Camera Case Study: HiSCI → now CaSSIS
(Colour and Stereo Surface Imaging System)

A camera for ESA's 2016 ExoMars Trace Gas Orbiter:
http://space.unibe.ch/pig/science/projects/cassis.html

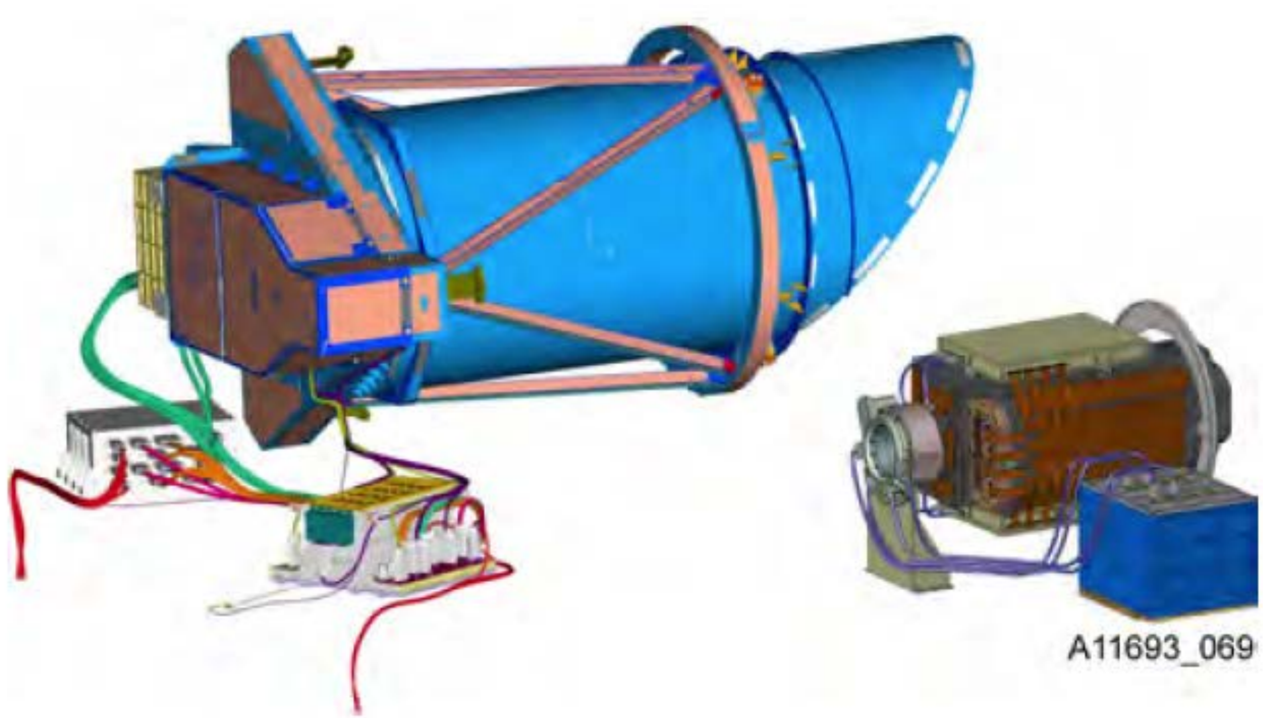


***Figure 2-2** – A scaled comparison of the size of HiRISE (left) vs. HiSCI (right).*

Mars Cameras: Technical Specifications

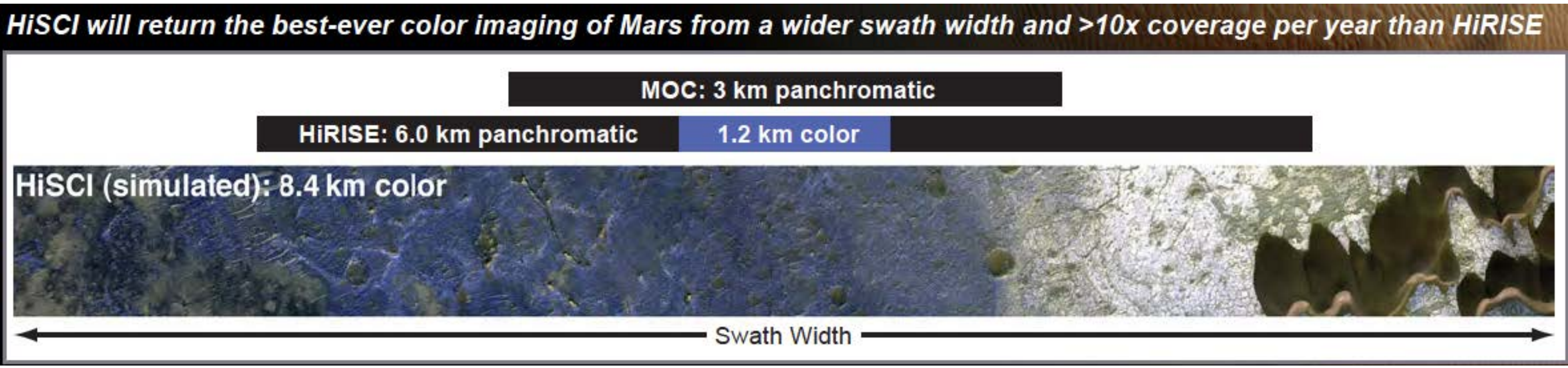
Table 1-1. *HiSCI provides ~20x the color and stereo coverage of HiRISE and a much wider color swath (green boxes) and higher quality images (combination of pixel scale, colors, SNR, and swath width) than other high-resolution imaging systems at Mars (orange boxes).*

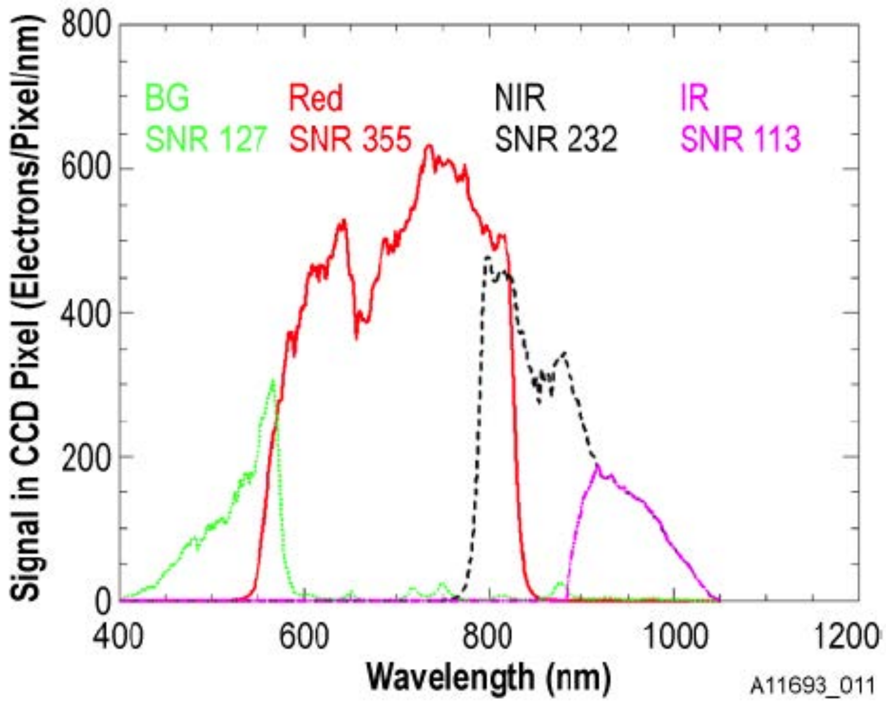
Camera	Scale (m/pixel)	# Colors	SNR$^{\Psi}$	Swath width	Color swath	% Mars coverage$^{\alpha}$	% color coverage$^{\alpha}$	% stereo coverage$^{\alpha}$
HiSCI	2.0	4	>300	8.5 km	8.5 km	2%	2%	1.0%
HiRISE	0.3	3	>150	6 km	1.2 km	0.5%	0.1%	<0.05%
MOC	1.5	1	<50	3 km	None	~1%$^{\beta}$	0%	<<1%
HRSC-SRC	2.3 *	1	<50	2.3 km	None	<<1%	0%	0%
HRSC	12-50	4**	<50	50-250 km	50-250 km	~20%	~20%	~20%
CTX	6	1	<50	30 km	None	30%	0%	<5%

Notes: $^{\Psi}$ dark region at full resolution, broadest bandpass, 45 deg illumination (McEwen et al., 2007; Malin et al., 1992; 2007; Jaumann et al., 2007; Oberst et al., 2008); $^{\alpha}$ cumulative coverage during 1 Mars year; $^{\beta}$ ~0.1% at <3 m/pixel; * out of focus; ** different photometric angles and atmospheric path length for each color.

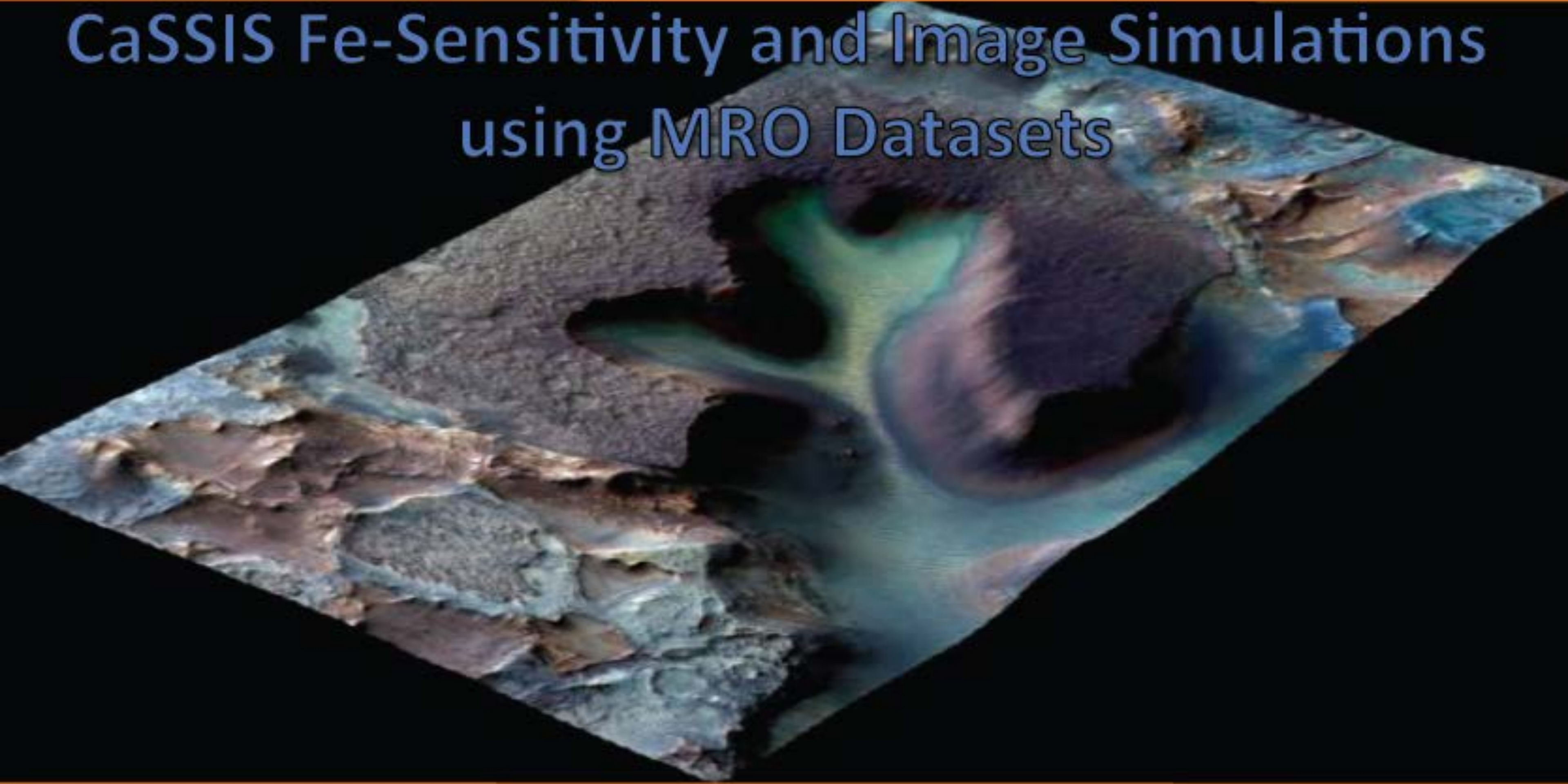
Note: CaSSIS will be 4.6 m/pixel instead. :-/
But, 9.4 km swath width!

