GeoEye-1 Stellar Radiometric Calibration

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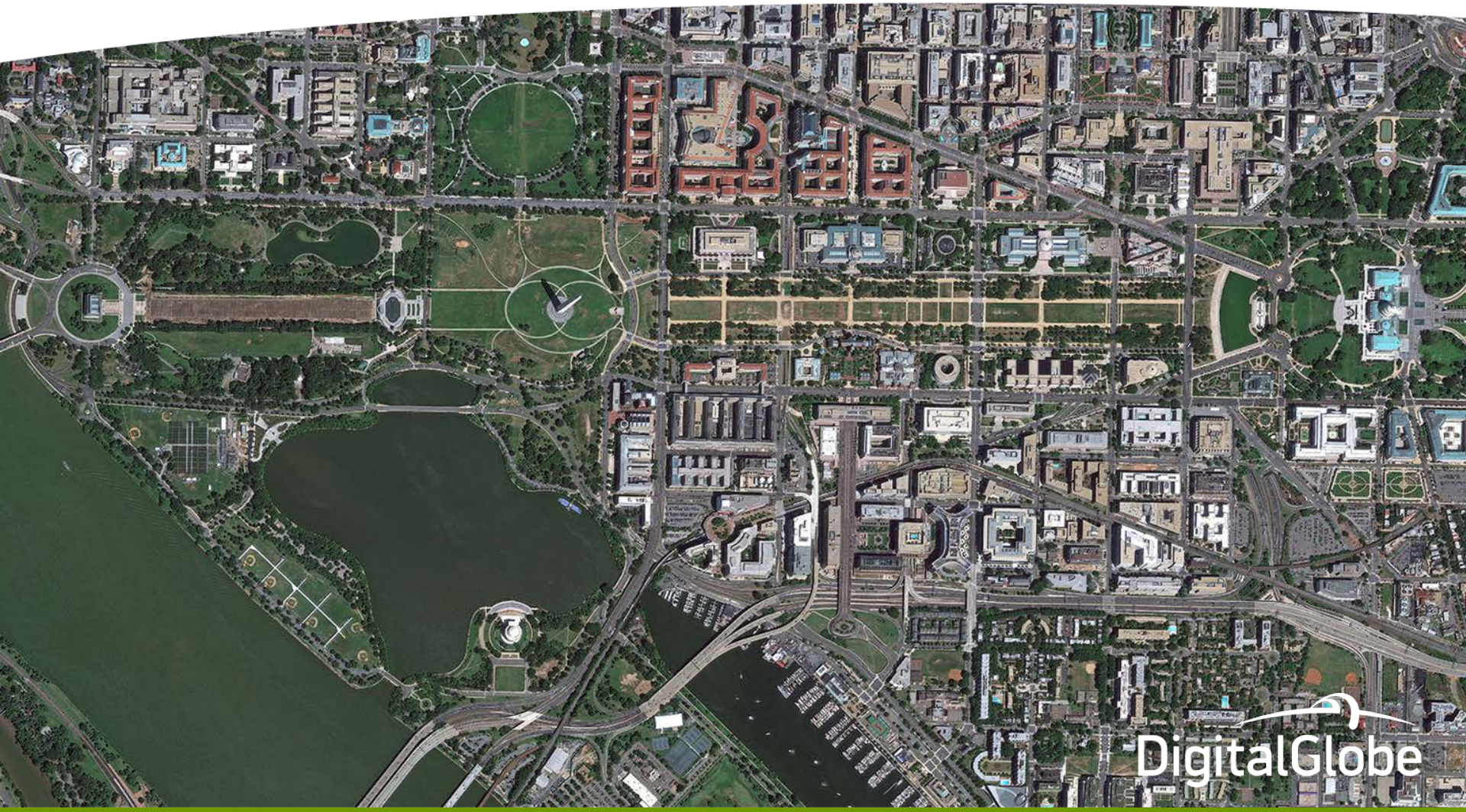

