Lunar Surface Science Workshop 2021

Resource Mapping in Extreme Environments

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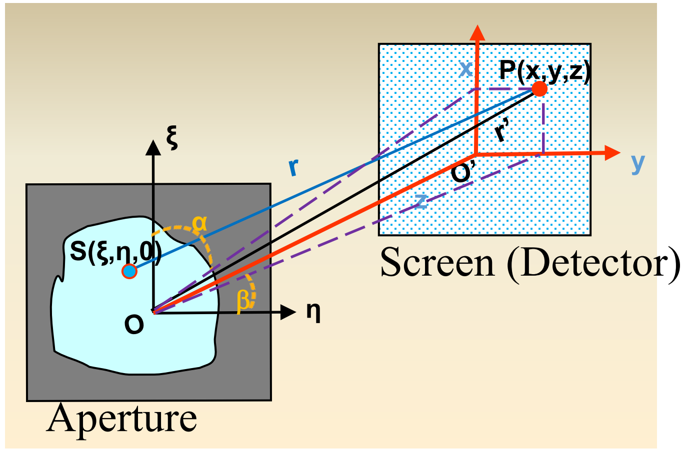
Approximation of Diffraction Phenomena

S(η,ξ,0) at a coordinate (η,ξ,0) on an aperture and illuminates a point,
P(x,y,z) at a coordinate (x,y,z) on a screen.



$$u(P) = \frac{iA}{\lambda}\iint \frac{e^{-ikr}}{r}\, d\xi d\eta$$

where λ = wavelength, k = wavenumber of light.

r is a temporary variable for integration,
r' is a fixed engineering parameter.

Approximation with r'

$$u(P) = \int\int_{-\infty}^{\infty} S(\xi,\eta,0)\exp[ik(l\xi + m\eta)]\,d\xi d\eta \qquad z > \frac{a^2}{\lambda}$$

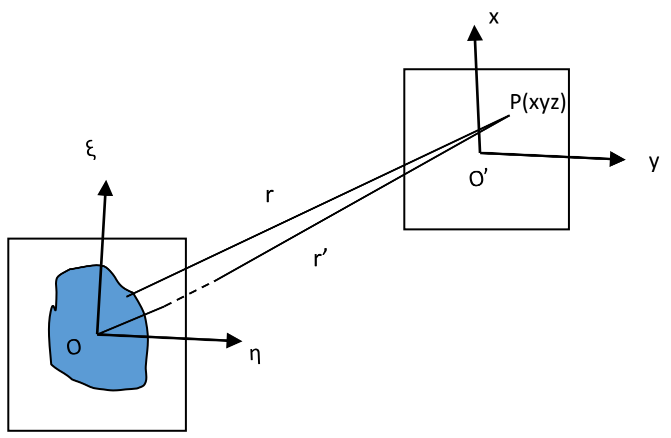
where $r \cong r' - (l\xi + m\eta)$, $l = \frac{x}{r'} = \cos\alpha;\ m = \frac{y}{r'} = \cos\beta$

$$r = \underbrace{\overbrace{r' - \frac{x\xi + y\eta}{r'}}^{\text{Fraunhofer Terms}} + \left[-\frac{(x\xi + y\eta)^2}{2r'^3} + \frac{\xi^2 + \eta^2}{2r'}\right]}_{\text{Fresnel Terms}} + \cdots$$

$$u(P) = \frac{i}{\lambda z}\exp[-ikz]\iint S(\xi,\eta,0)\exp\left[\frac{-ik}{2z}\left[(x-\xi)^2 + (y-\eta)^2\right]\right]d\xi d\eta \qquad a < z < \frac{a^2}{\lambda}$$

Diffraction & Fresnel Number

$$u(P) = \frac{iA}{\lambda}\iint \frac{e^{-ikr}}{r}\, d\xi\, d\eta$$



$$F = \frac{a^2}{z\lambda}$$

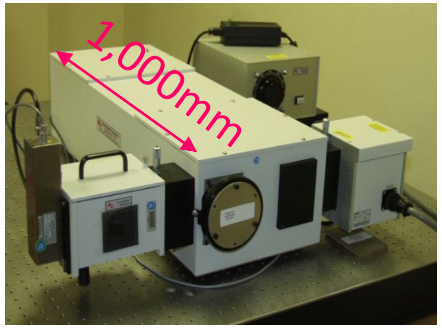
a = radius of aperture
z = distance along OA
λ = wavelength

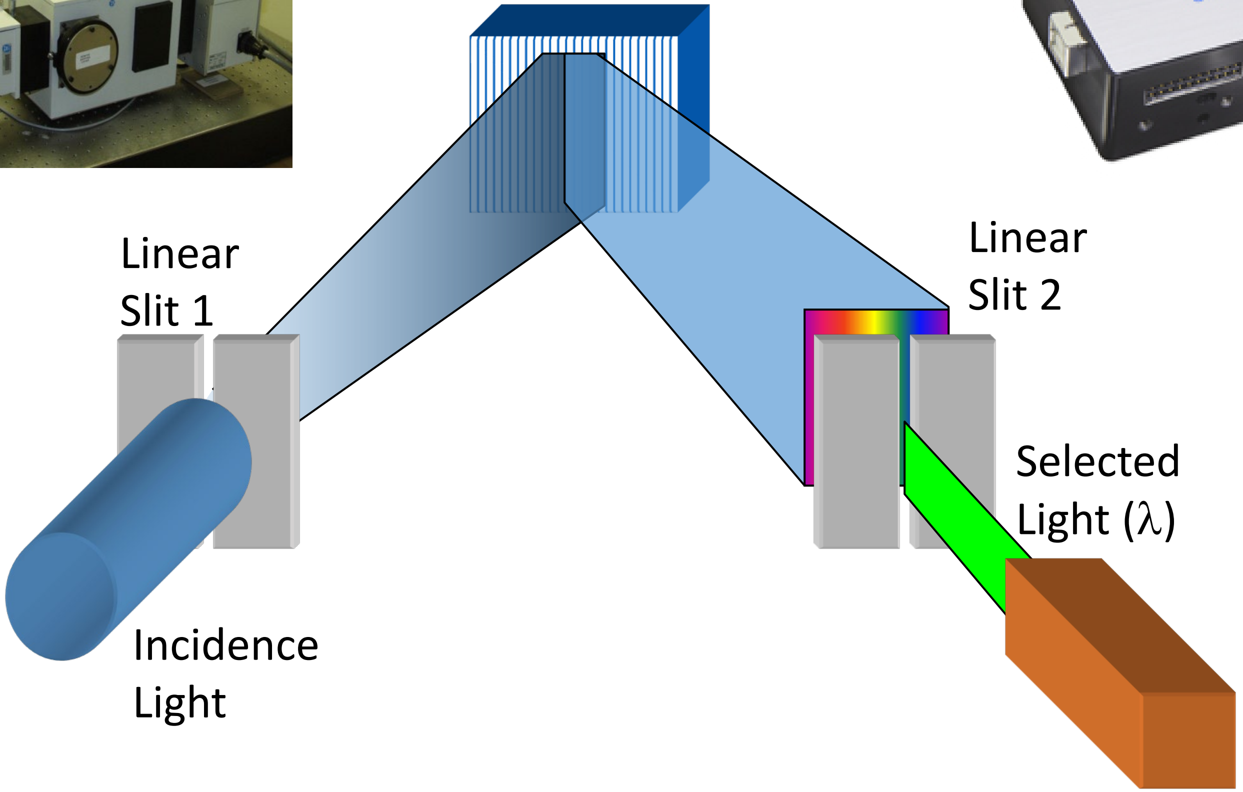
The value of F determines the valid diffraction approximation.

$F << 1$; Fraunhofer Diffraction
$F >> 1$; Fresnel Diffraction

Most modern conventional spectrometers use the Fraunhofer diffraction because the resolution improves with a longer optical path.