Case Study: HiSCI → now CaSSIS
(**Colour** and Stereo Surface Imaging System)





CaSSIS Fe-Sensitivity and Image Simulations using MRO Datasets



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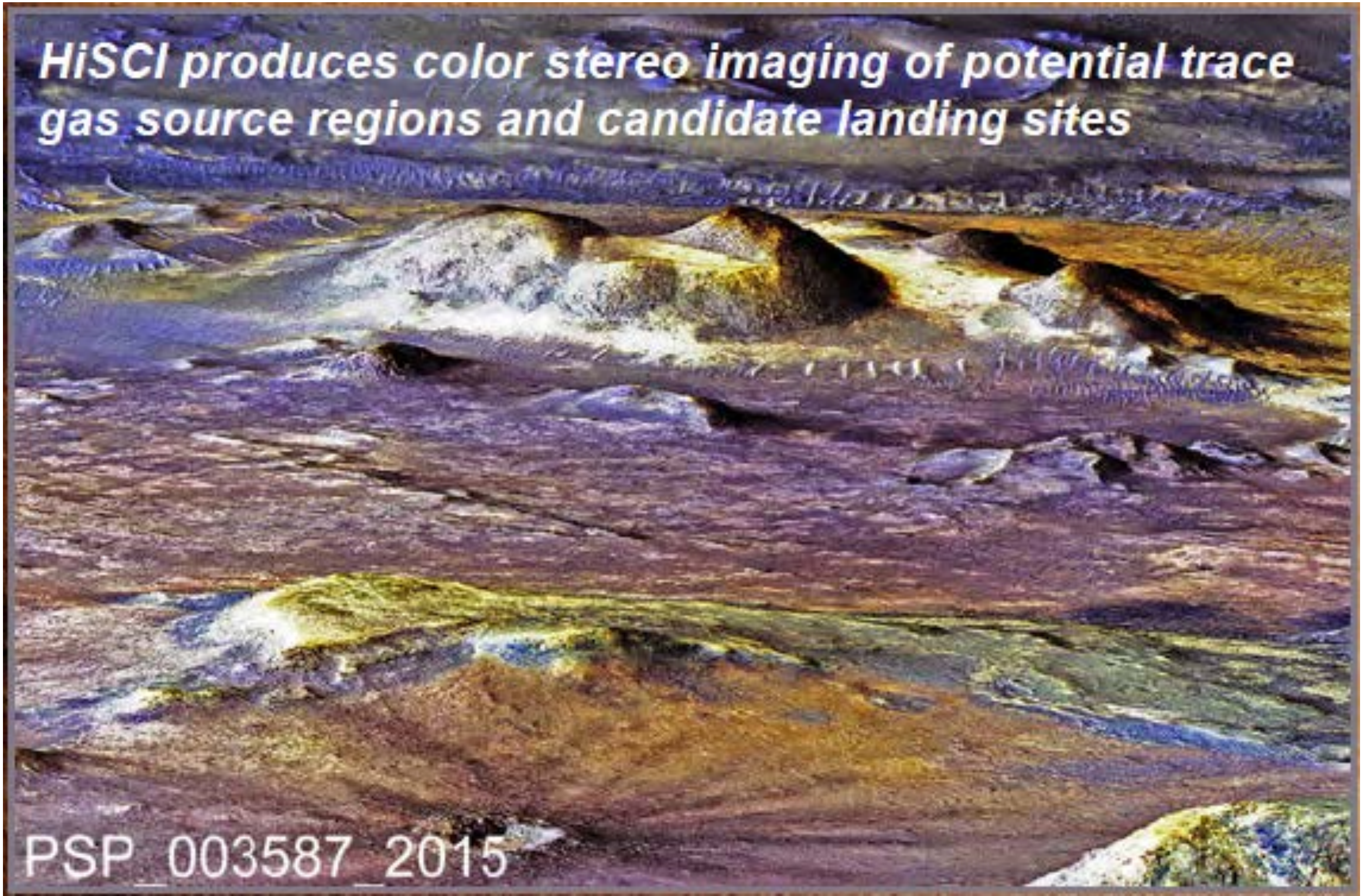
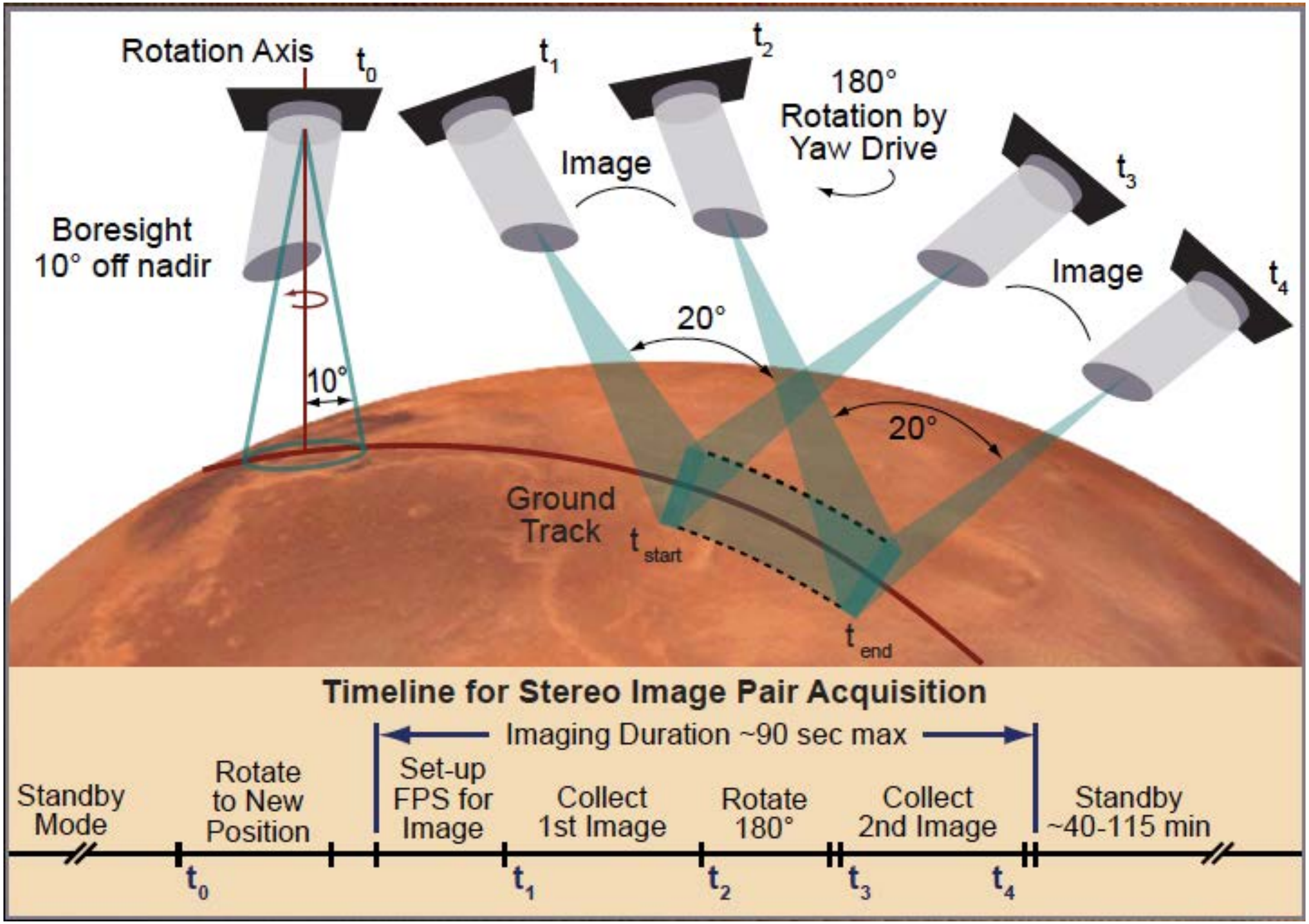
Case Study: HiSCI → now CaSSIS
(Colour and Stereo Surface Imaging System)

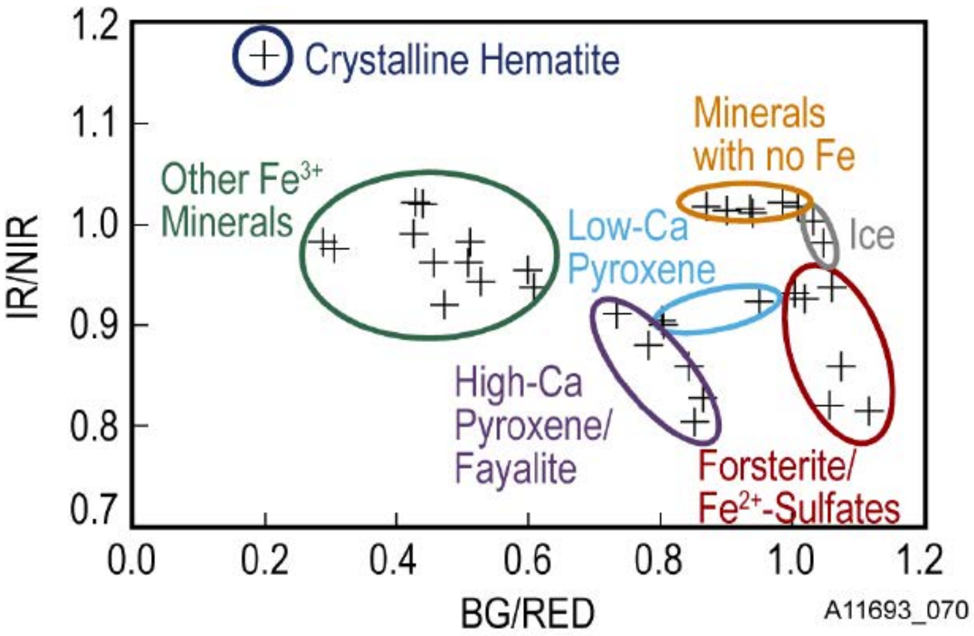


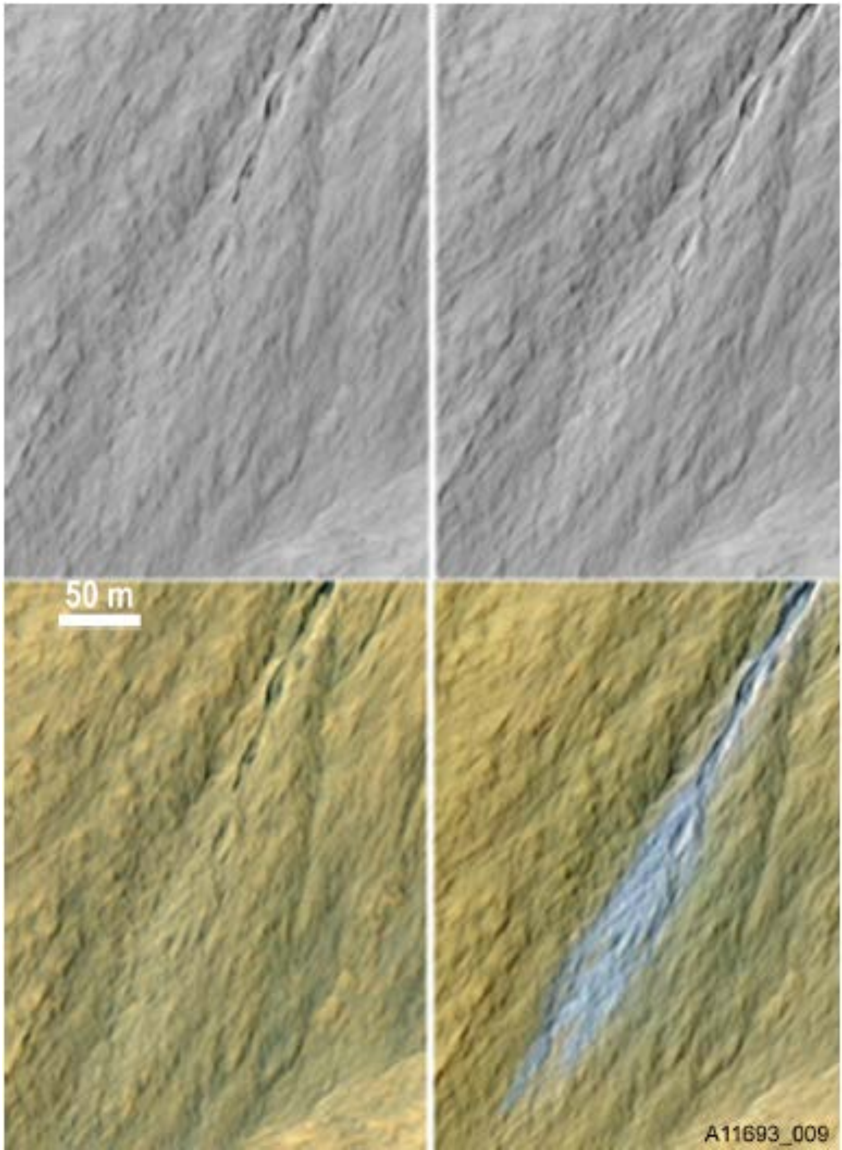
Case Study: HiSCI → now CaSSIS
(Colour and **Stereo** Surface Imaging System)



