UCL DEPARTMENT OF SPACE AND CLIMATE PHYSICS
MULLARD SPACE SCIENCE LABORATORY

Preparations for the ExoMars 2020 Rover PanCam Wide Angle Cameras:

Spectral Imaging System Simulation

Roger Stabbins[1,2],
Andrew D. Griffiths[1,2], M. Gunn[3], Andrew J. Coates[1,2],
and the PanCam Science Team

[1] Mullard Space Science Laboratory, University College London
[2] Centre for Planetary Science at UCL/Birkbeck, UK
[3] Department of Physics, Aberystwyth University, UK

International Workshop on Instrumentation
for Planetary Missions
Berlin, September 12th 2018

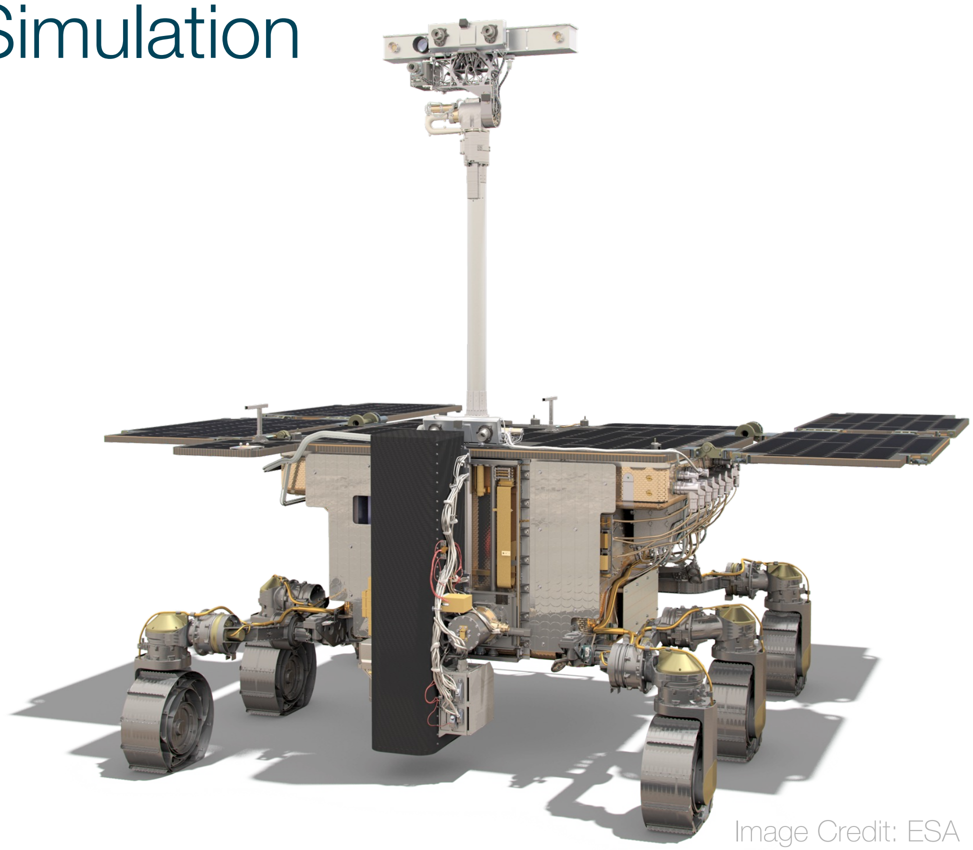
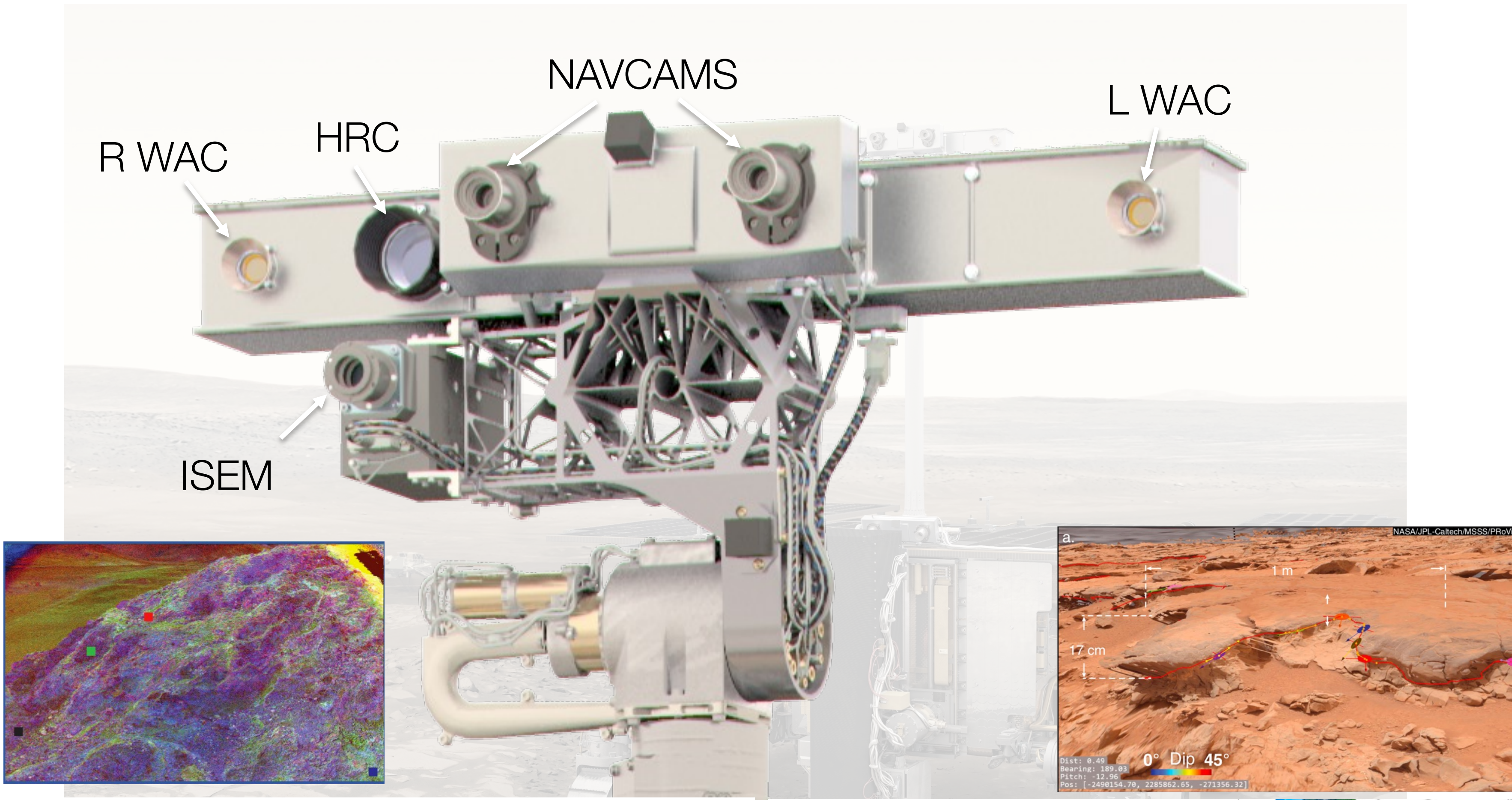


