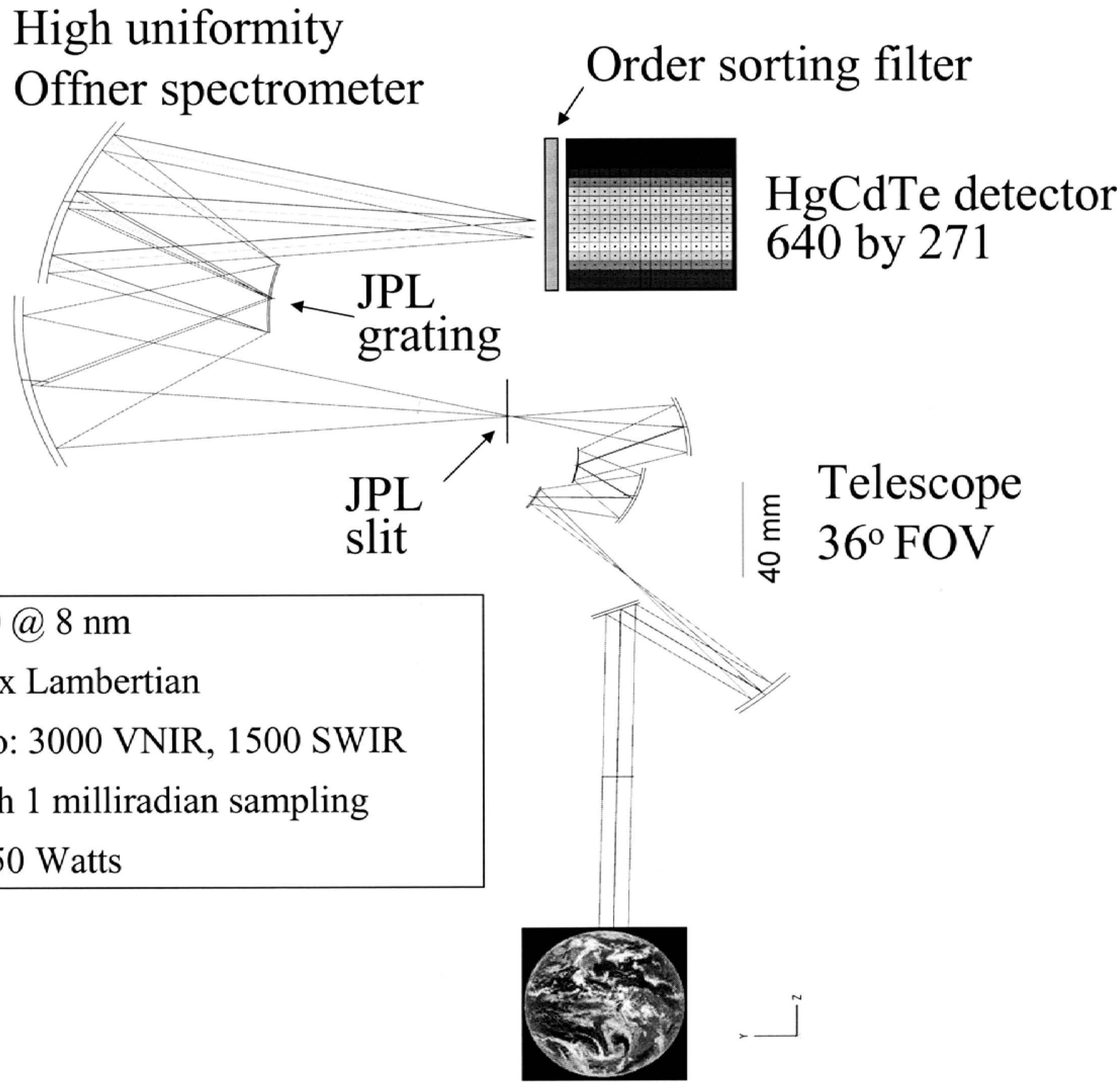
# AVIRIS-II Science Measurement Requirements

- Spectral Range: 380 to 2520 nm at 8 nm sampling
  - Spectral signatures of interest
- High spectral and spatial uniformity
  - Enables scientific imaging spectroscopy
- High Precision (Signal-to-noise ratio)
  - High accuracy retrievals, Low concentration components
- Spatial
  - Spatial swath 36° with 1 milliradian sampling 20 to 0.5 meters
  - Fly range of platforms from 500 to 20,000 meters
- Excellent calibration (spectral, radiometric, spatial)
  - Enables scientific imaging spectroscopy
- Other
  - Small, Light, Low power, Simple to operate, Deliver/transmit calibrated data

# AVIRIS-II Instrument Approach

- A simple, high uniformity and high throughput "Zakos" Offner imaging spectrometer design
- JPL convex three zone blazed e-beam lithographic grating
- JPL e-beam lithographic slit
- 640 by 480 element substrate removed HgCdTe detector array and 6604A readout (sensitive from 380 to 2520 nm)
- JPL 6 DOF mounts for 270 nm mechanical adjustment
  - Grating and Detector

# AVIRIS-II




Spectral: 350 to 2520 @ 8 nm

Radiometric: 0 to max Lambertian

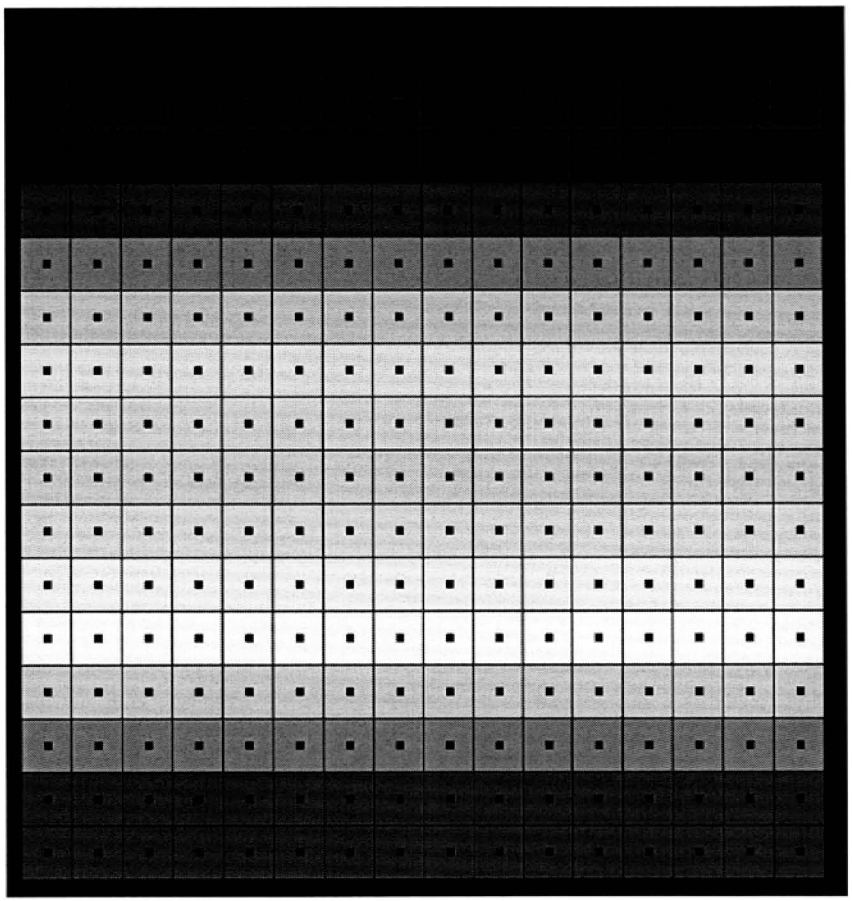
Signal-to-Noise Ratio: 3000 VNIR, 1500 SWIR

Spatial: 36° FOV with 1 milliradian sampling

<40 kg, <0.2 m^3, <50 Watts

# The AVIRIS-II Design Provides a Uniform Imaging Spectrometer

Cross Track Sample



Wavelength

Depiction
-Grids are the detectors
-Spots are the IFOV centers
-Colors are the wavelengths