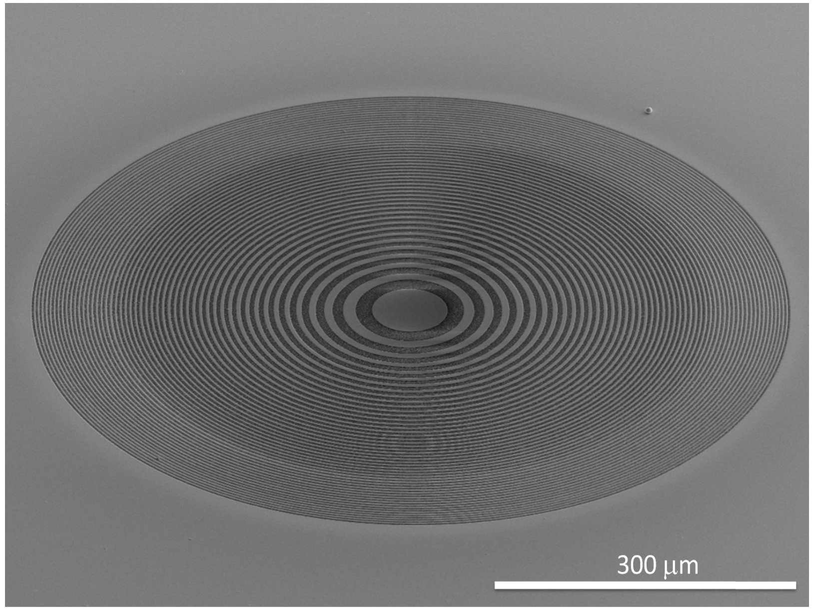
Conventional Fraunhofer Spectrometers

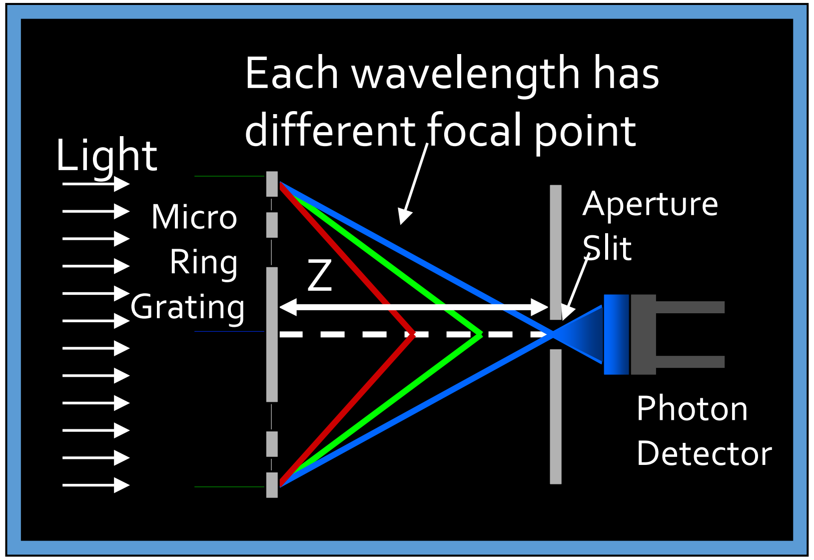


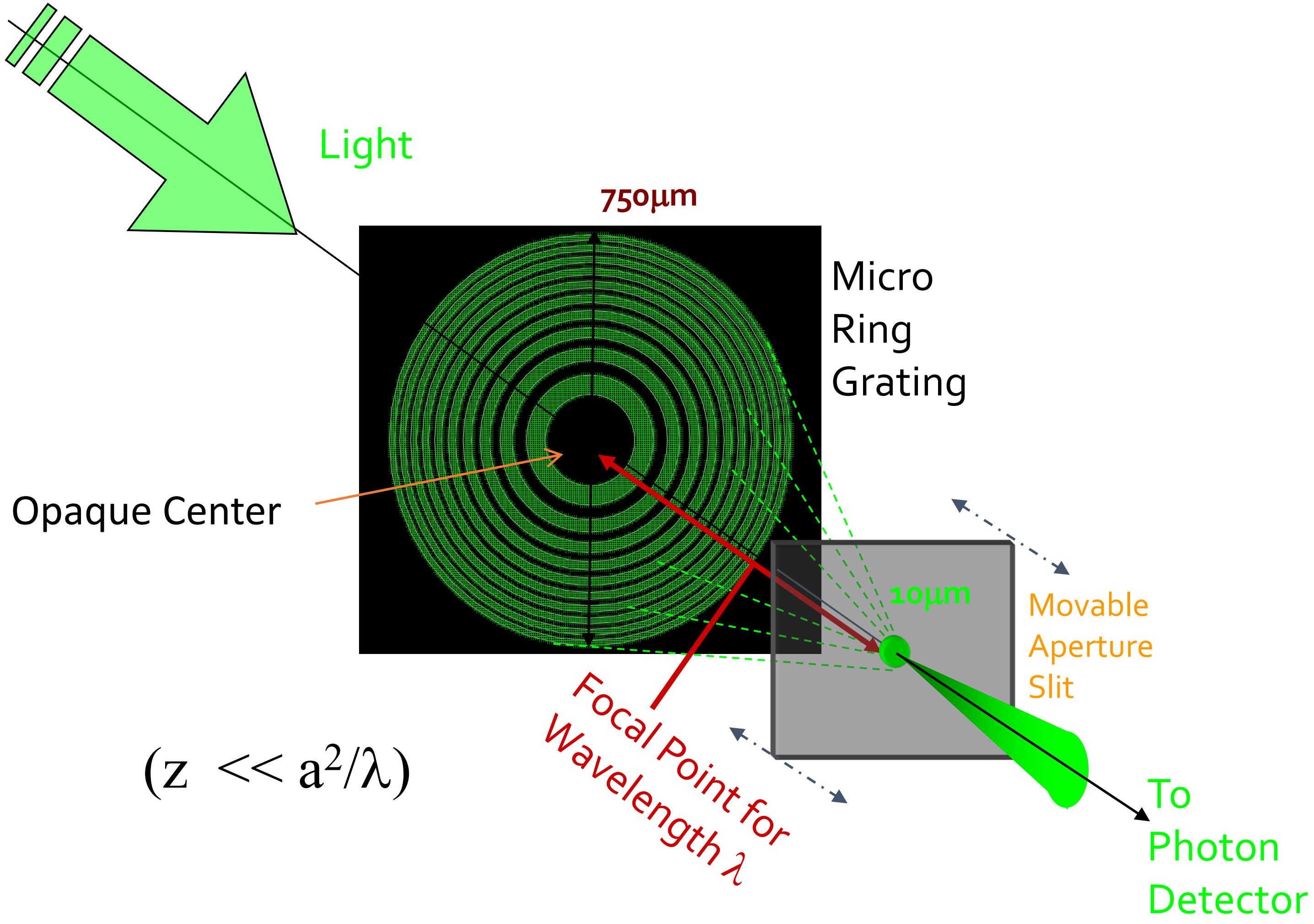


New Micro Spectrometer 1mm

Working Principle of Fresnel Spectrometer with Negative Zone Plate

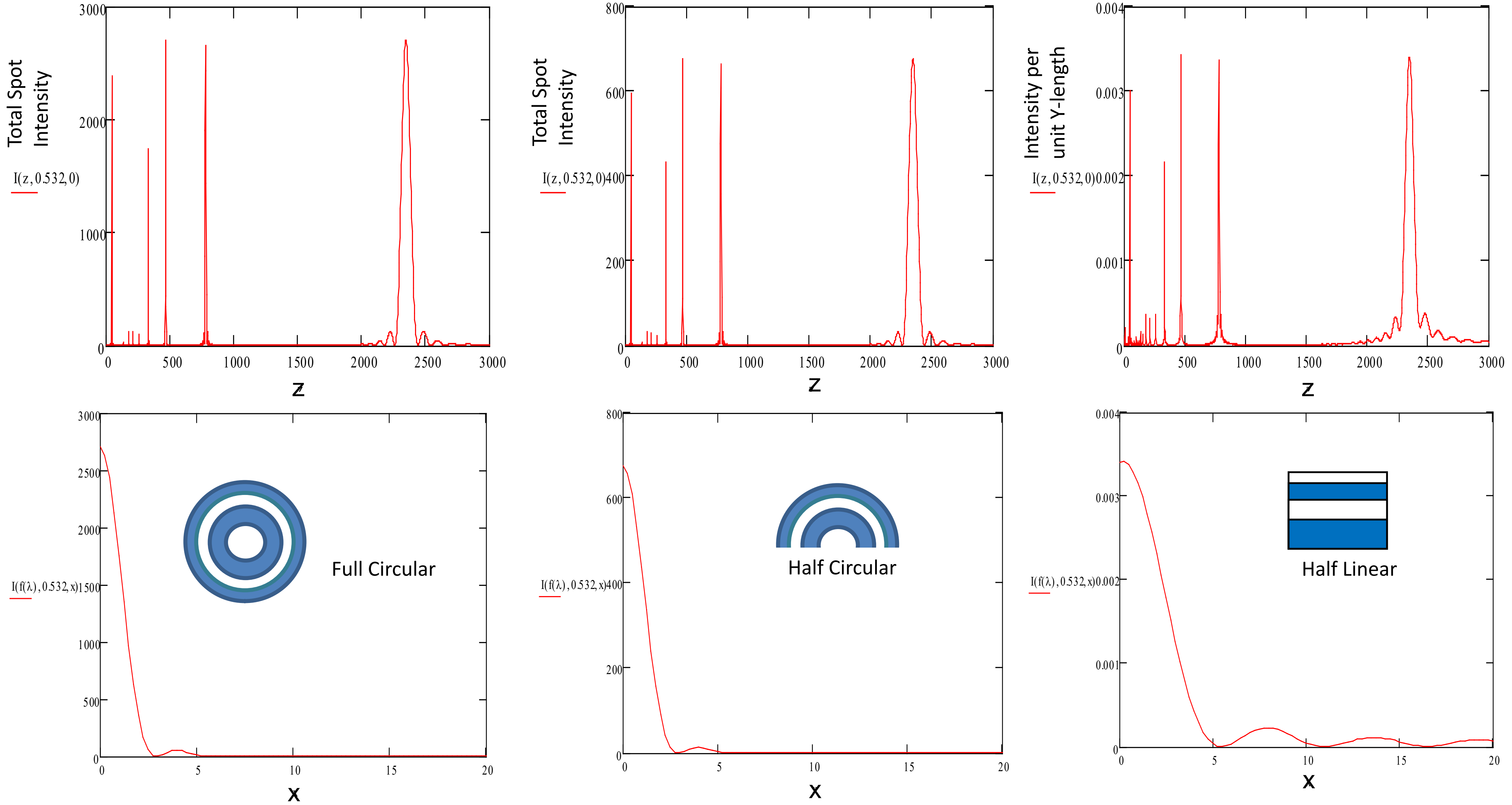




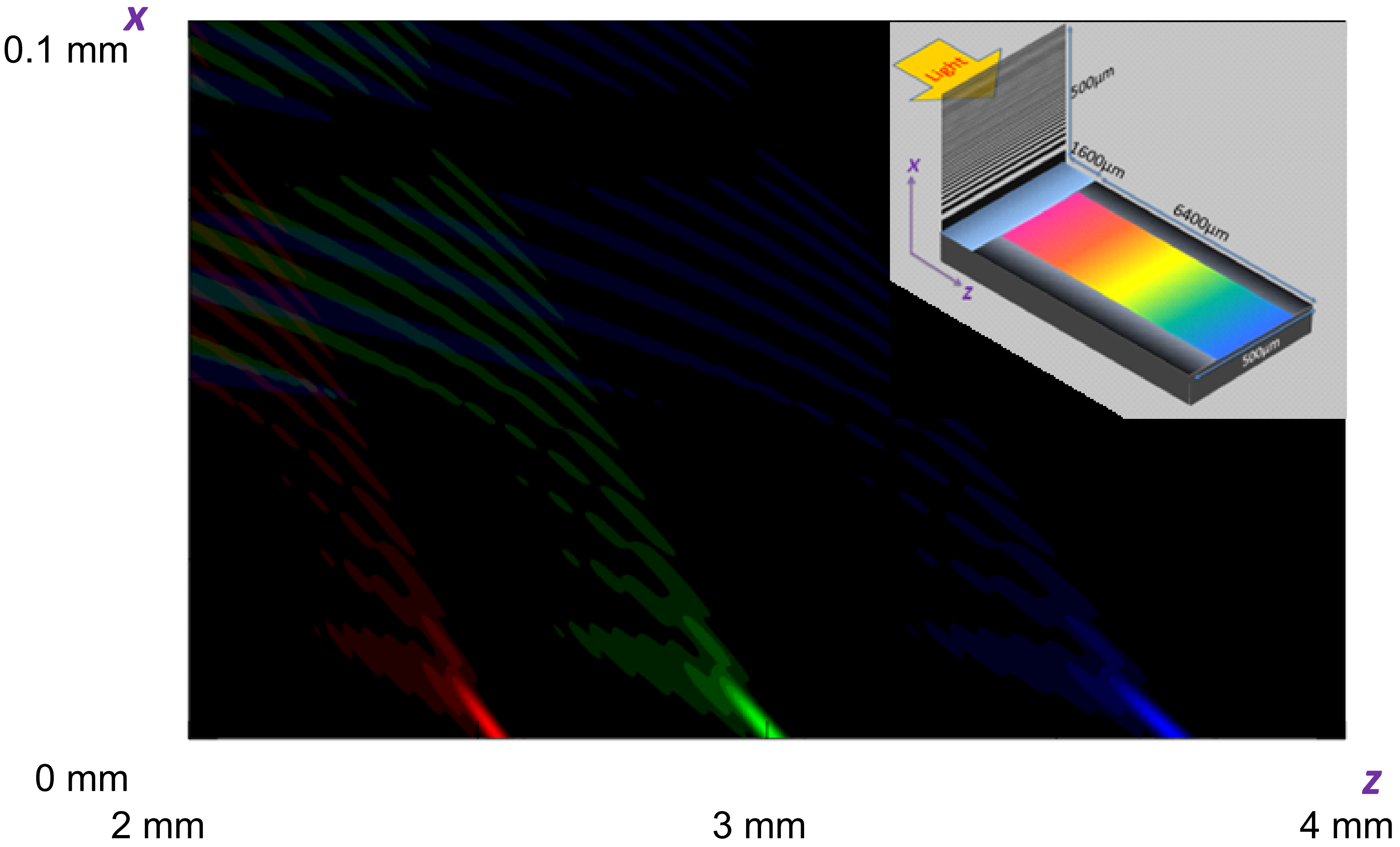


$$(z \ll a^2/\lambda)$$