GeoEye-1 Image of Washington D.C. | Acquired on August 22, 2011 | RGB multispectral image representation

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GeoEye-1 Overview

Launch Date	September 6, 2008
Orbit Type	Sun Synchronous
Altitude	681 km
Inclination Angle	98°
Descending Node	10:30am
Revisit Period	3 days

Imaging Feature	Panchromatic Sensor	Multispectral Sensor
Ground Sample Distance (nadir)	0.41m	1.64m
Array Type	Linear 64 stage TDI	Linear 24 stage TDI
Spectral Range	450 – 800 nm	Blue: 450 – 510 nm
		Green: 510 – 580 nm
		Red: 655 – 690 nm
		Near IR: 780 – 920 nm
Pixel Size	8 μm	32 μm
Stages of TDI	8, 16, 32, 48, 64	3, 6, 10, 14, 18, 21, 24
Pixel Aggregation	1x1, 2x2	1x1, 1x2, 2x2,
Imaging Pixels	37,544	9,386
Line Rates	20,000 and 10,000 lines / sec	2,500 lines / sec
Quantization Level	11 bits per pixel	11 bits per pixel per channel
On-board Compression	Visually lossless at 2.5 bpp	Visually lossless at 2.5 bpp per channel

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Absolute Radiometric Calibration

OBJECTIVE

- Obtain relationship between In Band Entrance Aperture Radiance and detector response (digital counts)

$$(CalCoef)*L = DC$$

where: ***L*** = In Band Entrance Aperture Radiance (mW/cm^2-sr)

DC = Detector response (digital counts)

CalCoef = Calibration coefficient (digital counts/[mW/cm^2-sr])

METHODS

- Vicarious Radiometric Ground Calibration
  - Conventional approach
  - Accuracy of method is well understood
  - Calibration activities may interfere with revenue collections
- Stellar Radiometric Calibration (*Bowen, 2002)
  - Less conventional approach
  - Collections can be made while in umbra
  - Does not require field measurements or calibration target set up

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Overview of Stellar Calibration Method

IMAGE COLLECTION

- Targets taken from Gunn and Stryker Stellar Atlas
- One degree scans of celestial sphere
  - 6 different scans per measurement
- Approximately 3 seconds of imaging per scan
  - Total collection time less than one minute
- Collections can occur in umbra
- MS: line rate = 2500 lps, TDI = 24