Image Credit: ESA

PanCam on the ExoMars Rover

UCL



The ExoMars Spectral Tool (ExoSpec): an image analysis tool for ExoMars 2020 PanCam imagery

Elyse J. Allender[a,c,*], Roger B. Stabbins[b], Matthew D. Gunn[c], Claire R. Cousins[a], Andrew J. Coates[b]

SPIE Remote Sensing 2018, Paper: 10789-17

Earth and Space Science

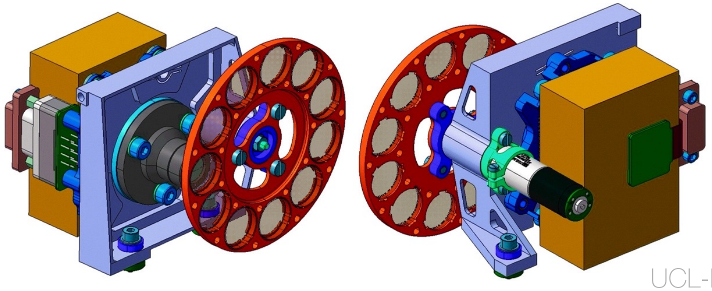
RESEARCH ARTICLE
10.1002/2018EA000374

Special Section:
Planetary Mapping: Methods, Tools for Scientific Analysis and Exploration

Geological Analysis of Martian Rover-Derived Digital Outcrop Models Using the 3-D Visualization Tool, Planetary Robotics 3-D Viewer—PRo3D

Robert Barnes[1], Sanjeev Gupta[1], Christoph Traxler[2], Thomas Ortner[2], Arnold Bauer[3], Gerd Hesina[2], Gerhard Paar[3], Ben Huber[3,4], Kathrin Juhart[3], Laura Fritz[2], Bernhard Nauschnegg[3], Jan-Peter Muller[5], and Yu Tao[5]

Image Credit: ESA



UCL-MSSL

Wide Angles Cameras (WACs)

Optics

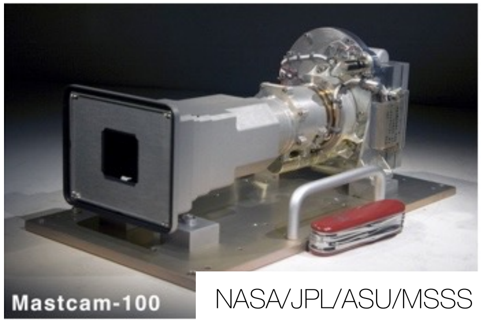
- 38.3×38.3 FOV (°)
- f# 10
- 21.85mm Fixed-Focus
- 11-slot filter wheel per camera

Detector

- Star 1000 Radiation Hard
- Monochrome Sensor
- CMOS APS 3T
- 1024x1024 pixels
- 15μm Pitch
- 10-bit ADC

Filters

- 6 RGB Broadband (3 per WAC)
- 4 Solar Narrowband (2 per WAC)
- 12 Geology Narrowband (6 per WAC)



NASA/JPL/ASU/MSSS

MSL Mastcam M-100

Optics

- 6.8x5.1 FOV (°)
- f# 10
- 100mm Fixed-Focus
- 8-slot filter wheel per camera

Detector

- Kodak KAI-2020
- RGB Bayer Sensor
- CCD Frame transfer
- 1600x1200 pixels
- 7.4μm Pitch
- 11-bit ADC

Key Differences:

Wide Angle: *Break down of uniformity assumptions*

CMOS APS: *No shutter-smear, Nonlinear electron-voltage transfer function*

Problem Statement

Performance Metrics

What do these properties mean for performance metrics?

Image Quality

What do these performance metrics mean for image quality?

Image Interpretation and Derived Products

How does the image quality effect quantitative analysis of these image data sets?

Operations

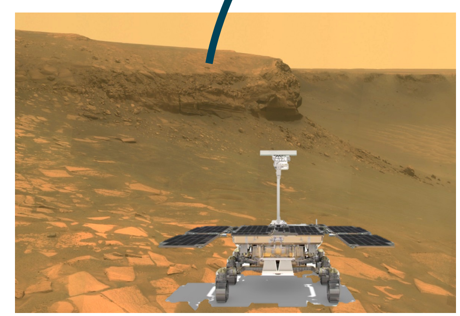
How do the camera properties impact operational sequences?

Can we have a neat function that receives camera specifications, and then helps us to answer these questions?