Optical Responses of Circular and Linear Gratings

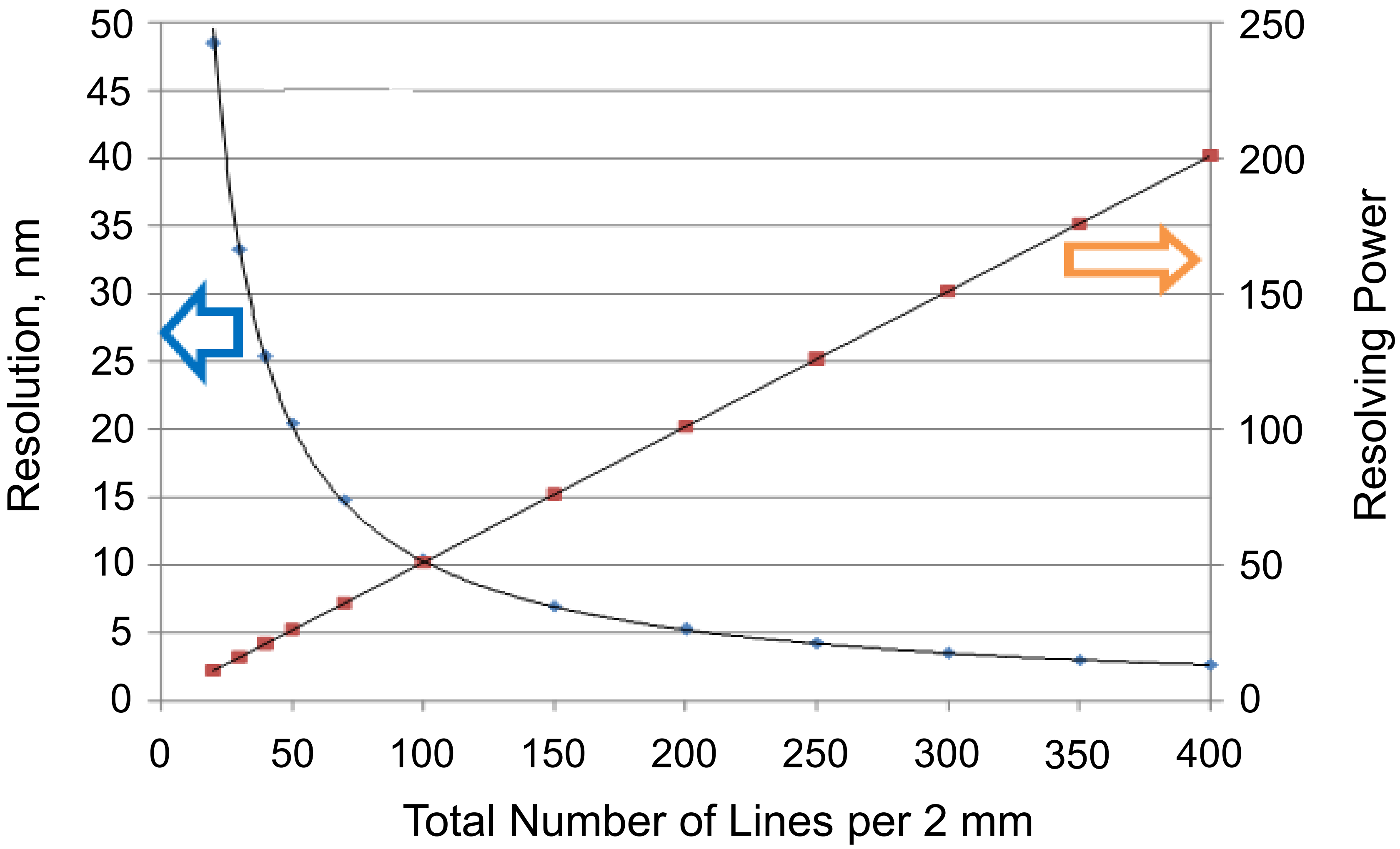


Fall of Lights onto Detector Surface

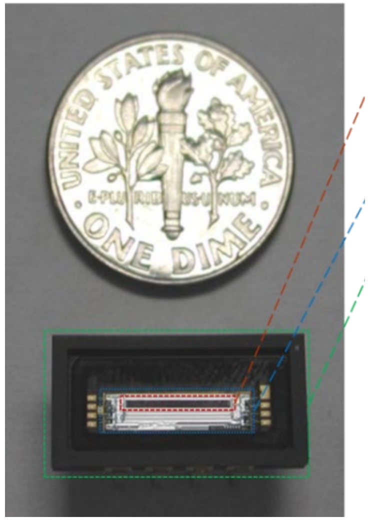


(632, 532, 432nm) ***156 lines in 500 μm***

Spectral Data & Resolution



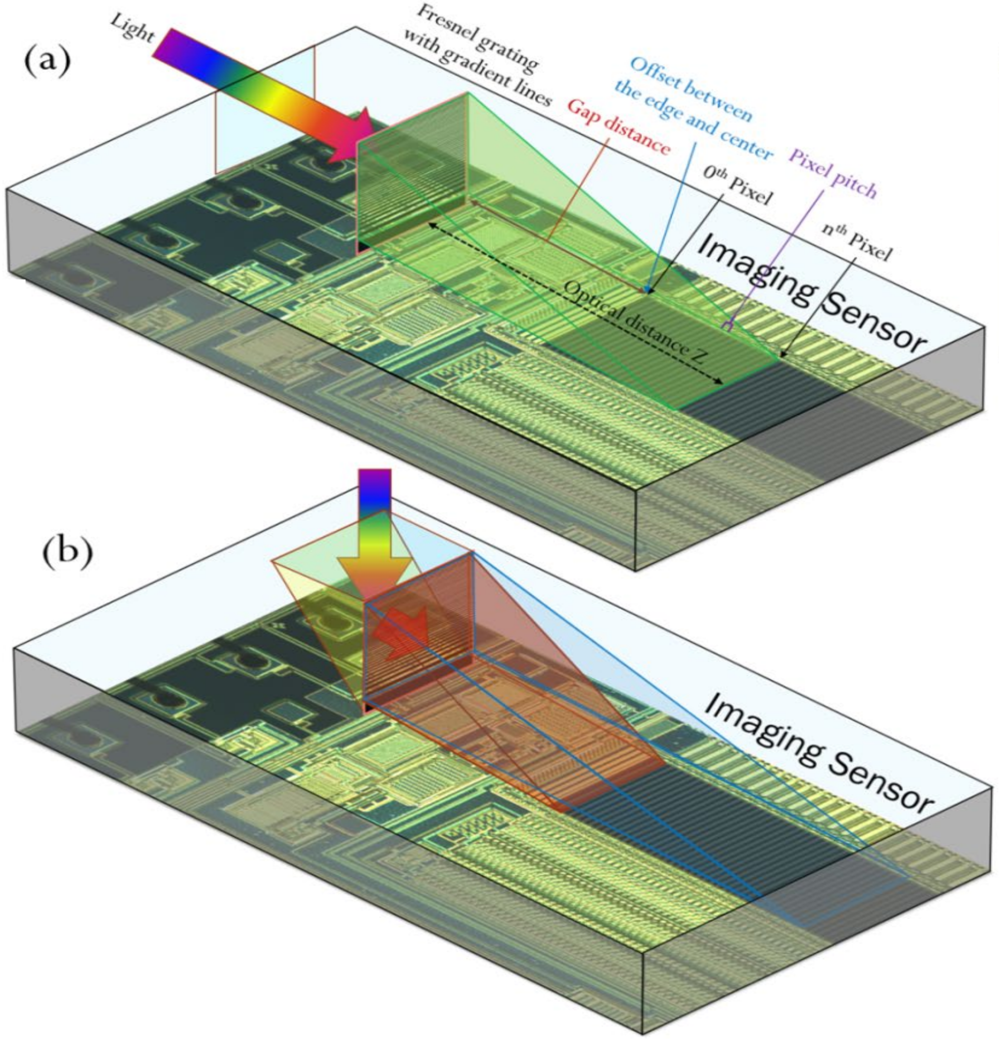
Spectrometer Chip

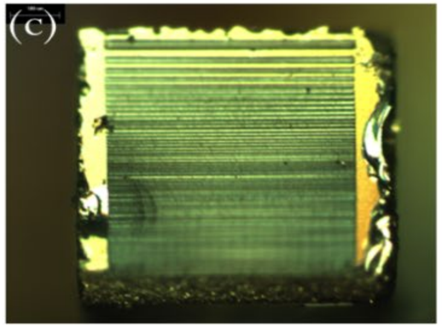


Active Area: 6.4 mm x 0.5 mm (Spectrum Area)