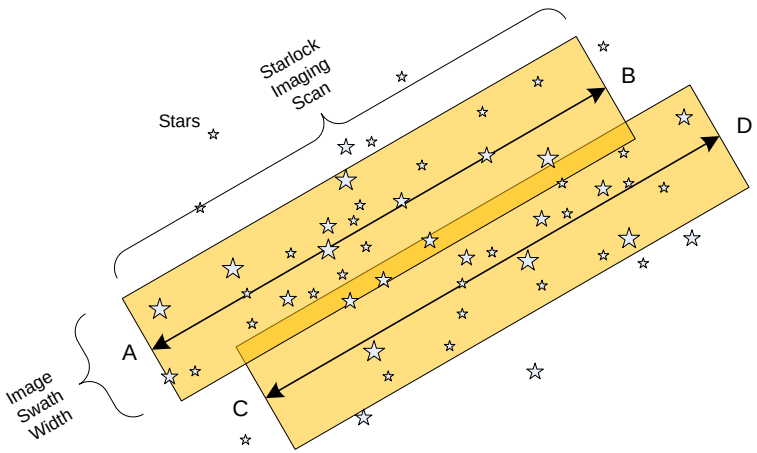

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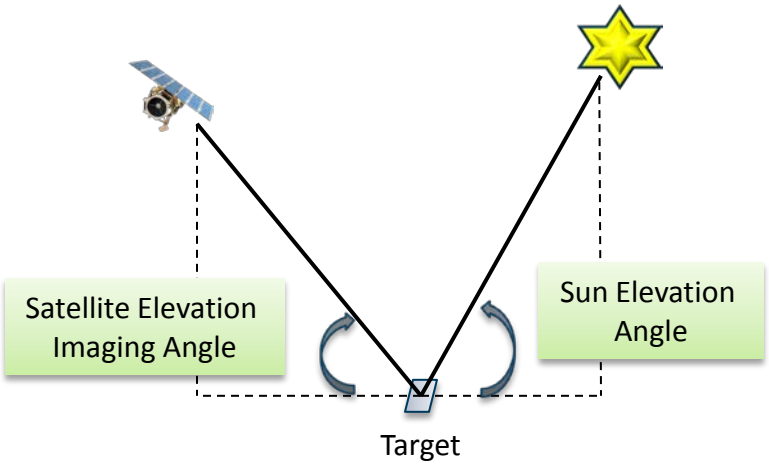
IMAGE COLLECTION (CONT.)

- GE-1 Time Delay Integration (TDI) stages:
  - Pan: 8, 16, 32, 48, and 64.
  - MS: 3, 6, 10, 14, 18, 21, and 24.



- Detector Exposure Time
  - CCD integration time = **TDI/line rate**

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Overview of Stellar Calibration Method

ANALYSIS

1. Calculate digital response (DC) produced by stellar target

2. Calculate the equivalent In Band Entrance Aperture Radiance (L)
   A. Convert normalized/de-reddened G&S catalog data to spectral irradiance
   B. Convert spectral irradiance to equivalent spectral radiance of uniform extended source
   C. Multiply spectral radiance by Relative Spectral Response (RSR) and integrate

3. Plot DC as a function of L using results obtained for various G&S stars
   A. Apply linear fit to obtain CalCoef

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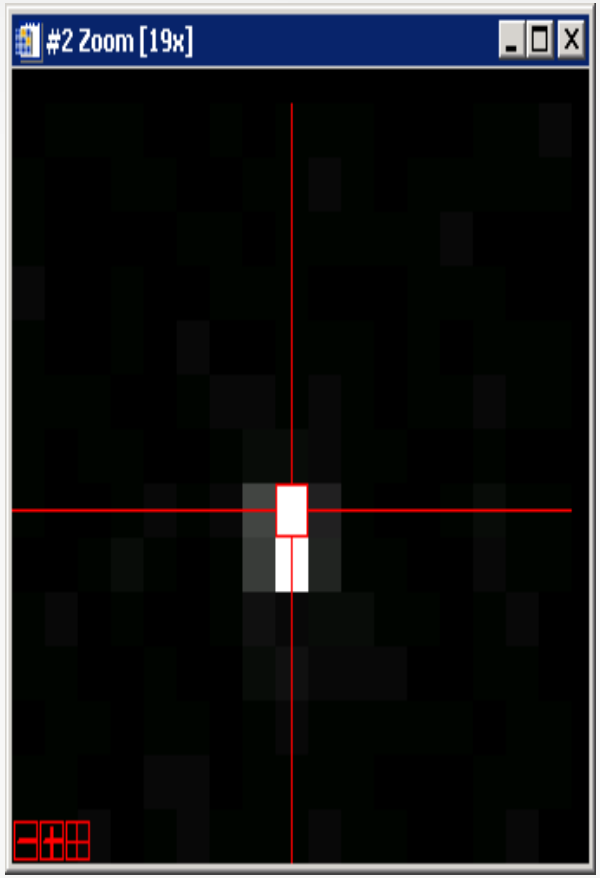
Analysis

CALCULATE DIGITAL RESPONSE (1)

- Locate star in image
  - Use attitude knowledge and camera math model
- Subtract dark response
- Sum digital counts in pixel region encompassing star
- Resulting sum is equal to DC_i



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Analysis

CALCULATE IN BAND RADIANCE (2A)

- G&S data reduction process (*J.E. Gunn and L.L. Stryker, 1983)
  - (1)De-redden measured spectral irradiance, (2)convert to AB magnitude, and (3)normalize