Spectral Cross-Track <5%

Spectral-IFOV-Shift <5%

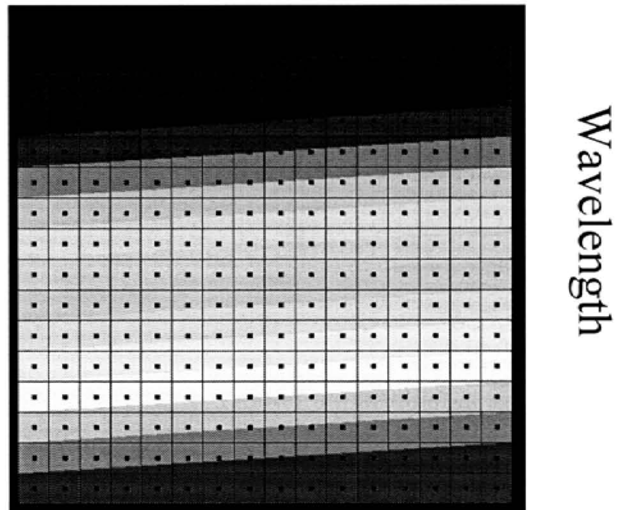
The keys to M3 are:
- Design
- Manufacture
- Alignment
- Stability

# Pushbroom Imaging Spectrometer are Not Inherently Uniform

## Example: Cross-Track Spectral Non-Uniformity

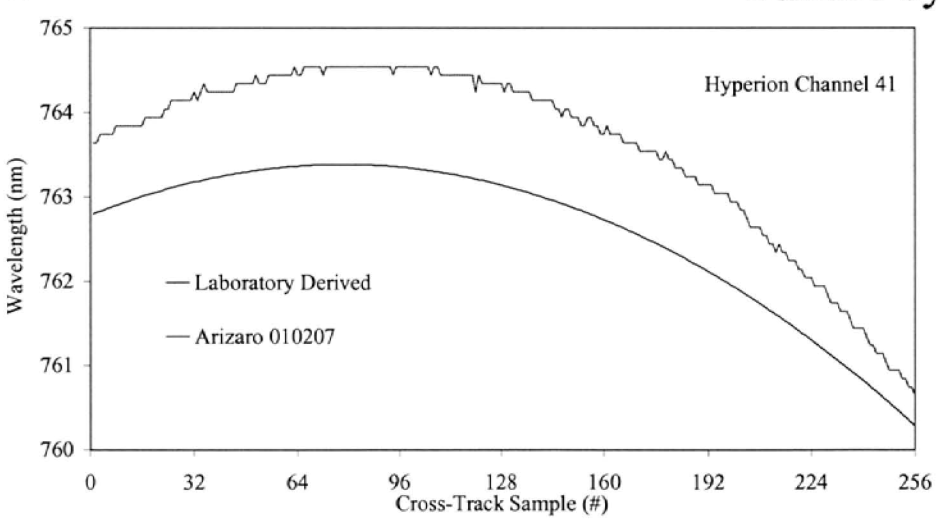
Depiction
-Grids are the detectors
-Spots are the IFOV centers
-Colors are the wavelengths

Cross Track Sample

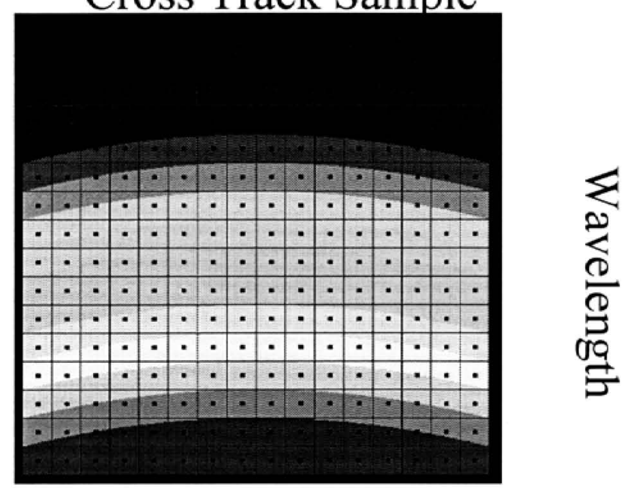



Failure by Twist

Hyperion 40% non-uniform




Cross Track Sample

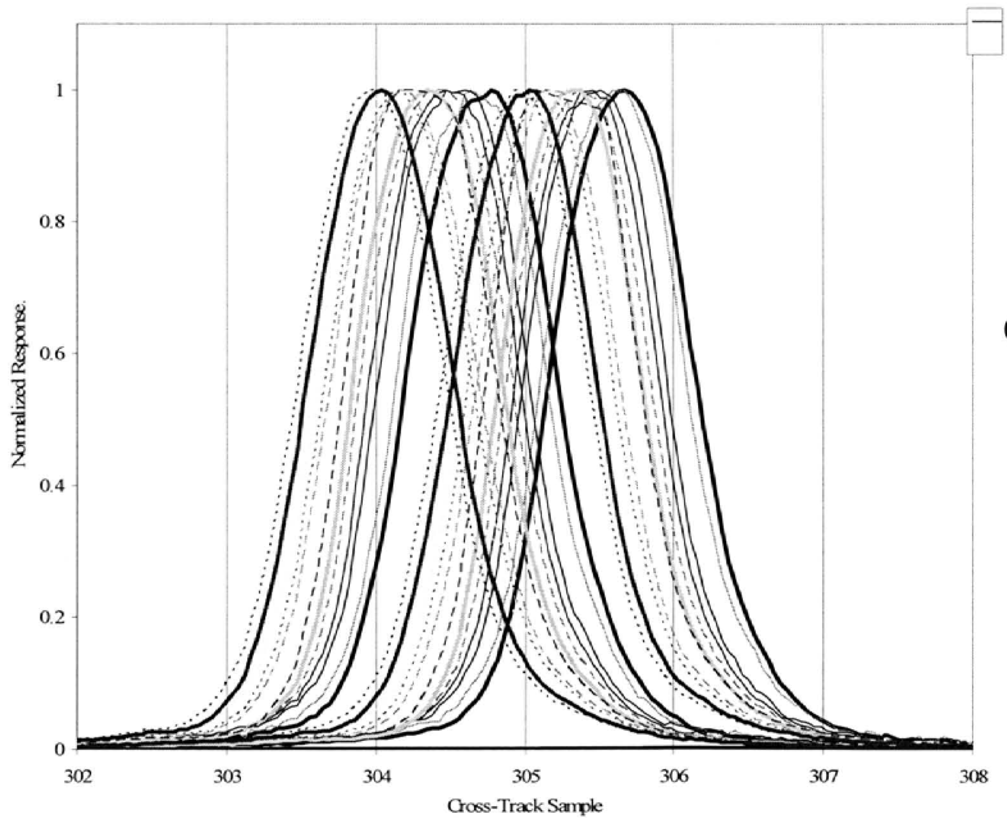



Failure by Frown

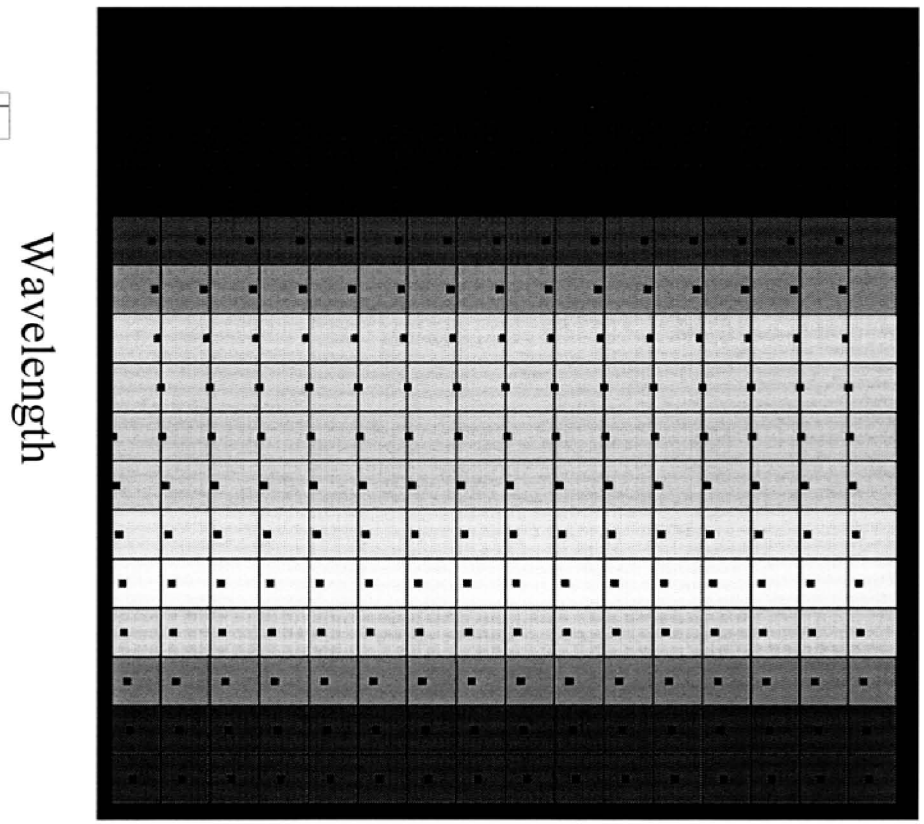
# Pushbroom Imaging Spectrometer are Not Inherently Uniform
# Example: Spectral-IFOV-Shift

Spectral-IFOV-Shift creates spectra where different wavelengths arrive from different locations on the ground.