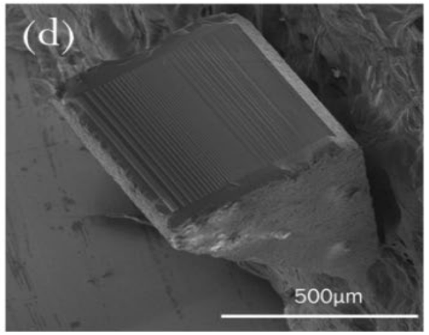
Die Size: 9.5 mm x 2.5 mm

Packaging: 15.8 mm x 7.87 mm



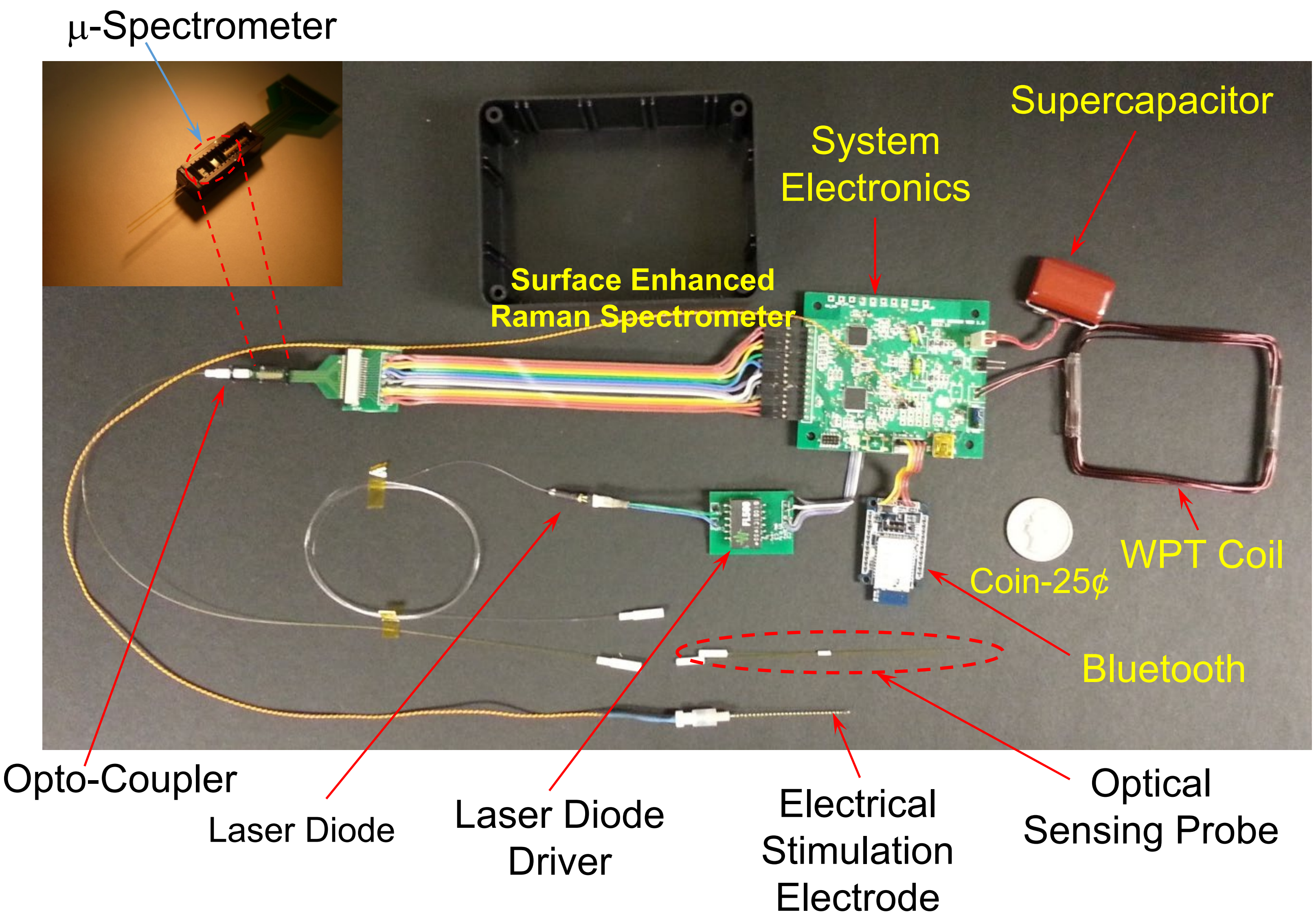


700 µm

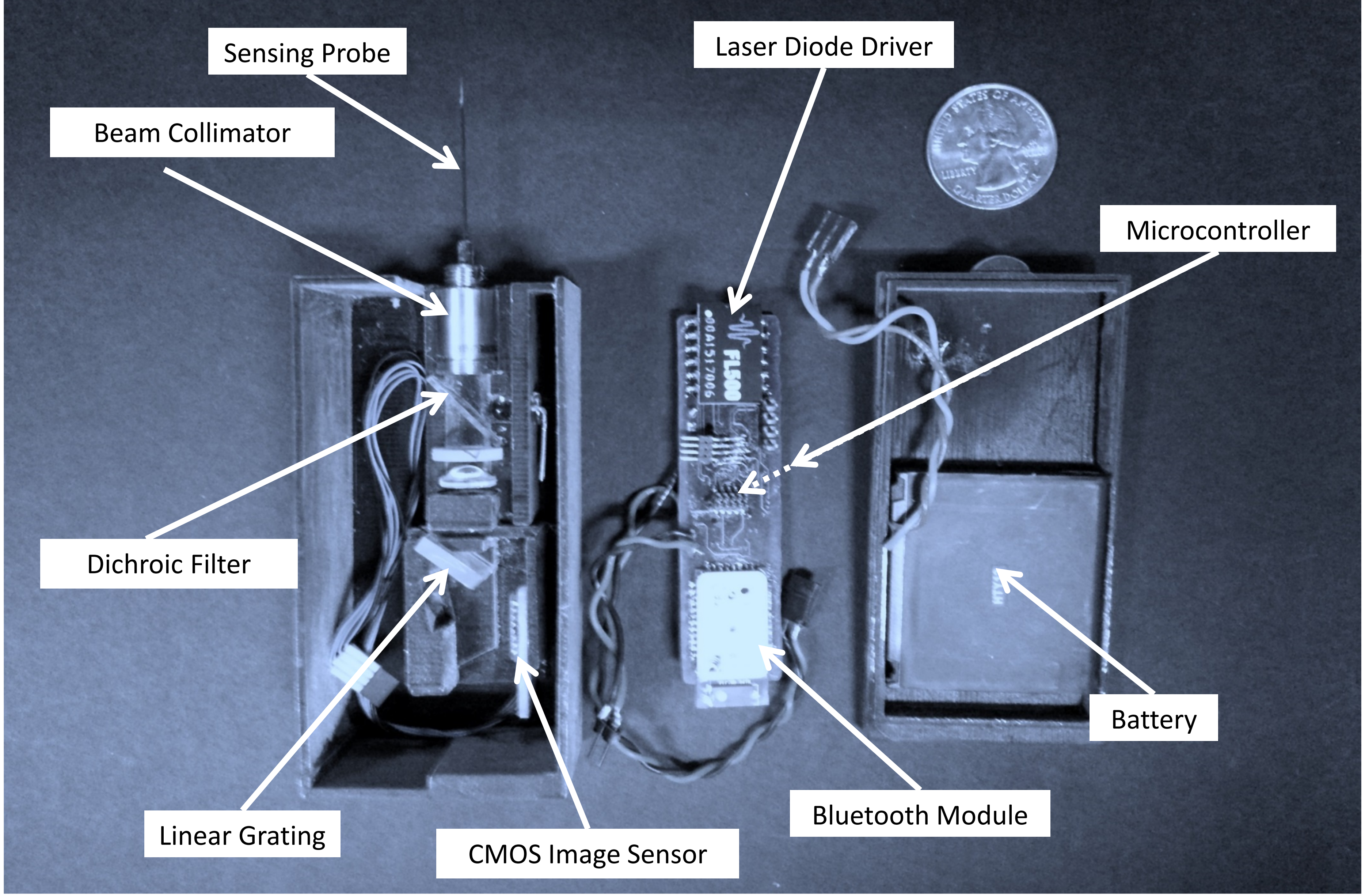


500 µm

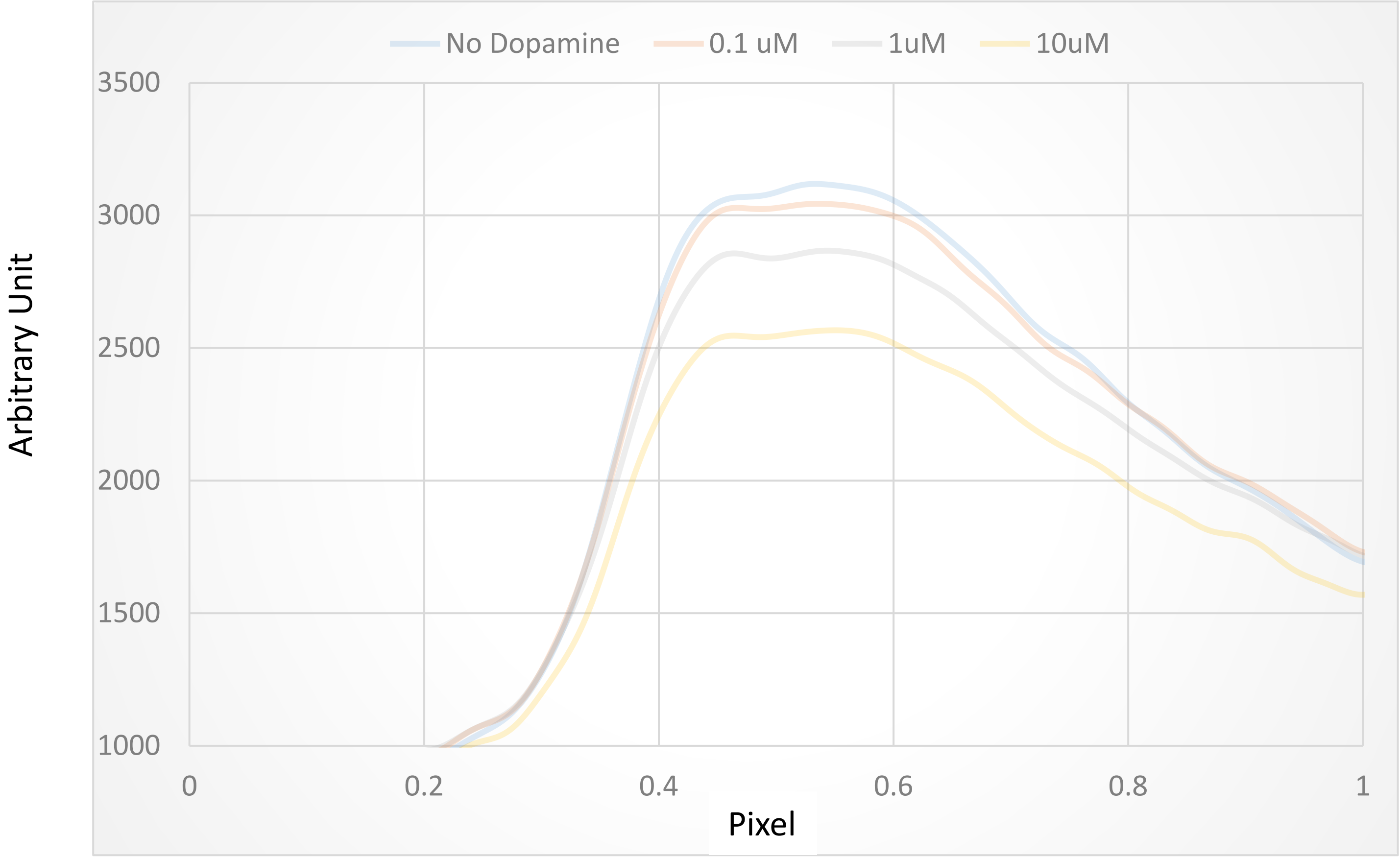
1-D Scan Prototype System



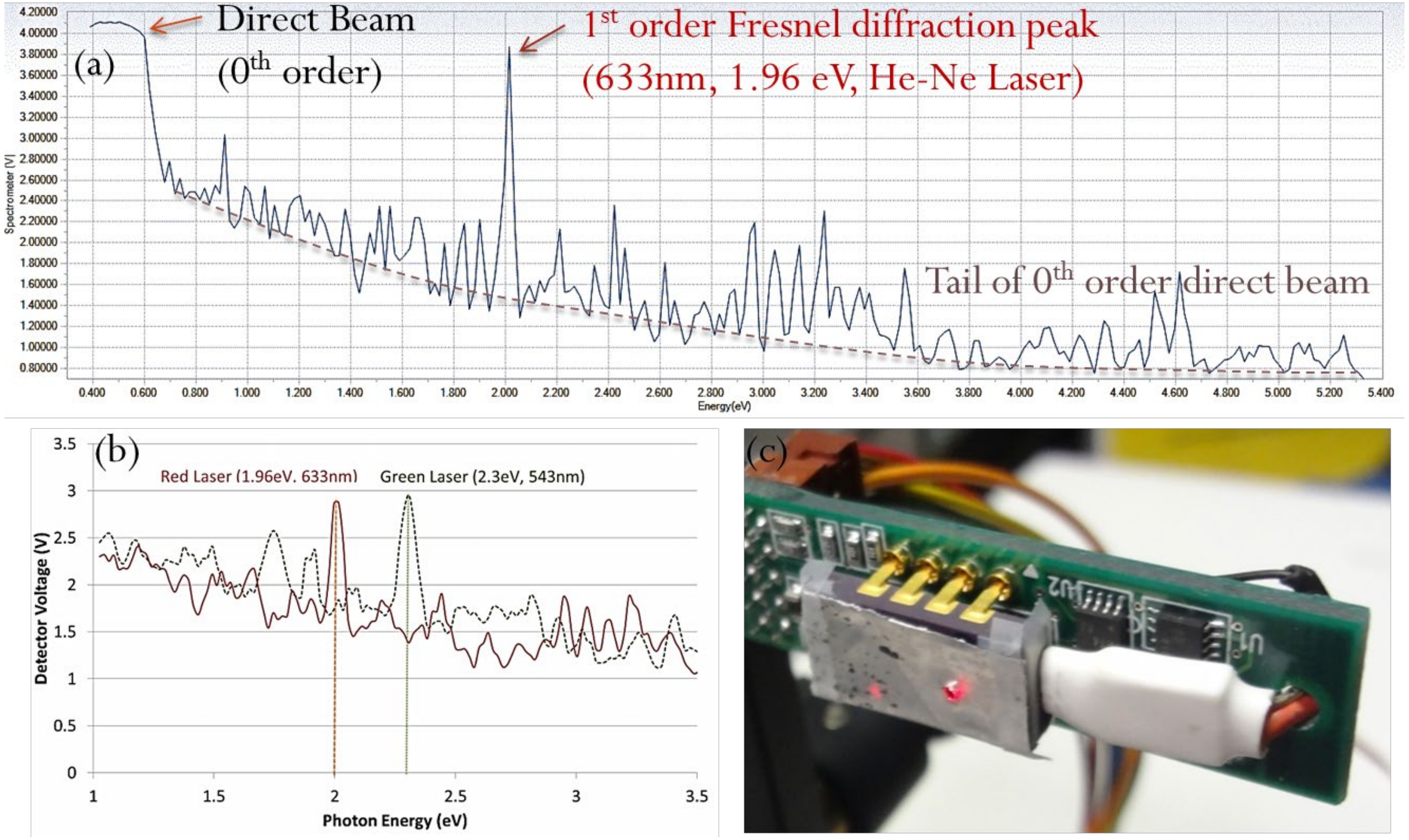