- Convert G&S catalog data to measured spectral radiance by reversing process ($\mathrm{F}(\nu) \rightarrow f(\nu)$)

1. $f_{de-red}(\nu) = \left(10^{(0.4*Av*A\lambda)}\right) * f(\nu)$

2. $AB(\nu) \stackrel{\text{def}}{=} -2.5 * \log_{10} f_{de-red}(\nu) - 48.6$

3. $F(\nu) = 10^{[-.4*(AB-V)]}$

$f(\nu) \equiv$ measured spectral irradiance ($^{erg}/_{s-cm^2-Hz}$)
$f_{de-red}(\nu) \equiv$ de-reddened spectral irradiance ($^{erg}/_{s-cm^2-Hz}$)
$Av \equiv$ visual absorption constant
$A\lambda \equiv$ wavelength dependent reddening constant

AB≡ monochromatic magnitude defined such that the zero point corresponds to 3631 Janskys

V≡ apparent visual magnitude
F(ν)≡ normalized G&S catalog data

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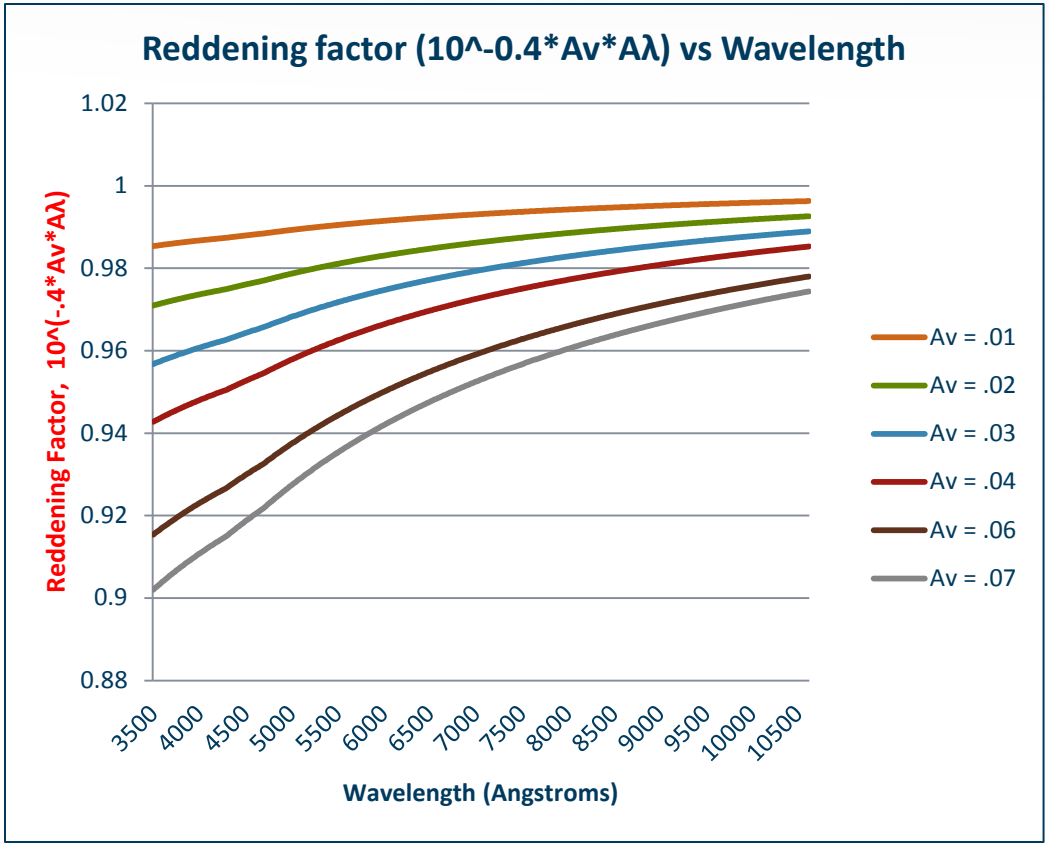
Analysis

