Radiometric Performance Model for AVIRIS

Robert O. Green

Jet Propulsion Laboratory/California Institute of Technology

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Overview

- Objective
- Signal and Noise
- Model components
- AVIRIS Modeled Performance
- Summary and Conclusions

Objective and Relevance

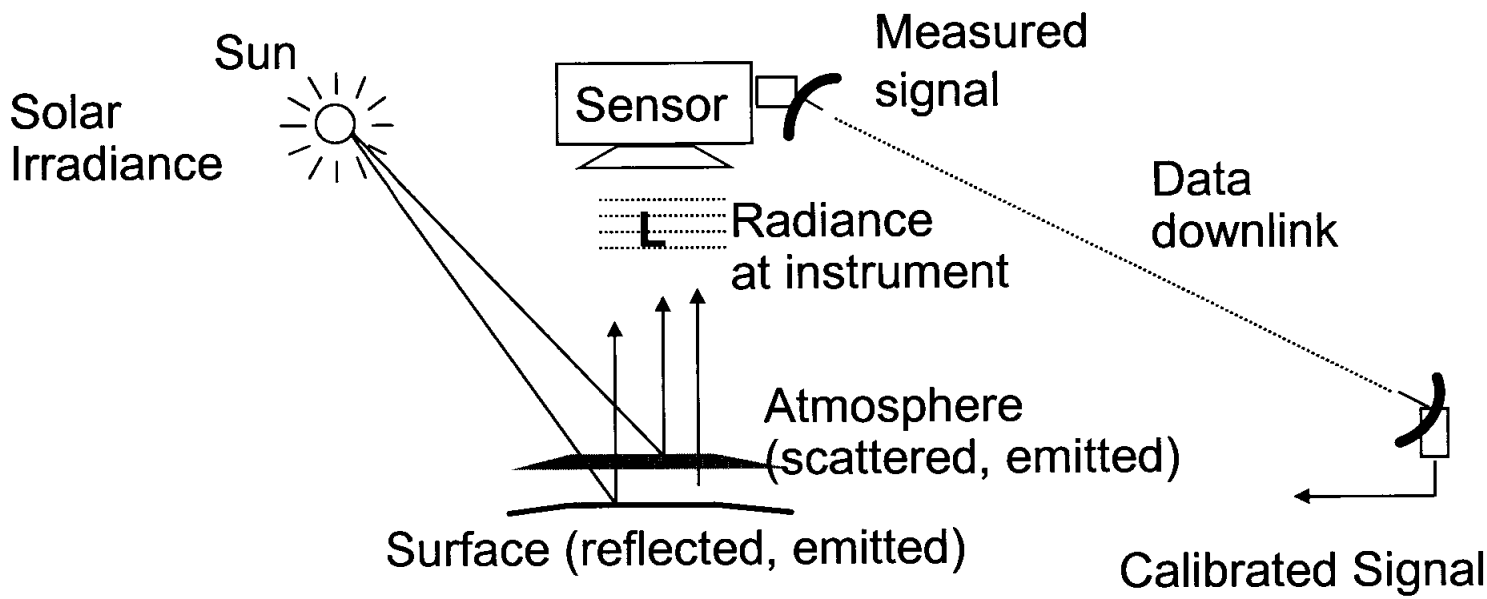
- The AVIRIS radiometric performance model allows estimation of the signal throughput and noise properties of AVIRIS at the component level.

- With an understanding of these properties areas for component improvement can be determined.

- Also, the signal-to-noise ratio properties may be estimated

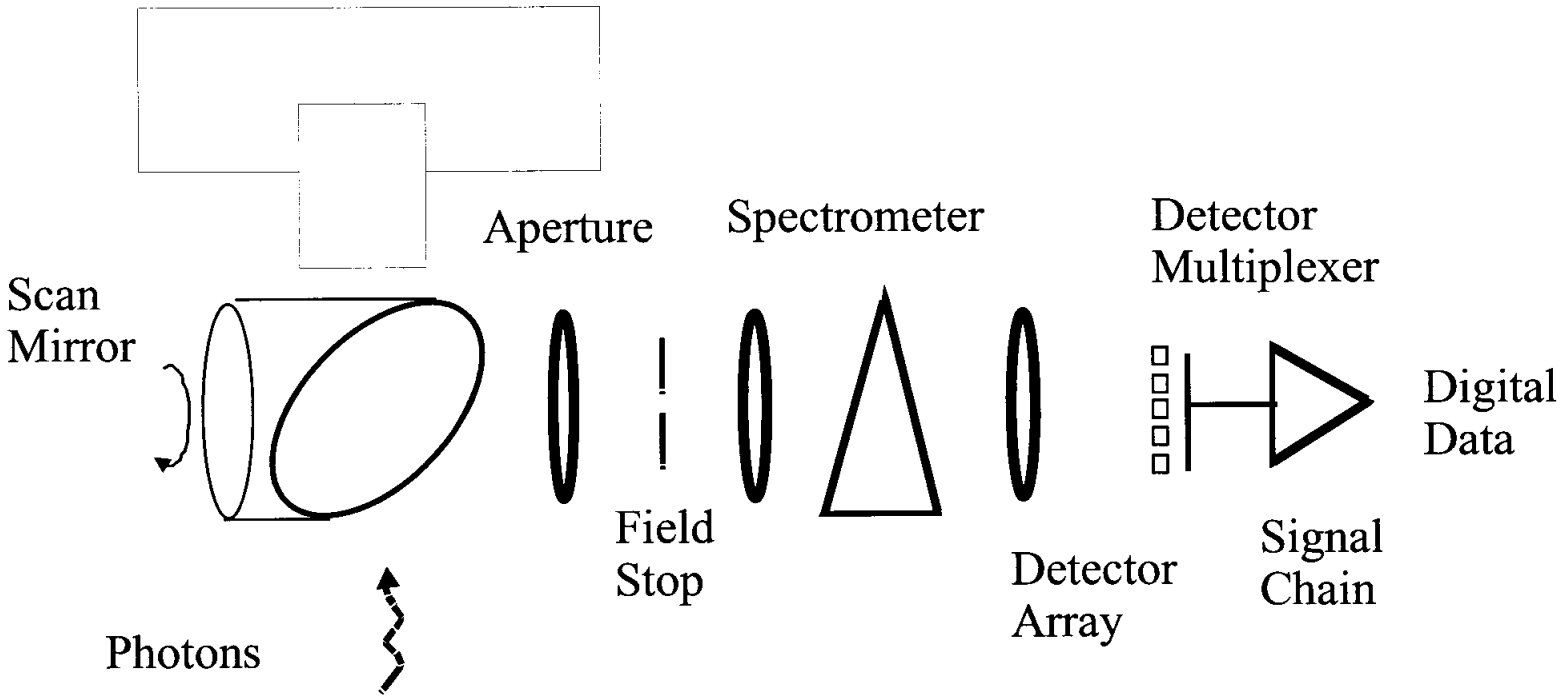
- An accurate radiometric performance model is essential for understanding existing instruments and designing new instruments.