High-quality stereo imaging via collection of two images under identical illumination conditions

Case Study: HiSCI → now CaSSIS
(**Colour** and Stereo Surface Imaging System)



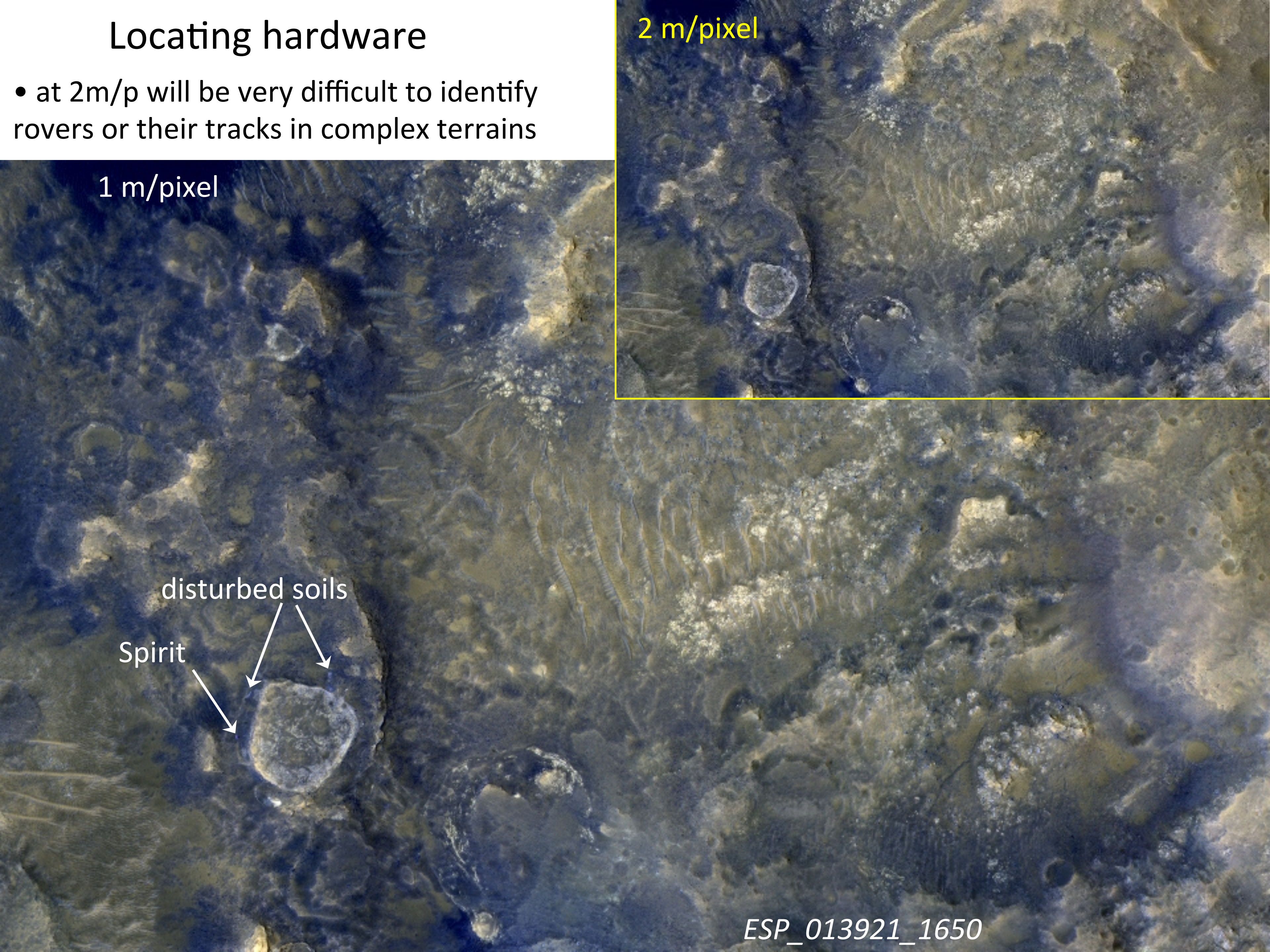


These wavelengths are useful for distinguishing iron-bearing minerals

Also useful for monitoring color changes over time

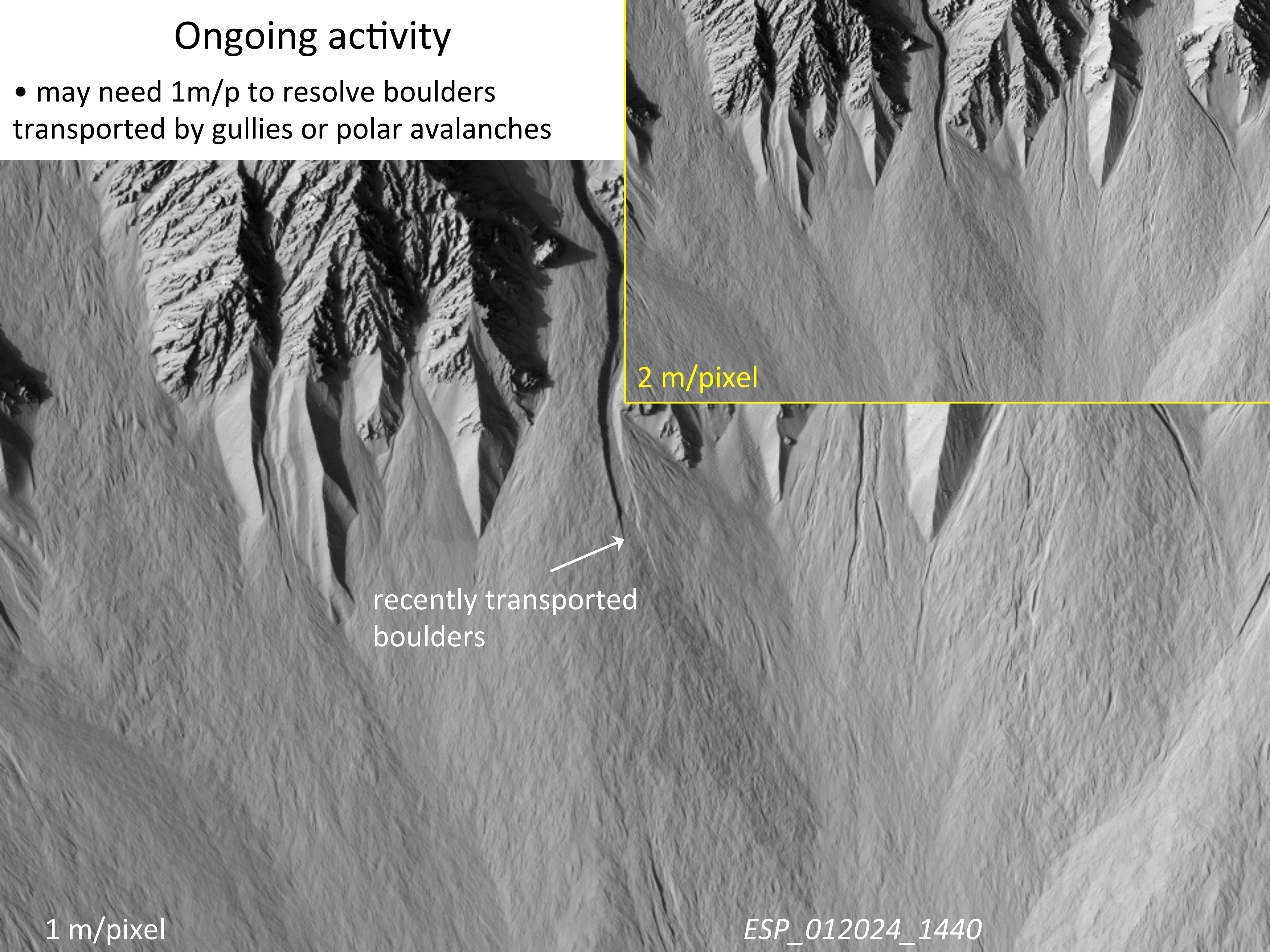
Locating hardware

• at 2m/p will be very difficult to identify rovers or their tracks in complex terrains



Ongoing activity

• may need 1m/p to resolve boulders transported by gullies or polar avalanches



Case Study: HiSCI → now CaSSIS
(Colour and Stereo Surface Imaging System)

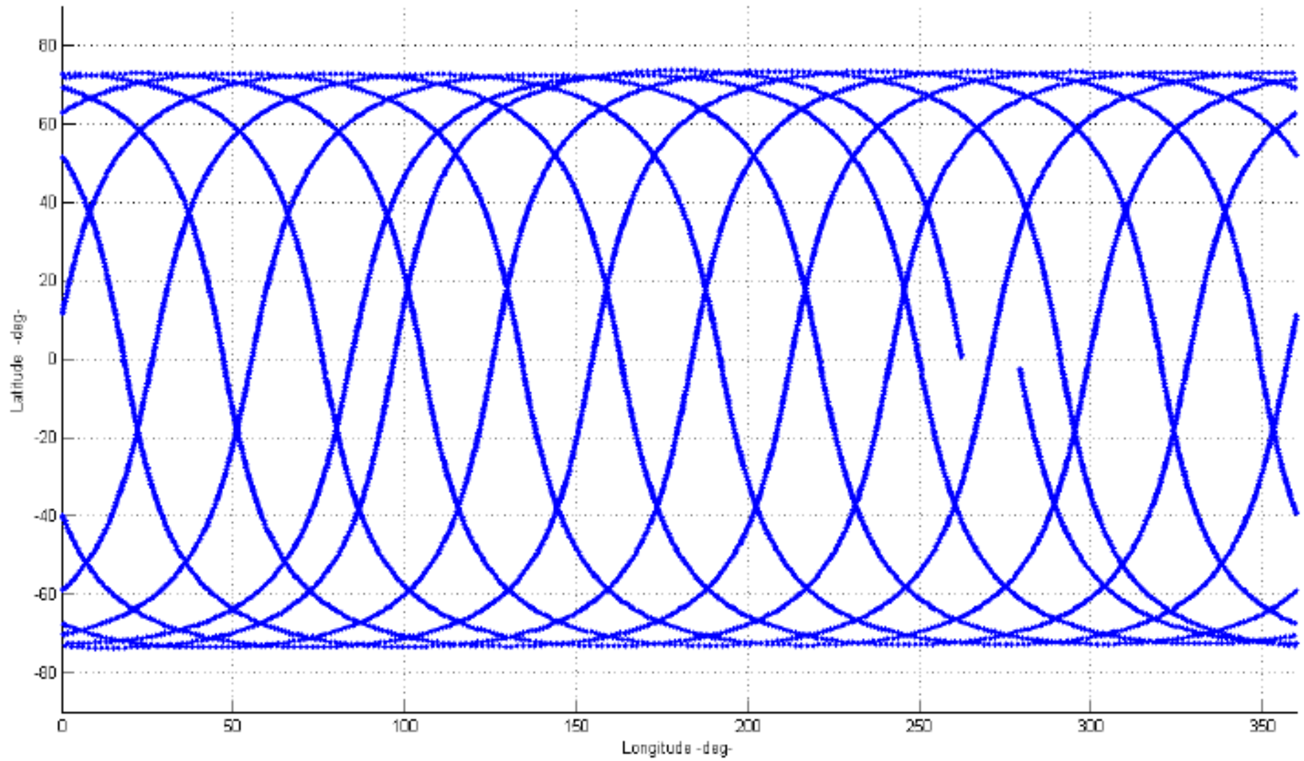


Figure 5.5-28 Ground track of observed point 1 day, 90 deg Sun elevation , -Z Looking instrument