Example 80% SIS

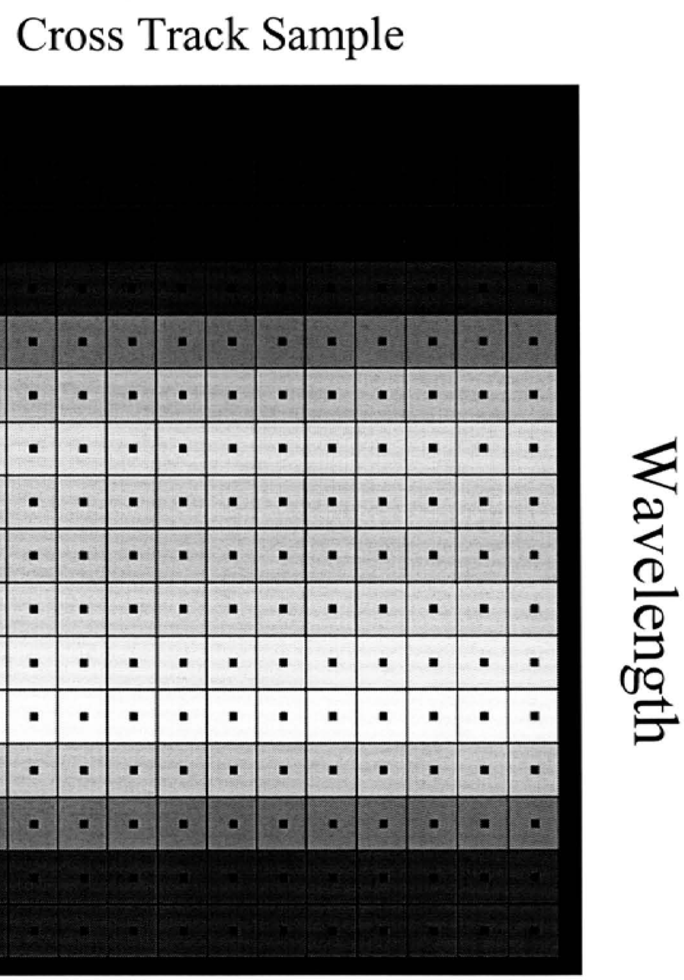



Depiction Below
- Grids are the detectors
- Spots are the IFOV centers
- Colors are the wavelengths




Failure by Spectral-IFOV-shift

# AVIRIS-II Design Provides a Uniform Imaging Spectrometer




M3 is designed with:

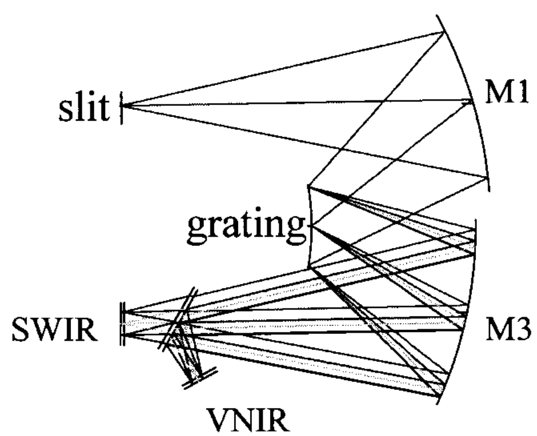
Spectral Cross-Track <5%

Spectral-IFOV-Shift <5%

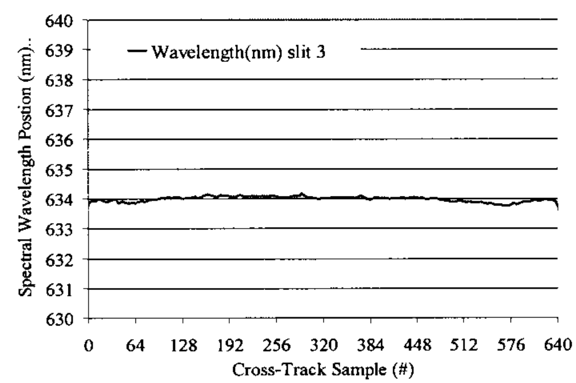
# AVIRIS-II Baseline Instrument Imaging Spectrometer

- The requirement for high signal-to-noise ratio drives the instrument to be optically fast.
- High uniformity suggests the Offner* spectrometer design form.
- The Offner design from uses a convex grating with multiple blazes to tune the optical efficiency across the spectrum.

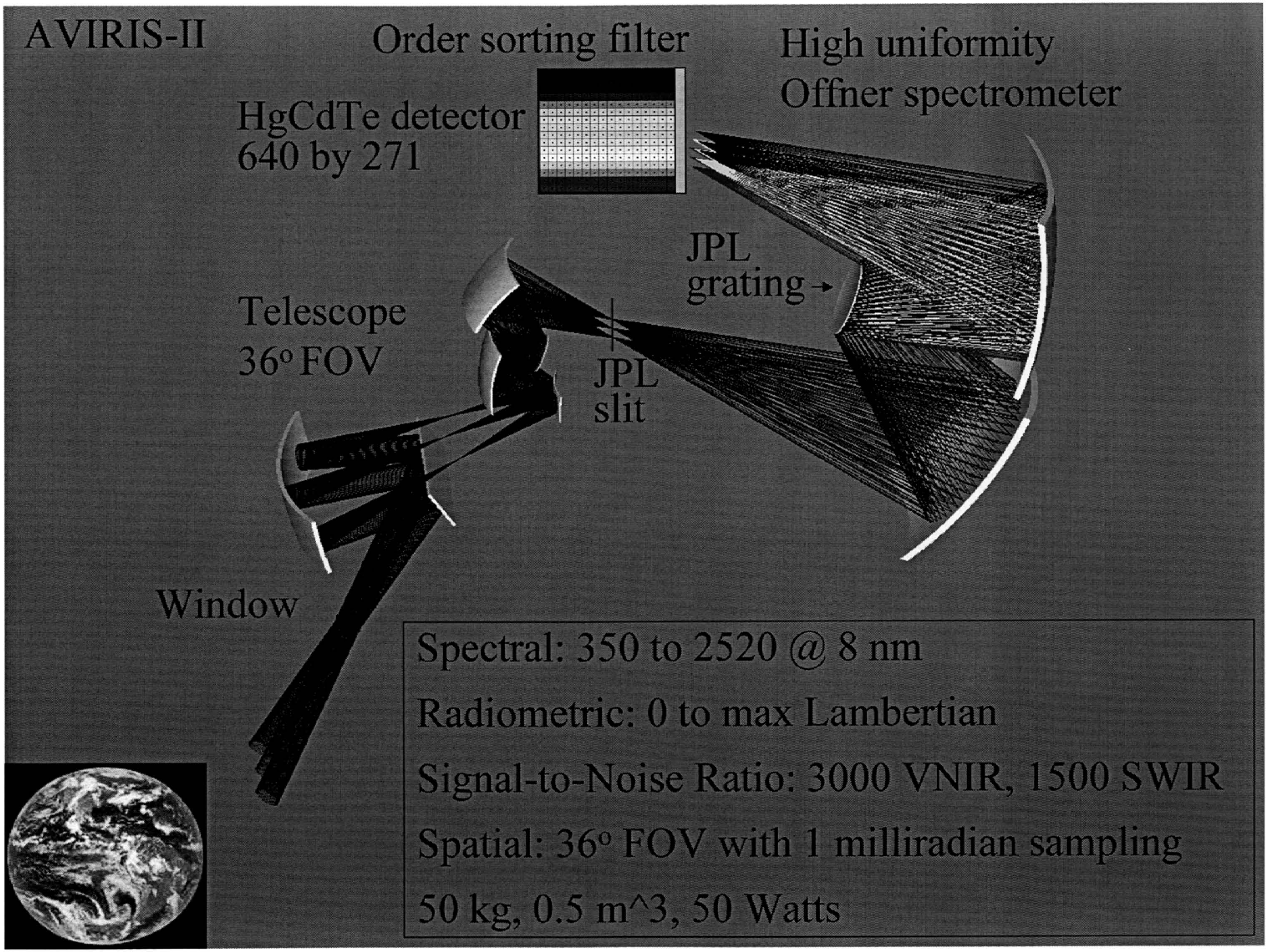
f/2.7 Offner (two detector type)