Radiometric Model Simulates the Effect of the Instrument

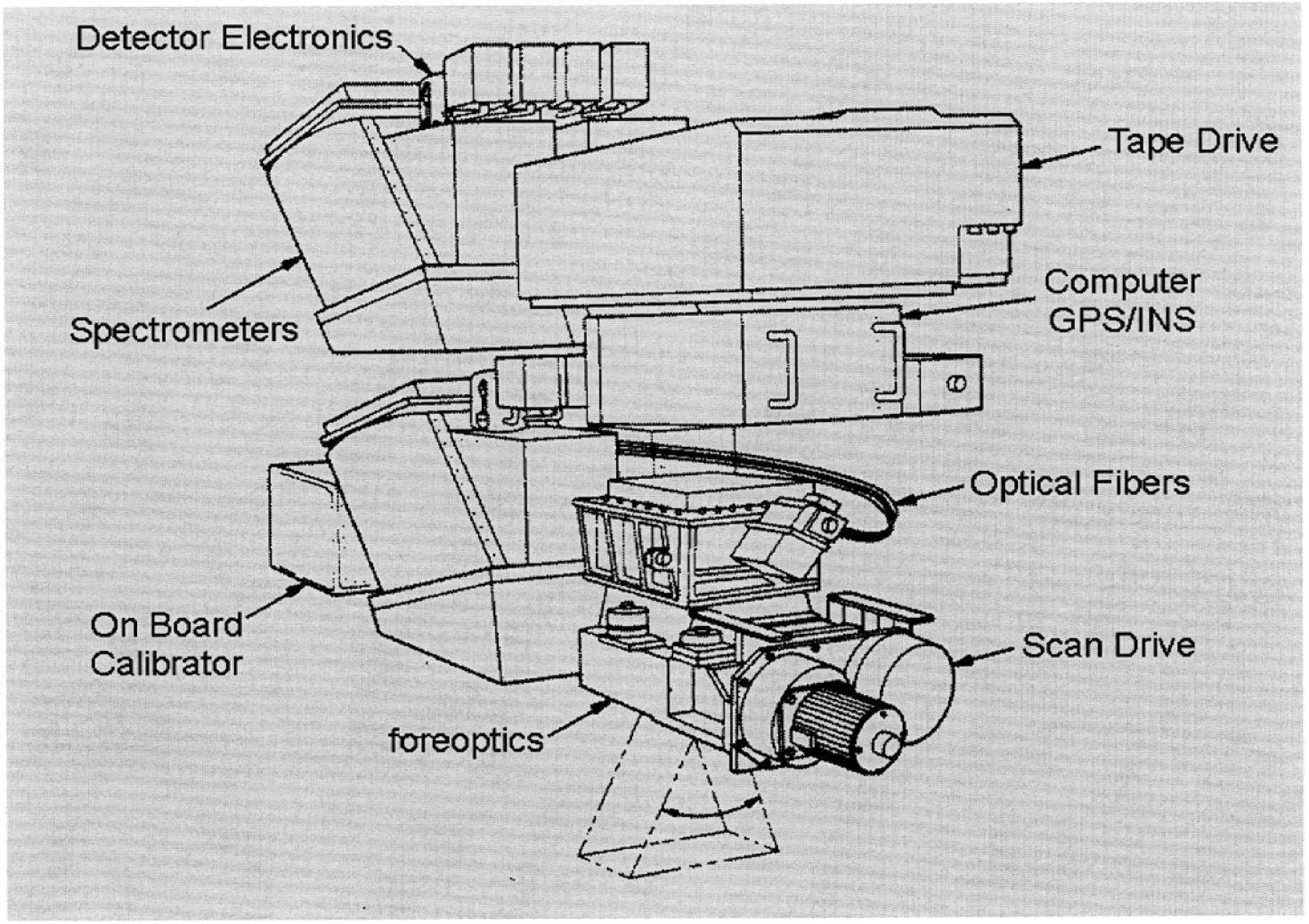


- Energy is emitted by the Sun as well as planet sources
- The energy is transmitted and scattered by the atmosphere and reflected from the surface
- The imaging sensor responds to the energy (L) within a field-of-view and spectral range
- Sensor signal is digitized and relayed to the ground and recorded
- The signal is calibrated, processed, and analyzed to answer the questions of interest

