Sensing on Strange New Worlds

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SUMO Speaker Series

4pm 31/03/21

THE UNIVERSITY OF SYDNEY

ACFR
AUSTRALIAN CENTRE FOR FIELD ROBOTICS

A little about me…

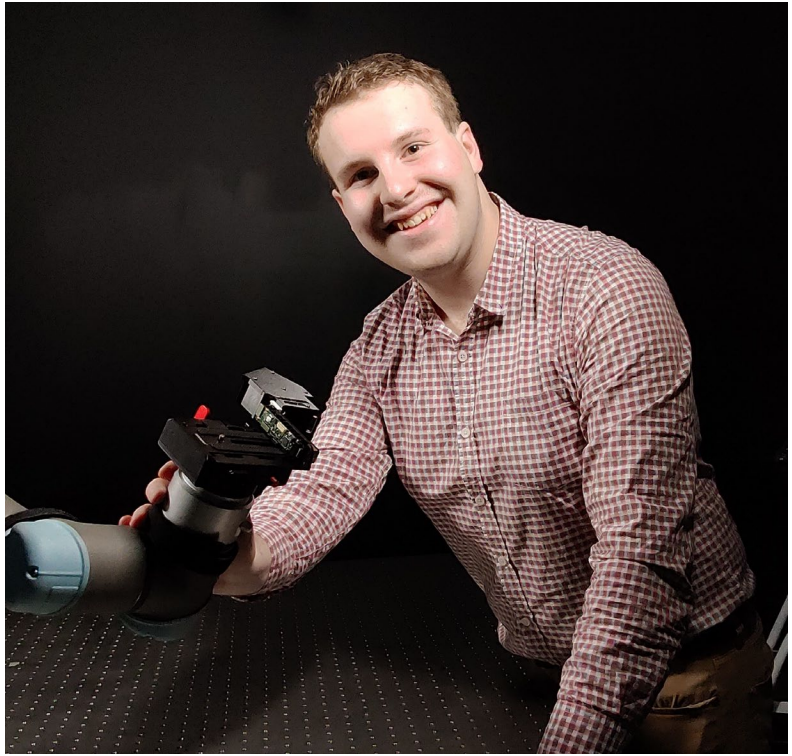
- Bachelor of Engineering (Mechanical) Hons./Bachelor of Science (Advanced) V

- Majors in Space Engineering, Physics

- ESIPS w/ Nearmap Semester 2

- Engineering Leadership Scholar

- Undergrad Research Student w/ ACFR



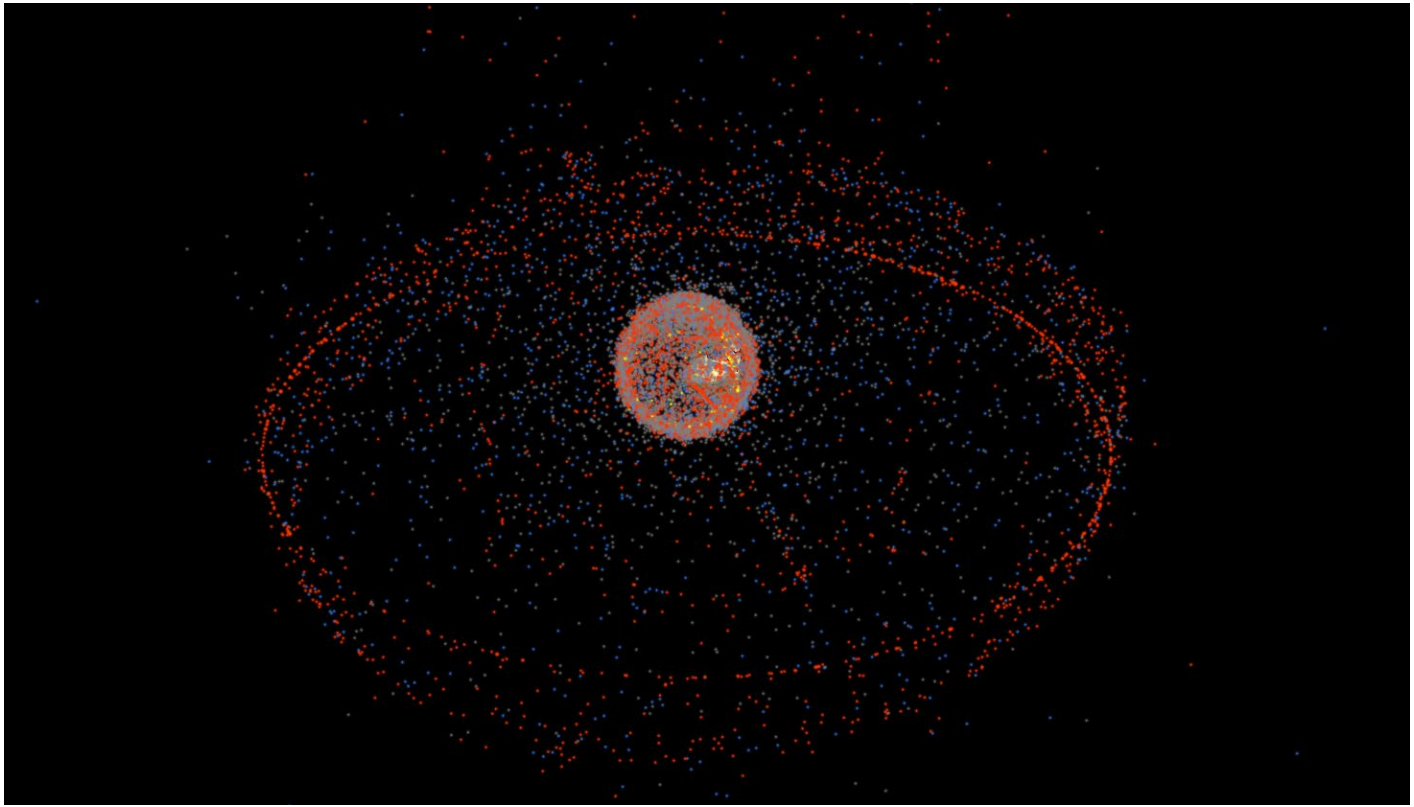
Robotic Imaging Research Group, Jan 2020

Headed by:
Dr. Donald Dansereau

Oh the places you'll go…

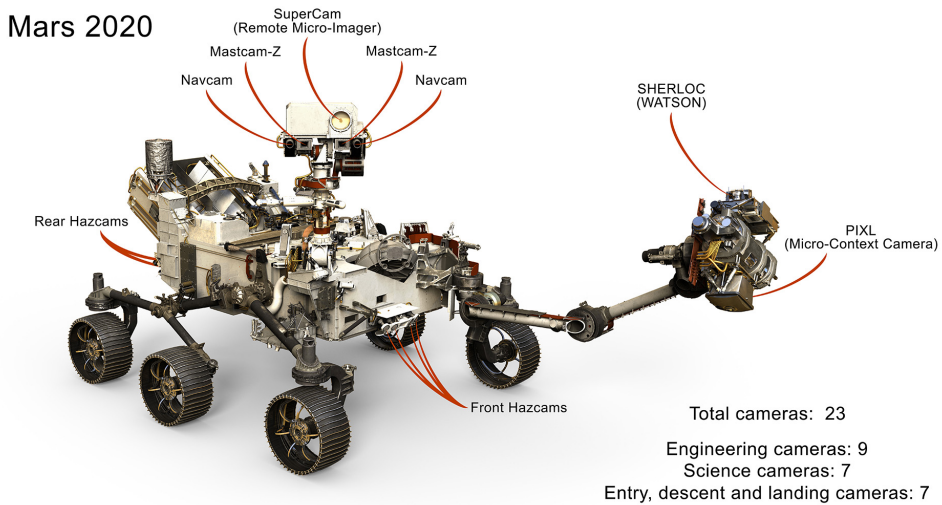
Minimise the unknowns

stuffin.space as at 30/3/21

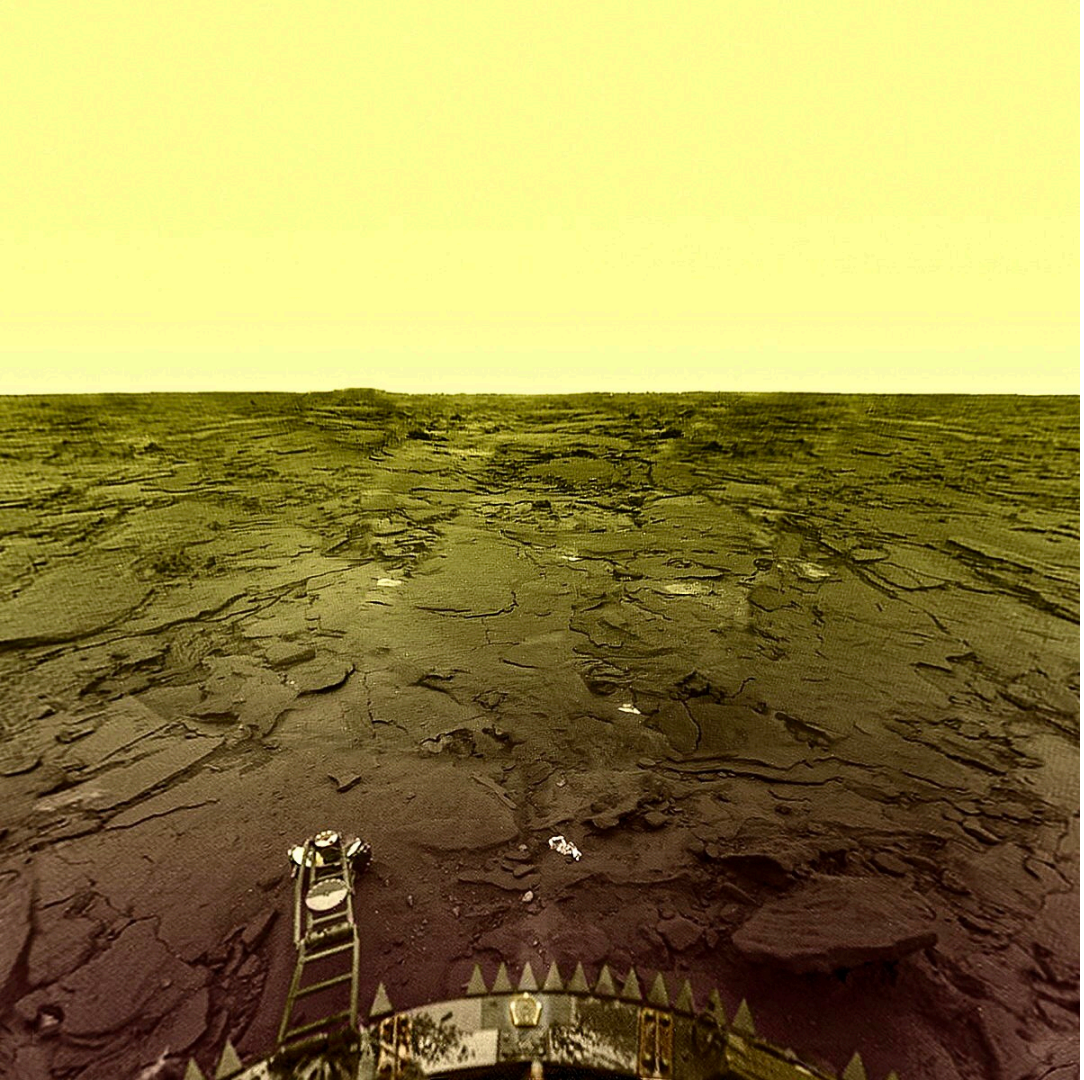


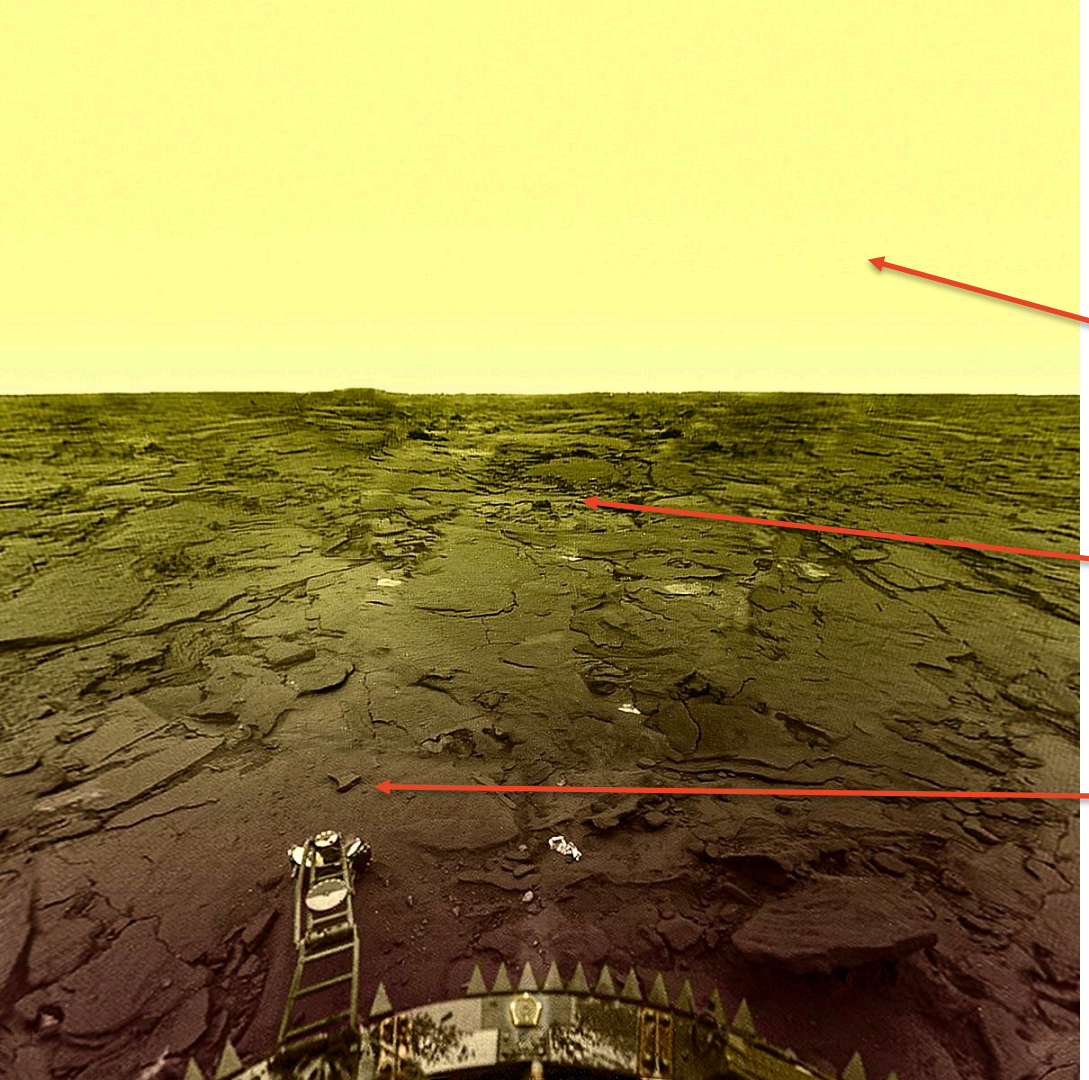
If you can't minimise the unknowns?