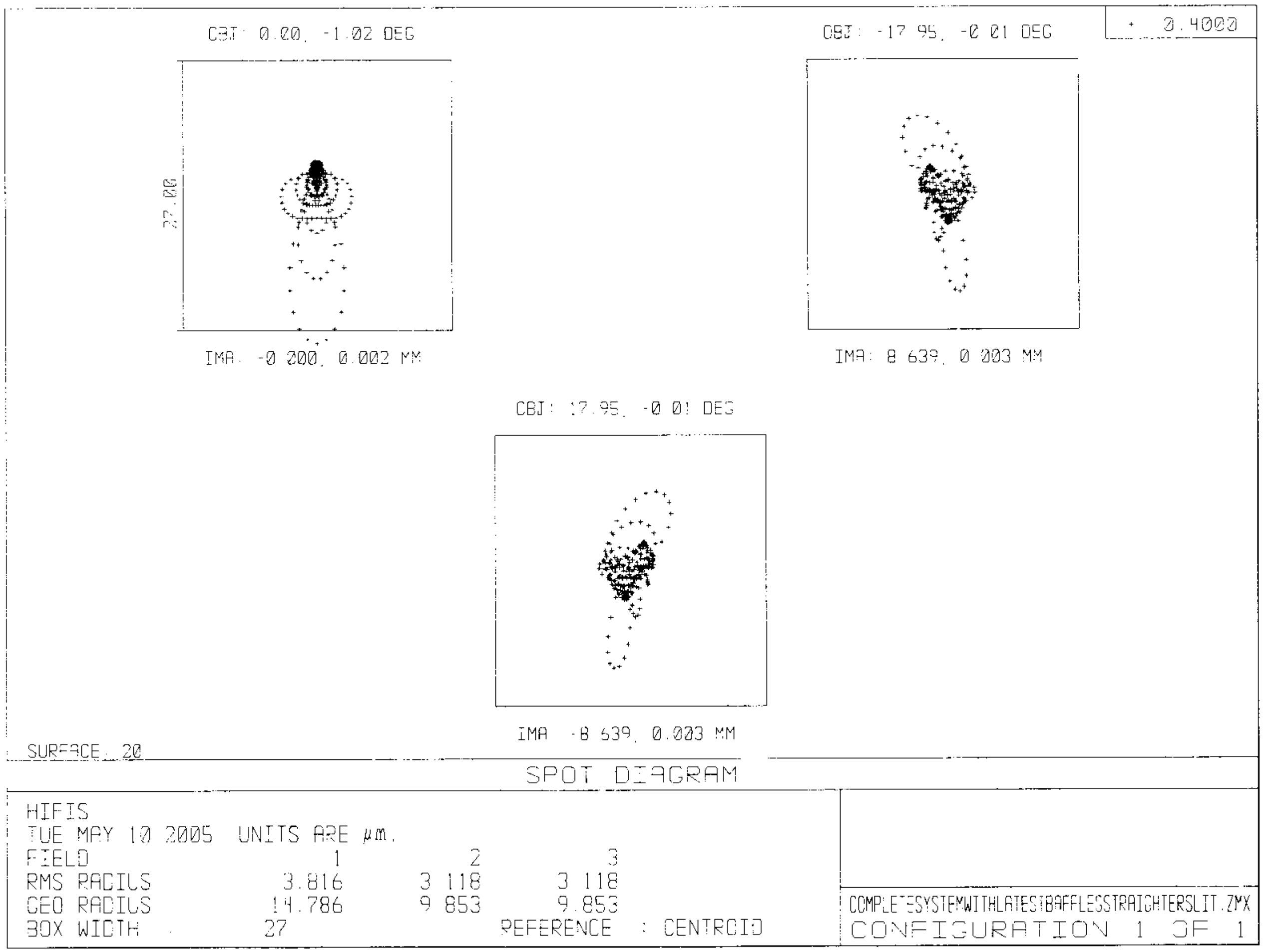

Testbed Uniformity




Mouroulis P, Green RO, Chrien TG, "Design of pushbroom imaging spectrometers for optimum recovery of spectroscopic and spatial information," APPL OPTICS 39: (13) 2210-2220 MAY 1 2000

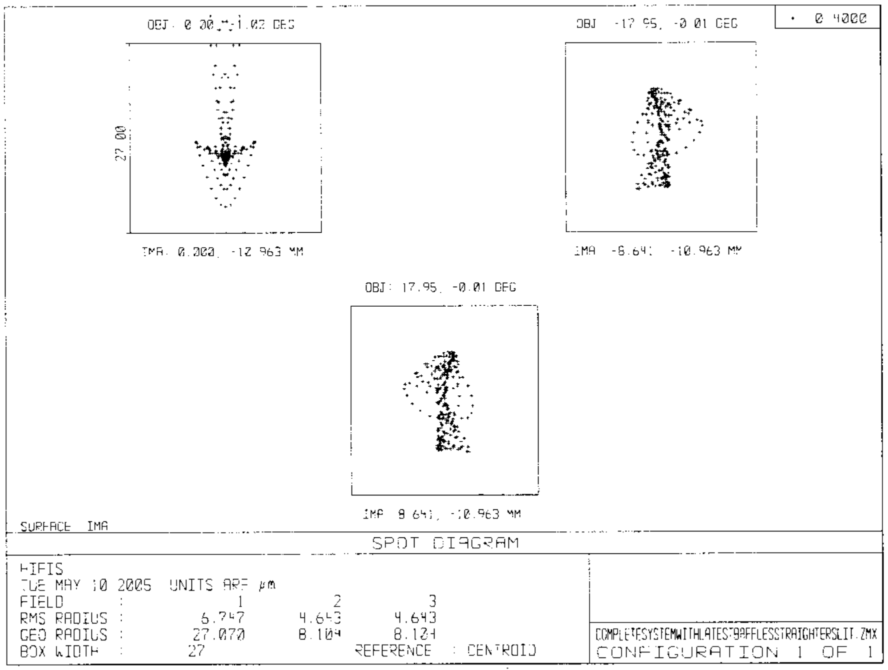

AVIRIS-II
Order sorting filter
High uniformity
Offner spectrometer
HgCdTe detector
640 by 271
JPL
grating
Telescope
36° FOV
JPL
slit
Window
Spectral: 350 to 2520 @ 8 nm
Radiometric: 0 to max Lambertian
Signal-to-Noise Ratio: 3000 VNIR, 1500 SWIR
Spatial: 36° FOV with 1 milliradian sampling
50 kg, 0.5 m^3, 50 Watts