1-D Scan Prototype System



Dopamine Sensing Results



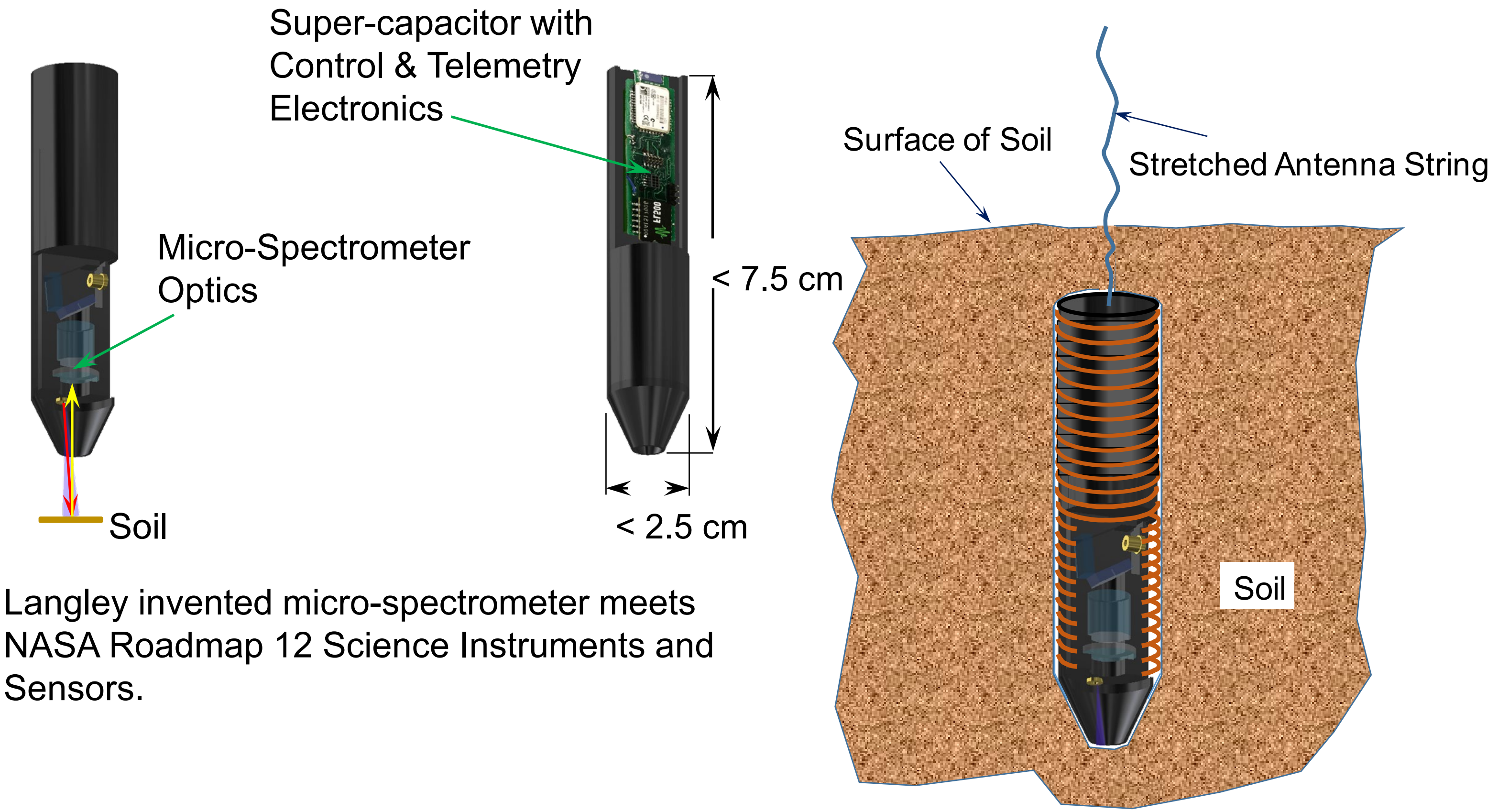
Optical Sensor Response



Bullet μ-Spectrometer

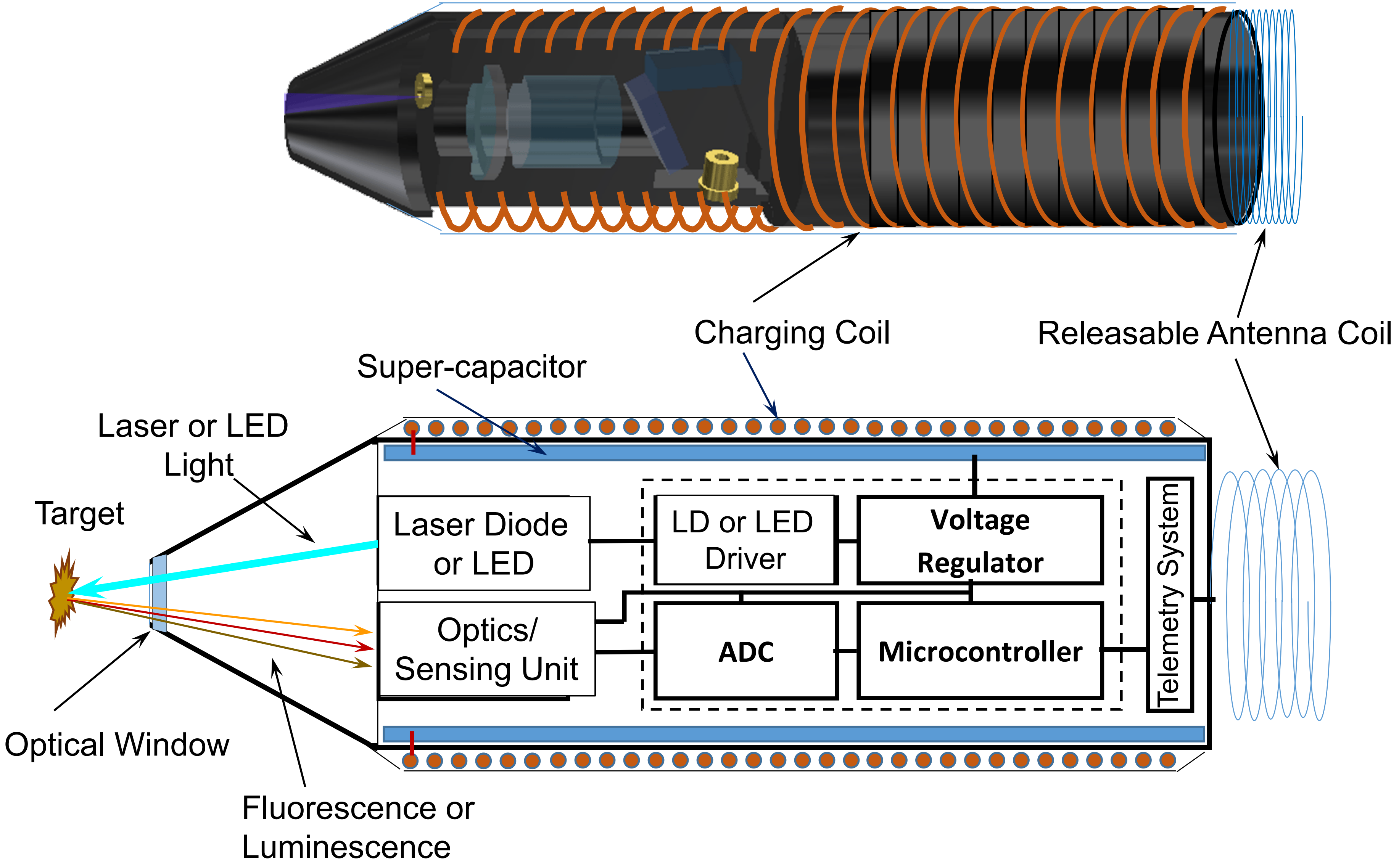
Micro-Spectrometer

- Principle of Fresnel diffraction
- Light source: Deep or vacuum UV from burst-mode LED