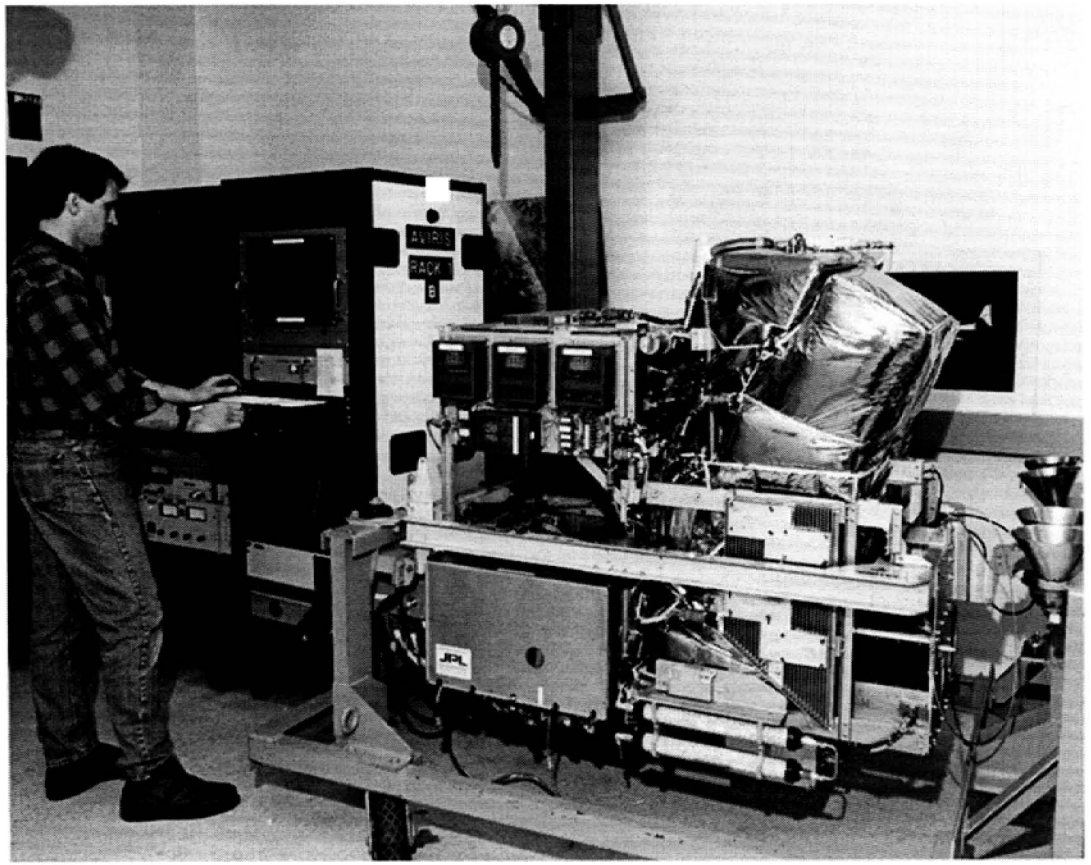
Basic Whiskbroom Scan Instrument



AVIRIS Instrument



AVIRIS Instrument

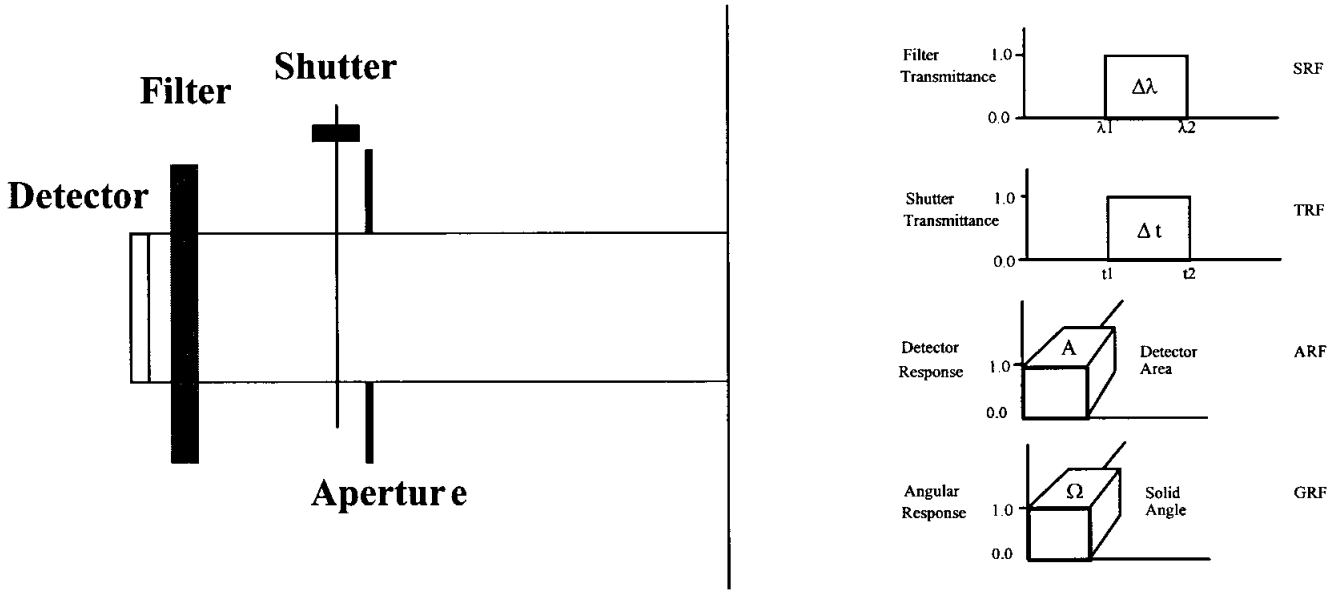


AVIRIS Technology Status

- Thermal control 1997
- Low Altitude 1998
- INU/GPS 1998
- Geo rectification 1998
- Onboard calibrator 1999
- Detector arrays 2000
- Digital signal chain 2001
- Onboard data storage 2001
- Scanner and fore optics 2003
- 16 bits and disk storage 2004

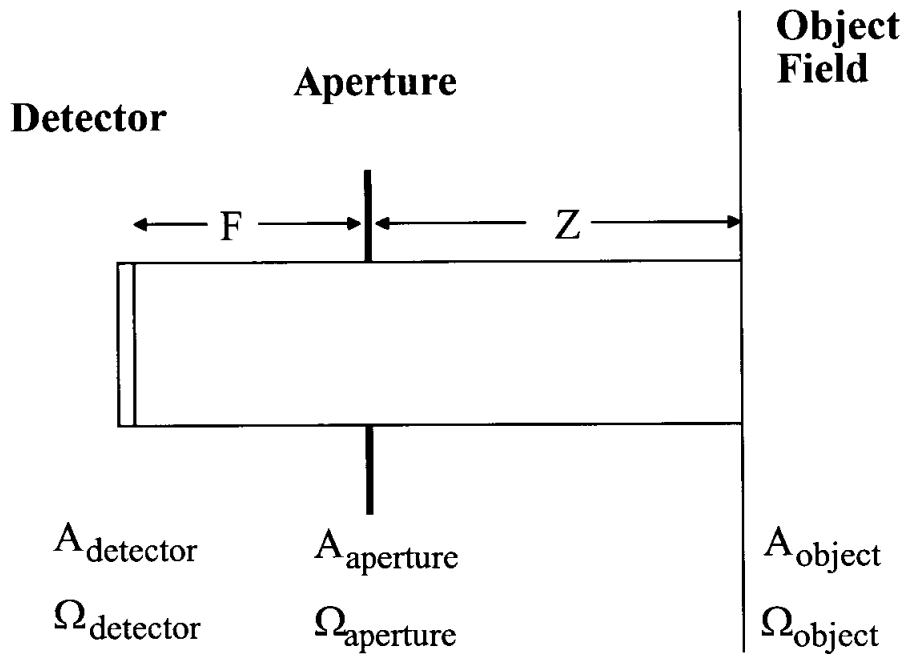
AVIRIS is designed with 200 μm detectors and F/1 optics. These large detectors and fast optics are essential to the success of AVIRIS

Signal



- Filter lets through all light within a limited bandpass, rejects all other light
- Shutter lets through all light within a limited time period
- Aperture lets through all photons within the solid angle subtended by the detector
- Detector converts all incident photons into into photoelectrons across its areal extent
- L is the spectral radiance field observed by the sensor

Signal Area Solid Angle Product ($A\Omega$)



$$\Omega_{detector} \cong A_{aperture} / F^2$$

$$\Omega_{detector} \cong f\#^2$$

$$\Omega_{aperture} \cong GIFOV^2 / Z^2$$

$$\Omega_{aperture} \cong IFOV^2$$

$$A_{detector}\Omega_{detector} = A_{aperture}\Omega_{aperture} = A_{object}\Omega_{object}$$

The area solid angle product defines the throughput or etendu of the optical system
This is the capacity of the optical system to convey radiance!