<u>Orbital constraints are also important:</u>

- 74° orbital inclination → cannot image polar caps
- Ground track + swath width → ~weekly repeat coverage (better if could point off-nadir)
- Orbit ***not*** sun-synchronous → unlike HiRISE, can observe at different times of day

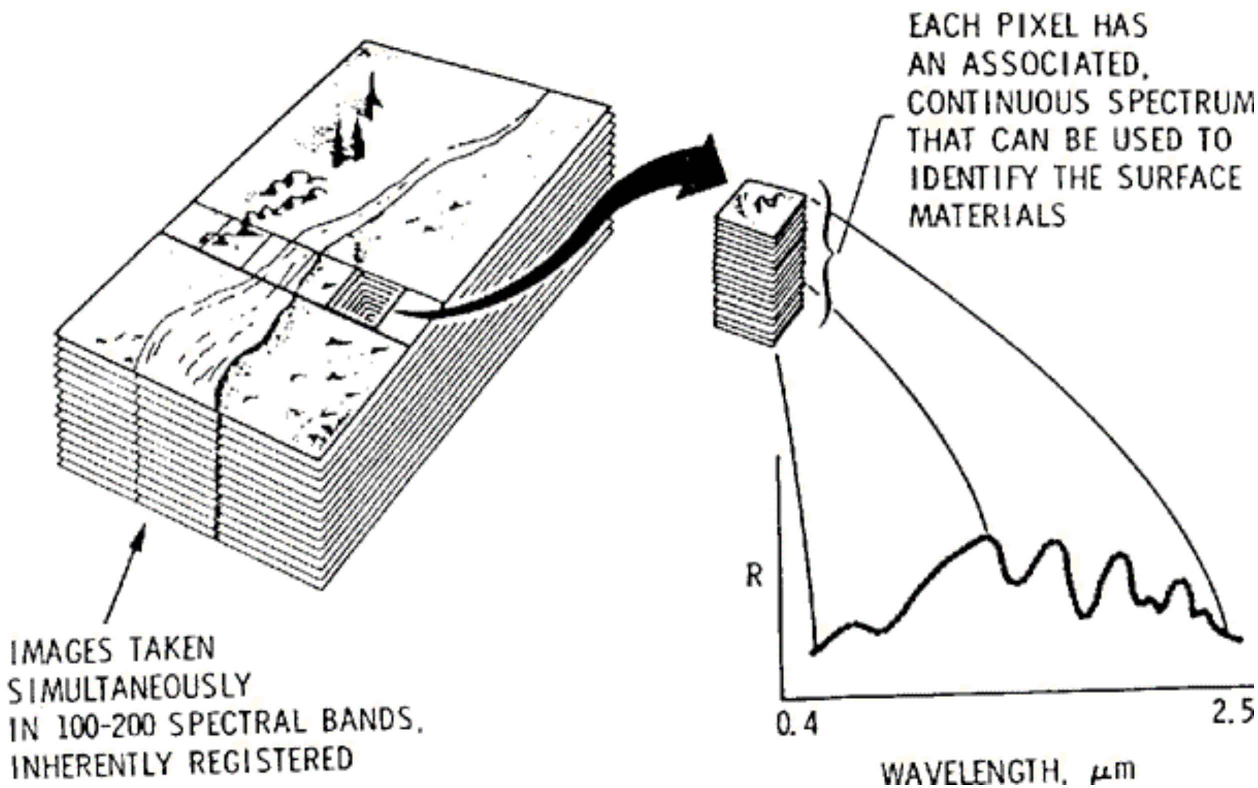
Instrumentation and Measurement

- Types of instruments
- Types of detectors
- Basic instrument parameters

Types of instruments

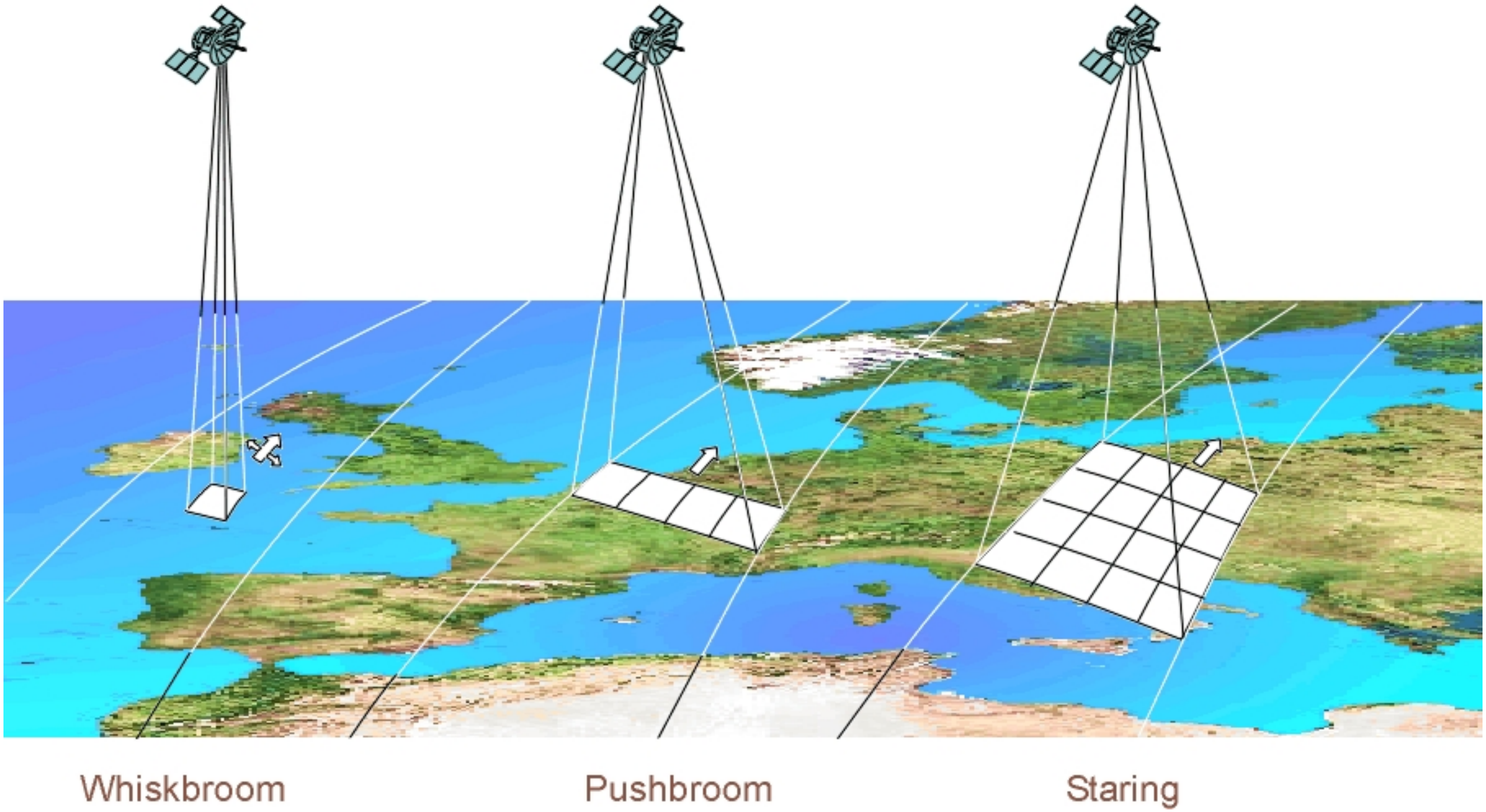
- Framing cameras
- Scanning systems
  - Whiskbroom imagers
- Pushbroom imagers

Multi- and Hyperspectral Image Cubes are 3-Dimensional Data Structures

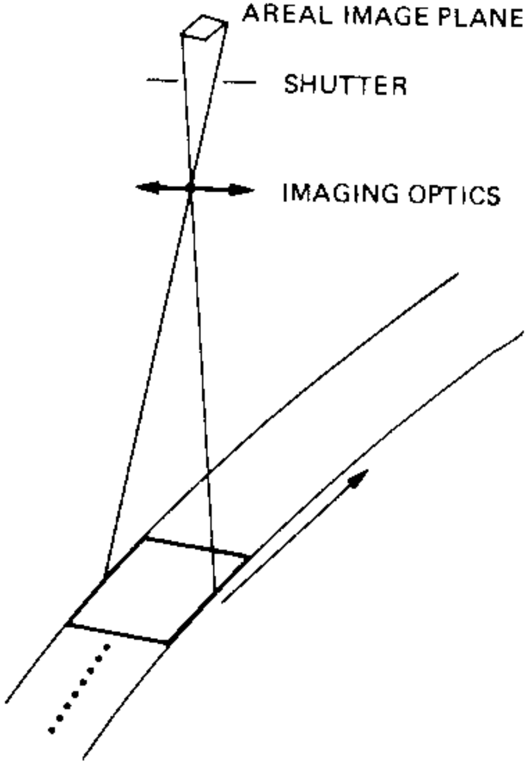


But a single detector cannot acquire all three dimensions at once.

Image Acquisition Modes



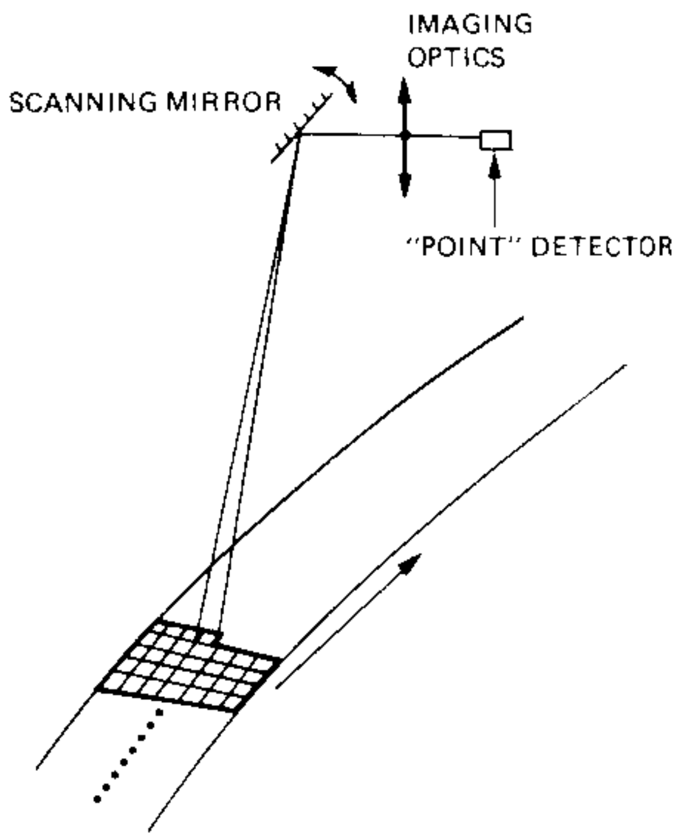
Framing Camera



a) FRAMING CAMERA

- Simultaneous sampling
- Good geometric control
- Not suited to high spectral resolution