- Equip your spacecraft with ways to deal with those unknowns
- Sensors, instruments, cameras
- "If you were in that environment, what would you need to have to get a better understanding of it?"



“Book me a one way ticket to…”





Venus (Venera 13)

– **First impressions?**

Atmospheric Scattering/Dust

Highly textured surface = tough to map/visually analyse

Visually similar scenes

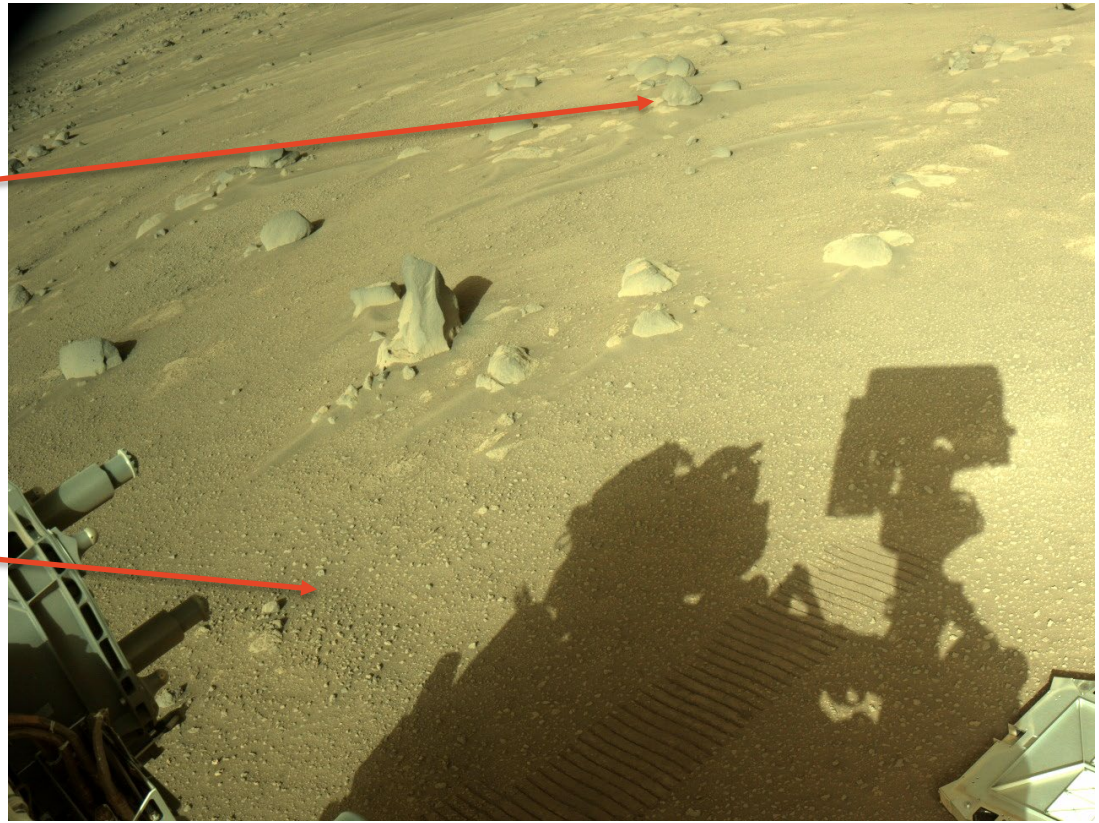
This isn't including the sulfuric acid in the atmosphere or temperature…

Mars

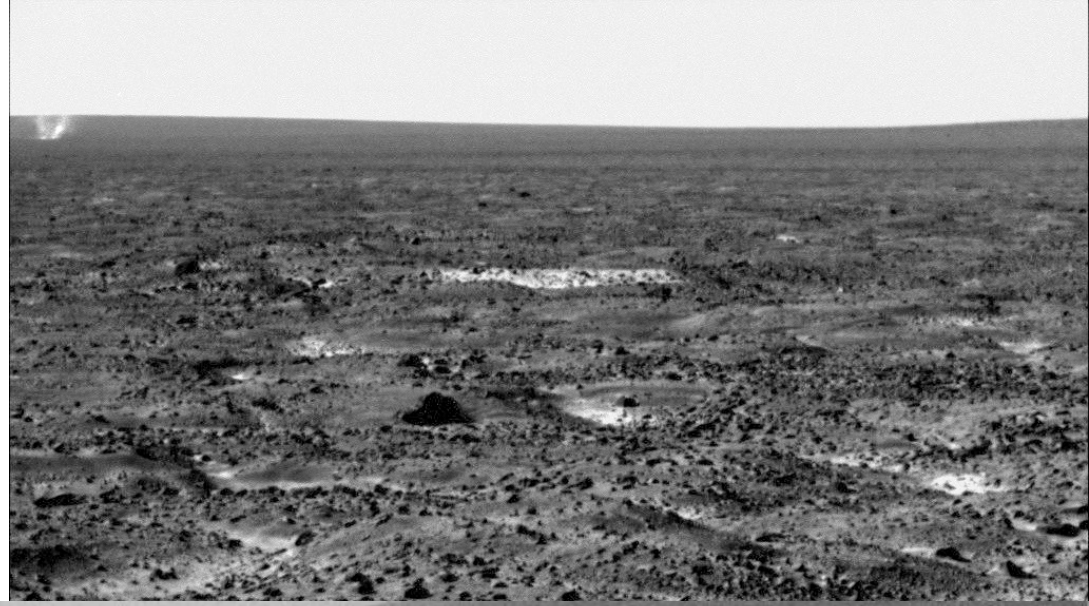
Colour variation

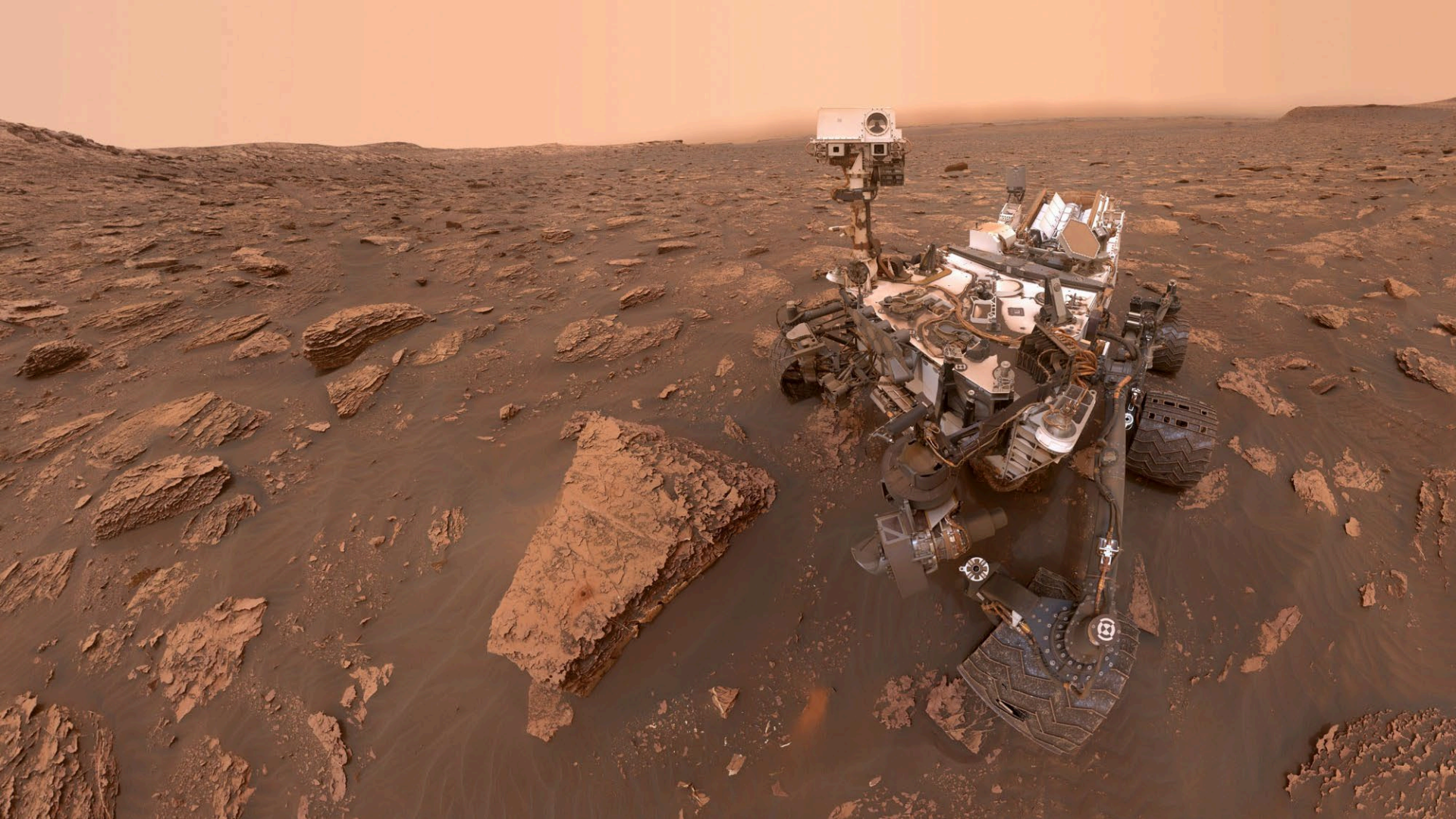
Sparse, well defined features

Shadows? Nice diffuse lighting? This seems promising…



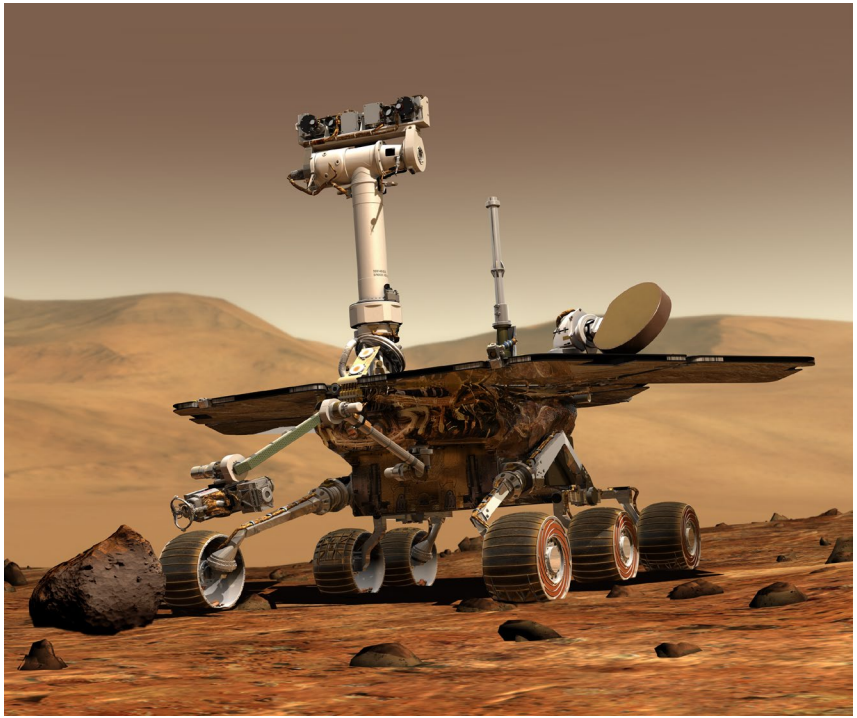
What makes Mars challenging?





Why is weather an issue?

- Driving in fog
- Without lights
- And your battery is running out

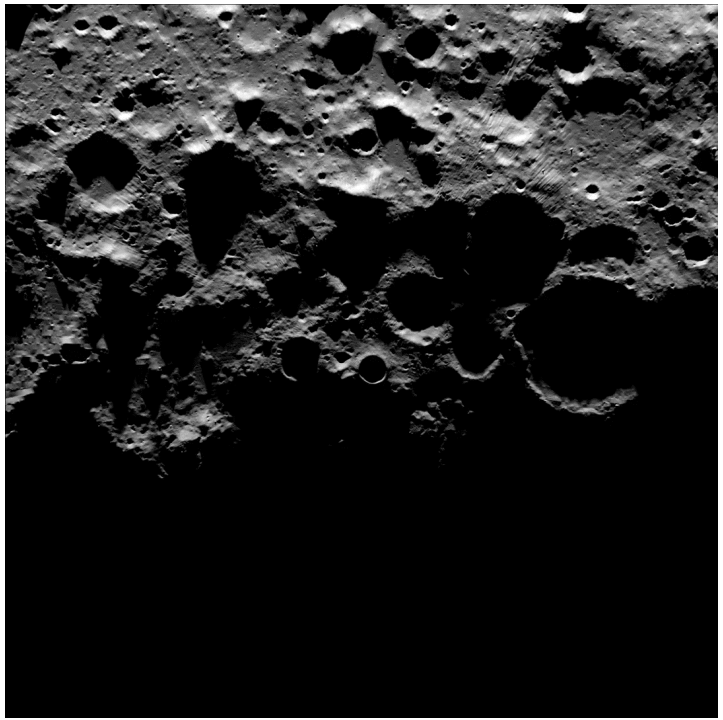


What's so special about the moon?

We've been there – surely we know everything?