Digital Image: Simulated

$\mathbf{S}_c^F[i, j]$

f_{Cam}



Scene Radiance:

Discrete Representation

$\mathbf{L}_c = L|_{\boldsymbol{x}_c, \hat{\omega}_c}[i, j, \hat{\lambda}]$

Image Credits: NASA/JPL-Caltech/MSSS

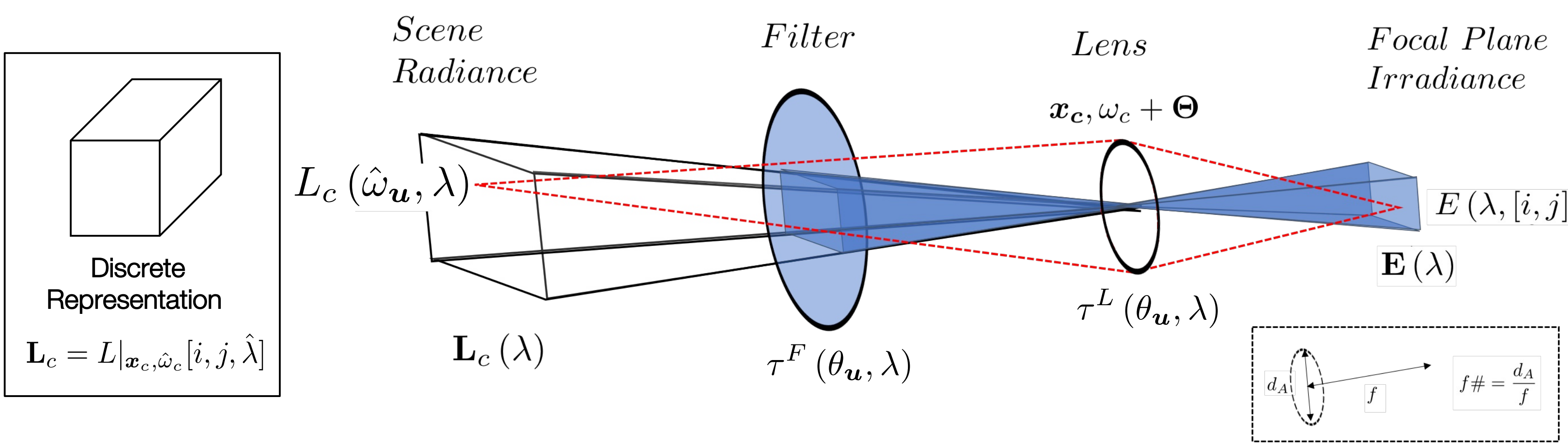
Simulation Module Overview

$$f_{Cam} : L_c[i,j,\hat{\lambda}] \mapsto S_c^F[i,j]$$

$$Scene\ Radiance \xrightarrow{f_{Optics}} Focal\ Plane\ Irradiance \xrightarrow{f_{Detector}} Digital\,Image$$

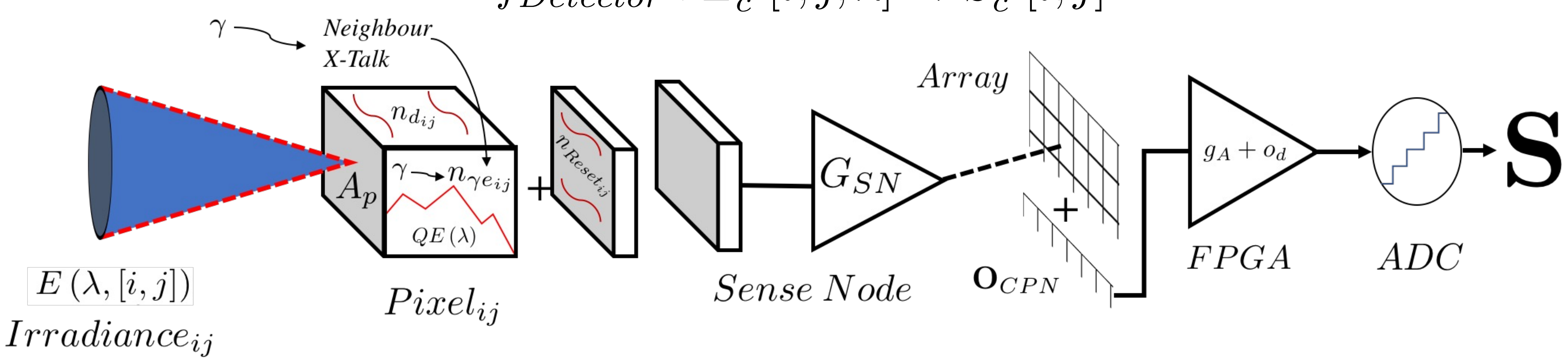
Optics Function

$$f_{Optics} : L_c[i,j,\hat{\lambda}] \mapsto E_c^F[i,j,\hat{\lambda}]$$



Detector Function

$$f_{Detector} : E_c^F[i,j,\hat{\lambda}] \mapsto S_c^F[i,j]$$



Simulation Software Key Features

Key Features

Optics:

- *Angular Spectral Transmission*
  - *Modelled or Data-constrained*

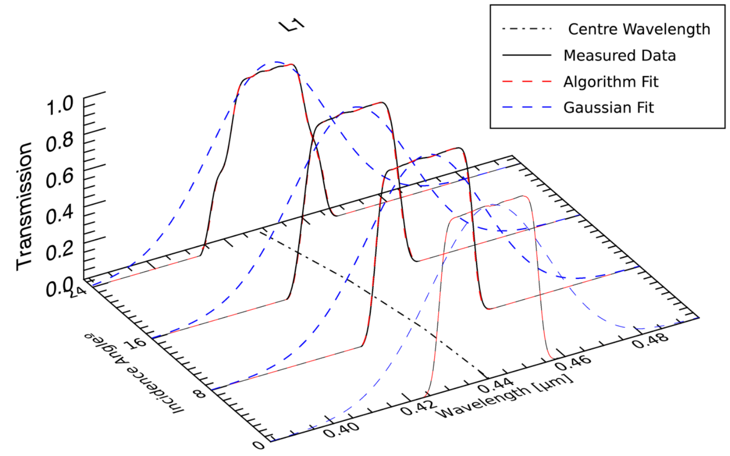
Detector:

- *Temperature Dependent Reset Noise*
- *Log-Normal Dark Signal Non-uniformity*
- *APS 3-Transistor Conversion Gain Model*
  - *Standard Conversion Gain Models for comparison*