Aspects of Area Solid Angle Time

- F/1 optics with 200 micron detectors and 1 milliradian IFOV lead to a 200 mm (8 inch) aperture for AVIRIS. Until 2004 AVIRIS had a 4 by 8 inch aperture. We were losing have the measurable light.

- F/2.7 and 27 micron detectors with a 1 milliradian IFOV lead to a 10 mm (0.4 inches) aperture.

- If you have a 2 milliradian system and take it to 1 milliradian without modifying the F/# or detector, you will lose 4 times in area and 2 times in time. This gives a reduction 8 times in throughput.

Idealized Radiometer Photon Calculation

$$N_{photons} = \int_A \int_\Omega \int_\lambda \int_t L*ARF*SRF*GRF*TRF \frac{\lambda}{hc} \cdot da \; d\Omega \; d\lambda \; dt$$

L is the incident spectral radiance

ARF is the aperture response function

GRF is the geometric response function

SRF is the spectral response function

TRF is the temporal response function

λ/hc is the photons per unit energy at the wavelength

For the idealized system this simplifies to:

$$N_{photons} = L*A*\Omega*\Delta\lambda*t_{int}*(\lambda/hc)$$

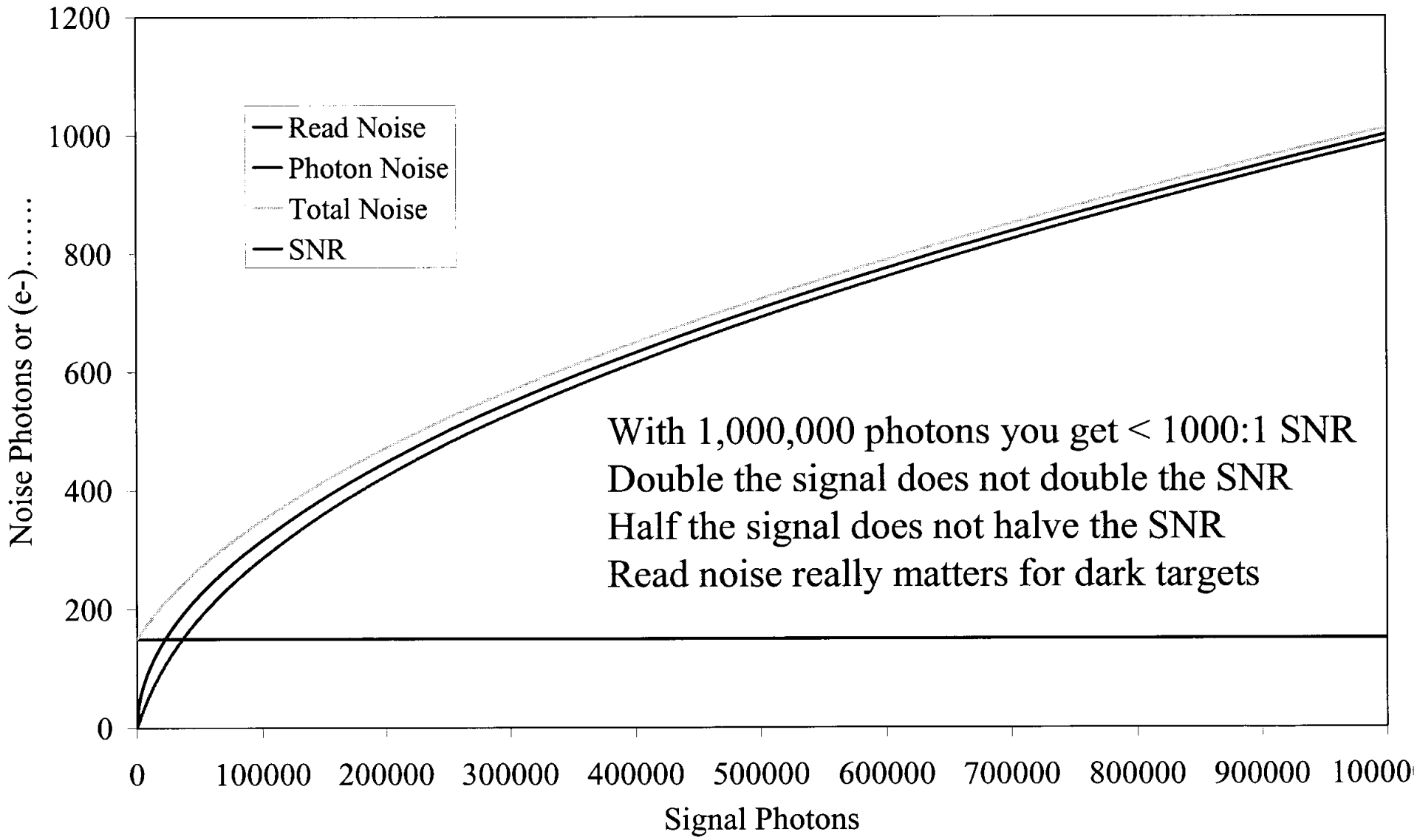
Noise

- One can conceptualize that there are two principle sources of noise to model.
  - Instrument read noise
  - Photon counting noise