Scanning Systems



b) SCANNING SYSTEMS

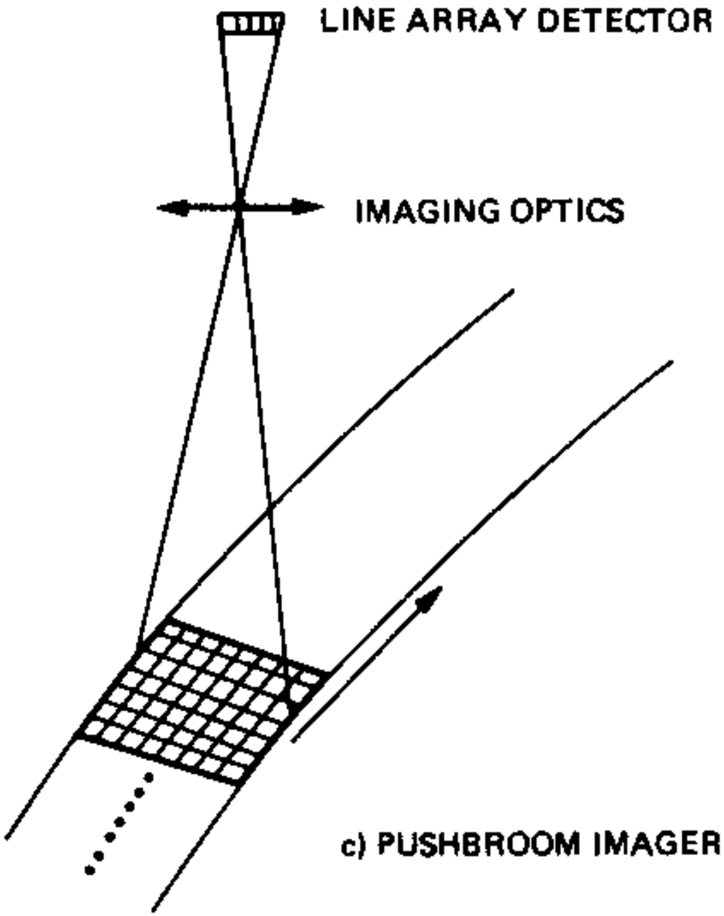
- Simple detector
- Easy to get multiple wavelengths

- Low detector dwell time

e.g., Landsat

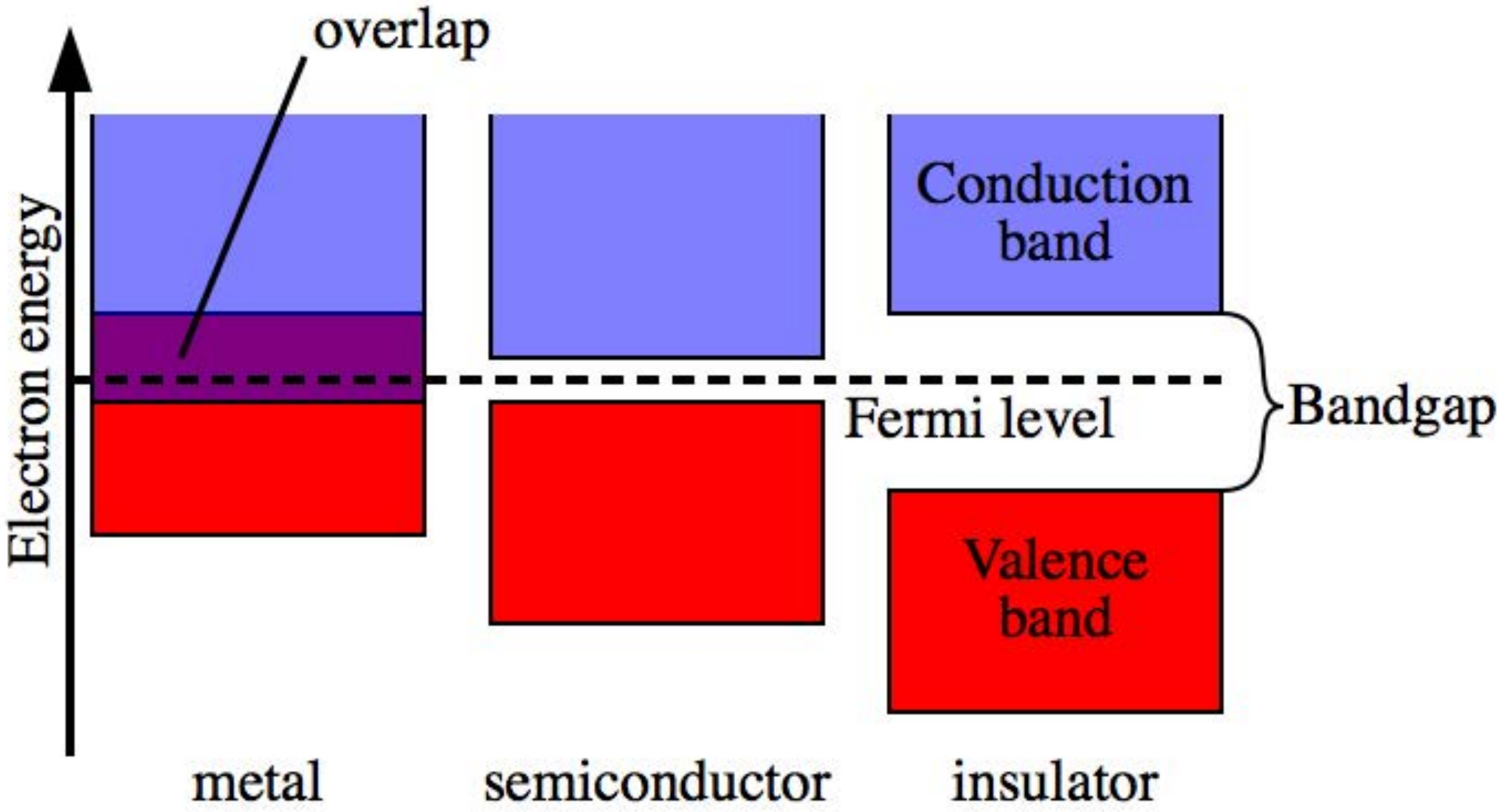
Pushbroom Imager

- Long detector dwell time
- Good cross-track fidelity
- No moving parts



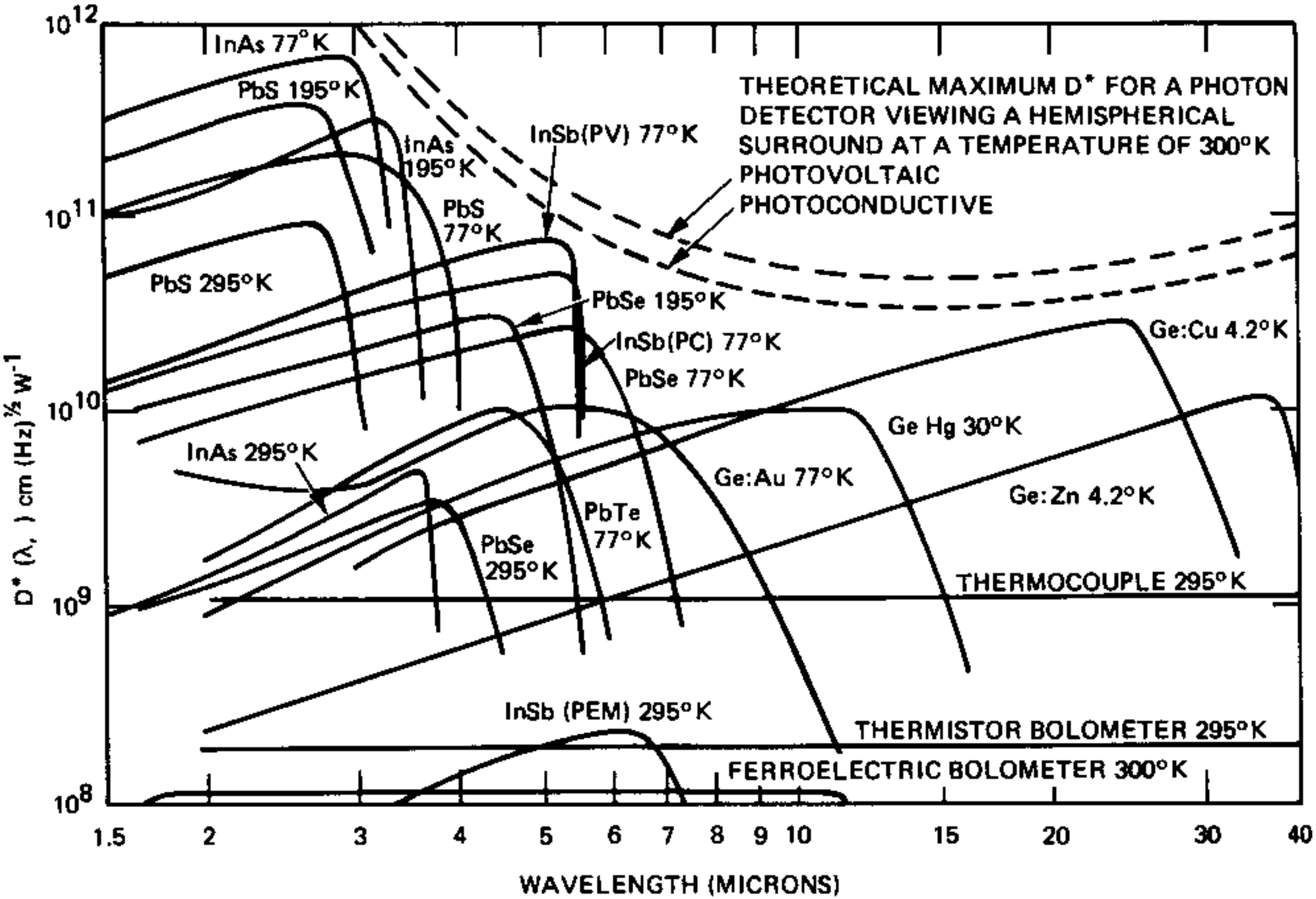
e.g., EO-1

Semiconductor-based detectors



- Incident radiation excites electrons into conduction band
- *Photovoltaic devices* measure the resulting current
- *Photoconductive devices* measure resulting change in conductivity (resistance)

Detector Materials



D^* ("detectivity") is a "figure of merit" for photodetectors

$$D^* \equiv \frac{\sqrt{A \times \Delta f}}{NEP}$$

- A is detector area in cm^2
- Δf is the signal bandwidth in Hz = $1/(2\pi\tau)$, where τ is the required integration time ("time constant")
- *NEP* (noise-equivalent power) is power in watts required on the detector to produce S/N = 1

Silicon at visible wavelengths

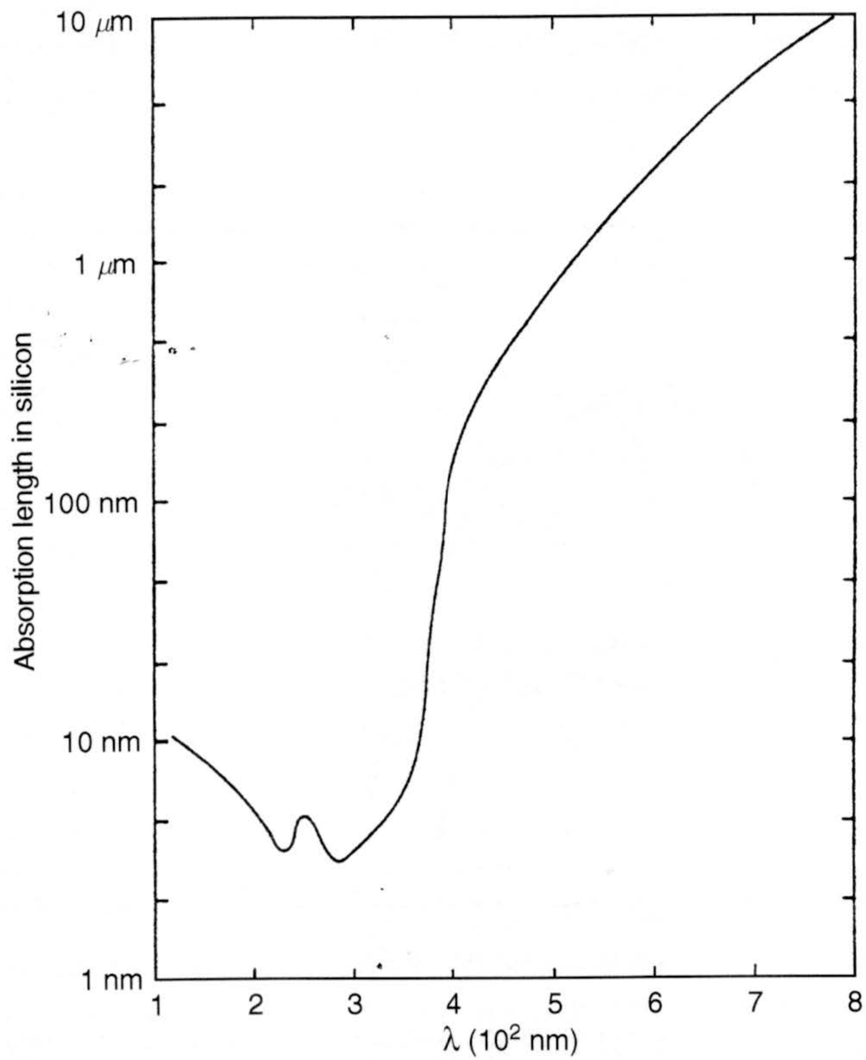


Fig. 3.1. The photon absorption length in silicon is shown as a function of wavelength in nanometers. From Reicke (1994).