Characterising the Polar Lunar Environment

- **No atmospheric attenuation**
- **Shallow illumination angle (<10°)**
- **Shadows:**
  - Elongated (up to several km)
  - Fast moving (cm/s)
- **Regolith is retroreflective**

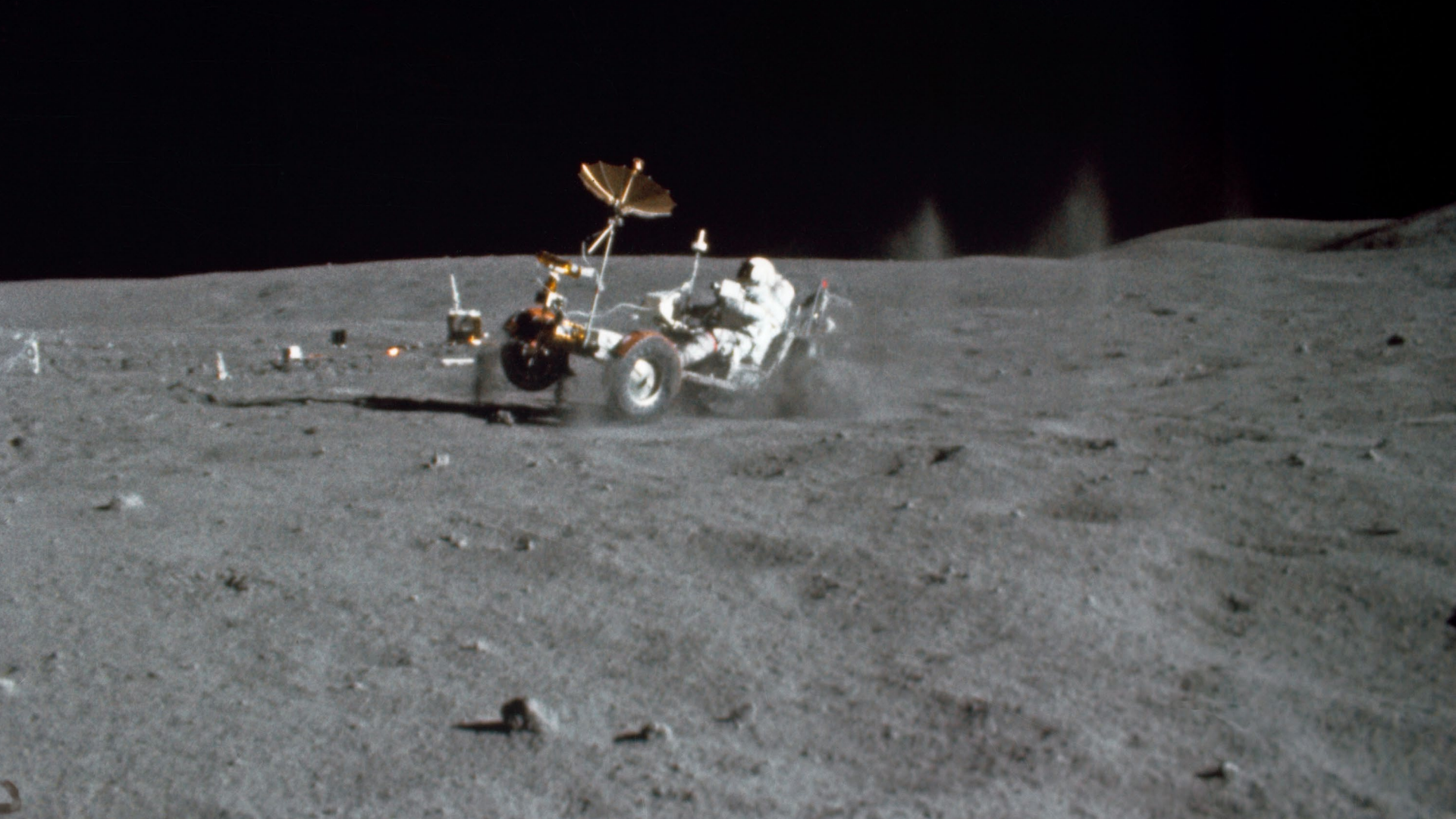


Simulated South Pole illumination over 28 days, NASA 2013

Retroreflection (Apollo 16)

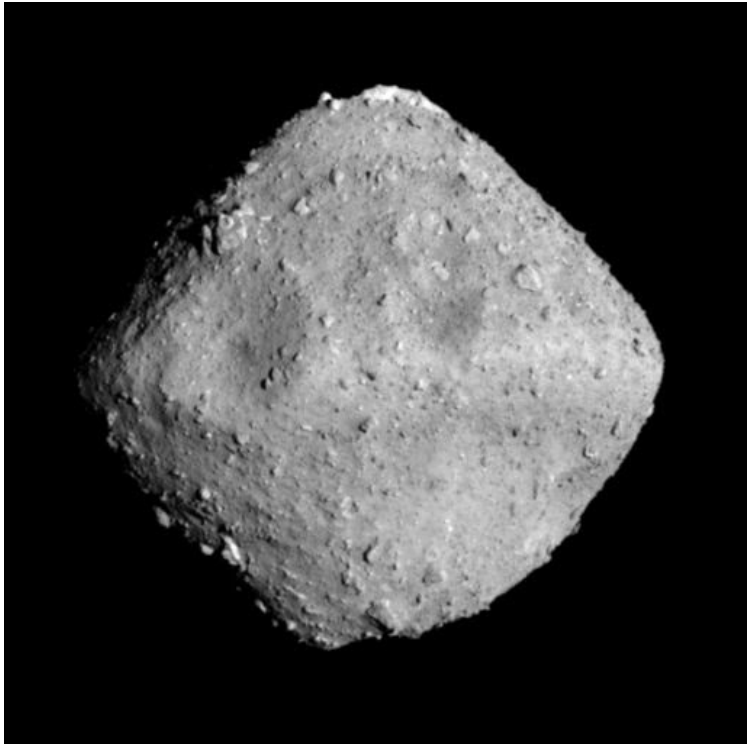
Along Sun Vector

Across Sun Vector

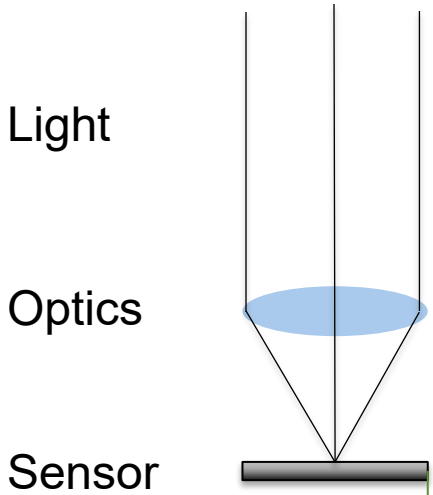


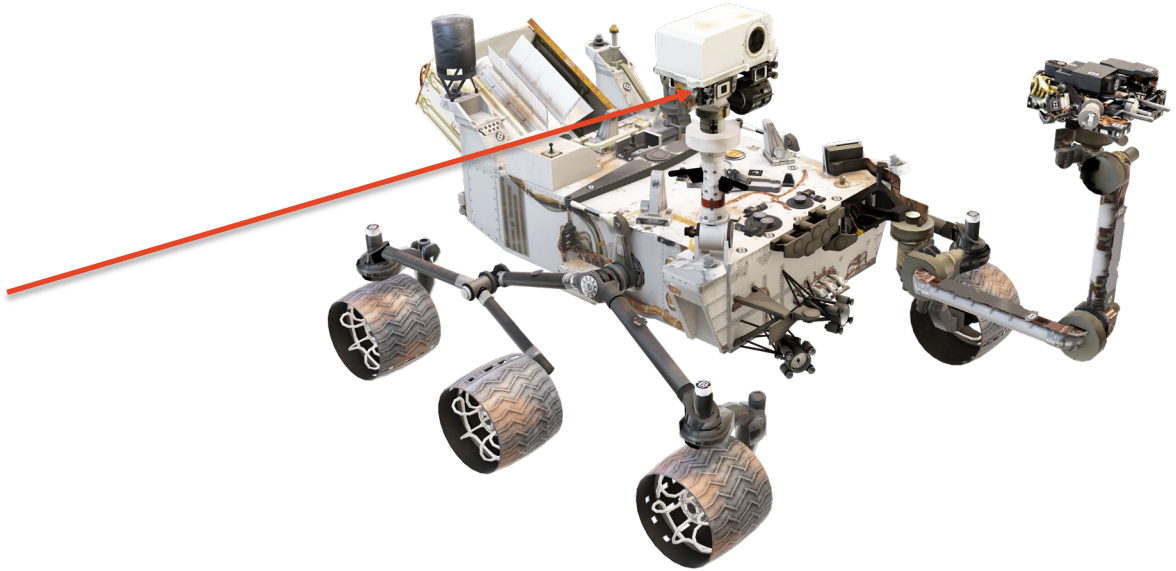
What about in-orbit robotics?

Navigating small rocky bodies?



Cameras





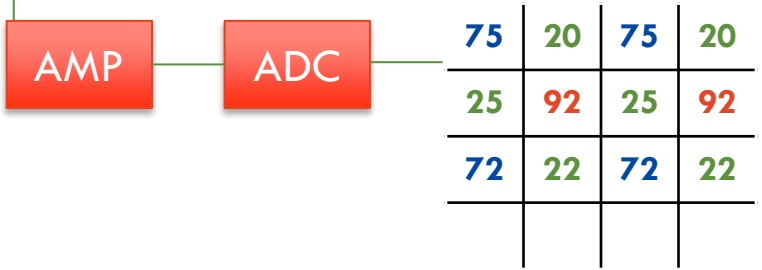
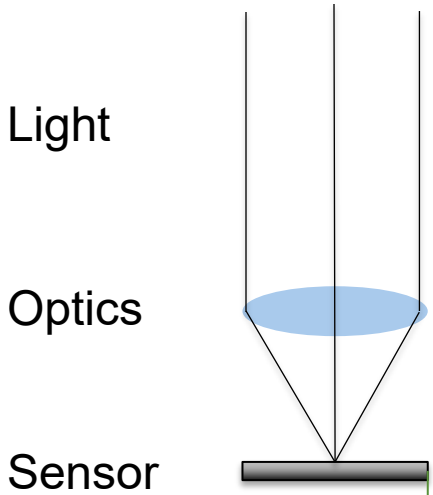
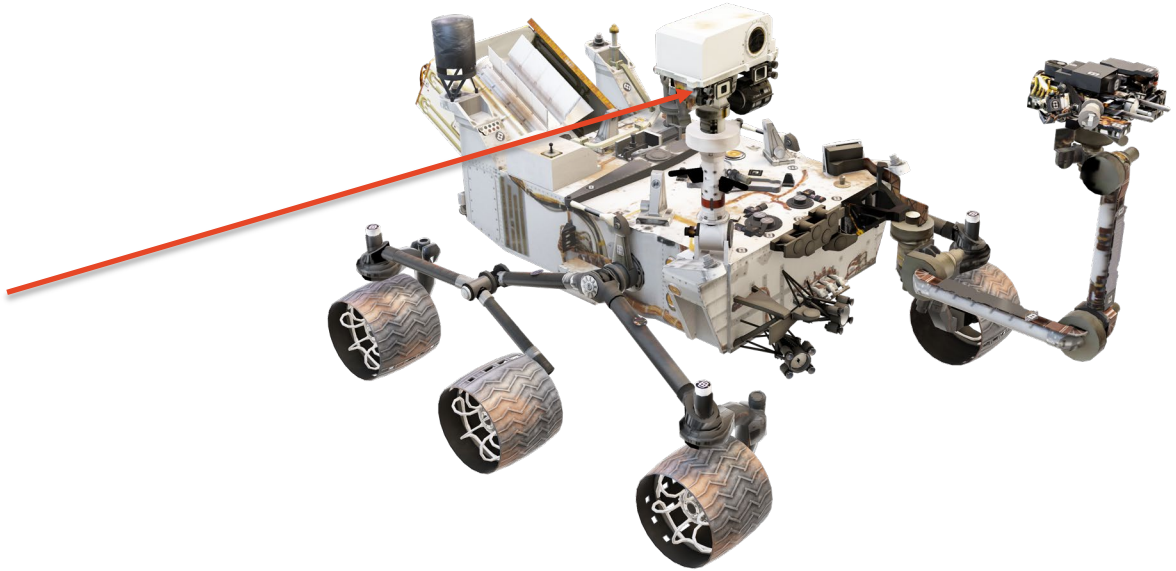
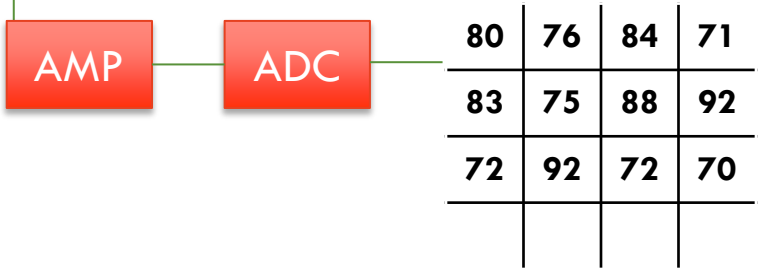


Image
(Bayer Filter - Colour)

Cameras







80	76	84	71
83	75	88	92
72	92	72	70

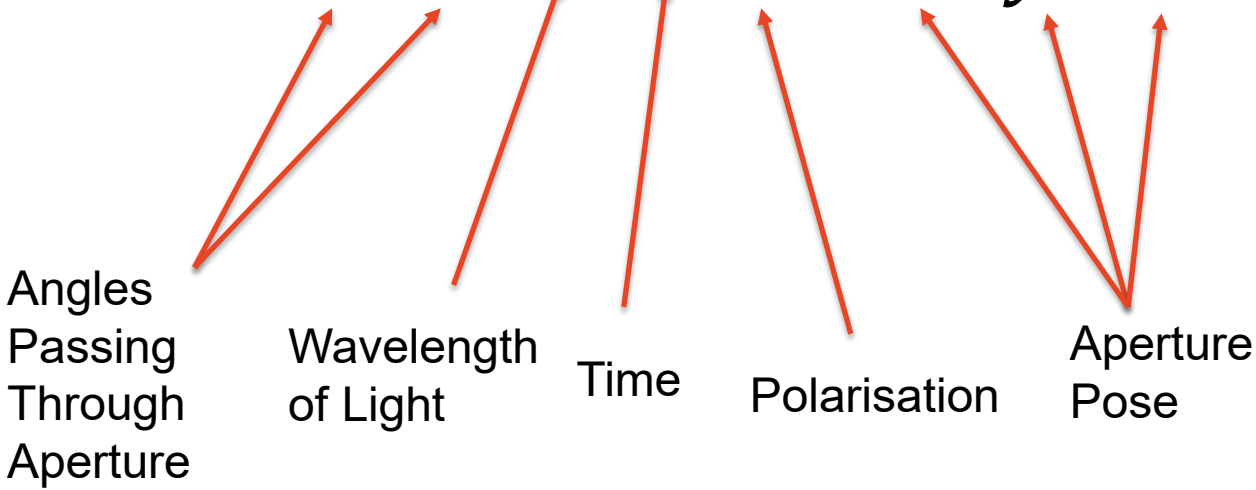
Image (Mono)

So what's so good about an image?