- Pulse mode power feed from super-capacitor
- Bullet-like consumable micro-spectrometers (< $100)
- Shooting by compressed air gun

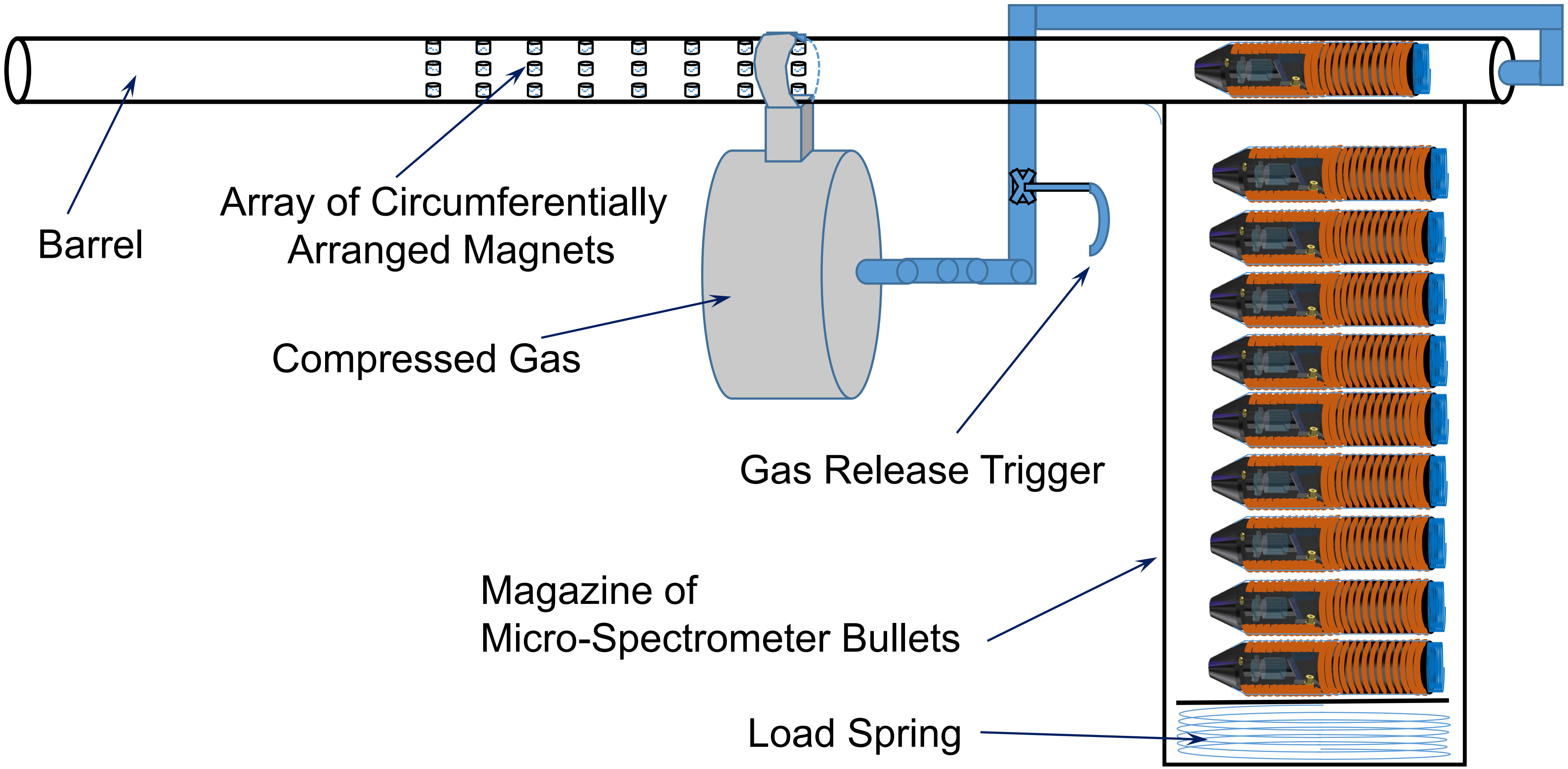


Langley invented micro-spectrometer meets NASA Roadmap 12 Science Instruments and Sensors.