Most Common Detector Materials

- 0.4 – 1.0 μm: Silicon (Si)
  - E.g., Mars Reconnaissance Orbiter CRISM VNIR
- 1.0 – 5.0 μm: Indium Antimonide (InSb)
  - E.g., Mars Express OMEGA
- 8 – 14 μm (or shorter IR wavelengths w/ larger x): Mercury Cadmium Telluride ($Hg_{1-x}Cd_xTe$)
  - E.g., Mars Reconnaissance Orbiter CRISM IR

Basic Instrument Parameters

Spatial, Spectral, and Radiometric Properties

- Spatial:
  - Instantaneous Field of View (IFOV)
  - Ground Sampling Distance (GSD)
  - Field of View (FOV) or Field of Regard
  - Image size (pixels)

Important spatial properties in images

° Field of view ("FOV")

- Distance across the image (angular or linear)

° Pixel size

- Instantaneous Field of view ("IFOV")

Size in meters or is related to angular IFOV and height above ground

ex: 2.5 milliradian, at 1000 m above the terrain

*1000 m * (2.5 * 10^{-3} rad) = 2.5 m*

Each pixel represents a ~square area in the scene that is a measure of the sensor's ability to resolve objects

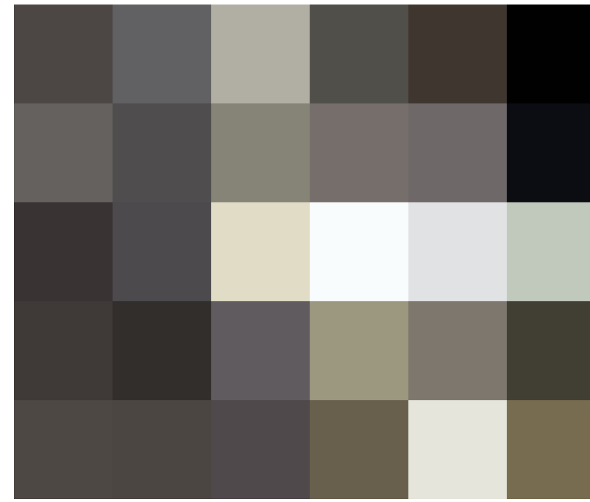
Examples:

Landsat 7 / ASTER VIS	15 meters
Landsat 5 / ASTER NIR	30 meters
ASTER TIR	90 meters

Spatial Resolution

15 m/pixel

100 m/pixel

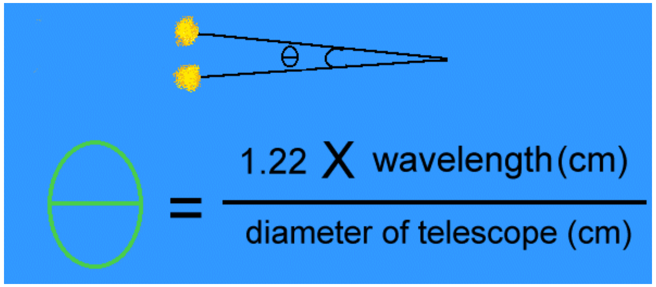


3000 m/pixel

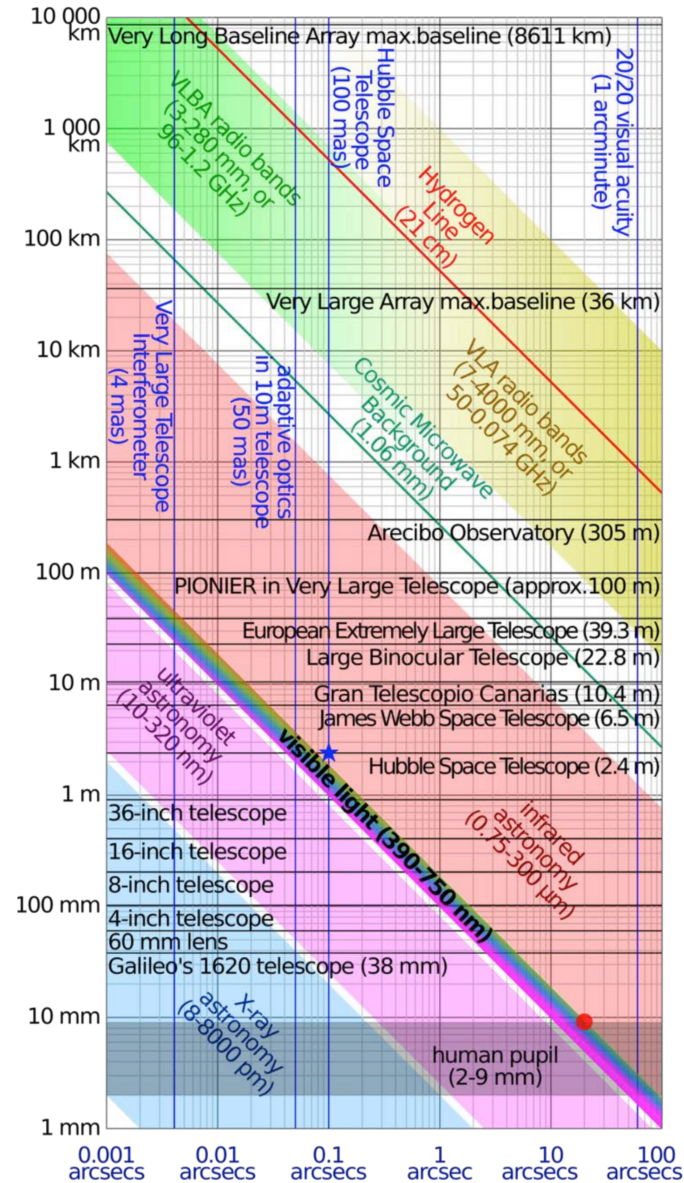
Note: Angular resolution is an instrumental property. Spatial resolution (GSD) is an experimental property (it is determined both by the instrument and how it is used).

Diffraction Limit

- Best possible angular resolution as a function of wavelength:



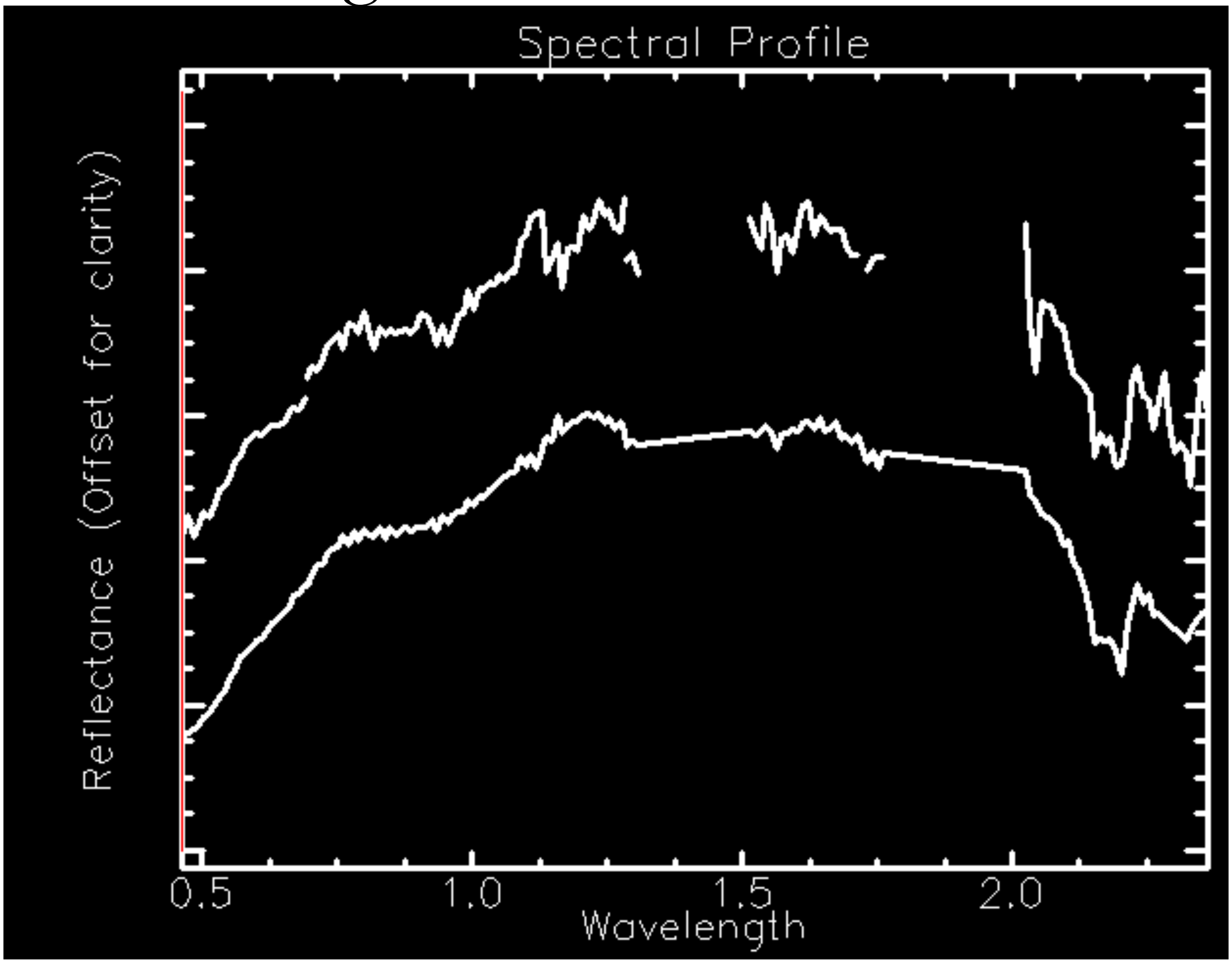
(θ is in radians)



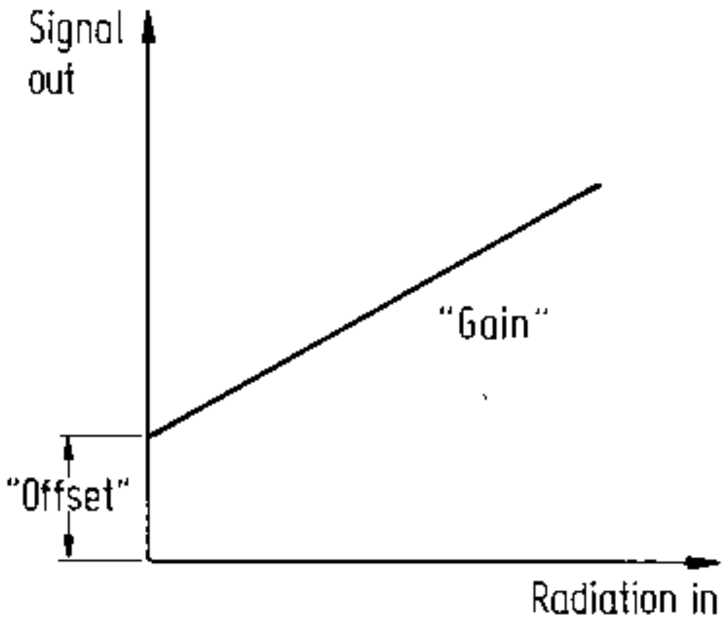
Basic Instrument Parameters

- Radiometric
  - Signal to Noise Ratio (SNR)
  - Dynamic Range
  - Linearity

Signal to Noise Ratio



Linearity



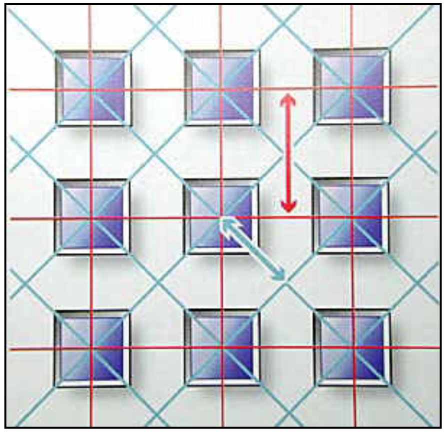
DN = (Radiance)*Gain + Offset

Digital Images

A Charged Couple Device replaces the photographic film.