- Dense information representation
- Cheap – data/energy wise
- Visual information is how we have evolved – a human sense
- Cameras can provide a lot of things:
- Enter: The Plenoptic Function

What is the most we can ask the camera?

$$P(\theta, \phi, \lambda, t, p, V_x, V_y, V_z)$$



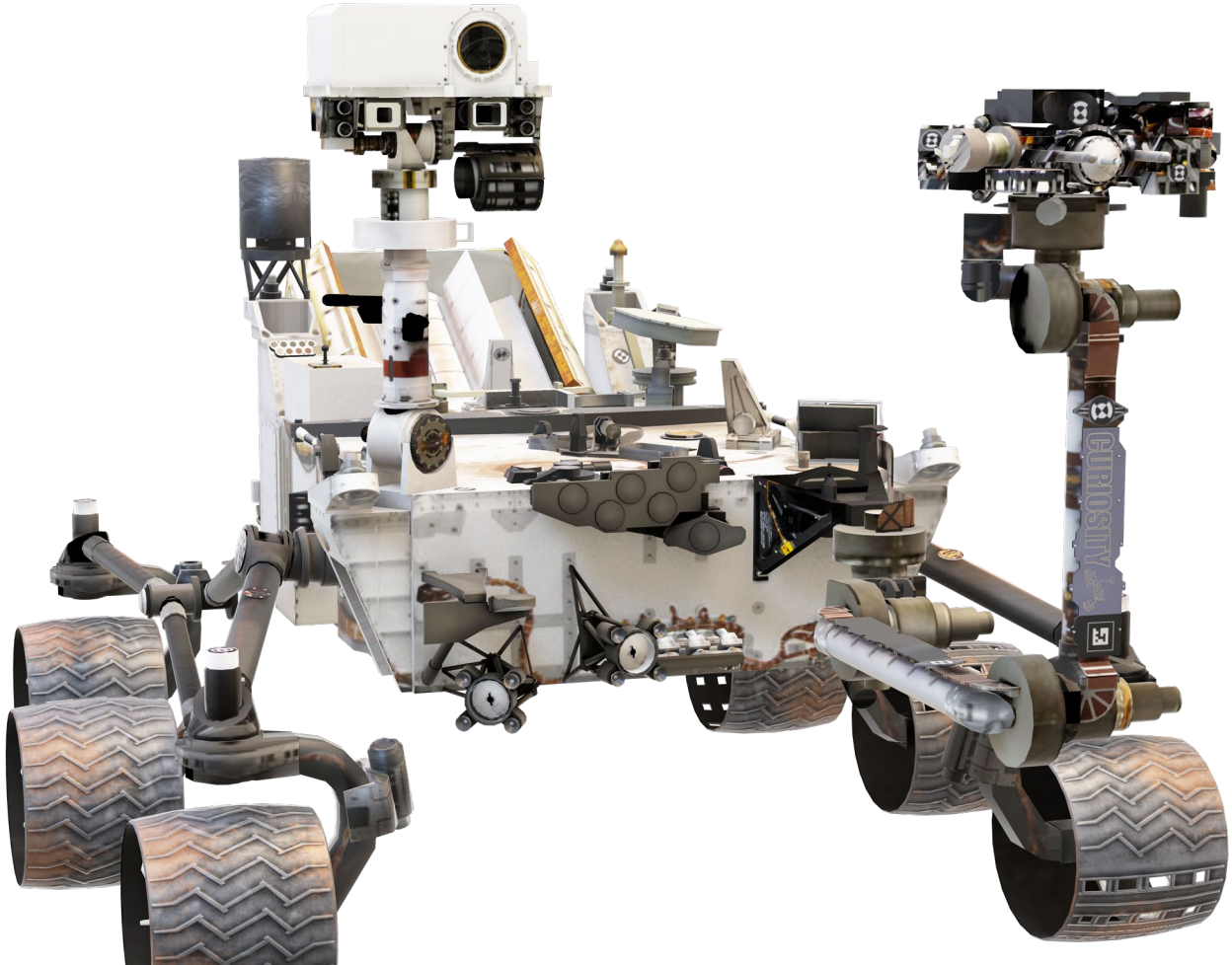
What is the most we can ask the camera?

$$P(\theta, \phi, \lambda_{vis}, t, p, V_x, V_y, V_z)$$

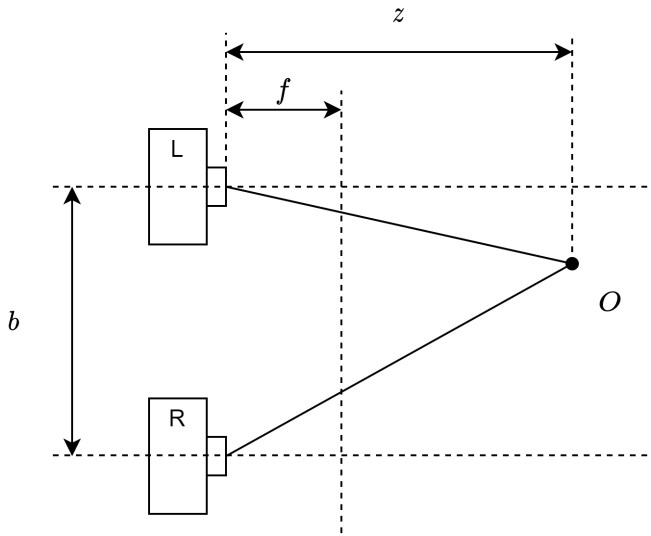
Regular Camera
(And t just implies videos)

Other cameras can give different, and sometimes greater range of the plenoptic function.

Depth?



Depth?



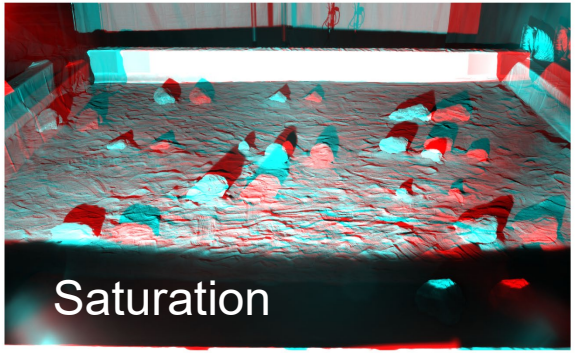
Turns out we have 2 eyes for a reason…

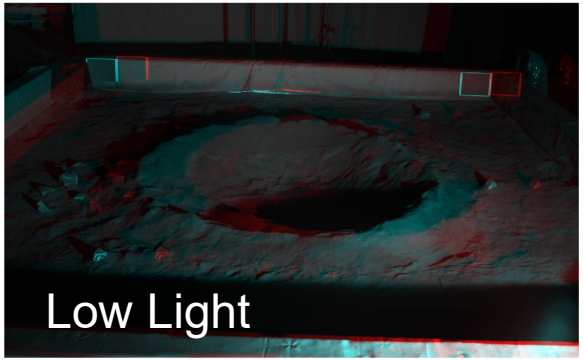
Stereo Imagery

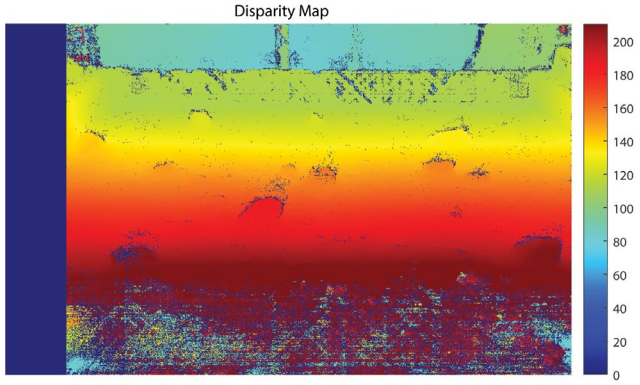
$$z = \frac{bf}{d}$$

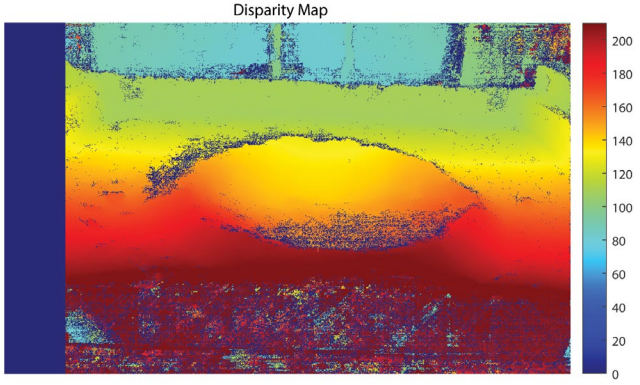
$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = zK^{-1} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix}$$

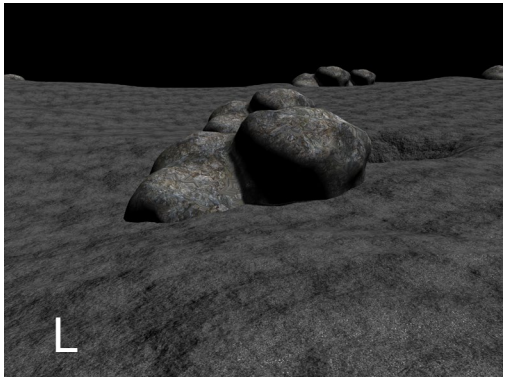
Dynamic Range (Stereo)

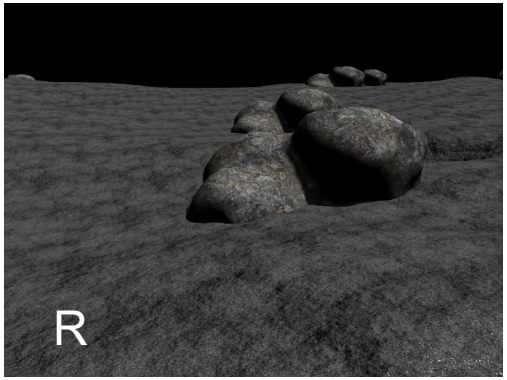









L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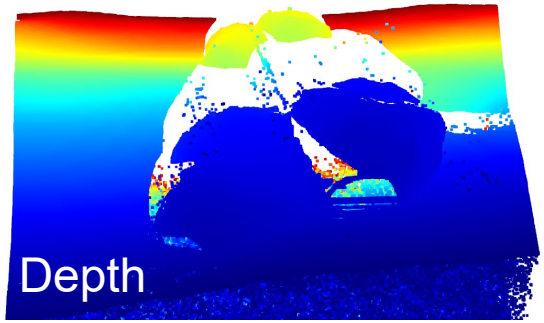
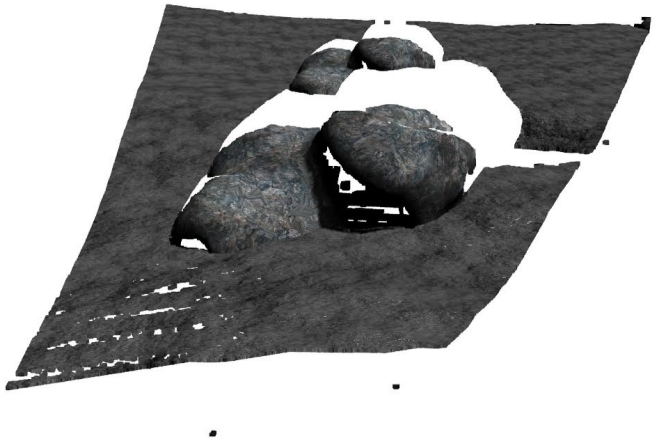

Depth



EVERY ROVER HAS USED STEREO

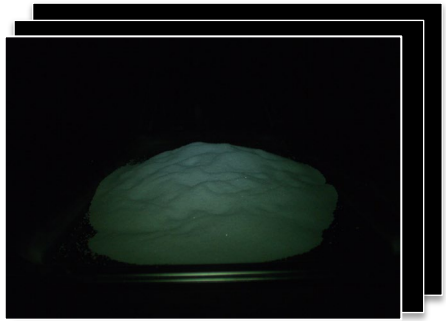
Would stereo fail on this?

Likely, yes.

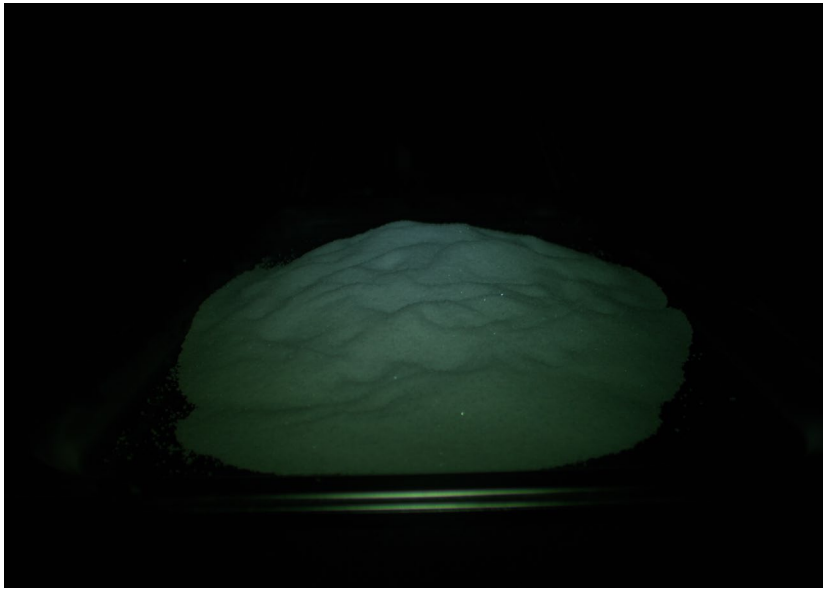
If there is no texture and visually similar, what should we do…

What if we create some texture!