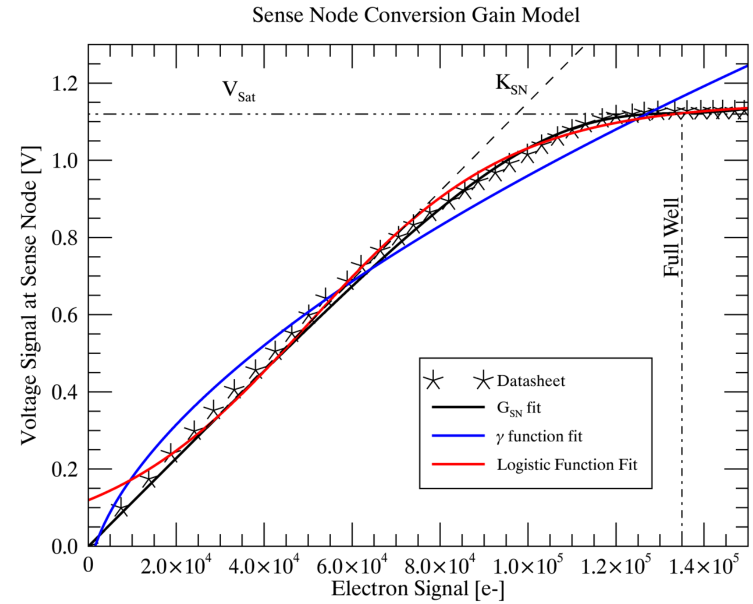
Implementation Features

- Object Oriented IDL Implementation
- Efficient data storage and recollection
- Quick 'New Build' routines

Angular Spectral Transmission



CMOS APS 3T Conversion Gain Model



Synthetic Test Scenes

Synthetic Test Scene

Illumination

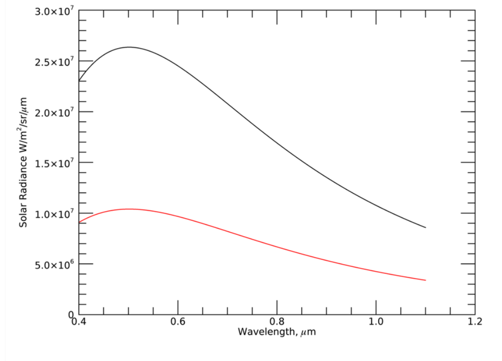
Sun : Zenith

Mid-Summer, Equator

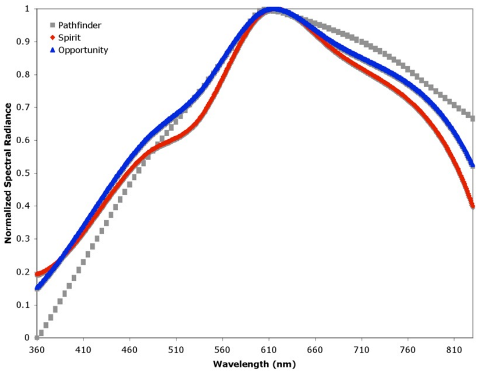
Sky : SPD from Bell et al 2006 JGR

OD 0.93, Airmass 1

Direct Illumination



Diffuse Illumination



Ground

Refl. Spec from Bell et al 2007

Bright Soil (bl, bc)

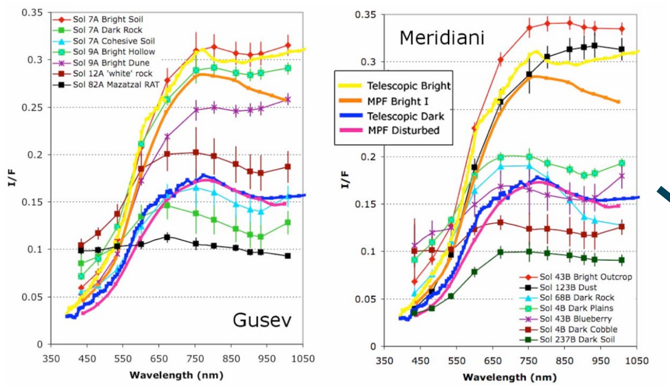
Dark Rock (br)

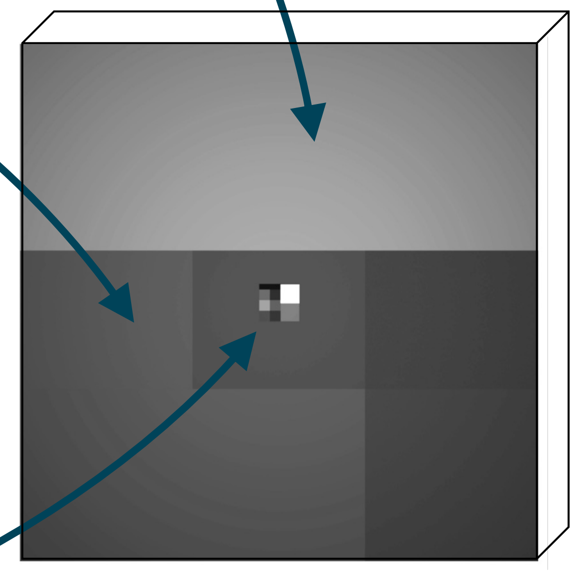
White Rock (cl)

Bright Dune (cc)

Dark Rock (cr)