CALCULATE IN BAND RADIANCE (2A)

- Scattering increases with frequency
- Overall attenuation a function of visual absorption (Av) of stellar source



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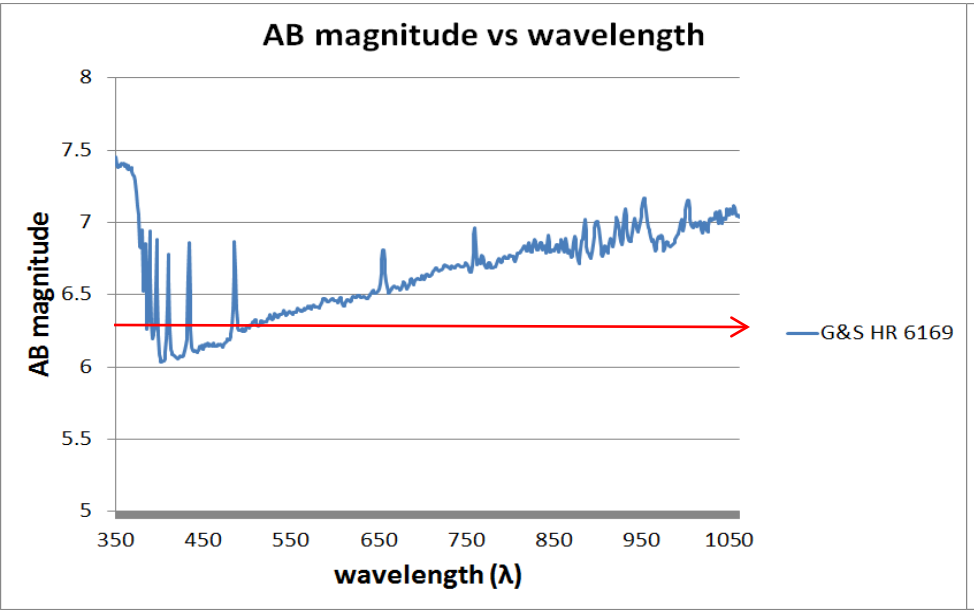
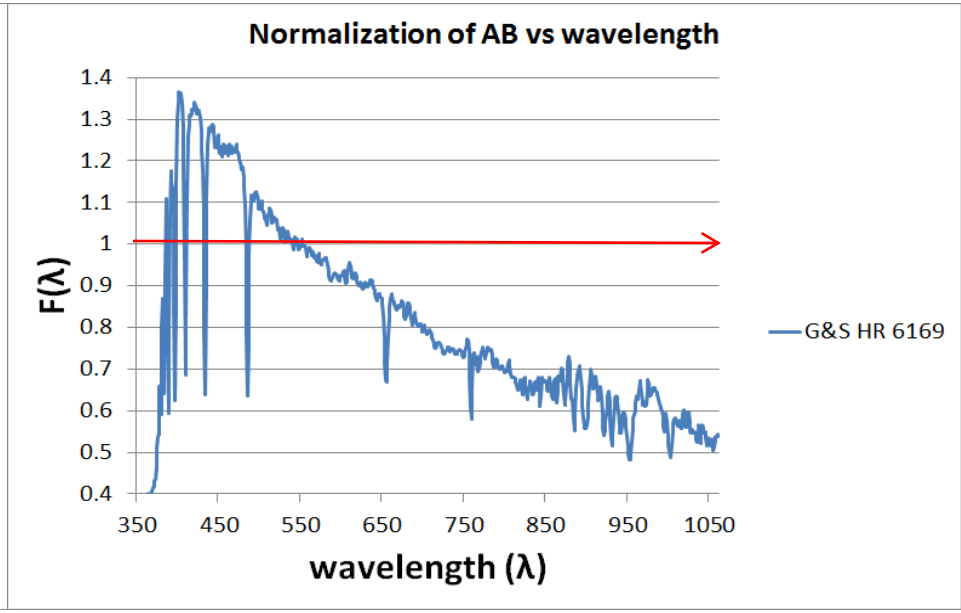
Analysis