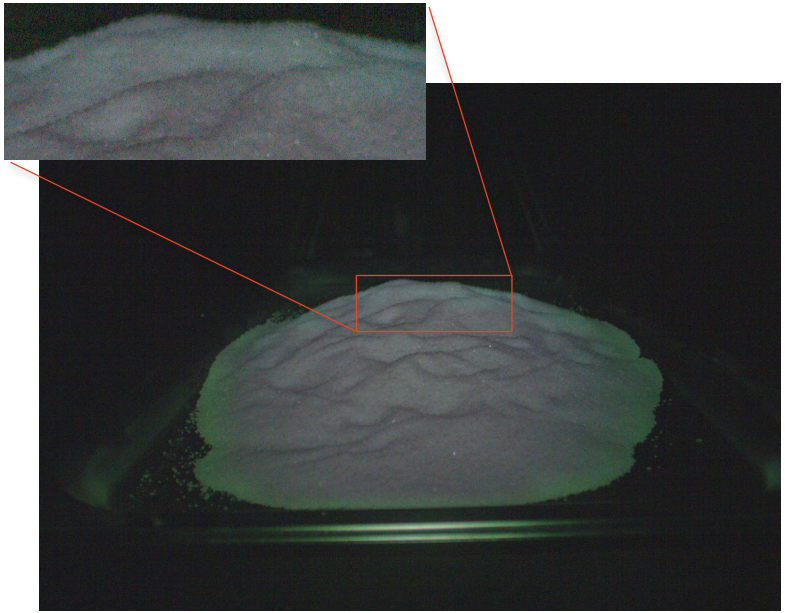
Burst Imaging for HDR



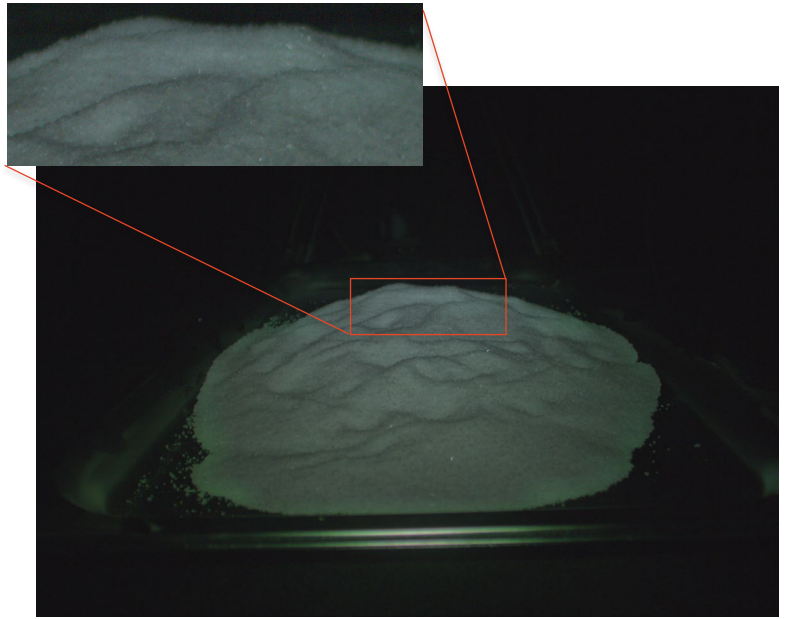
47 Frame Burst



Reconstructed

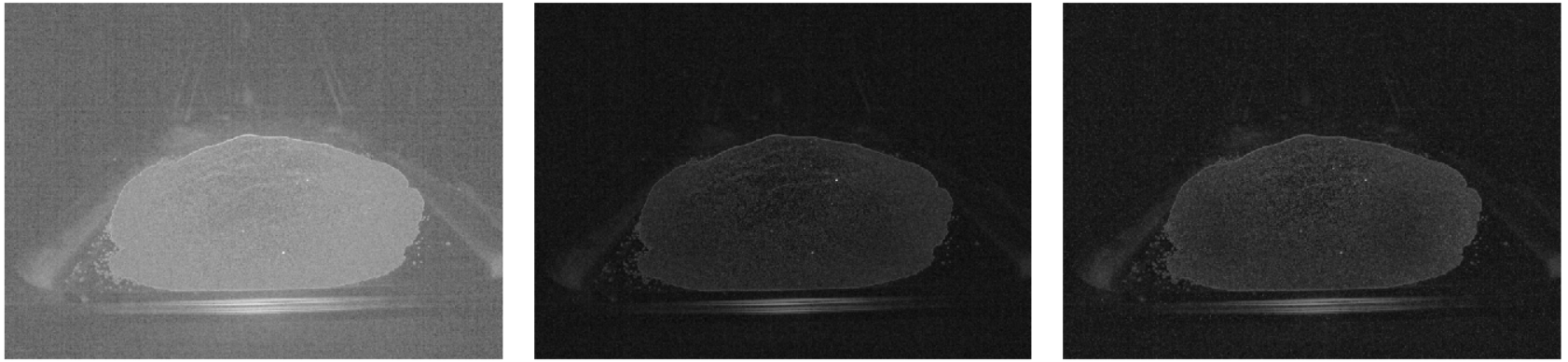


Single Frame

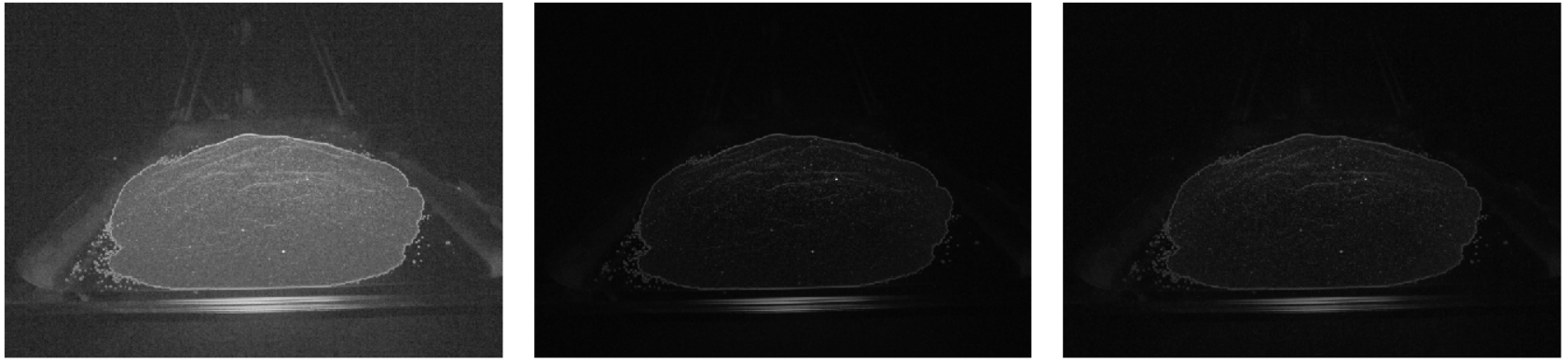


Reconstructed

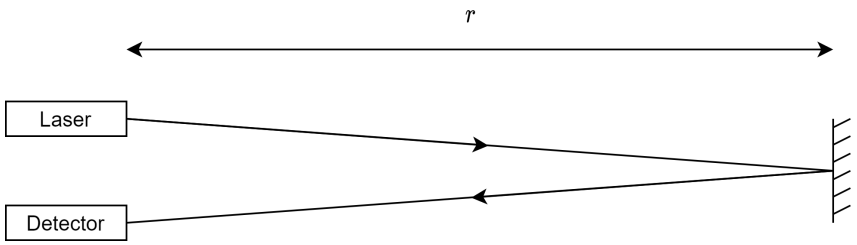
Single Frame: Local Entropy, Local Standard Deviation, and Local Range