Surface Material Reflectance



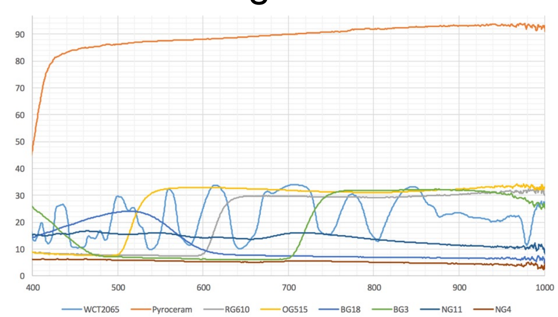


Calibration Target

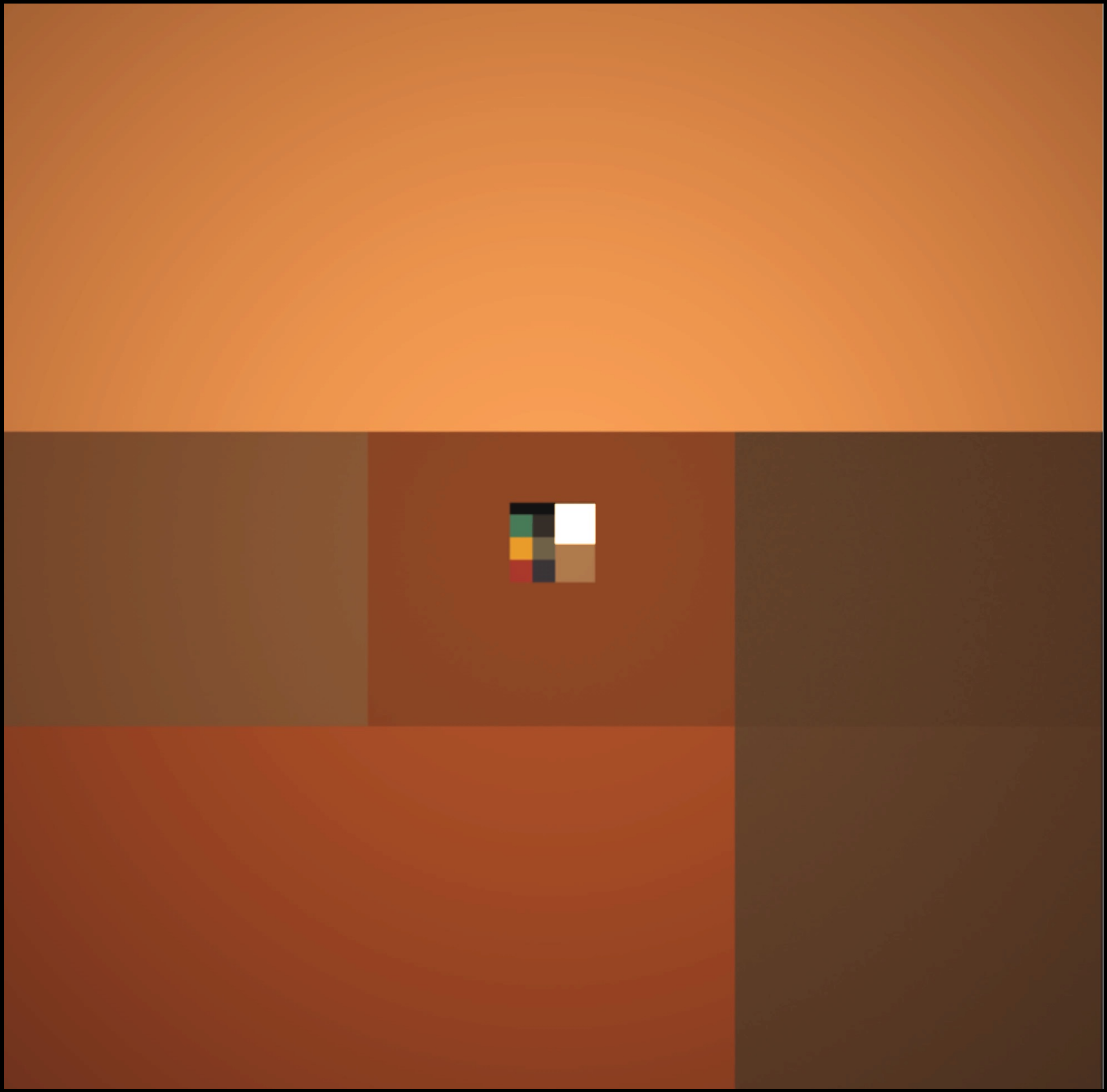
Refl. Spec from Aber U.

Size simulated by Aber U.