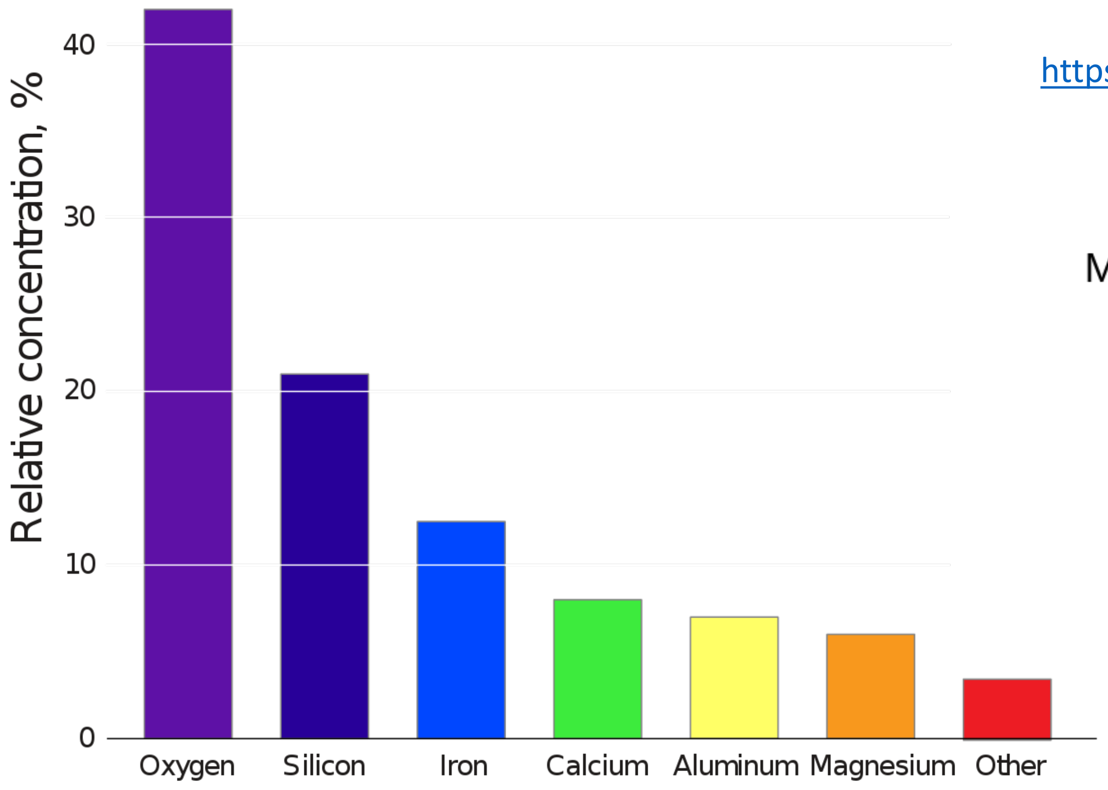
Bullet μ-Spectrometer



Gas Gun for Bullet μ-Spectrometer

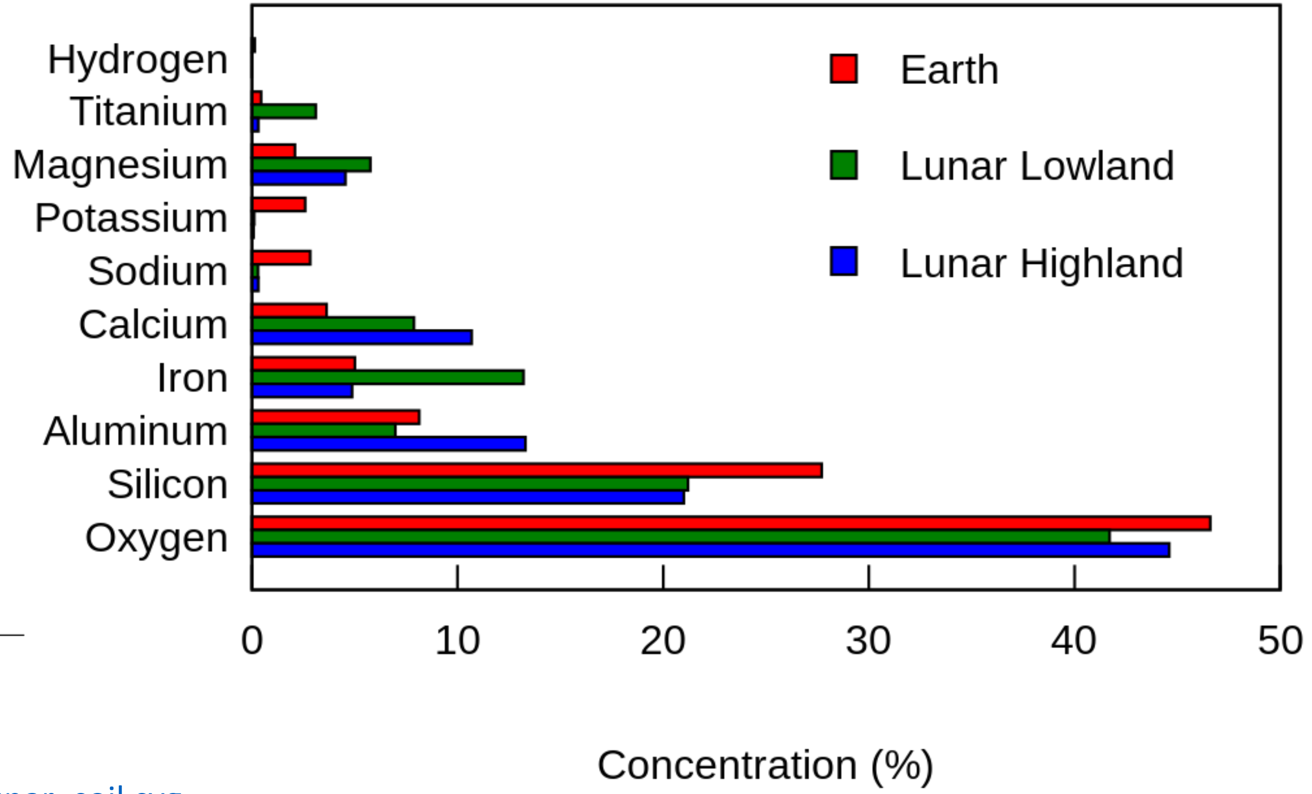


Composition of Lunar Regolith



https://en.wikipedia.org/wiki/Lunar_soil#/media/File:Composition_of_lunar_soil.svg

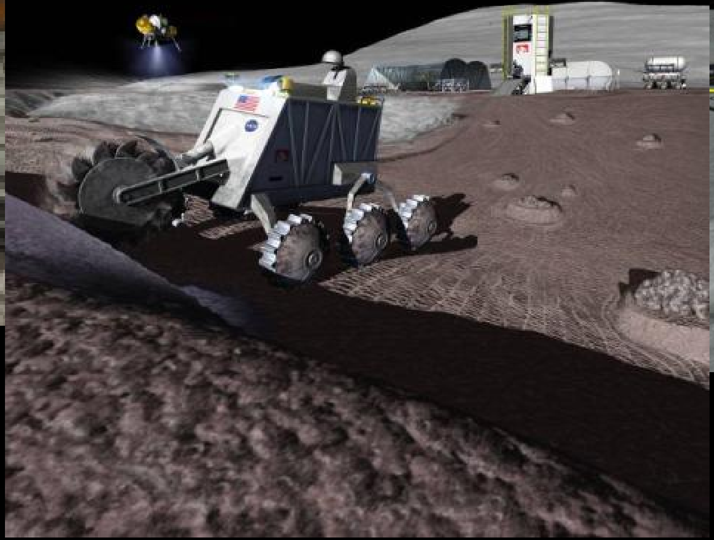
https://en.wikipedia.org/wiki/Lunar_soil#/media/File:Moon_vs_earth_composition.svg



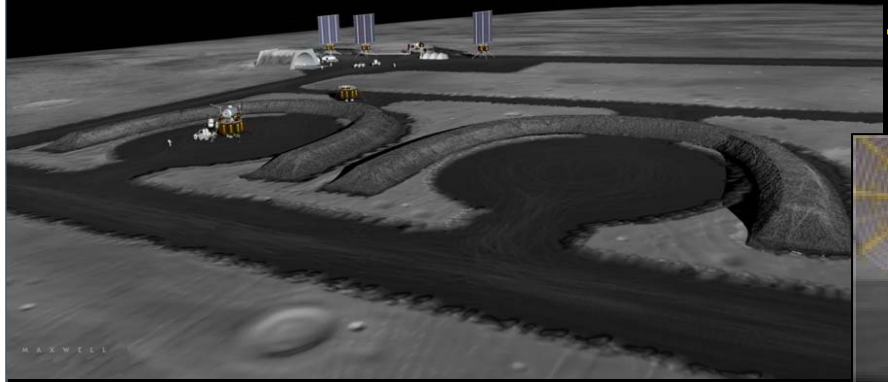
Images credit: NASA

Resource Prospecting – Looking for Resources

Excavation & Regolith Processing for H_2 & O_2 Production, Binders & Aggregates

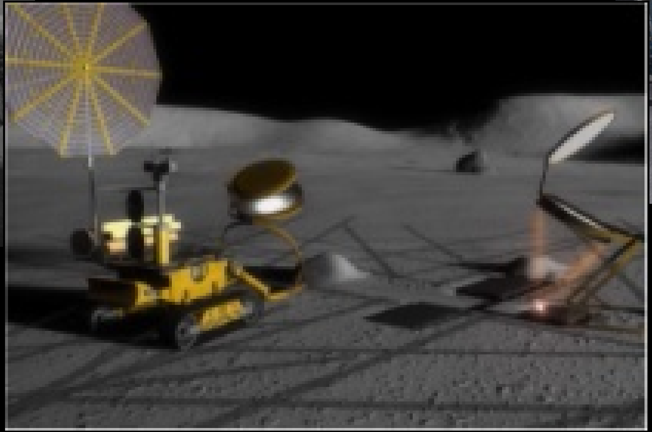


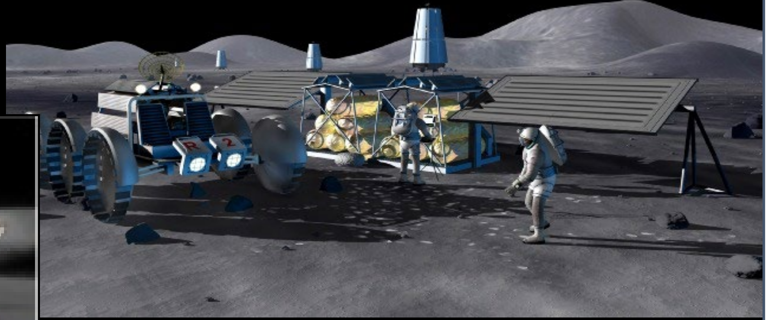
Propellant Processing with Lander & Pad Infrastructure



Habitat, Hangars, Dust Free Zones, Landing Pads, Berm, and Road Construction

Thermal Energy Storage Construction

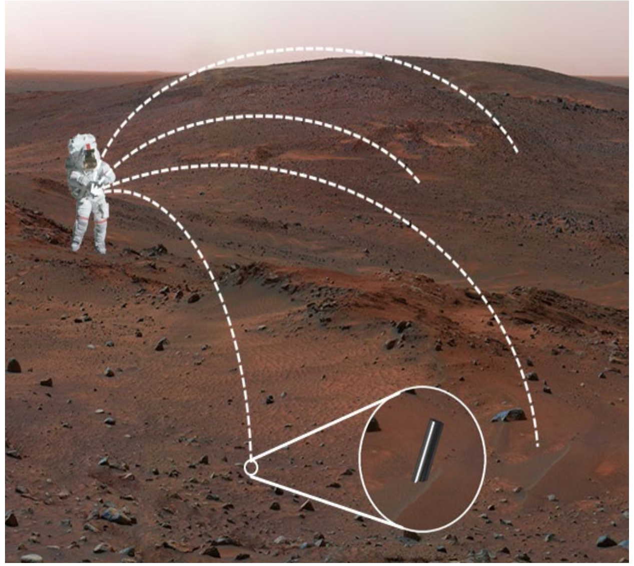




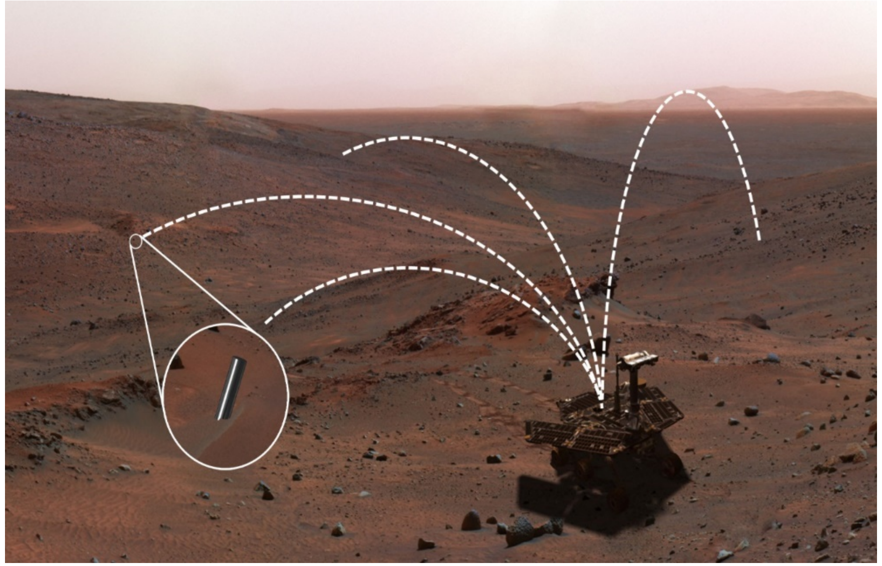
Construction of Consumables Depots for Crew & Power (O_2, H_2)