CALCULATE IN BAND RADIANCE (2A)

- AB magnitude and normalization of G&S HR 6169
  - Apparent Visual Magnitude = 6.373
  - F(λ)=1 corresponds to AB=6.373 (denoted by red arrow below)





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Analysis

CALCULATE IN BAND RADIANCE (2B)

- Convert stellar spectral irradiance to equivalent spectral radiance of uniform extended source:
  - $IFOV = ({}^{p}/_{f})^{2}$, $p \equiv$ *detector pitch* , $f \equiv$ *focal length*, $IFOV \equiv$ *solid angle subtended by detector (steradian)*
  - $l(v) = f(v)/IFOV$, $l(v) \equiv$ *equivalent spectral radiance of extended source*

- Convert units:

$$(ergs/s - cm^2 - Hz - sr) \xRightarrow{(\frac{c}{\lambda^2})_{cgs} * 10^{-12}} (mW/cm^2 - \text{Å} - sr)$$

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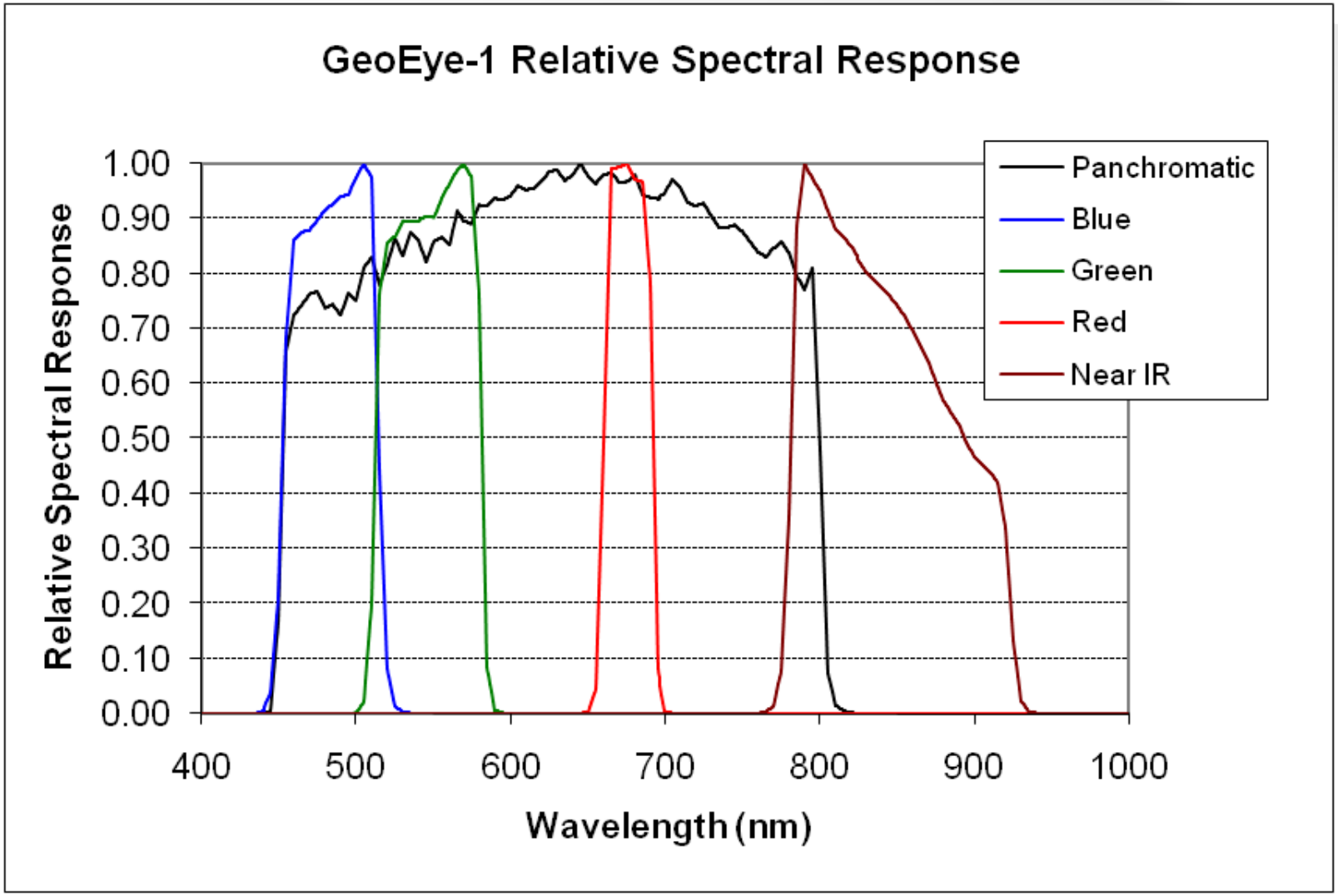