Calibration Target Reflectance

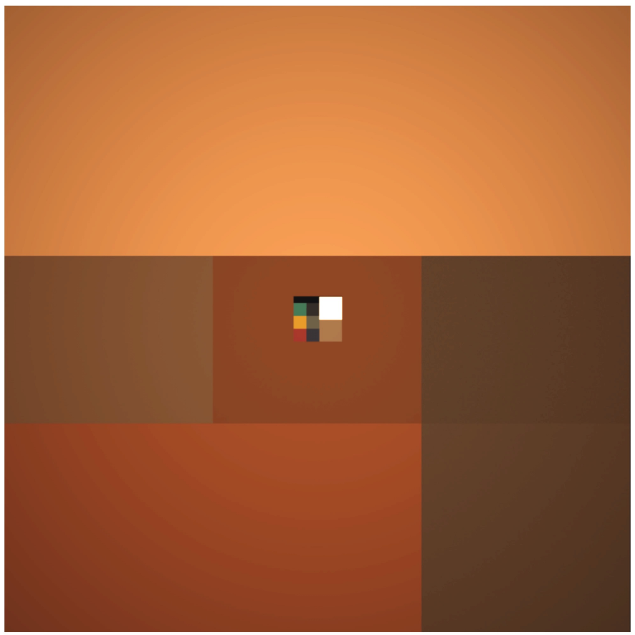


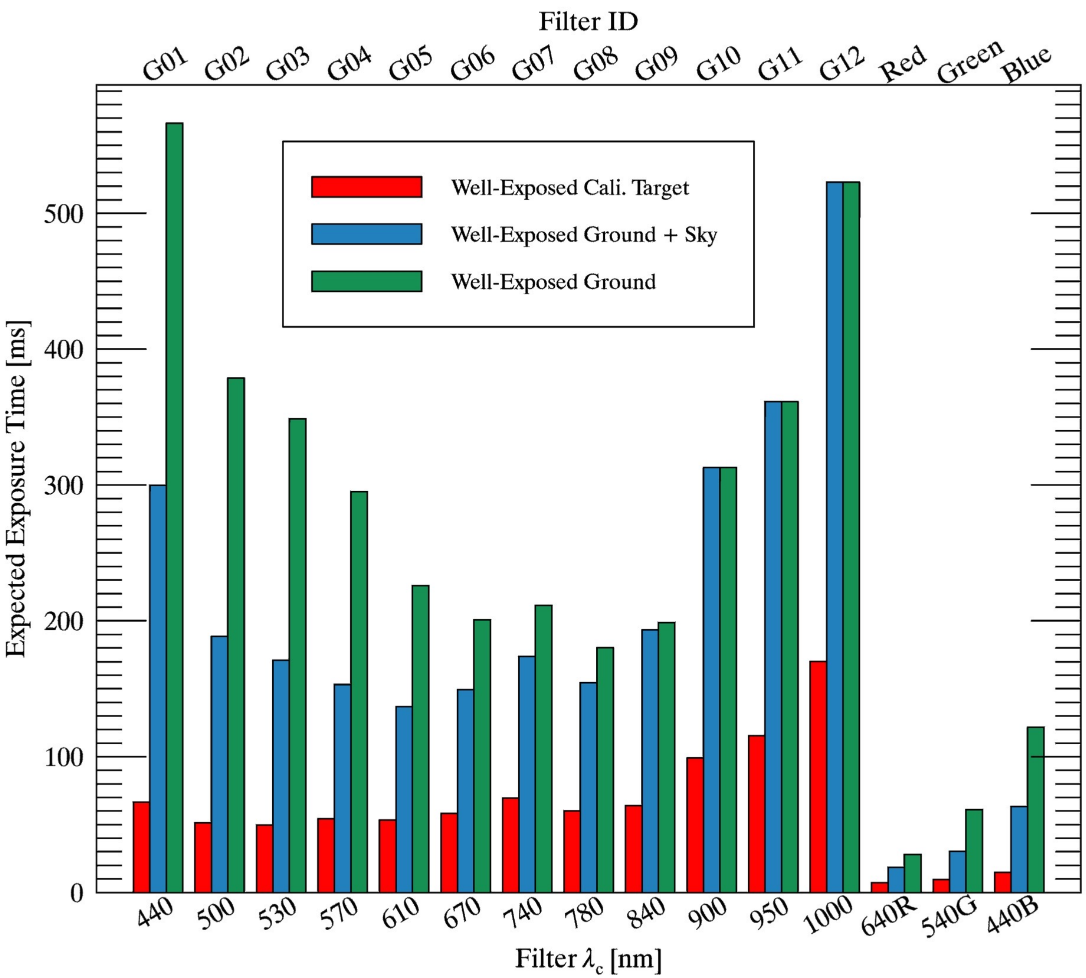
Synthetic Test Scene: WAC RGB



Predicted Optimal Exposure Times

'Optimal' defined by scaling Region of Interest Max. Radiance to ~75% Full Well

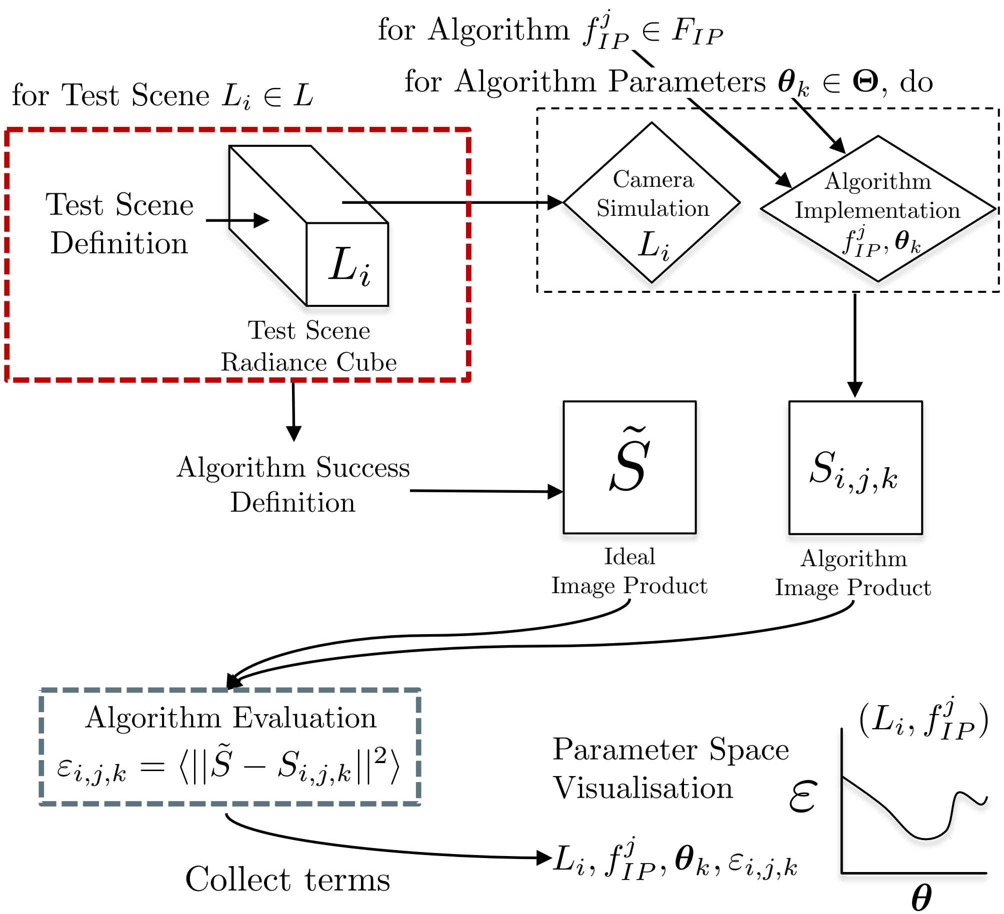




Applications: Simulated Algorithm Evaluation

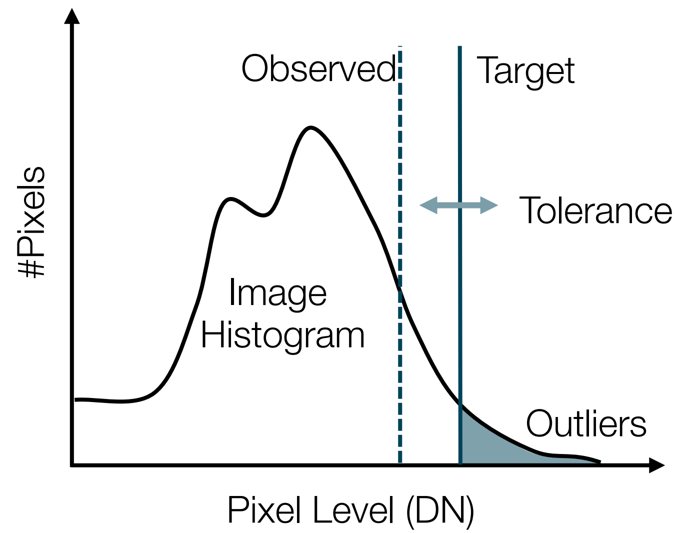
Image Processing Algorithm Optimisation:

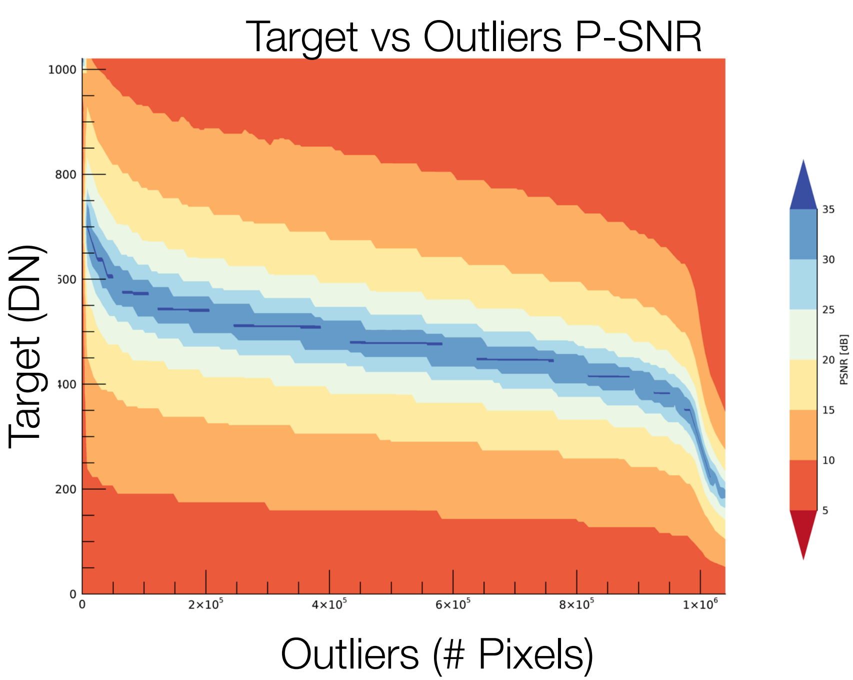
- Processing pipelines have a goal of enhancing some property of the final image.
- The goal is usually to give a more accurate representation of the scene radiance.
- We can directly compare image products to controlled, well-defined, input Test Scenes.
- We can compare image products from a set of candidate algorithms and parameter values to an 'Ideal' image product.
- This poses a convex optimisation problem.

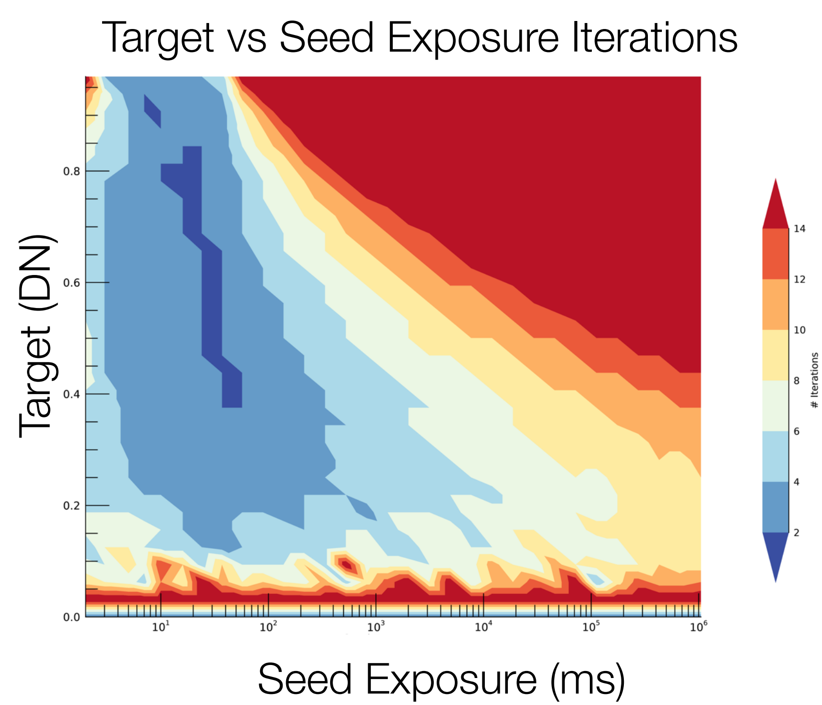


Example – Auto-Exposure:

- Optimise settings for an Auto-Exposure algorithm.
- Process over 1×10^6 parameter combinations
- Search for optimal combinations
- Find parameter – performance dependencies