spot diagrams at slit (telescope focus), inside 27um box

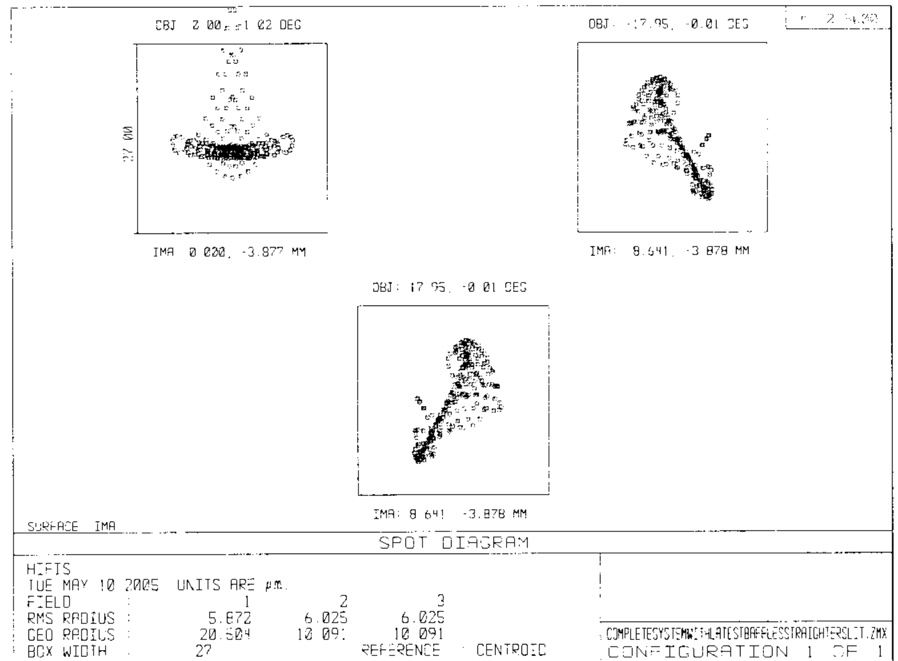


# spot diagrams at detector inside 27um box

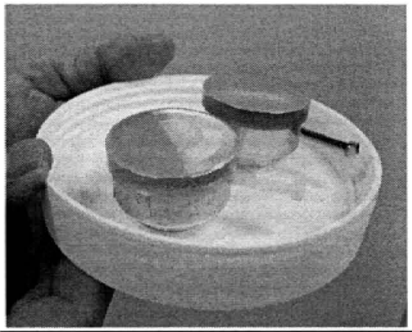
## 400 nm



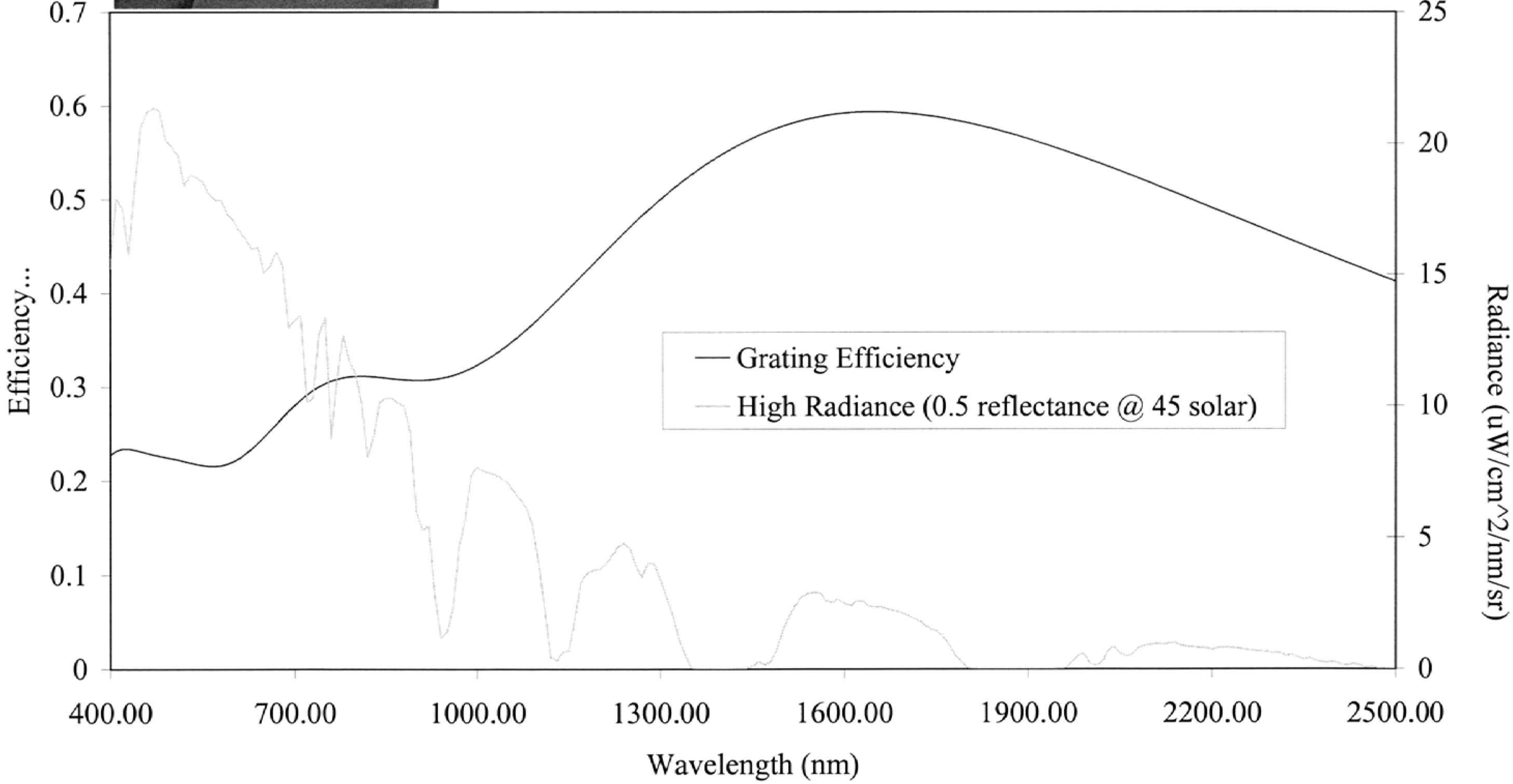

## 2500 nm




Design smile and keystone: 1% (0.3 um)

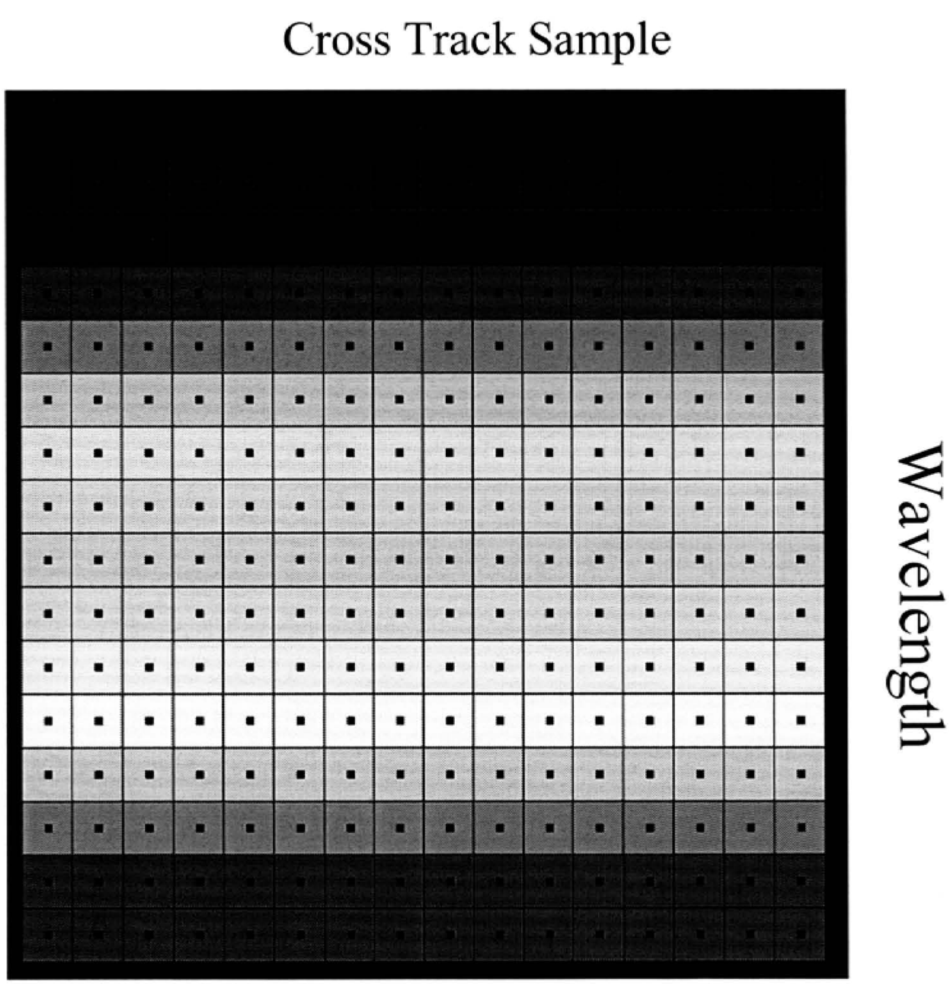


# Multiple Blaze e-Beam Grating




For NASA imaging spectroscopy, JPL has developed the ability to create this high efficiency, low scatter, multi-blaze convex gratings.