450 -510 nm 510-580 nm 655-690 nm 780-920nm

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Analysis

CALCULATE IN BAND RADIANCE (2C)

- Multiply spectral radiance by RSR and integrate to obtain In Band Radiance for ith band

$$L_i = \int_{\lambda_1}^{\lambda_2} l(\lambda) * RSR_i(\lambda)\, d\lambda$$

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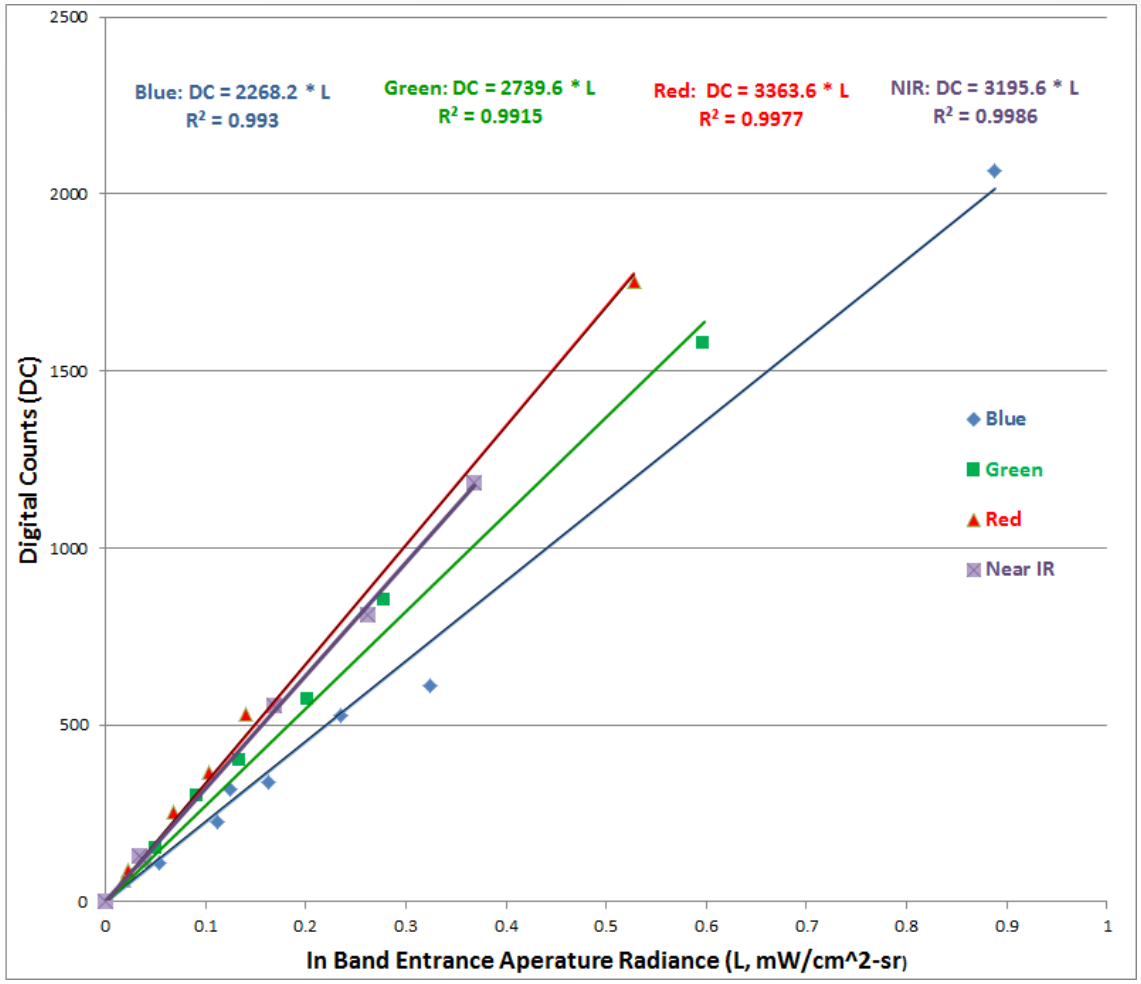
Analysis