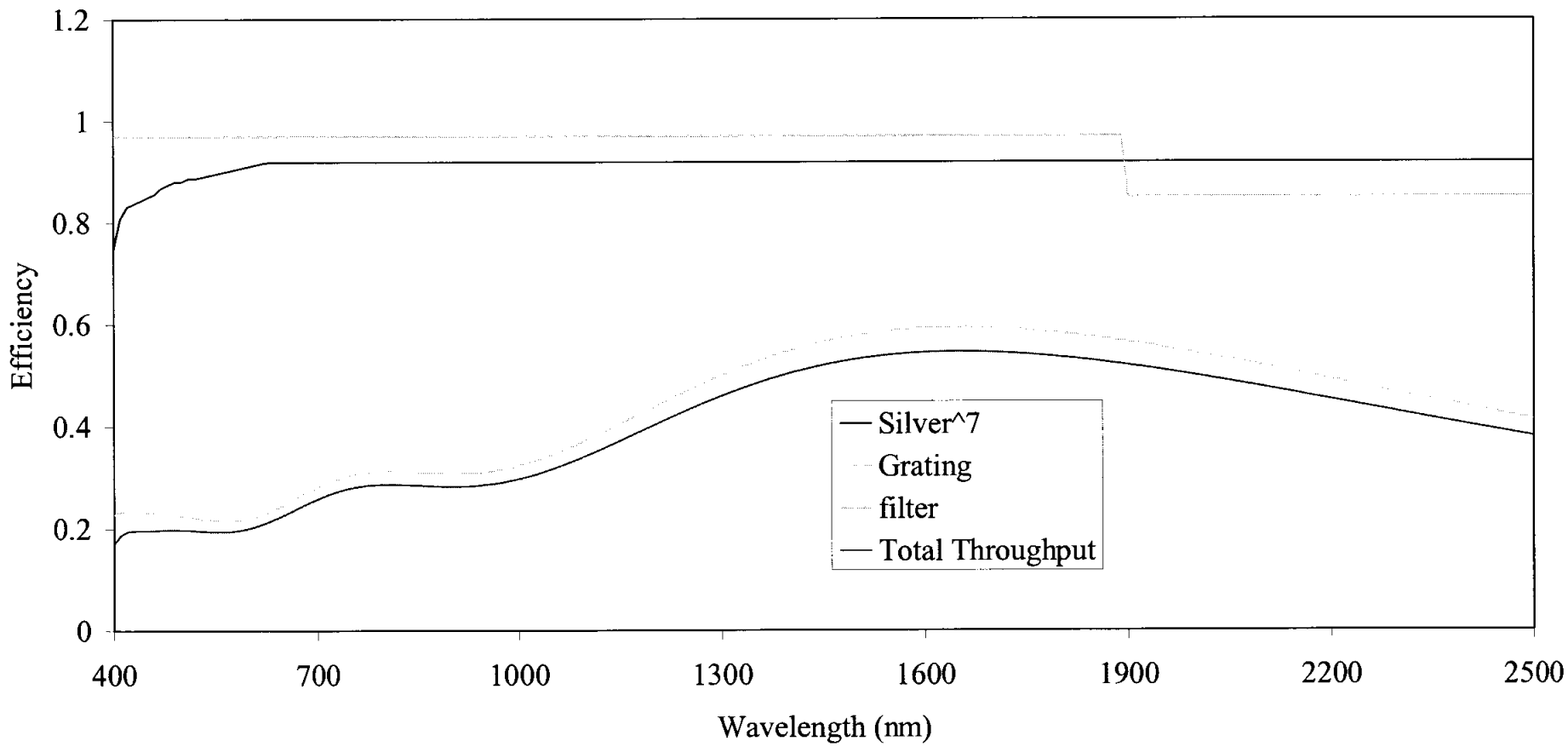
- Instrument read noise is the variation in the measured signal with the dark shutter closed.

- Photon counting noise is the variation in the knowledge of the arriving radiance as a function of the number of photons measured.
  - Because at the detector we count photons, we can only every know the photon flux to the precision of the square-root of the number of photons counted.
  - If 1,000,000 photons are measured then the uncertainty is sqrt(1,000,000) or 1000. The corresponding SNR is 1,000,000/1,000 or 1000:1

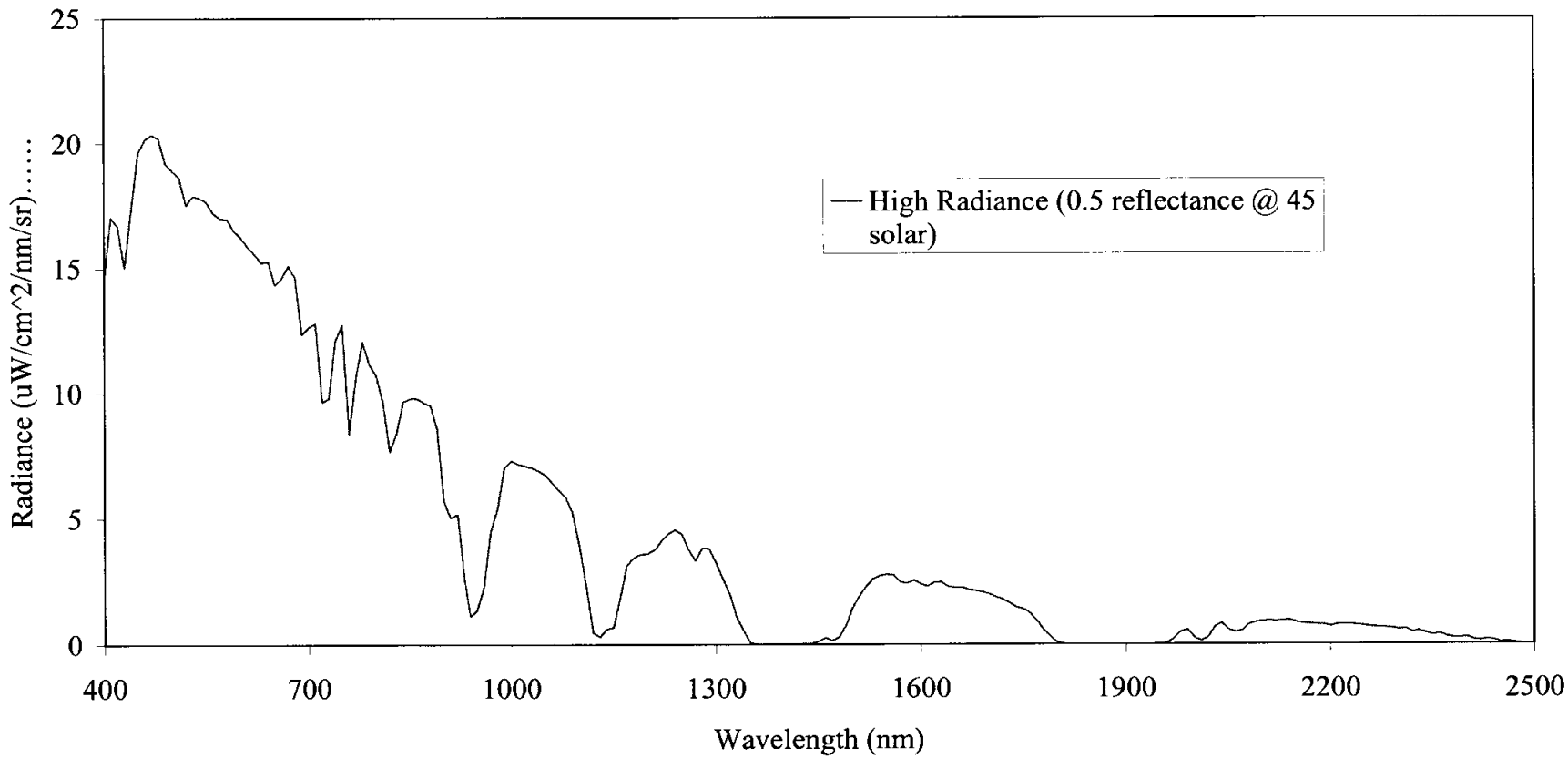
Noise


1200
1000
800
600
400
200
0
Noise Photons or (e-).....
Read Noise
Photon Noise
Total Noise
SNR
With 1,000,000 photons you get < 1000:1 SNR
Double the signal does not double the SNR
Half the signal does not halve the SNR
Read noise really matters for dark targets
0
100000
200000
300000
400000
500000
600000
700000
800000
900000
10000
Signal Photons