# AVIRIS-II Mechanical Design Challenge




AVIRS-II is designed with:

<u>Spectral Cross-Track <5%</u>

<u>Spectral-IFOV-Shift <5%</u>

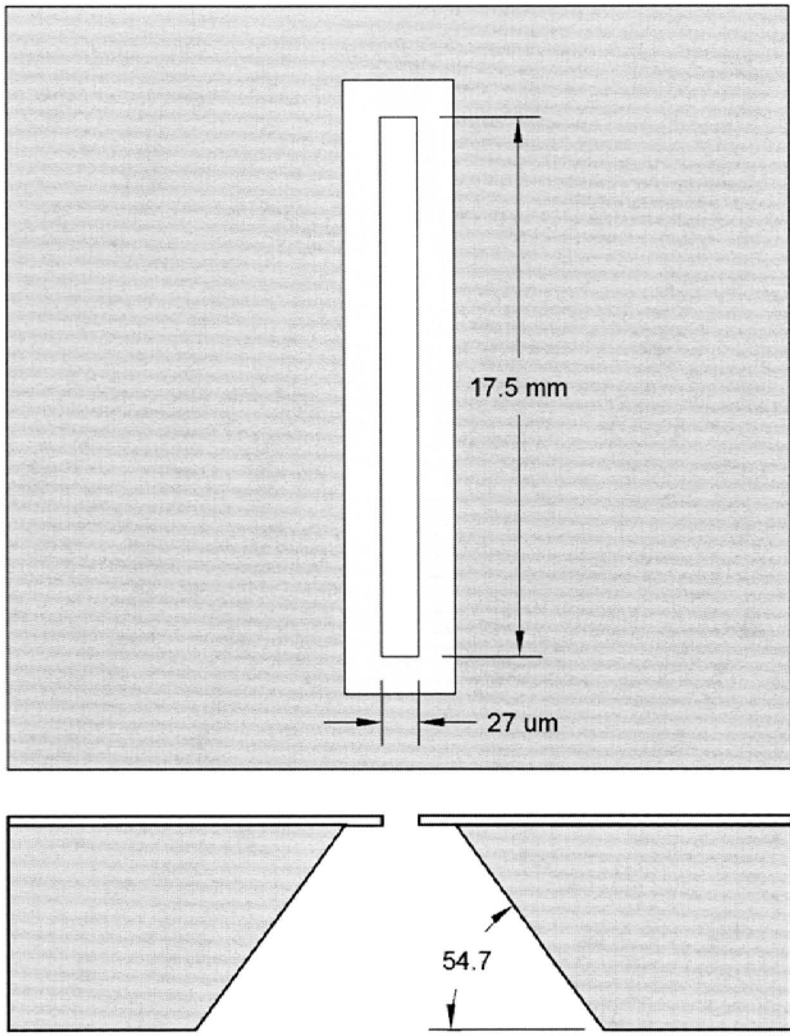
To achieve the required uniformity one would like mechanical alignment and adjustment at the 1% level.

This is 1% of 27 micron or 270 nm.

This is smaller that the shortest wavelength of light we care about.

For NASA imaging spectroscopy, JPL has developed 6 DOF mount that offer this level of adjustment and are stable.

# The Challenge of the Slit




We would like spectral uniformity at the 1% level.

The corresponding mechanical dimension is 1% of the slit width of 27 micron.

1% of 27 microns is 270 nm.

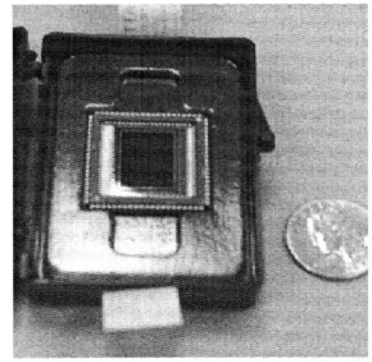
We want the slit to be straight and parallel for 18 mm with no variation greater than 270 nm.

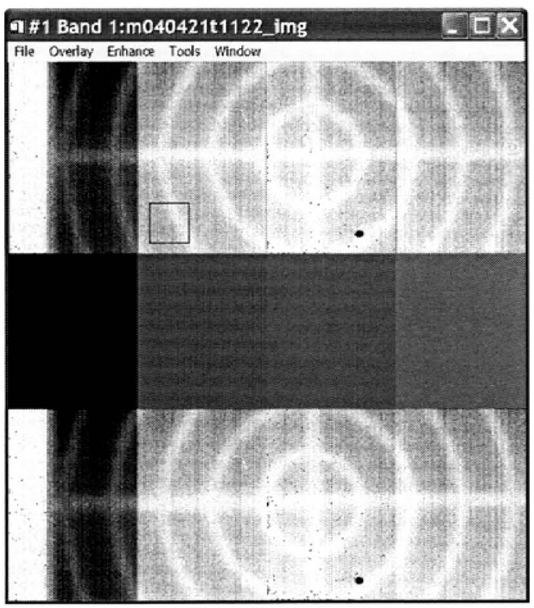
270 nm is smaller than the shortest wavelength of light we care about!

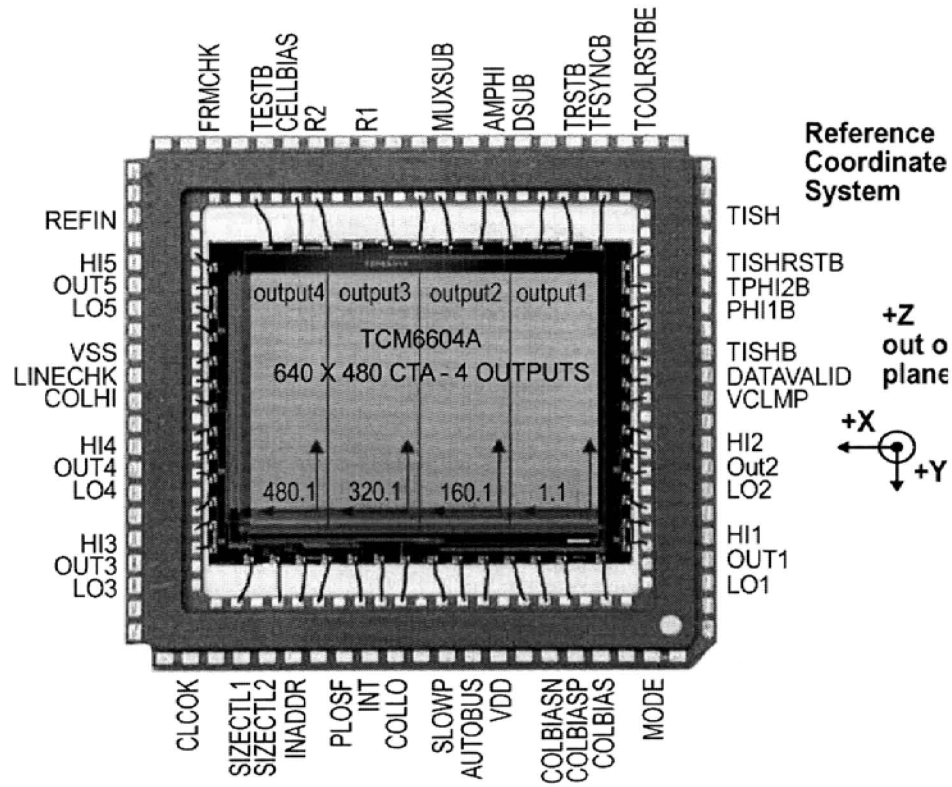
For NASA imaging spectroscopy JPL has developed a technique to make these slits.