CCD

- silicon wafer
- solid-state electronic component
- array of individual light-sensitive cells
- each = picture element ("pixel")



Each CCD cell converts light energy into electrons.

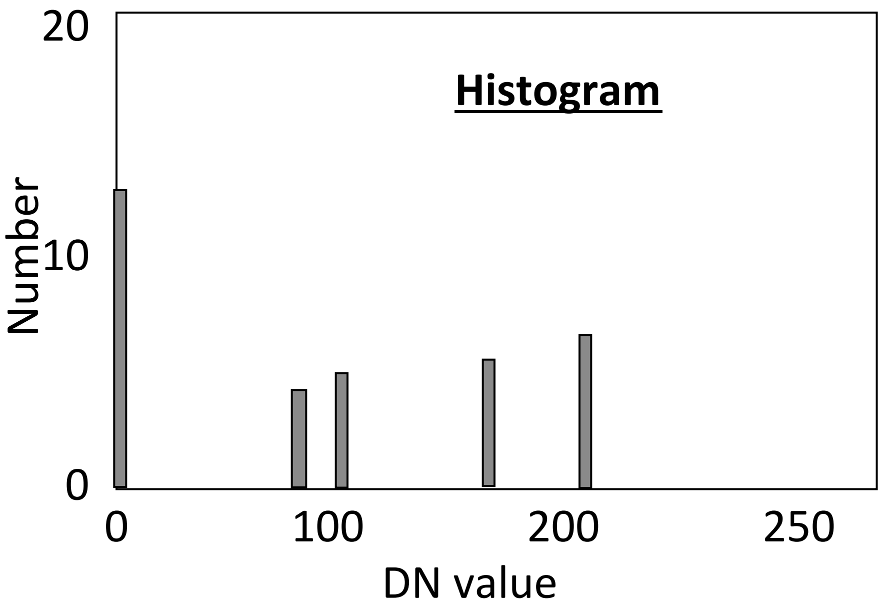
A digital number ("**DN**") is assigned to each pixel based on the magnitude of the electrical charge.

In the case of digital cameras: Each pixel on the image sensor has red, green, and blue filters intermingled across the cells in patterns designed to yield sharper images and truer colors.

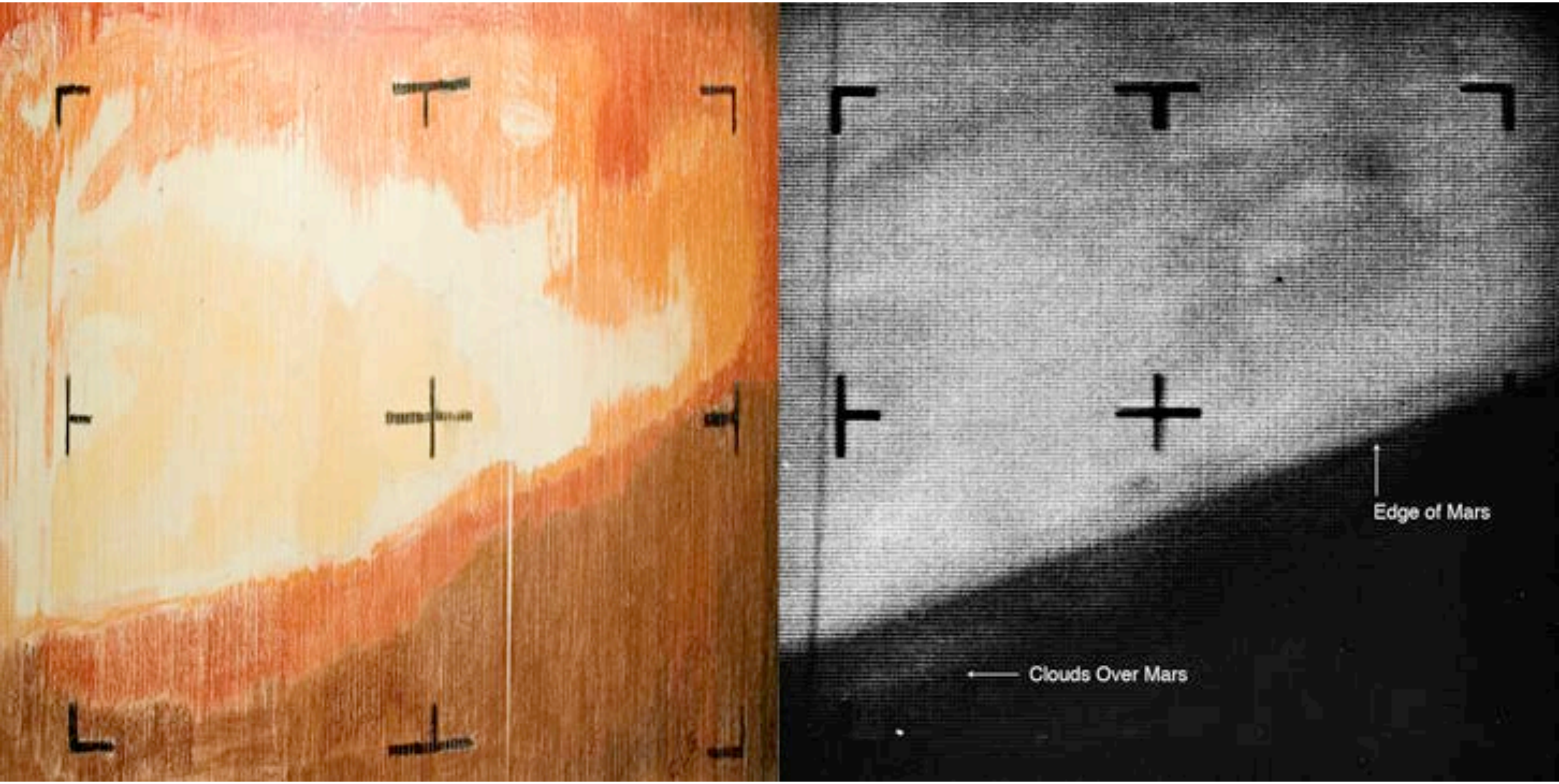
Digital images

Each pixel is assigned a DN

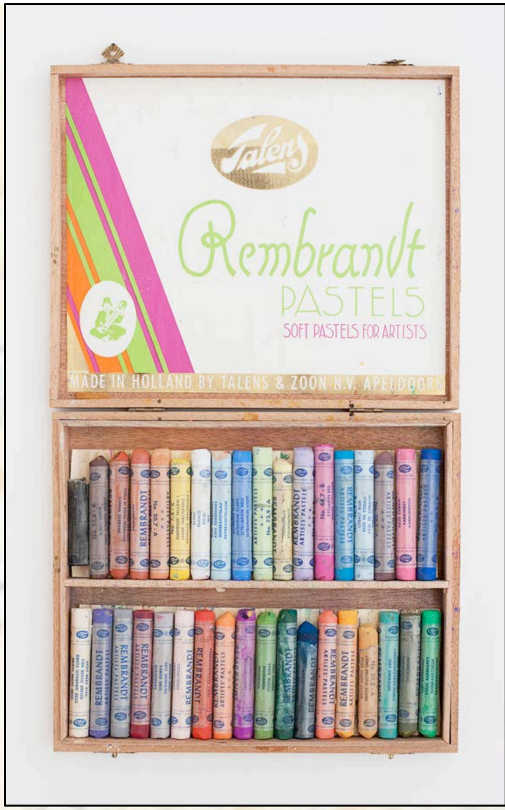
0	0	0	0	200	100
100	0	198	75	0	198
198	0	0	0	100	75
198	0	75	168	75	168
0	0	0	167	168	199



First image from Mars (Mariner 4)

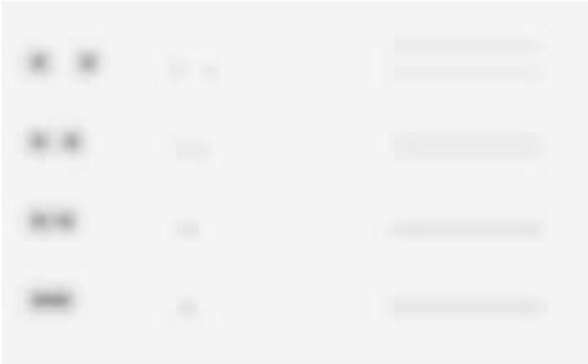


First image from Mars (Mariner 4)