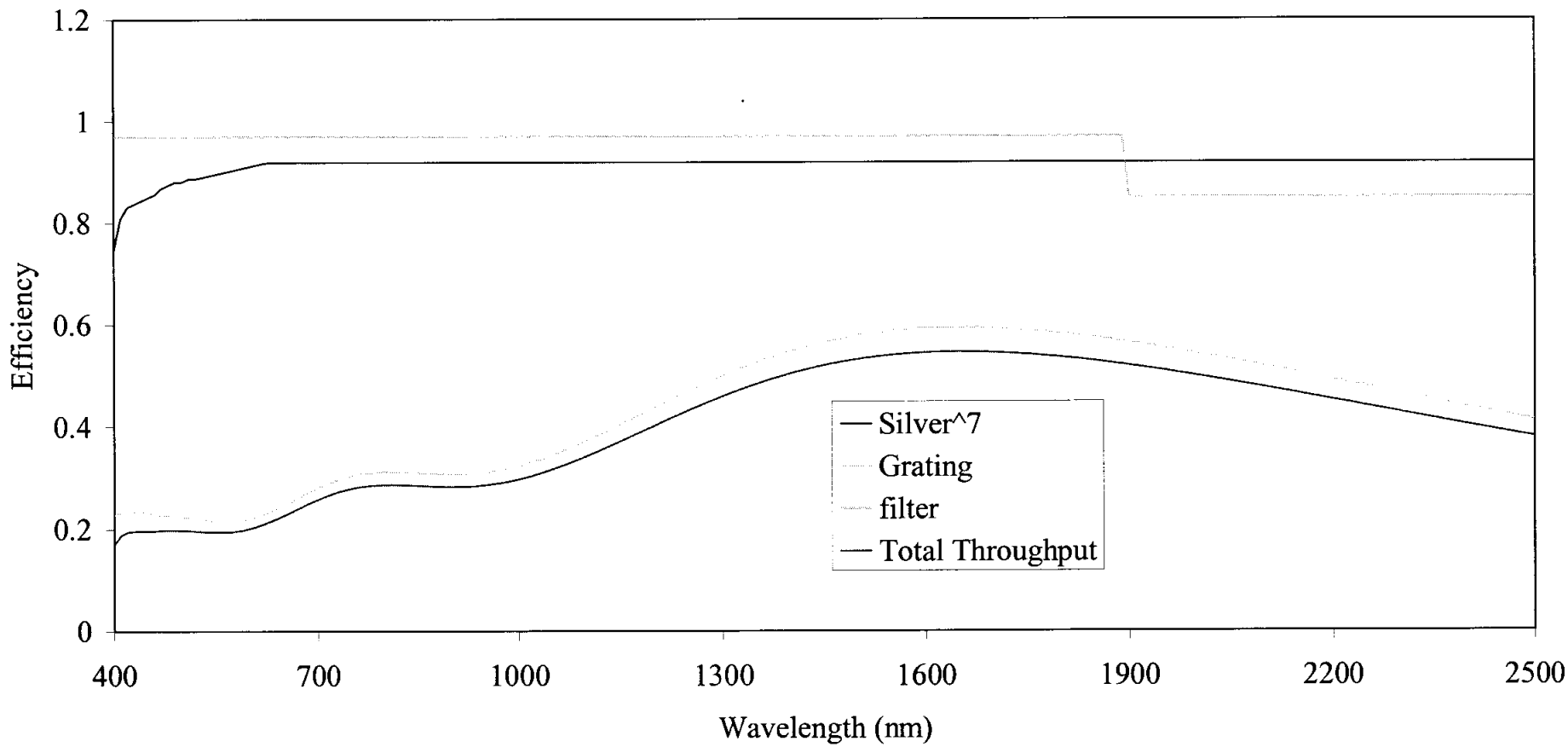
Signal Throughput Efficiency



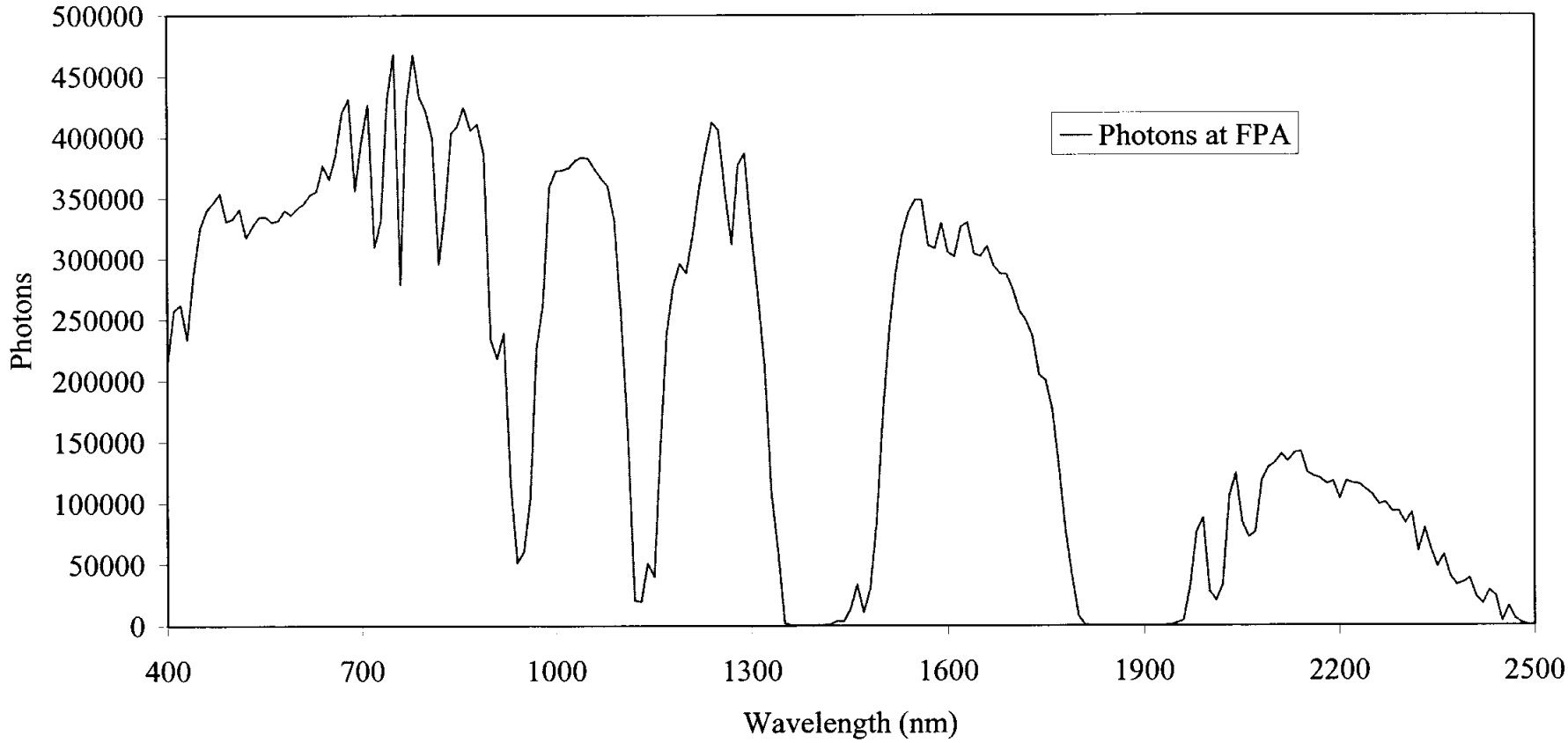
Input Radiance



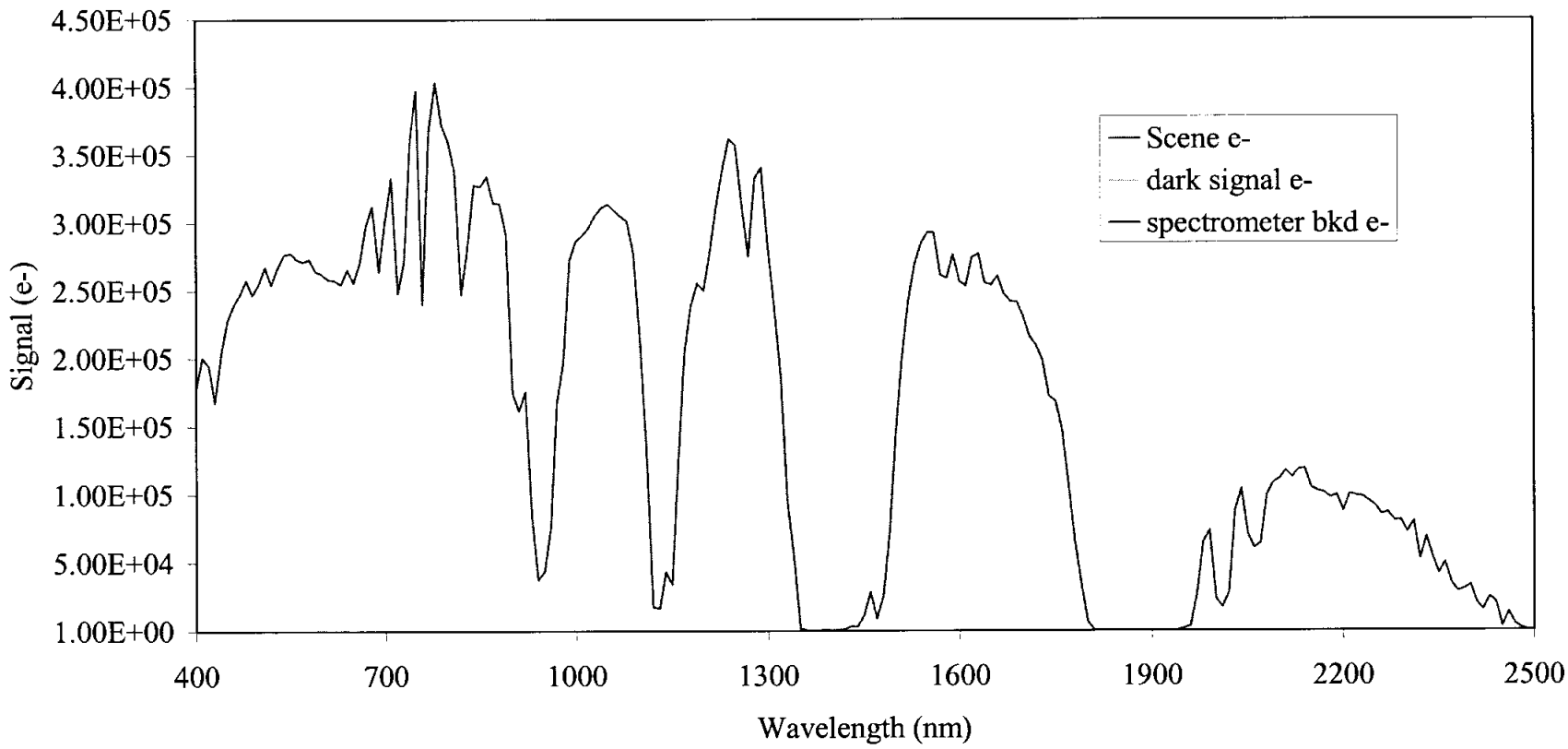
Signal Throughput Efficiency



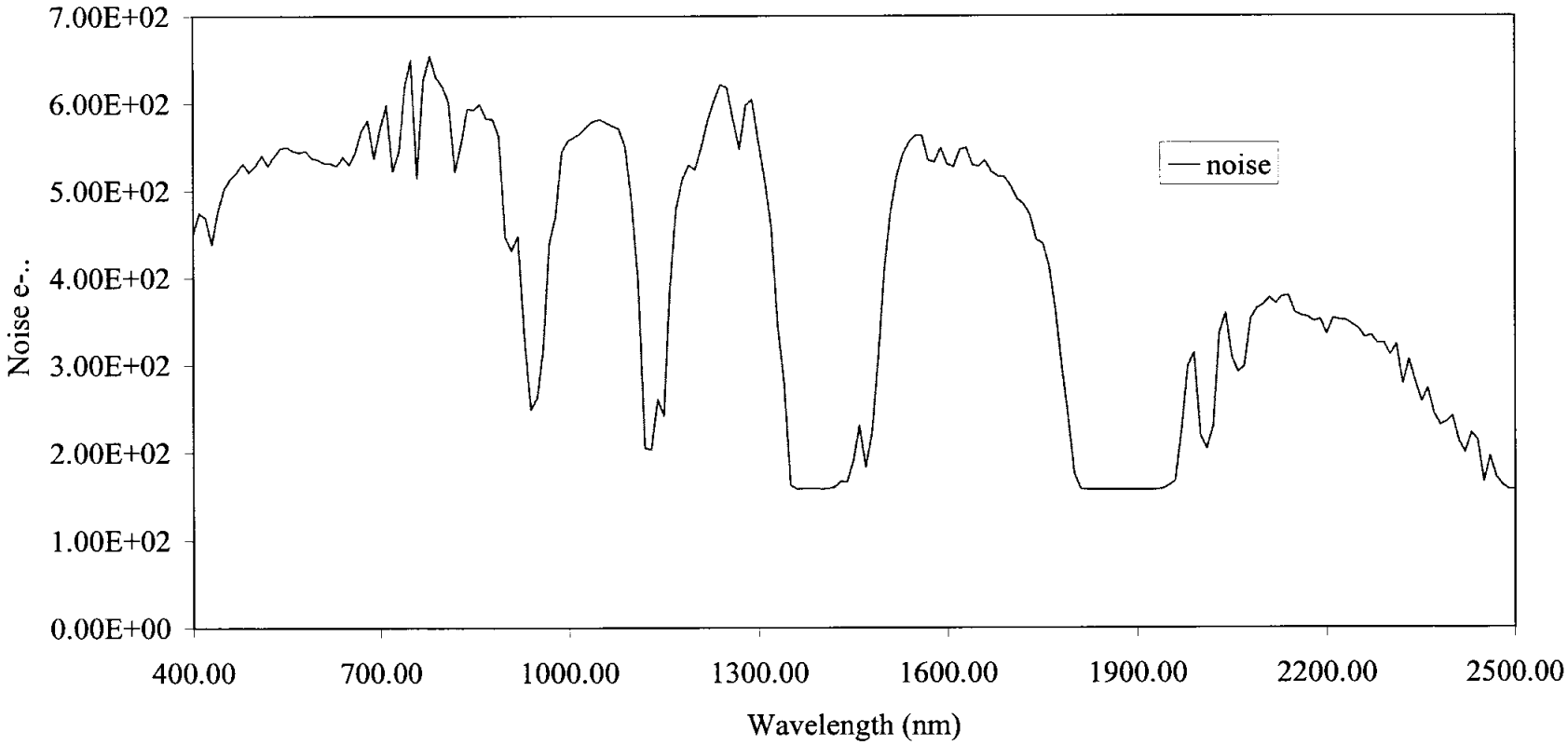
Photons at the Detector



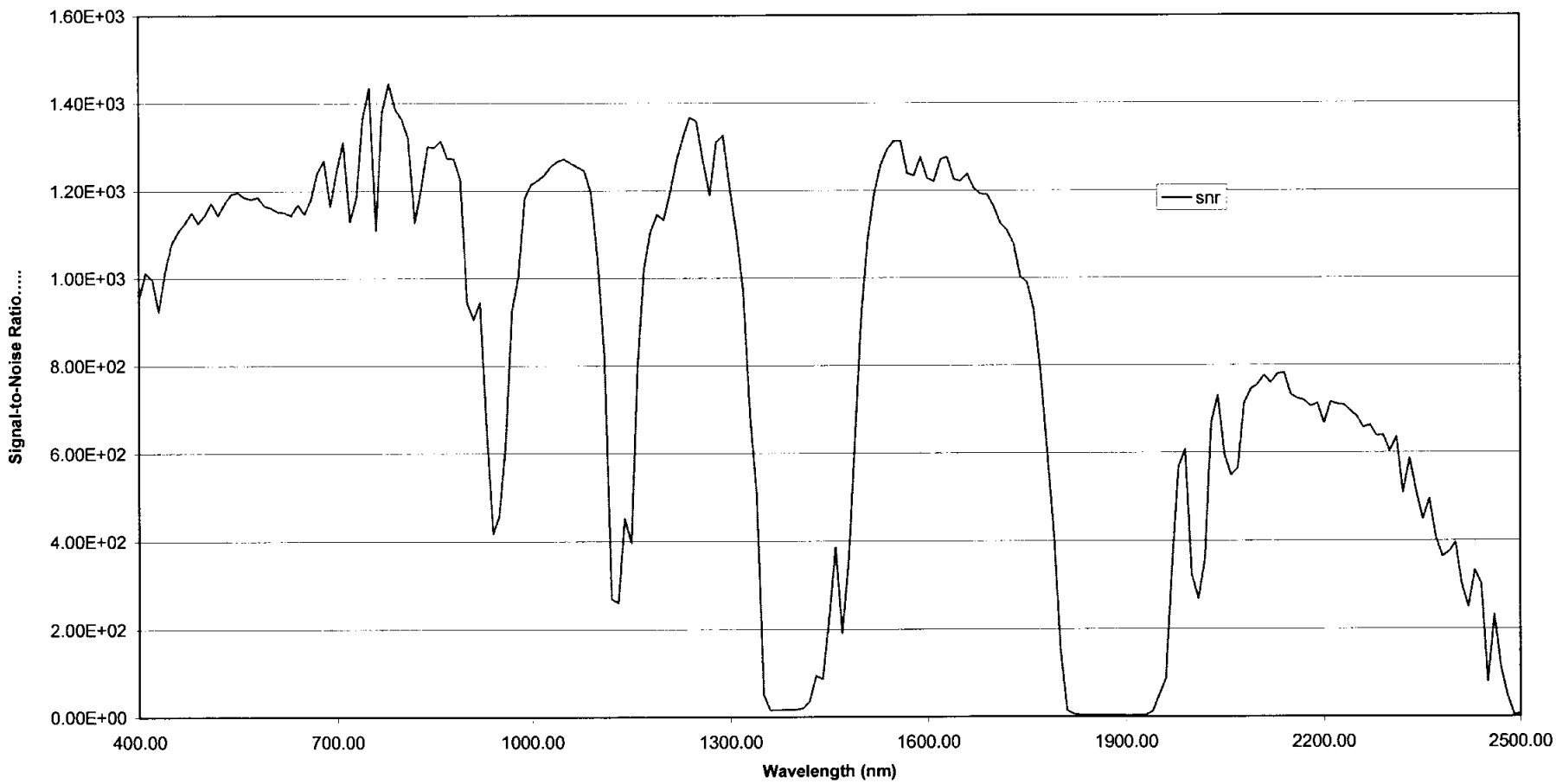
Signal e-


4.50E+05
4.00E+05
3.50E+05
3.00E+05
2.50E+05
2.00E+05
1.50E+05
1.00E+05
5.00E+04
1.00E+00
Signal (e-)
400
700
1000
1300
1600
1900
2200
2500
Wavelength (nm)
Scene e-
dark signal e-
spectrometer bkd e-

Noise e-


7.00E+02
6.00E+02
5.00E+02
4.00E+02
3.00E+02
2.00E+02
1.00E+02
0.00E+00
Noise e-..
400.00
700.00
1000.00
1300.00
1600.00
1900.00
2200.00
2500.00
Wavelength (nm)
noise

Signal-to-Noise Ratio



Summary and Conclusions

- Radiometric performance models are essential to developing and understanding imaging spectrometers for scientific objectives.
- A complete radiometric performance model of AVIRIS has been developed.
- The model incorporates all the recent improvements to AVIRIS
- This model show AVIRIS04 to have a VNIR SNR approaching 1500 and a SWIR SNR approaching 800
- Any scientific analysis that requires an accurate representation of the precision of the measurement must take into account the photon noise.

Questions