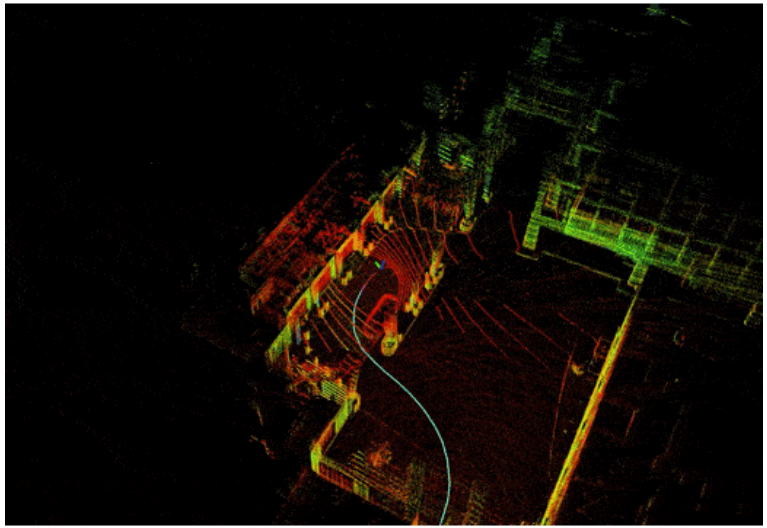


Burst Reconstructed: Local Entropy, Local Standard Deviation, and Local Range



LiDAR





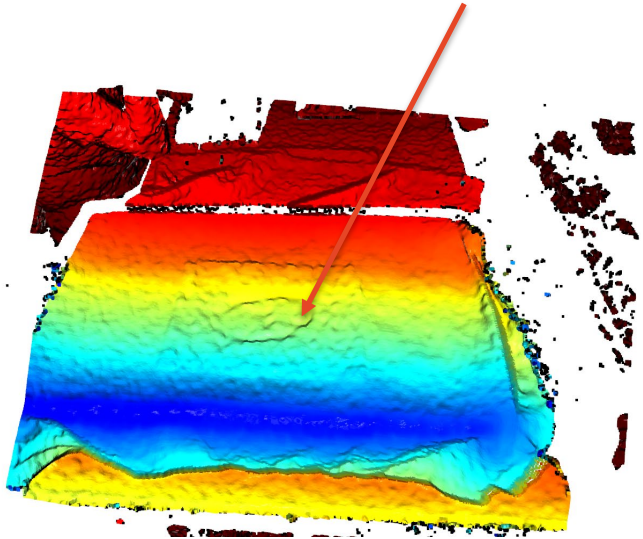
Time of Flight: $r = \frac{ct}{2}$

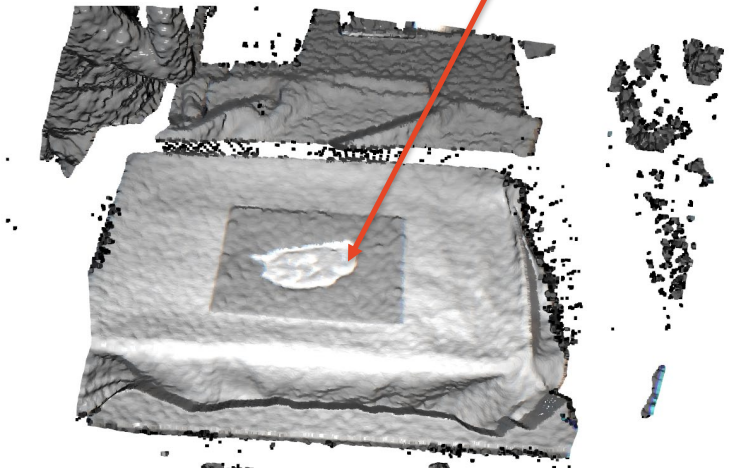
LiDAR

Ranging Error

Retroreflection

Depth



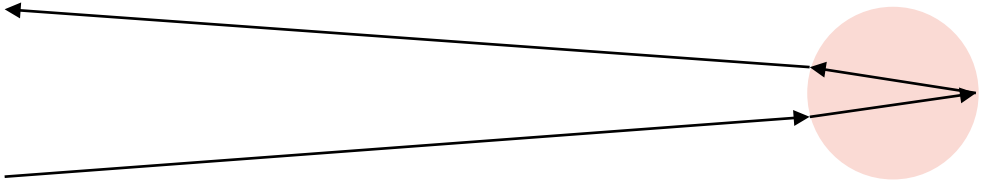


IR

$$r = \frac{1}{2}\sum_i \frac{ct_i}{n_i}$$

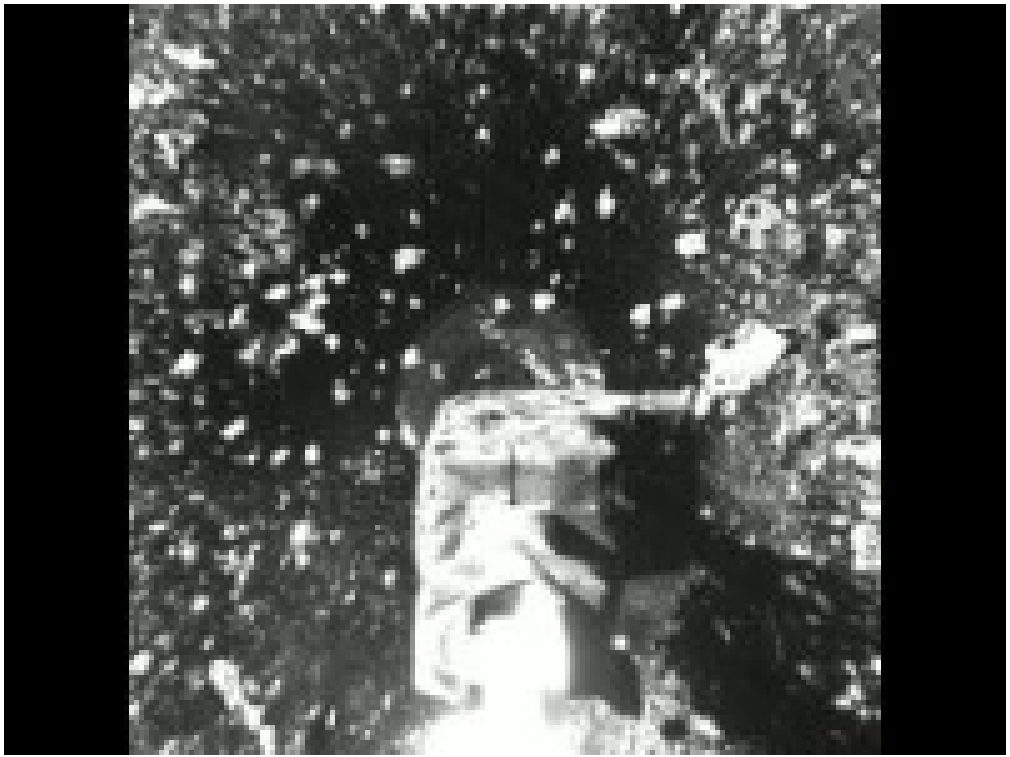
Air
n = 1

Glass Bead
n = 1.5-1.7

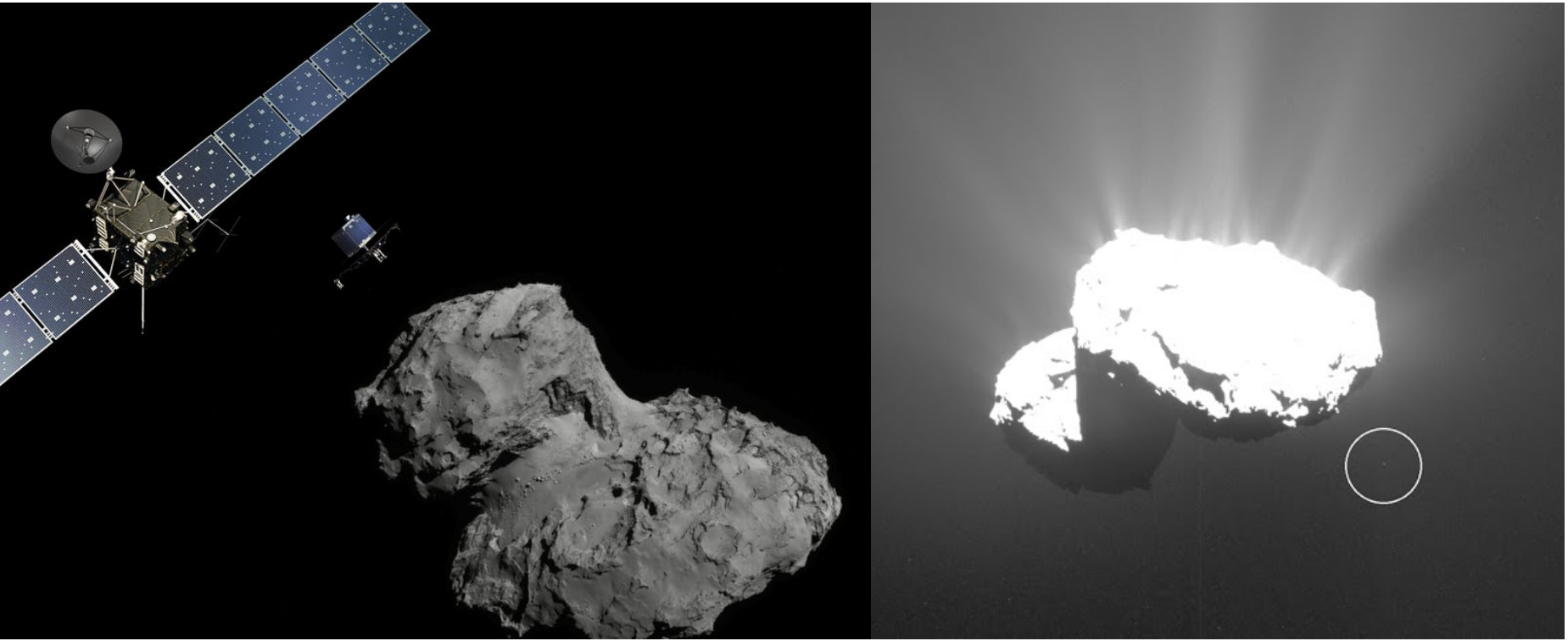


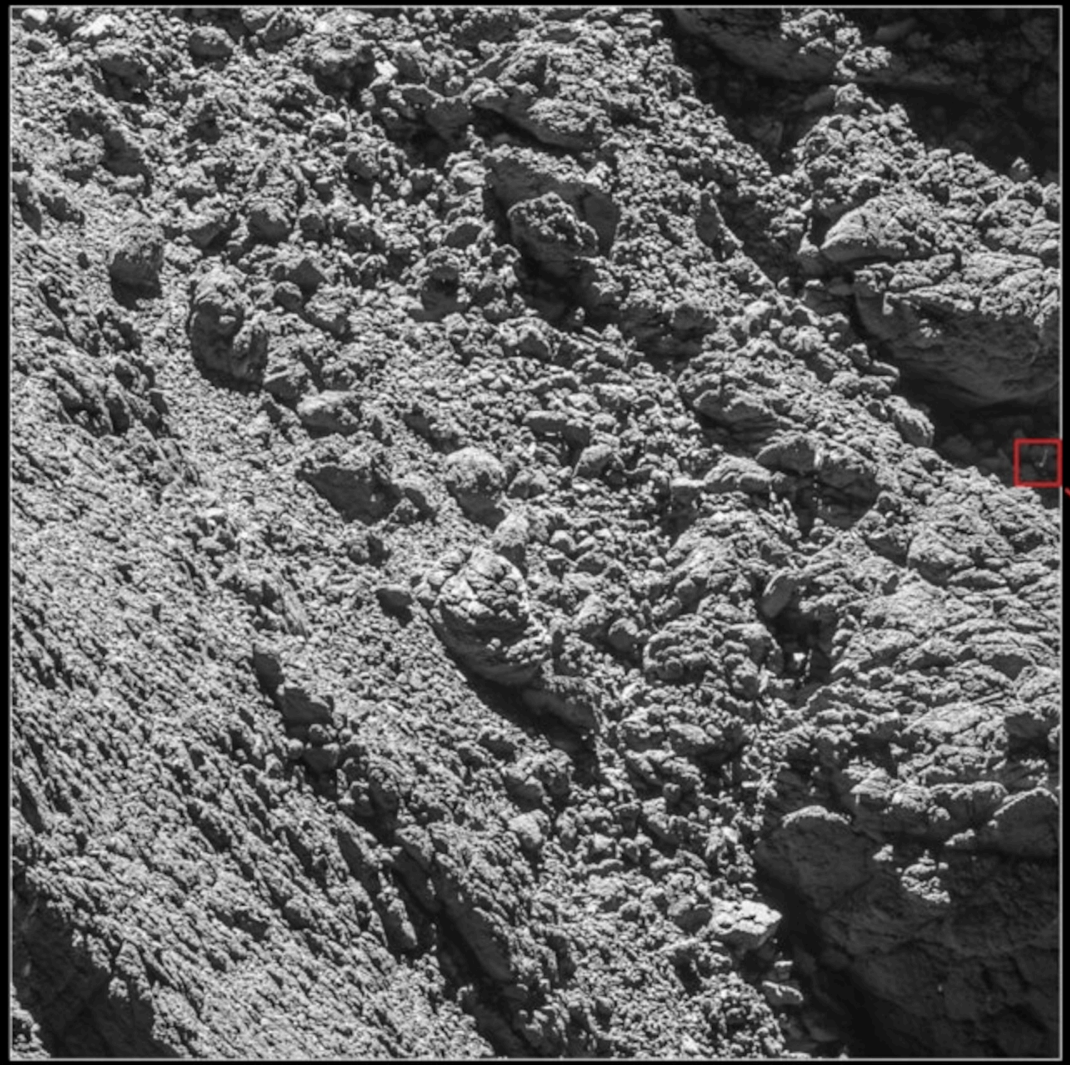
$\Delta \mathrm{OPL} = 3 - 5$ mm

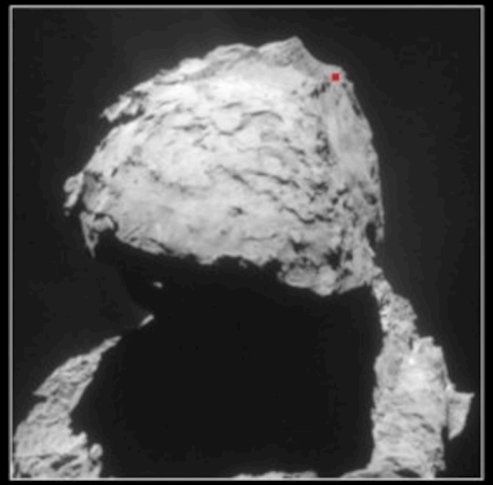
Has seen use in space – just not on a Rover! (Yet!)



If only Rosetta had a LiDAR…

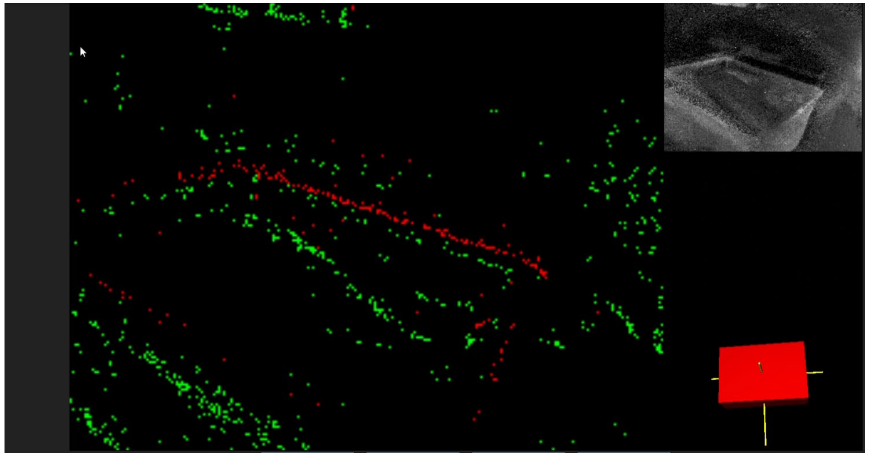


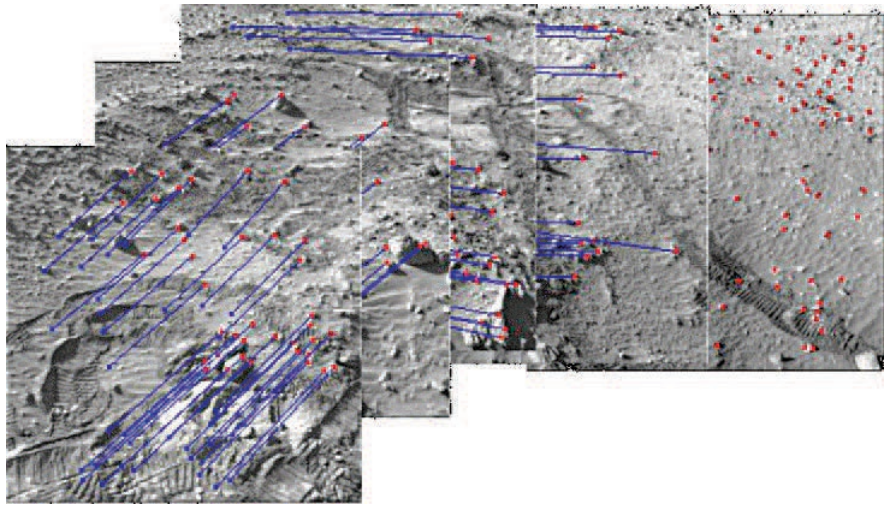




Lucky there was a camera!