# 6604A Detector Array

- Dimension 640 by 480 w/ 4 taps
- Detector pitch 27 microns
- Full well 700,000 e-
- 150 e- RMS noise
- JPL has Full signal-chain running through image capture





# AVIRIS-II Measurement Requirement

| | |
|---|---|
| **Spectral** | |
| Range | 350 to 2510 nm in the solar reflected spectrum |
| Sampling | 8 nm across spectral range |
| Response | FWHM 1.2 of sampling |
| Accuracy | Calibrated to 1% of sampling |
| Precision | Stable within .1% of sampling |
| **Radiometric** | |
| Range | 0 to Max Lambertian Radiance |
| Sampling | 14 bits measured |
| Response | Linear to 1% (after calibration) |
| Stability | 1% between calibrator views |
| Accuracy | 2% absolute radiometric calibration |
| Precision (SNR) | >3000 @ VNIR and >1500 @ SWIR |
| **Spatial** | |
| Range | 36 degree field-of-view |
| Sampling | 1.0 milliradian cross and along track |
| Response | FWHM of IFOV @ 1.2 of sampling |
| **Spectral-Spatial-Uniformity** | |
| Spectral-Uniformity | < 5% variation of spectral position across the field of view |
| Spectral-IFOV-Shift | < 5% IFOVs variation over the spectral range |

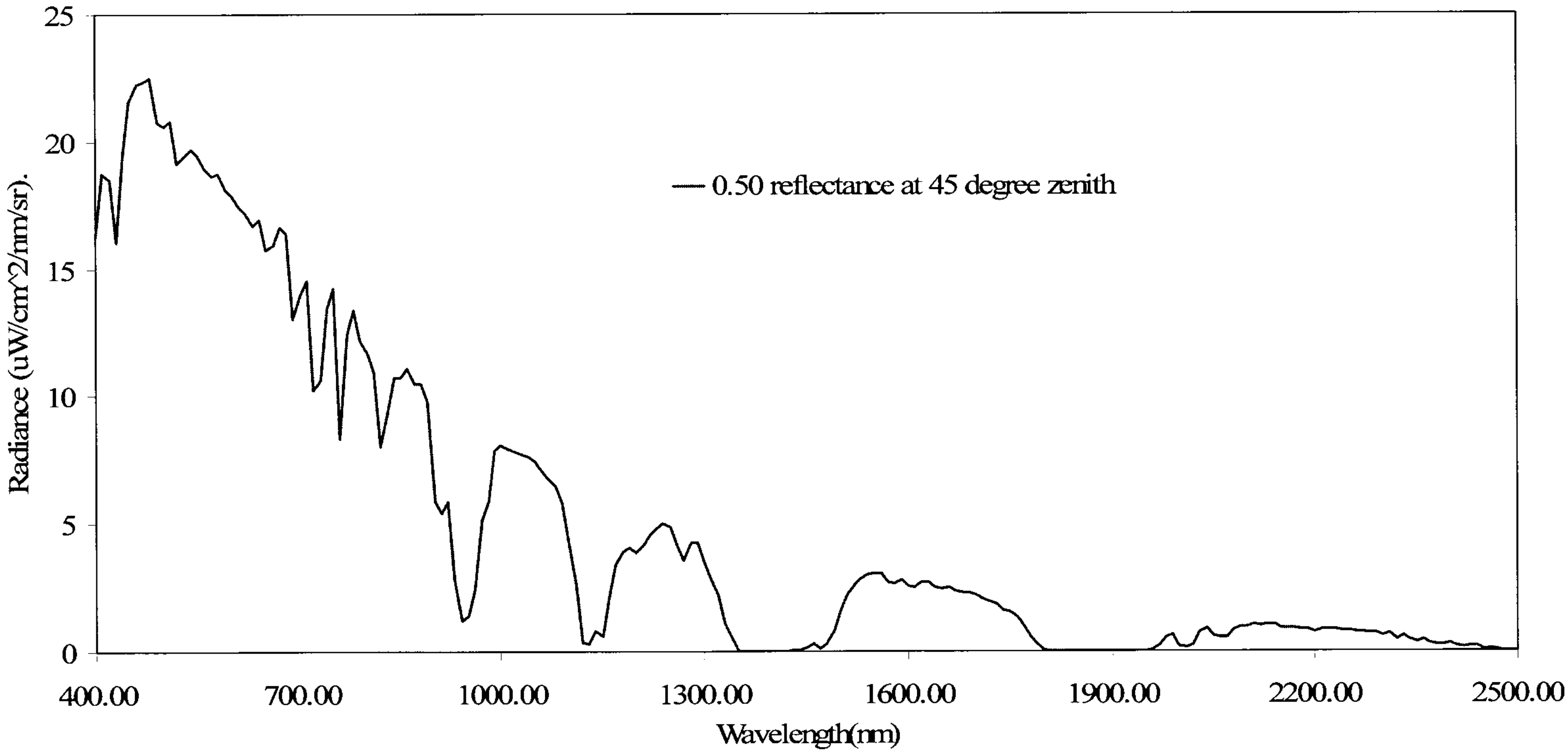
# AVIRIS-II Radiometric Performance Model

- An end-to-end radiometric performance model for AVIRIS-II has been developed.
  - Accounts for a transmissive elements
  - Accounts for a noise components

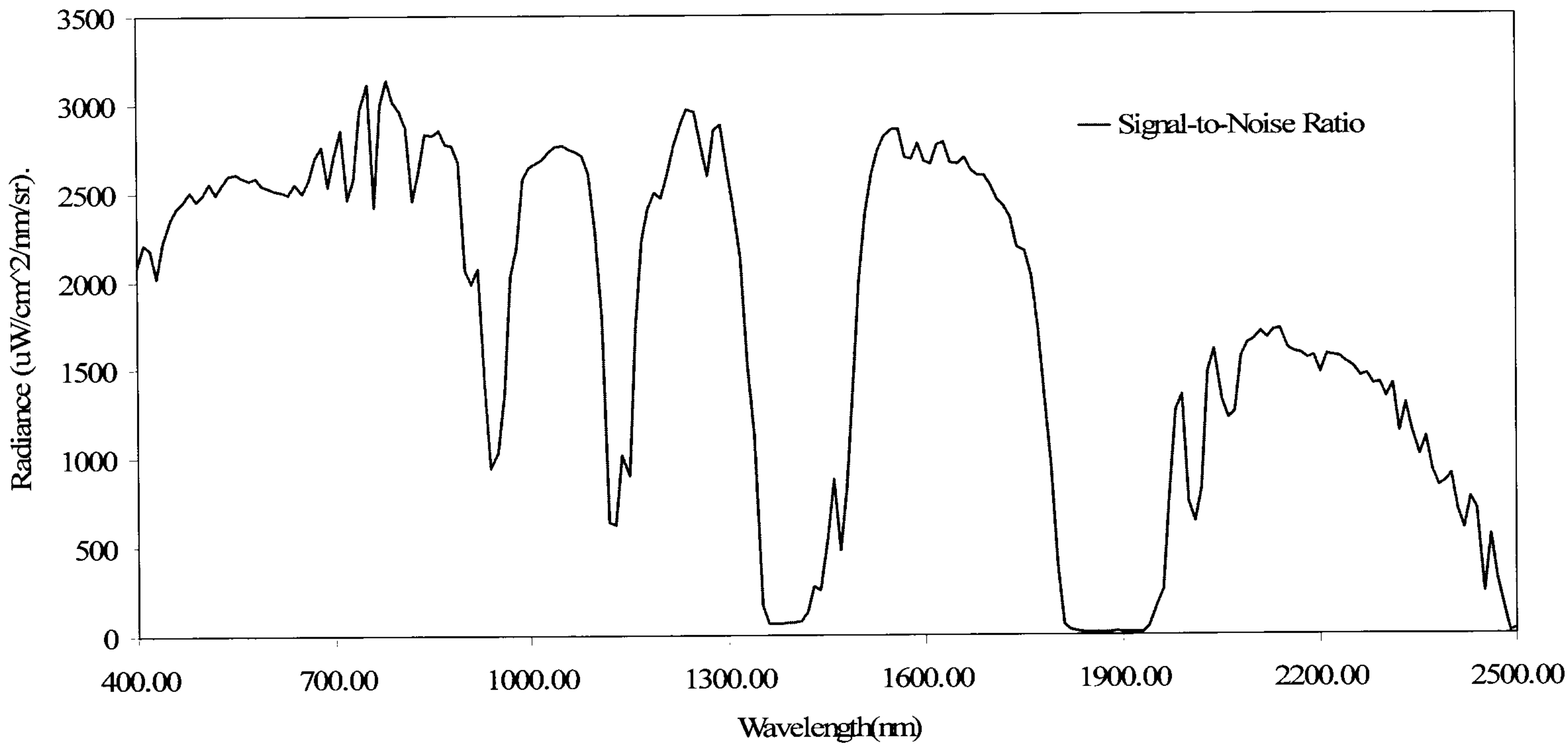
- With a full radiometric model the expected signal levels, noise levels and signal-to-noise ratio may be calculated for a specified input radiance spectra.