PanCam Engineering Model

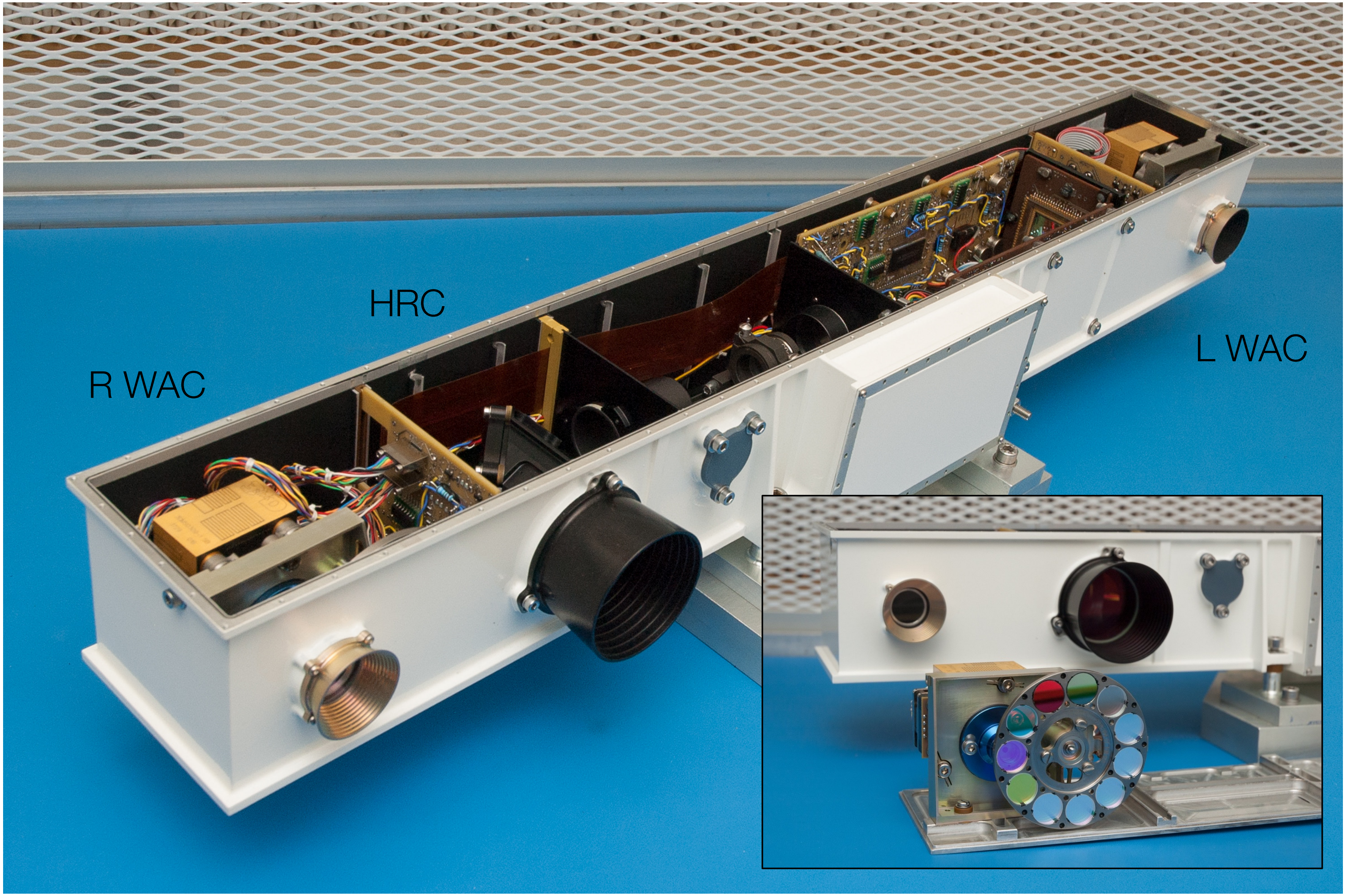
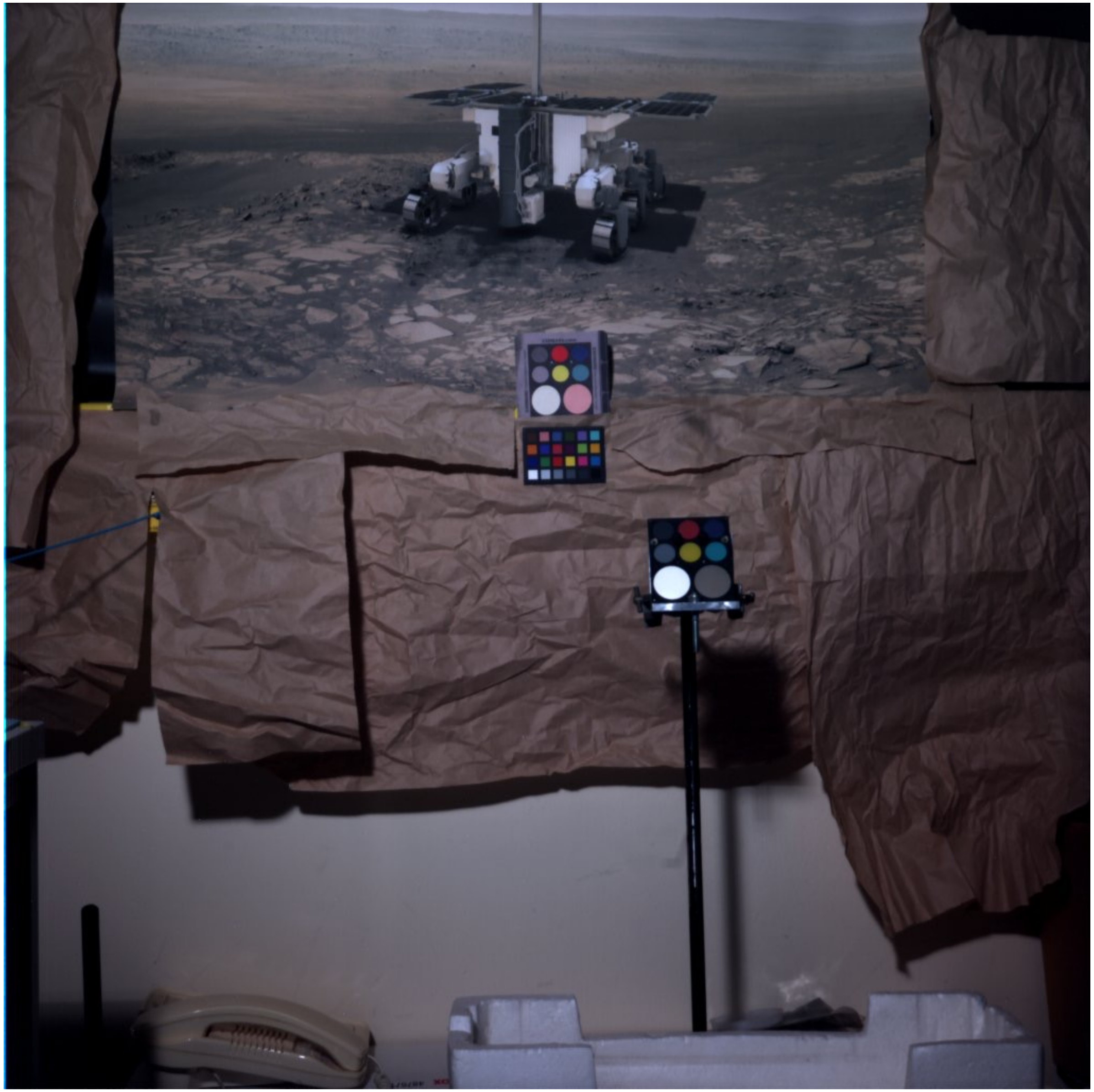


Image Credit: M. de la Nougerede, UCL/MSSL 2018

Validation of Auto-Exposure: LWAC RGB (Raw Stack)



UCL DEPARTMENT OF SPACE AND CLIMATE PHYSICS
MULLARD SPACE SCIENCE LABORATORY

Roger Stabbins

roger.stabbins.10@ucl.ac.uk

UCL

UK SPACE AGENCY

CONCLUSIONS:

- PanCam: 3 Camera system, enabling stereo, multispectral, and high-resolution VNIR imaging.
- Camera Response simulation software has been developed, from spectral radiance to raw DN.
- Applications include performance predictions, and system comparisons.
- Simulation scenes can be synthesized and visualised.
- Image processing algorithms can be evaluated across large combinatorial spaces.