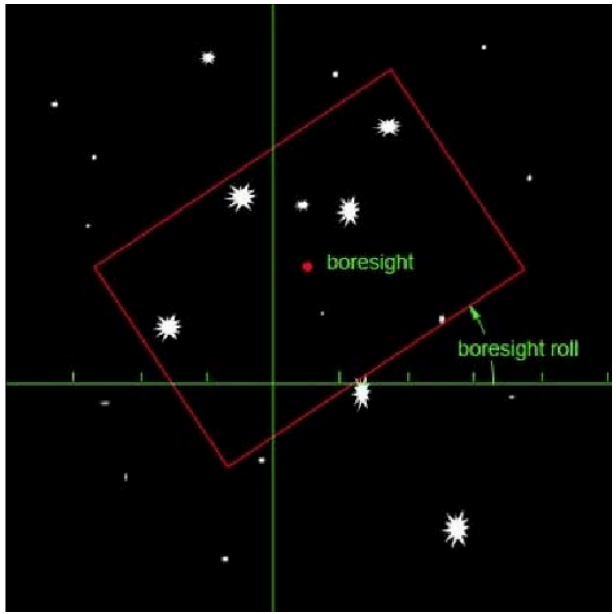
Localisation and Visual Odometry

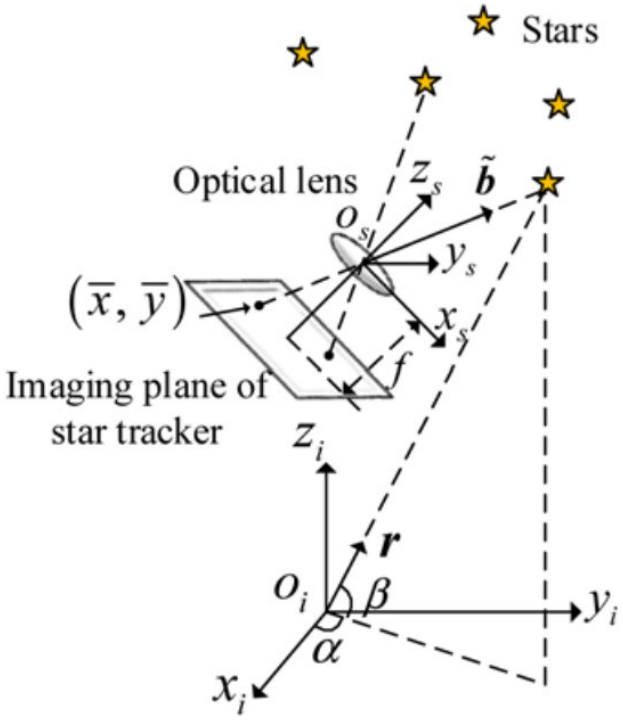


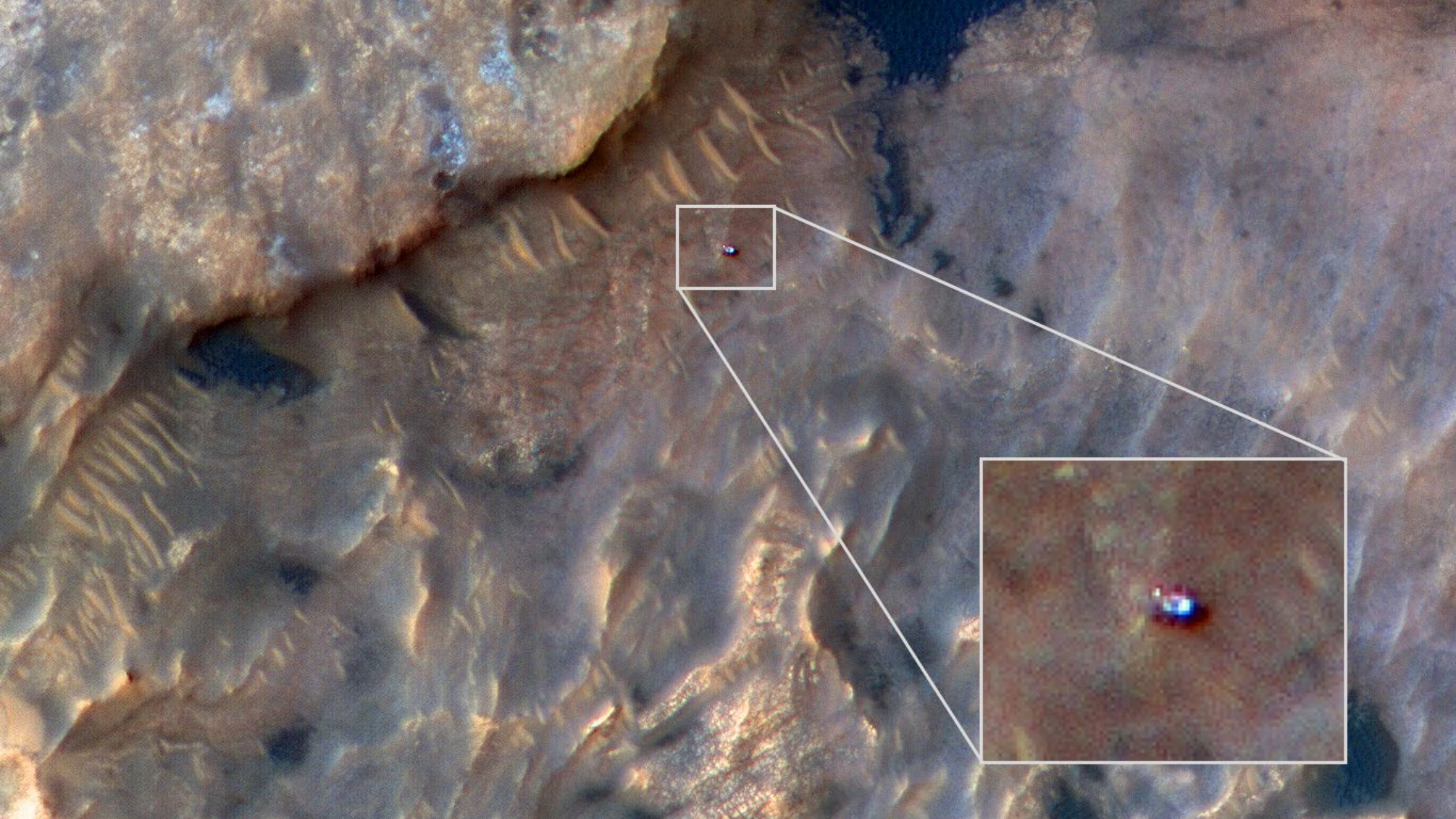


Satellites and Rovers aren't too different…

– "Compass" in space



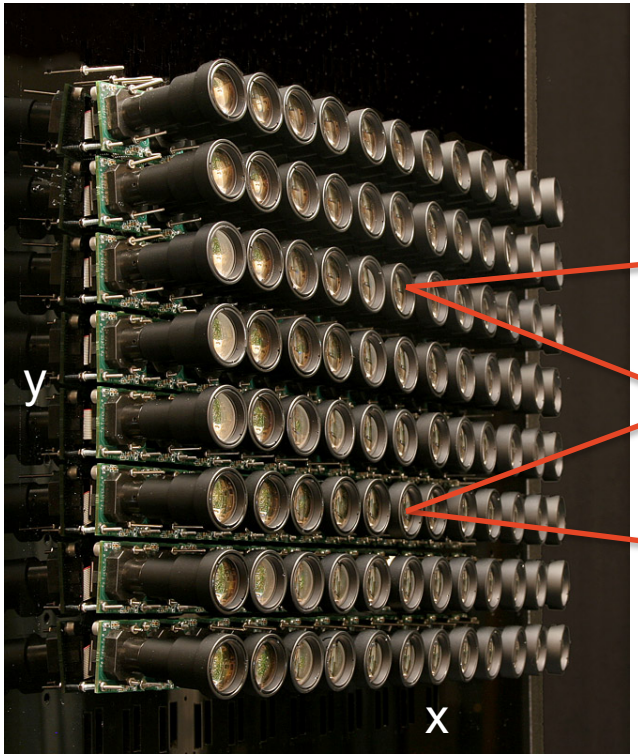


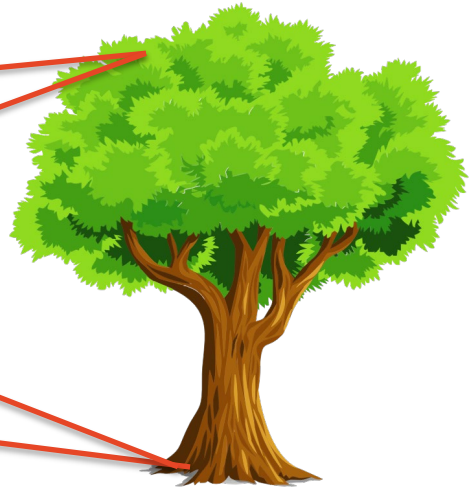


Back to the Plenoptic Function

- We were restricted by aperture remember…
- What if we increased the number of apertures…
- Enter: the Light Field!

A Light Field Camera





$$P(\theta, \phi, \lambda, t, p, V_x, V_y, V_z)$$

What's so special about this?

- **We know where the light has come from**

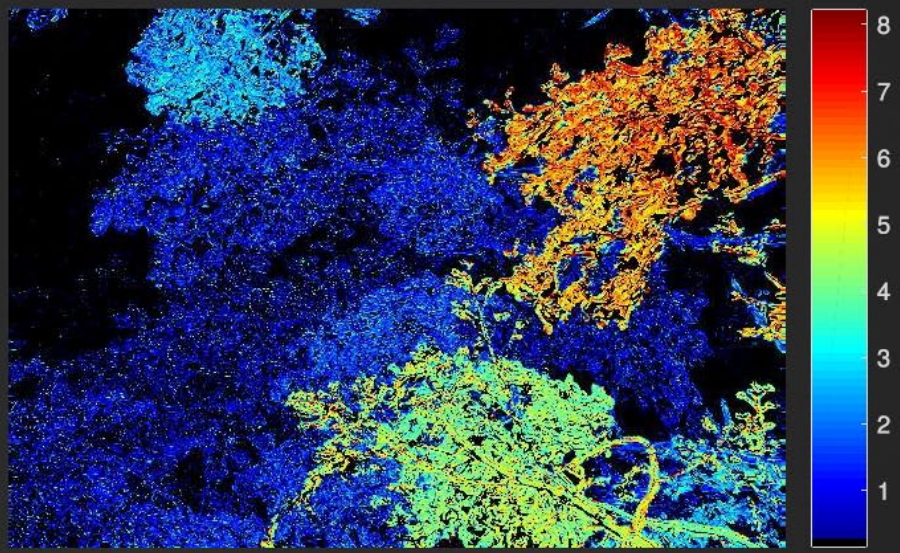
- **Can use this to select subsets of sampled light**
  - i.e. render new views after the photo has been taken
  - And interestingly… change the "camera" after the image has been taken

What does this look like?

Dansereau et al, 2015

Dansereau et al, 2015

Light Fields in Space? Depth!



Courtesy: D. Dansereau

Light Fields Are Also Computationally Efficient: Everything Is Lin-Alg!

$$\begin{bmatrix} s \\ t \\ u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} H_{1,1} & 0 & H_{1,3} & 0 & H_{1,5} \\ 0 & H_{2,2} & 0 & H_{2,4} & H_{2,5} \\ H_{3,1} & 0 & H_{3,3} & 0 & H_{3,5} \\ 0 & H_{4,2} & 0 & H_{4,4} & H_{4,5} \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i \\ j \\ k \\ l \\ 1 \end{bmatrix}.$$

$\Phi = Hn$ and $n = H^{-1}\Phi$

Dansereau et al, 2015

Synthetic Aperture Photography (A subset of Light Fields)

A quick aside…

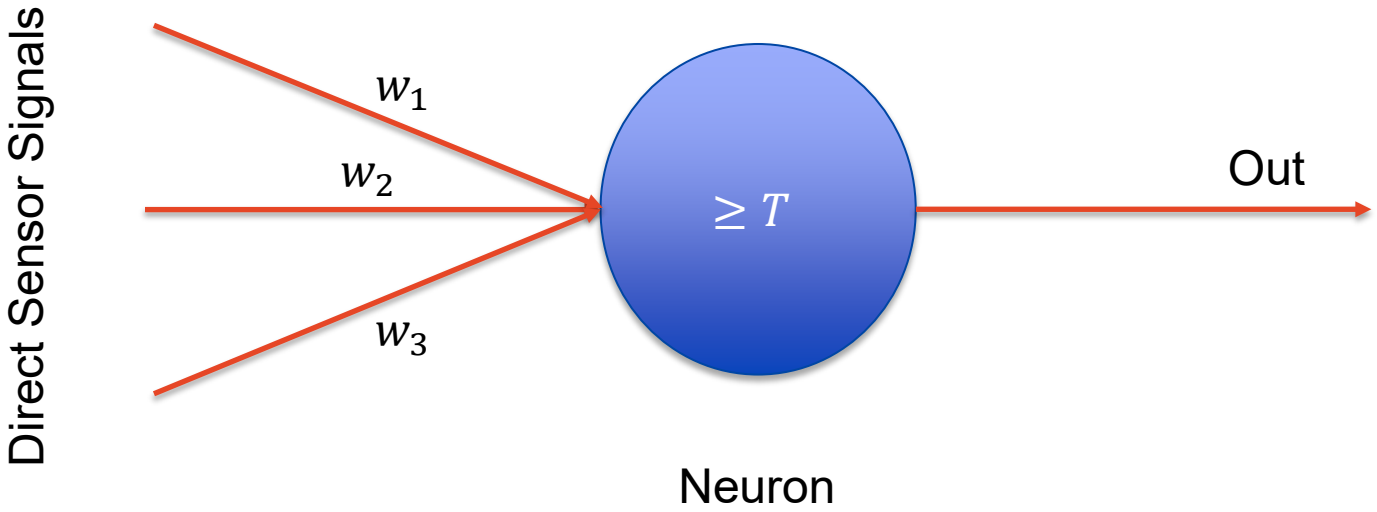
- This is all algorithmically intensive…

- What could be in the future of space robotics that would make this sensing a little less slow/hard?

A quick aside…

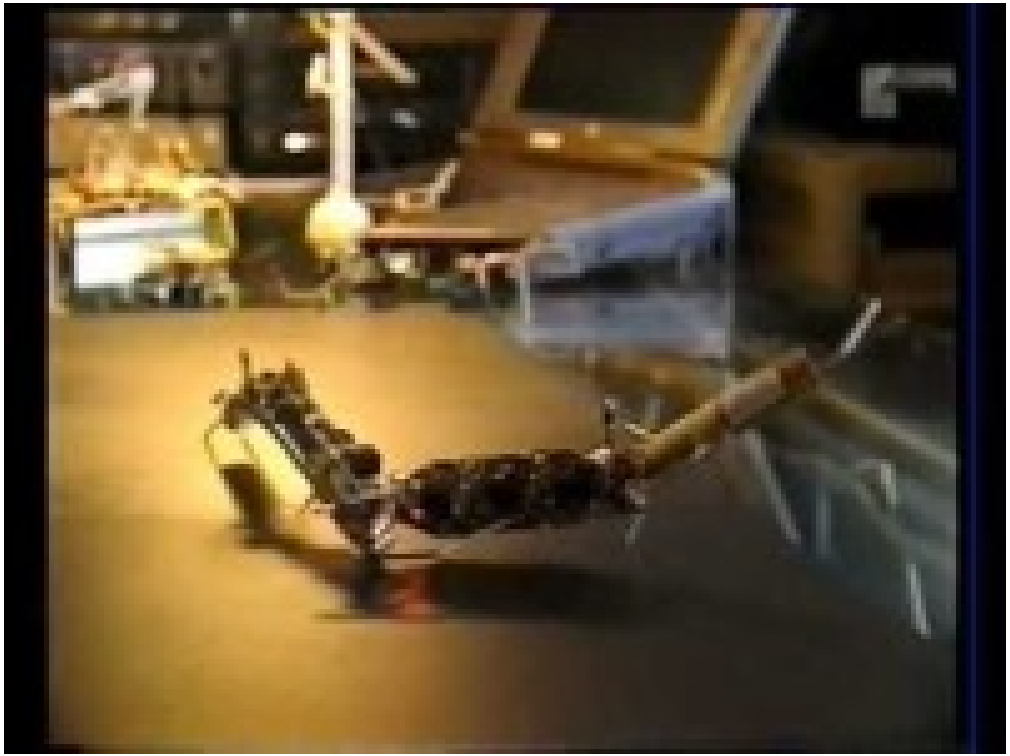
- **This is all algorithmically intensive…**
- **What could be in the future of space robotics that would make this sensing a little less slow/hard?**
- **You were thinking of neurorobotics. Me too.**
  - Great minds think alike.

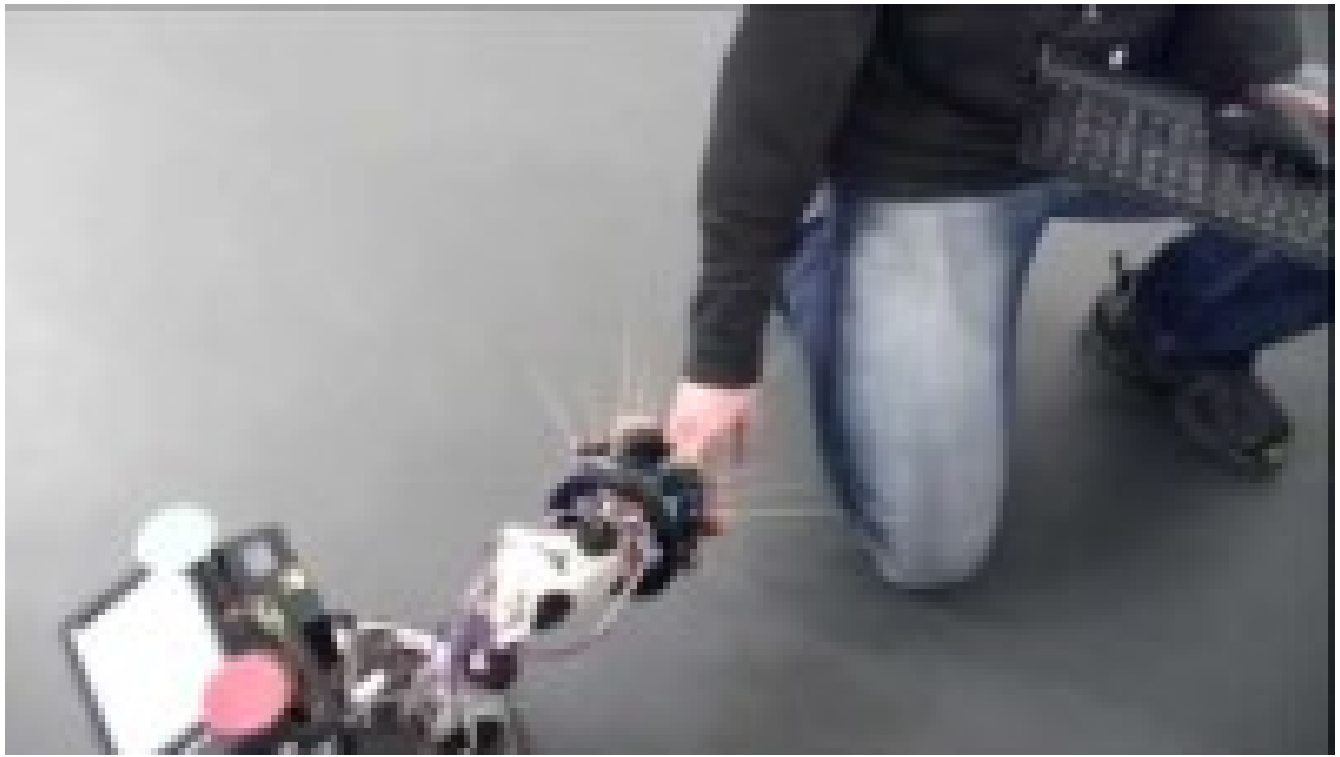
Giving Robots a Brain



This looks a little like Intro to AI right?

What does a neurorobot look like?

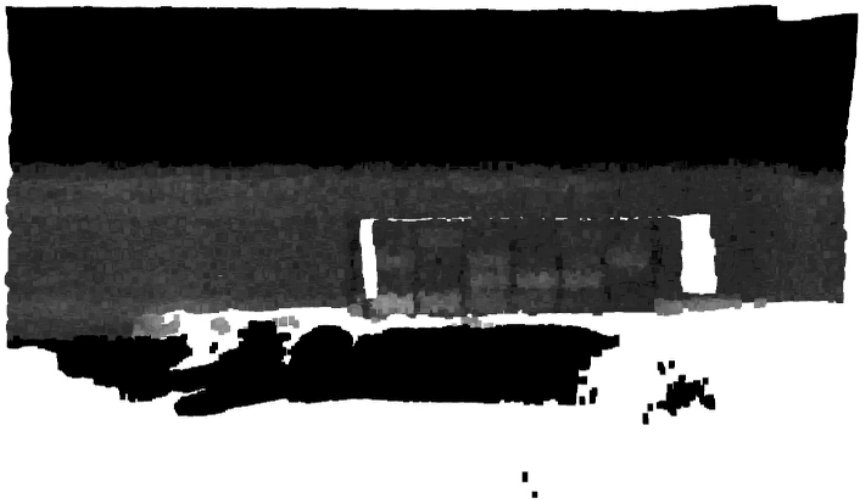




What about λ in the Plenoptic Function?