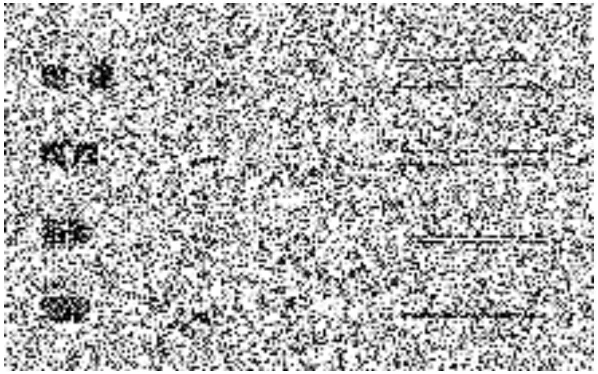


Resolution, contrast & 'noise' affect **detectability**

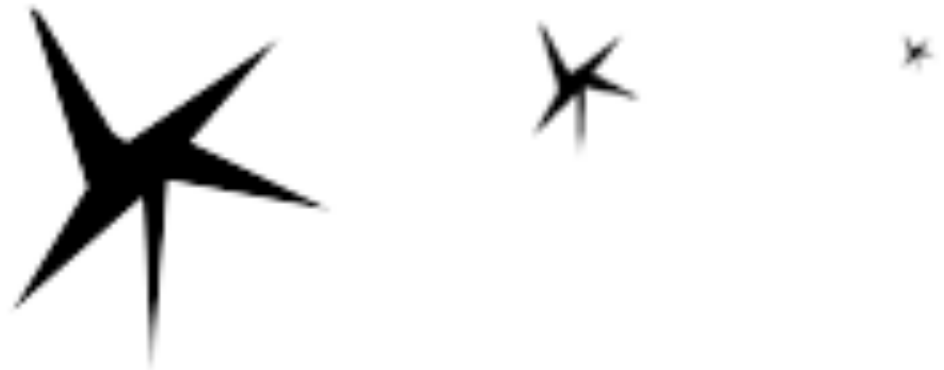
High contrast



Low contrast & blurred



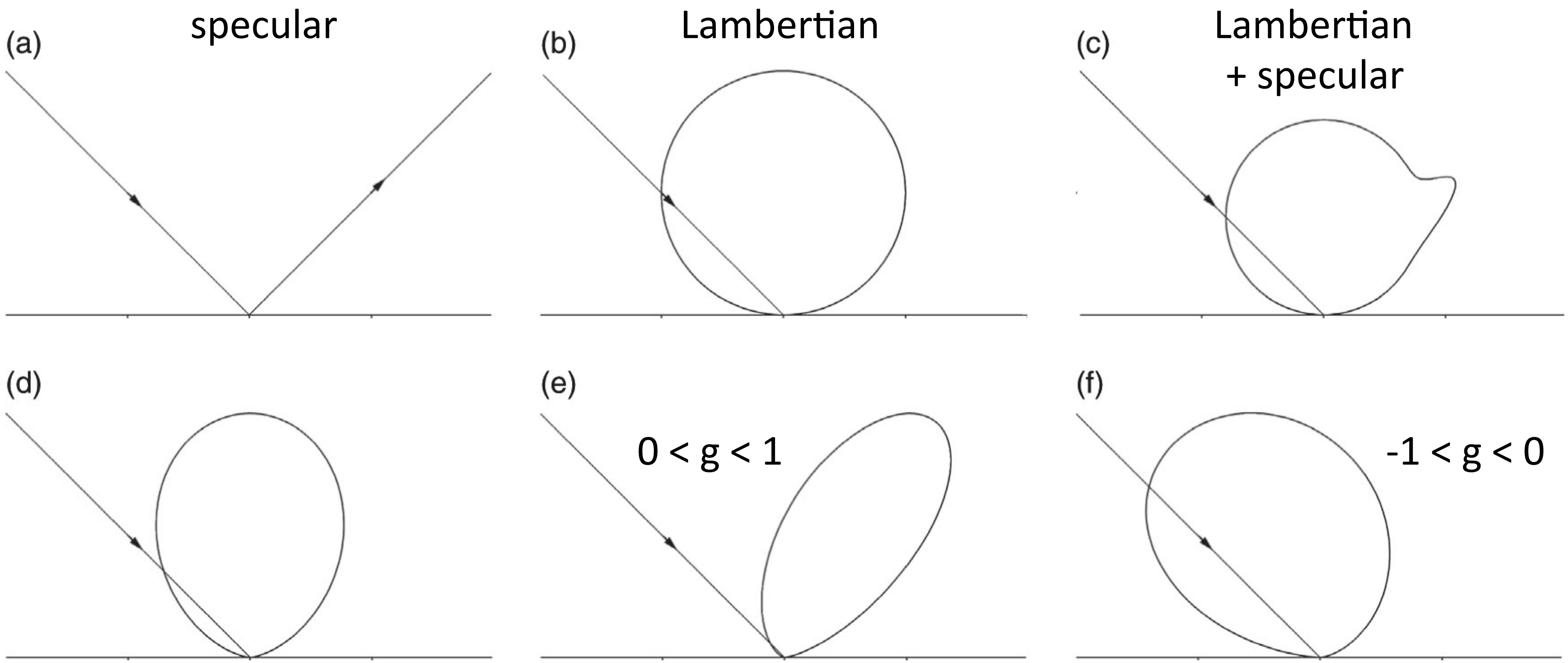
Low signal/noise



Recognition of shape is affected by resolving power

Homework #2: Surface scattering

$$\frac{dL_f(\theta,\phi)}{dz} = -(\gamma_a + \gamma_s)L_f(\theta,\phi) + \frac{\gamma_s}{4\pi}\int_{4\pi} L_f(\theta',\phi')p(\cos\Theta)\,d\Omega' + \gamma_a B_f$$



Minnaert

BRDF ~ $(\cos\theta_0 \cos\theta_1)^{\kappa-1}$

Henyey-Greenstein

BRDF ~ $(1 - g^2) / (1 - 2g\cos\Theta + g^2)^{3/2}$

Rees Fig. 3.10

Surface scattering study show-and-tell

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Surface scattering properties at the Opportunity Mars rover's traverse region measured by CRISM

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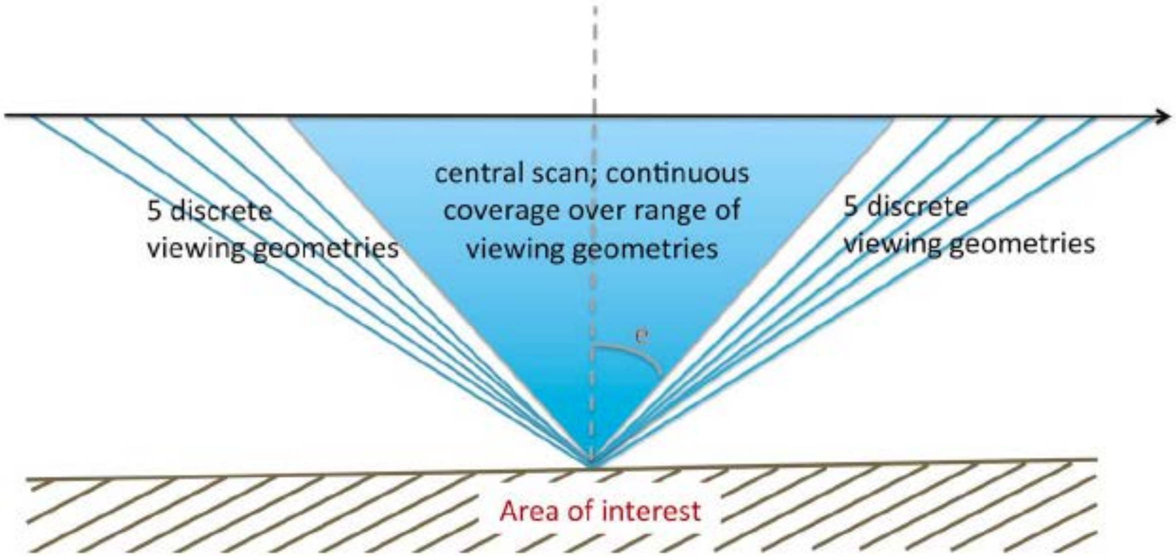
Received 21 December 2012; revised 5 July 2013; accepted 1 August 2013.

Used Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on MRO



Broad range of emergence angles, narrow range of incidence angles; moderate range of phase angles

Table 1. Emergence, Phase, and Incidence Angle Coverage for Each Image in FRT0000B6B5[a]

FRT Image Segment	Emergence Angle Coverage (°)	Phase Angle Coverage (°)	Incidence Angle Coverage (°)
01	68.1–68.5	105.6–106.5	55.6–56.0
02	61.4–61.6	100.6–101.4	55.8–56.1
03	54.7–55.4	95.4–96.8	55.9–56.2
04	58.3–48.8	90.5–91.8	56.0–56.2
05	41.9–43.5	85.5–87.6	56.0–56.2
07	0.1–21.3	43.9–65.9	56.2–56.6
09	44.8–46.1	39.2–40.9	56.5–56.7
0A	50.9–51.3	39.9–41.4	56.6–56.9
0B	56.6–57.4	41.2–42.6	56.6–56.9
0C	~63.1	43.4–44.5	56.7–57.0
0D	69.4–69.9	46.2–47.2	56.7–57.2

[a]Ranges given are for the region where all 11 image segments overlap.

Methods: Hapke modeling

I/F = $$rf = \left(\frac{w}{4}\right)\left(\frac{\mu_0}{\mu_0+\mu}\right)[p(g) + \mathrm{H}(\mu_0)\mathrm{H}(\mu) - 1] \quad (1)$$

Henyey-Greenstein $$p(g) = \frac{1-b^2}{\left[1+b^2+2b\cos(g)^{3/2}\right]} \quad (2)$$

multiple scattering $$\mathrm{H}(\mu) \sim \frac{1+2\mu}{1+2\sqrt{1-w\mu}} \quad (3)$$

g = phase angle
μ_0 = cos(incidence angle)
μ = cos(emergence angle)

w = single scattering albedo
b ranges from -1 to 1 (back- vs. forward-scattering)

These are what we want to know, to better understand surface properties

Key Results

- Bedrock has higher single-scattering albedo than soils
- Bedrock is less back-scattering than soils
- Most strongly back-scattering areas were Victoria crater ejecta, with high density of hematite spherules
- Can perhaps use back-scattering to map spherules at much higher spatial resolution than Thermal Emission Spectrometer data allow

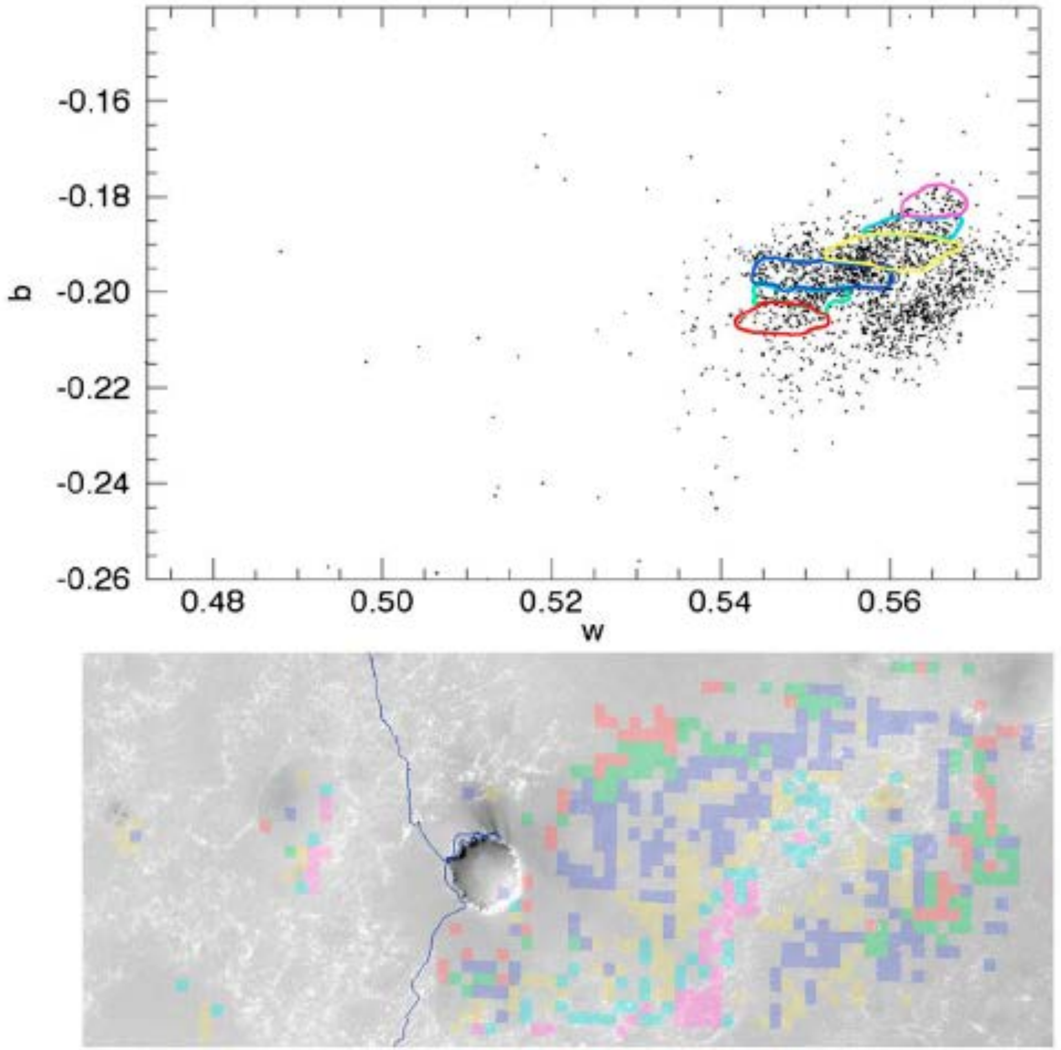


Figure 18. A closer look at the *b* versus *w* trend line. The top panel shows a plot of *b* versus *w* at 0.801 μm for entire study area, with different sections along the positive trend line designated by color and mapped to location in the bottom panel. Note that the regions designated by pink and red represent bedrock-rich and bedrock-poor endmembers, respectively (see Figures 19 and 20).