APPLY LINEAR FIT (3A)

- Apply linear fit to obtain CalCoef for ith band

$$(CalCoef)_i * L_i = DC_i$$



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GeoEye-1 Product Metadata

- Calibration coefficients provided in GE1 product metadata are defined differently
  - $l_u = CalCoef_u * DC$, where l_u is the equivalent entrance aperture uniform spectral radiance which would produce the digital response DC

- The relationship between $CalCoef_u$ and $CalCoef$ is derived below

$$\int_{\lambda_1}^{\lambda_2} l_u * RSR(\lambda)d\lambda = L = (CalCoef)^{-1} * \mathrm{DC}$$

$$(CalCoef_u * DC) * \int_{\lambda_1}^{\lambda_2} RSR(\lambda)d\lambda = \mathrm{L} = (CalCoef)^{-1} * \mathrm{DC}$$

$$CalCoef_u = (CalCoef * k)^{-1} \rightarrow \ k = \int_{\lambda_1}^{\lambda_2} RSR(\lambda)d\lambda$$

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Results Summary

- CalCoefs shown in table below with corresponding coefficients of determination (R^2)

Band	CalCoef (cnts/(mW/cm^2-sr))	R^2
Blue	2268.2	0.993
Green	2739.6	0.992
Red	3363.6	0.998
NIR	3195.6	0.999

- Table below shows standard deviation of digital response measurements

G&S Star	V magnitude	Av	Blue (1σ as % of mean DC)	Green (1σ as % of mean DC)	Red (1σ as % of mean DC)	NIR (1σ as % of mean DC)
HR 8924A	6.104	0.073	2.96	1.01	2.09	0.76
HR 7467	6.481	0.13	4.62	3.81	3.23	6.15
HD 7331	7.156	0.08	4.93	3.26	8.51	3.08
HD 72184	5.67	0.061	0.74	0.44	1.37	1.61
HD 131111	5.336	0.049	2.57	0.77	0.65	0.25

- Results support measurement precision and temporal stability

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Future Goals

- Compare results with Vicarious Ground Calibrations for accuracy assessment
- Assess and quantify stability of digital response over time
- Develop database of preferred stellar targets
- Investigate additional corrections described by Bowen in 2006 JACIE presentation
  - Encircled Energy Function
  - Spectral Correction Function (SCF)

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Acknowledgements

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Sources

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- J. E. Gunn and L.L. Stryker, "*Stellar Spectrophotometric Atlas*", 3130<λ<10800A, Astrophysical Journal Supplement Series 52, 121-153, 1983.
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