– This is where I come in!

Reconstructed RGB



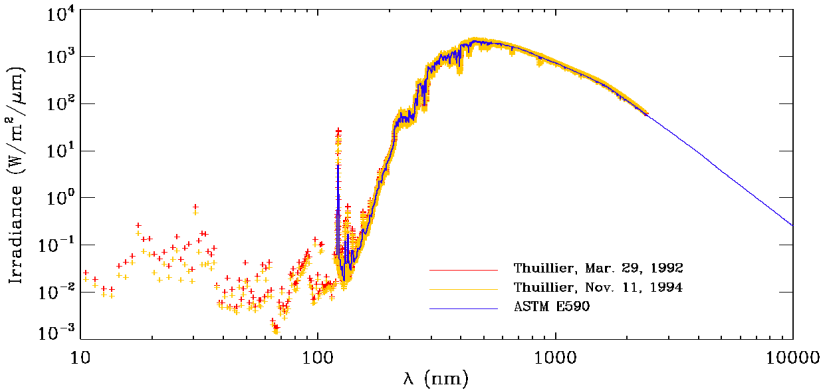
400-710nm in 50nm Steps Aligned to Pointcloud

HS Imaging Systems

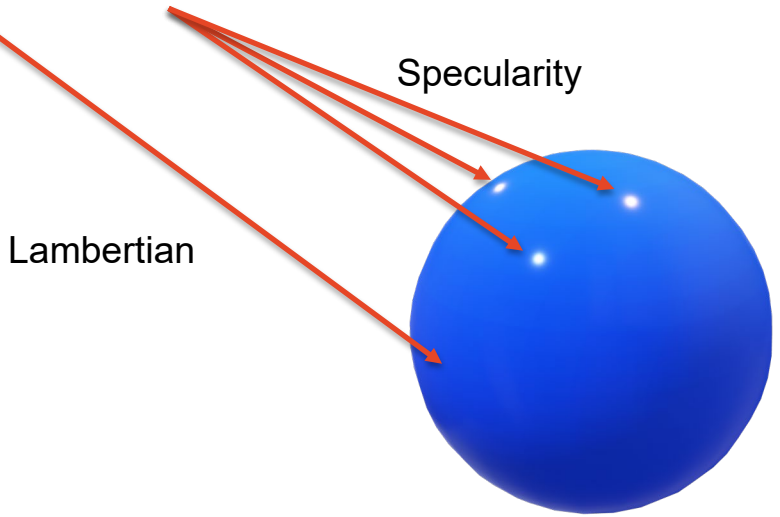
- **Intensity of wavelengths can be imaged**

$$I_\lambda = I_\mathcal{L}(I_I)I_S(I_I)$$

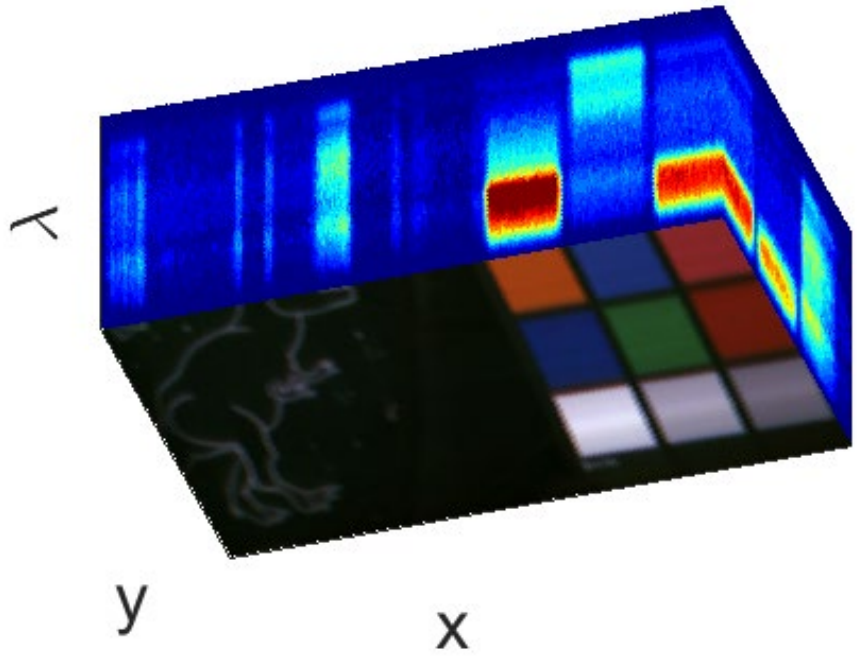
I_I = incident spectrum



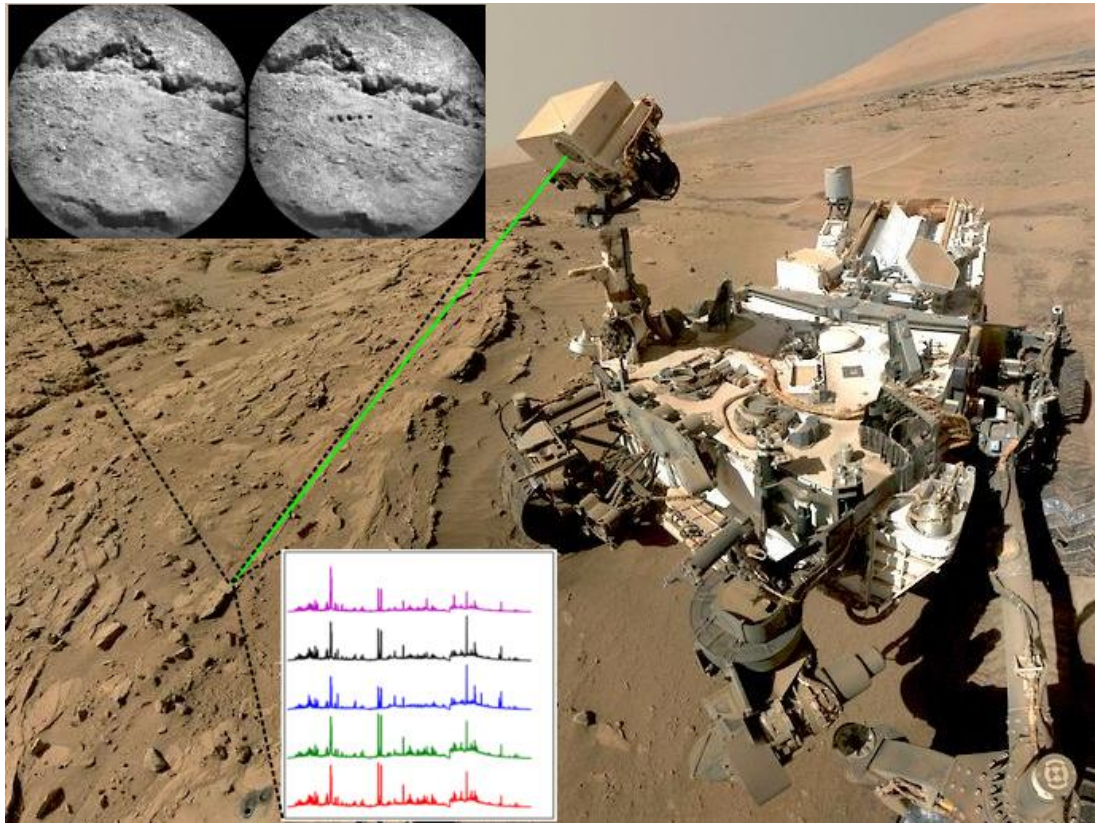
Source: NASA



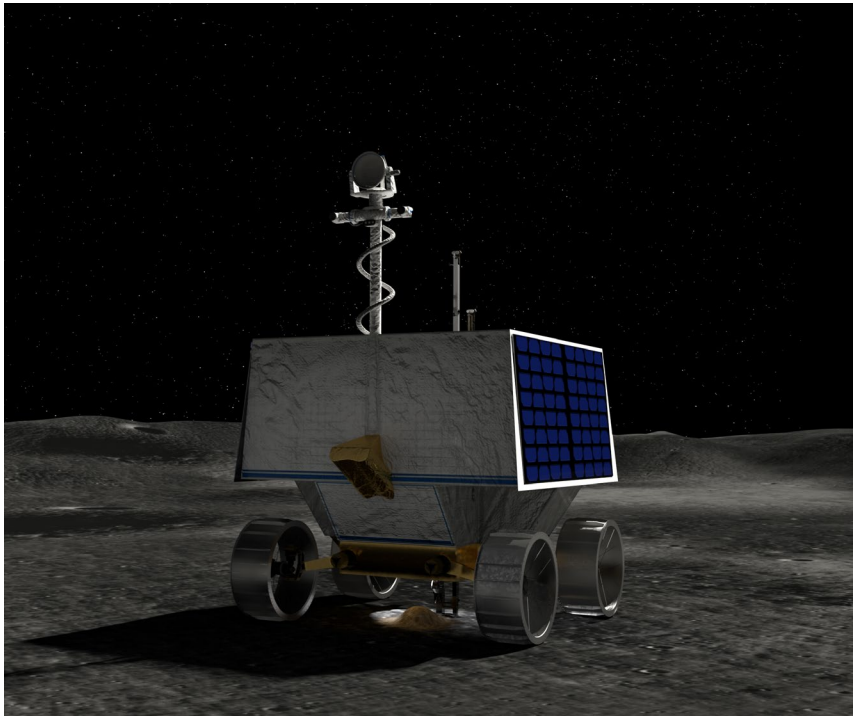
Hyperspectral Cube (2D x N Image)

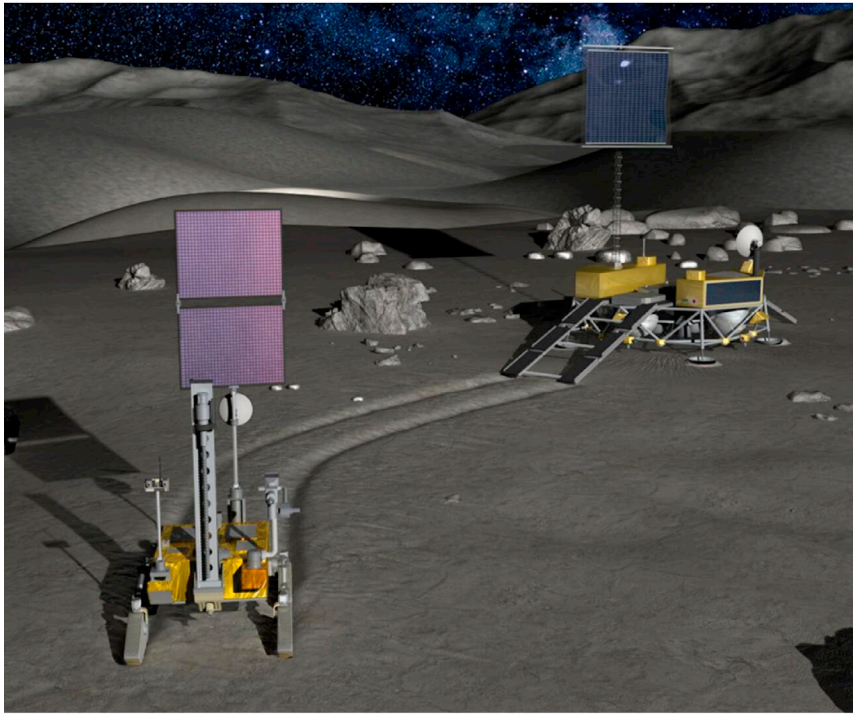


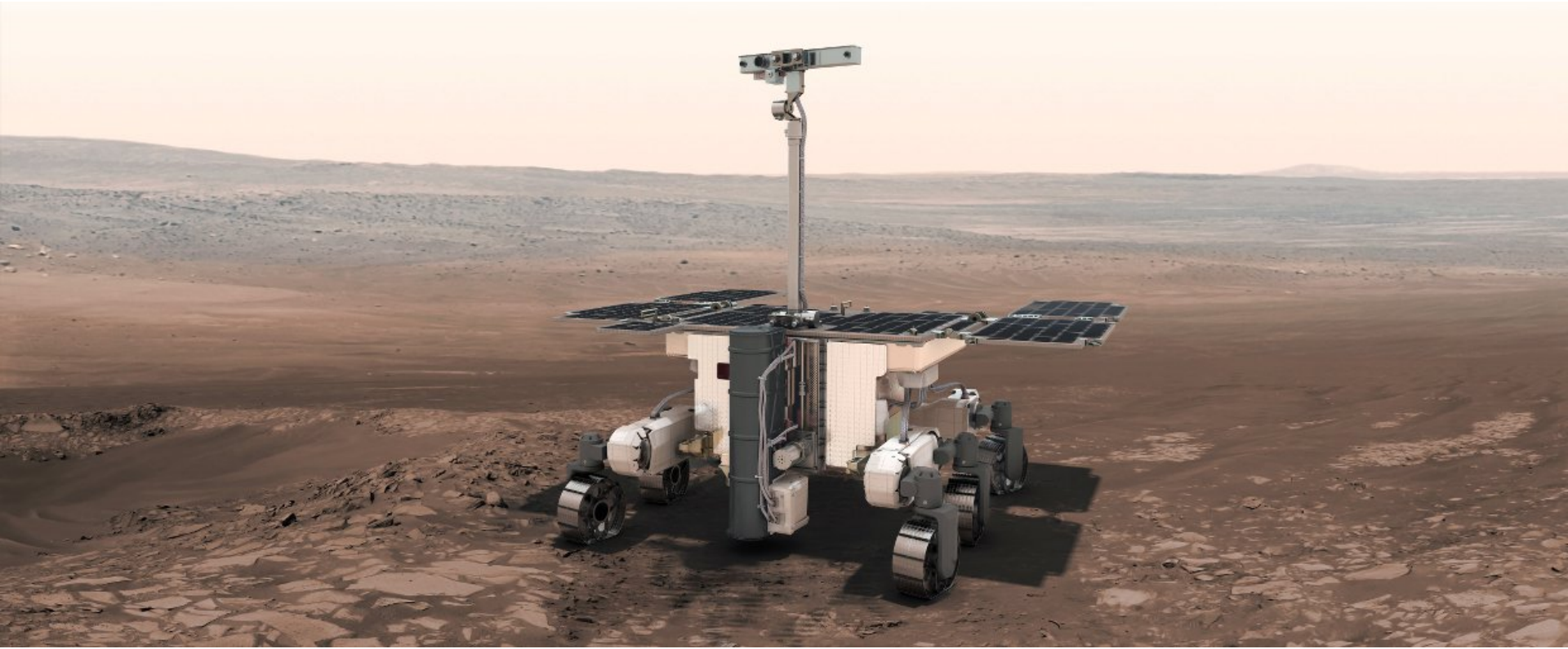
HS In Space?



Where to next?







Q&A

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