- The following slides show the expected SNR performance for high and low level benchmark radiance spectra.

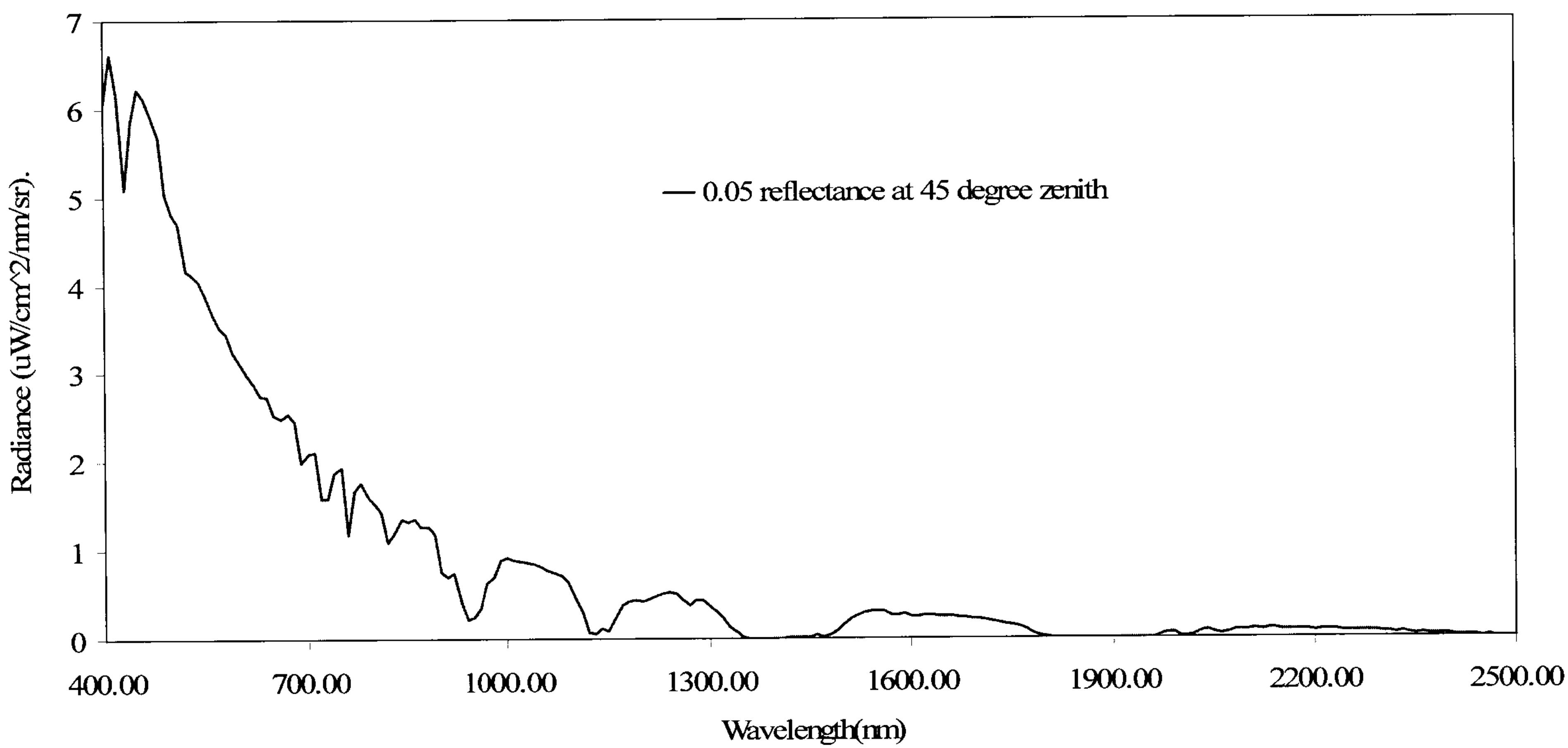
# High Signal Reference Radiance



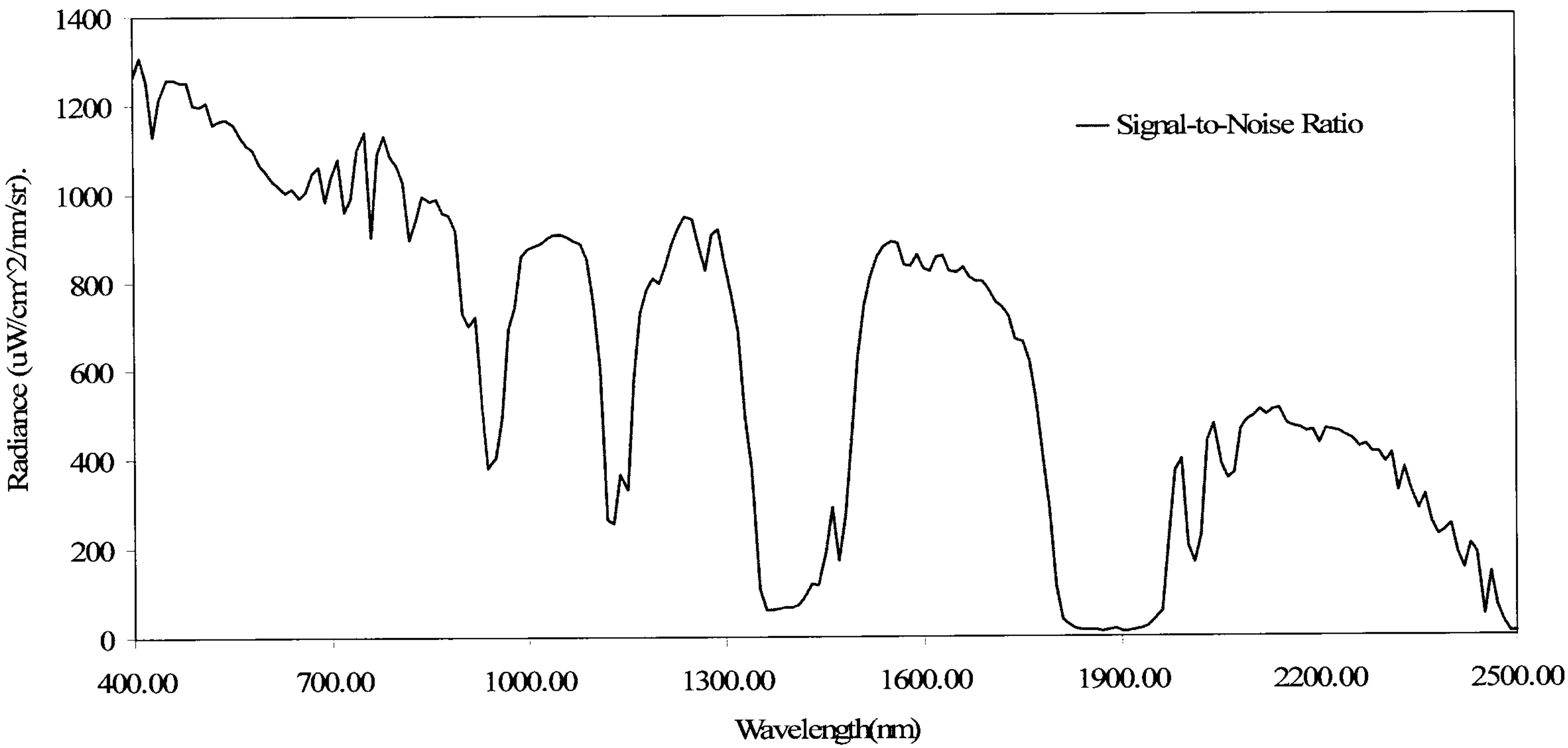
# High Signal SNR



# Low Signal Reference Radiance



# Low Signal Signal-to-Noise Ratio



# Summary and Conclusions

- Using recently available, yet mature, technology a design has been developed for a modern solar reflected airborne imaging spectrometer (AVIRIS-II).

- The design takes full advantage of JPL focus on critical components for a high uniformity and high SNR imaging spectrometer.
  - Grating, slit, tuned-uniform-design, high precision-stable mounts, and full range detector

- This design offers very uniform spectral and spatial performance and exceptional signal-to-noise ratio.

- The design is also amenable to production of multiple copies.

Thank you

Questions?