Mars Soil Assay by Bullet μ-Spectrometer

Astronaut with Micro-Spectrometer Gun

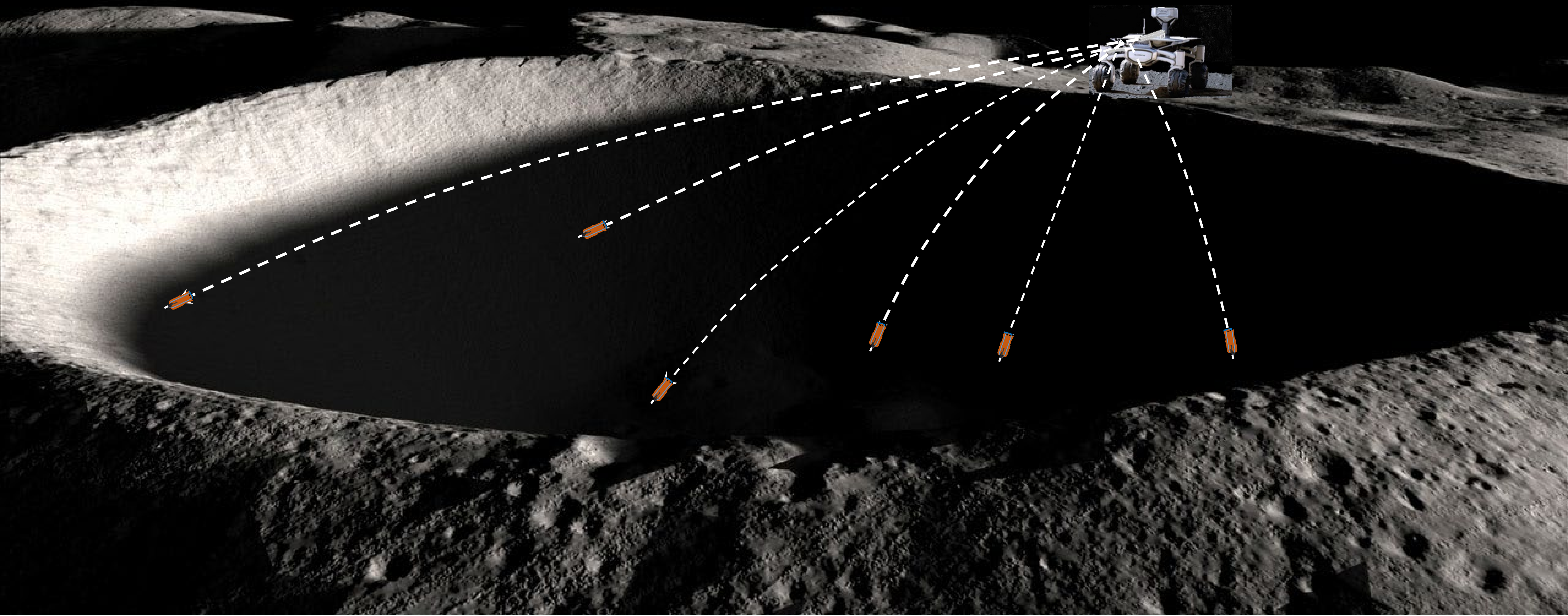


Rover with Micro-Spectrometer Gun

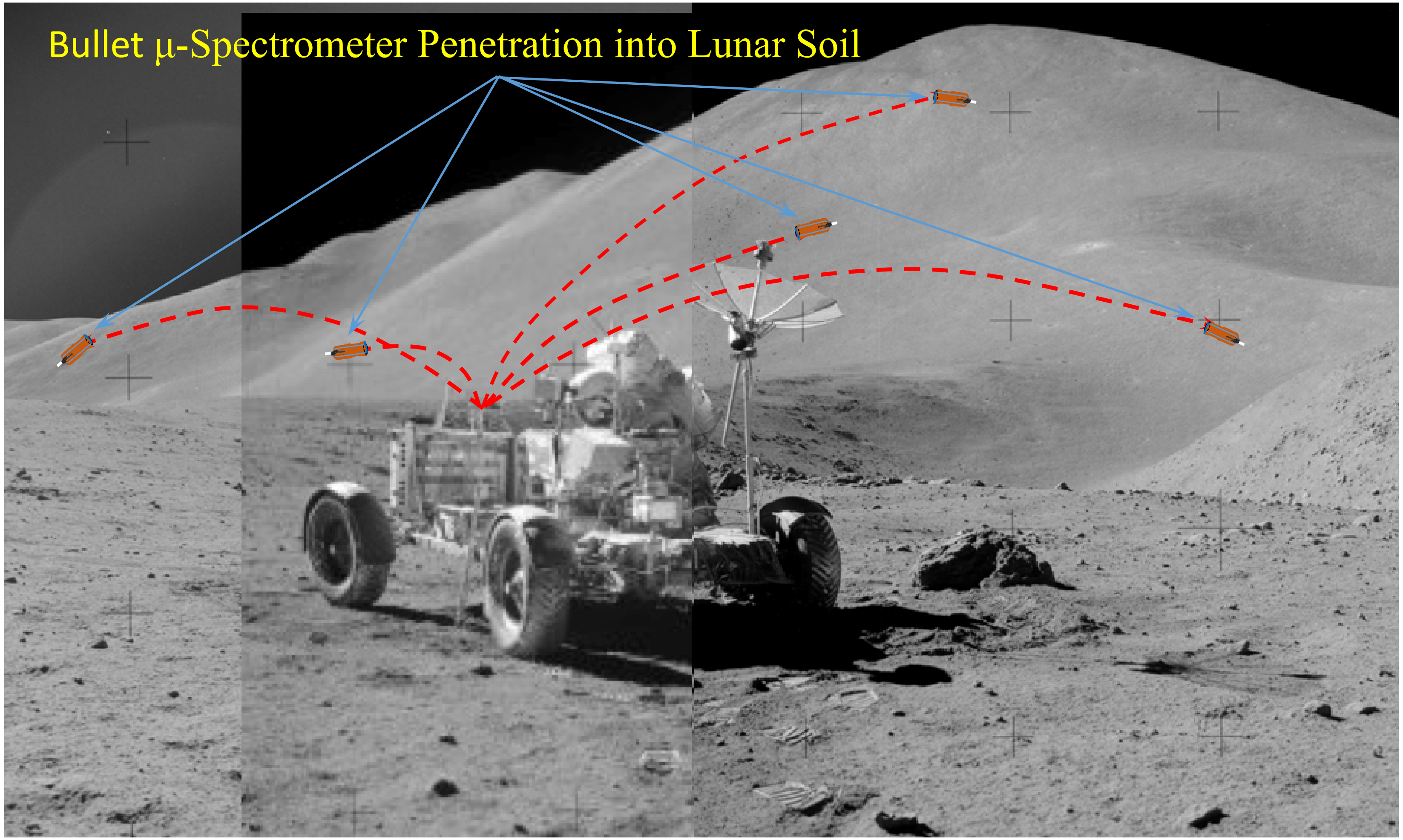


Bullet-like micro-spectrometers are shot out broadly to assay organic and inorganic components of Lunar/Mars/Asteroids soils.

Lunar Soil Assay by Bullet μ-Spectrometer

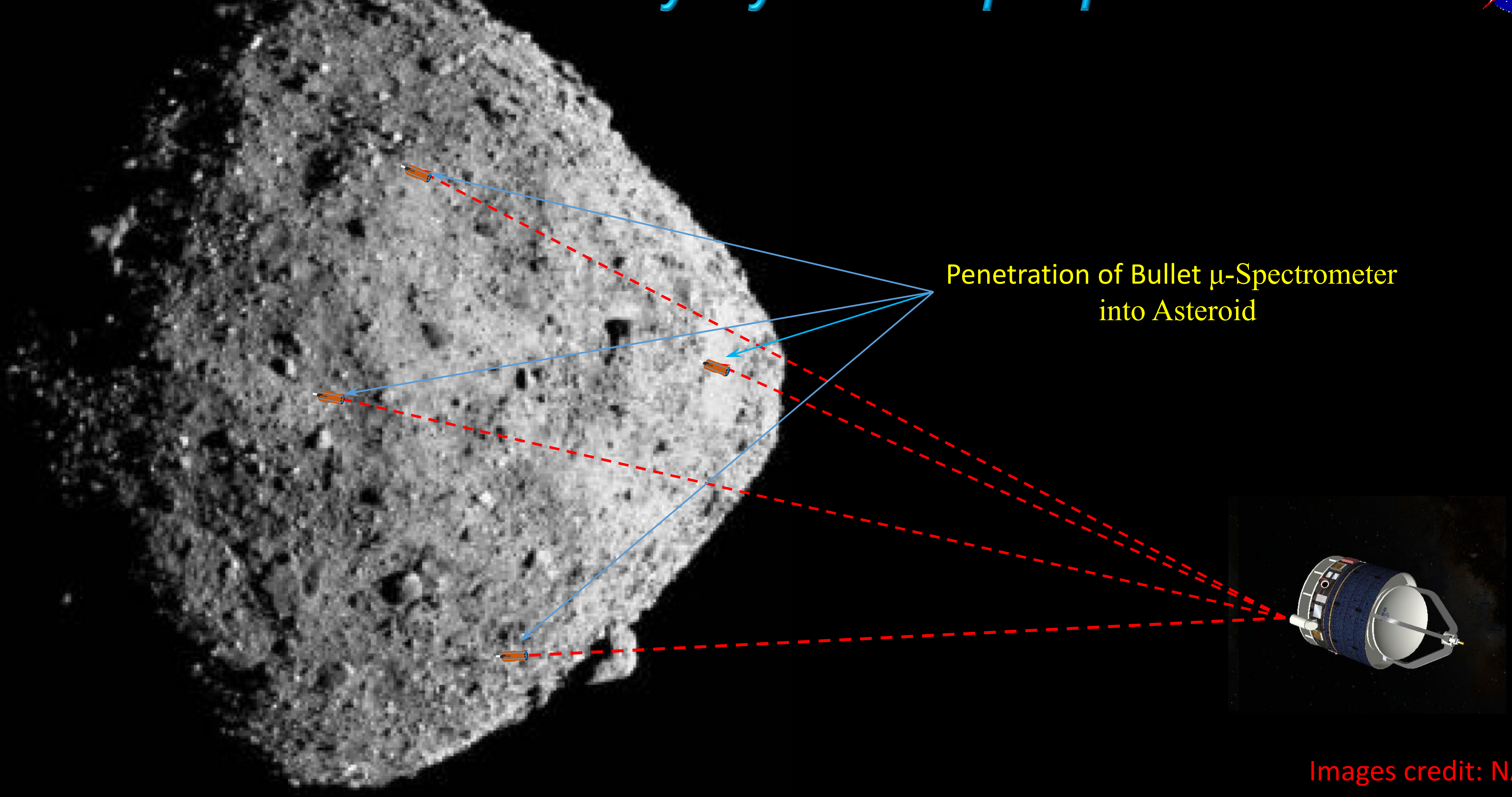


Lunar Soil Assay by Bullet μ-Spectrometer



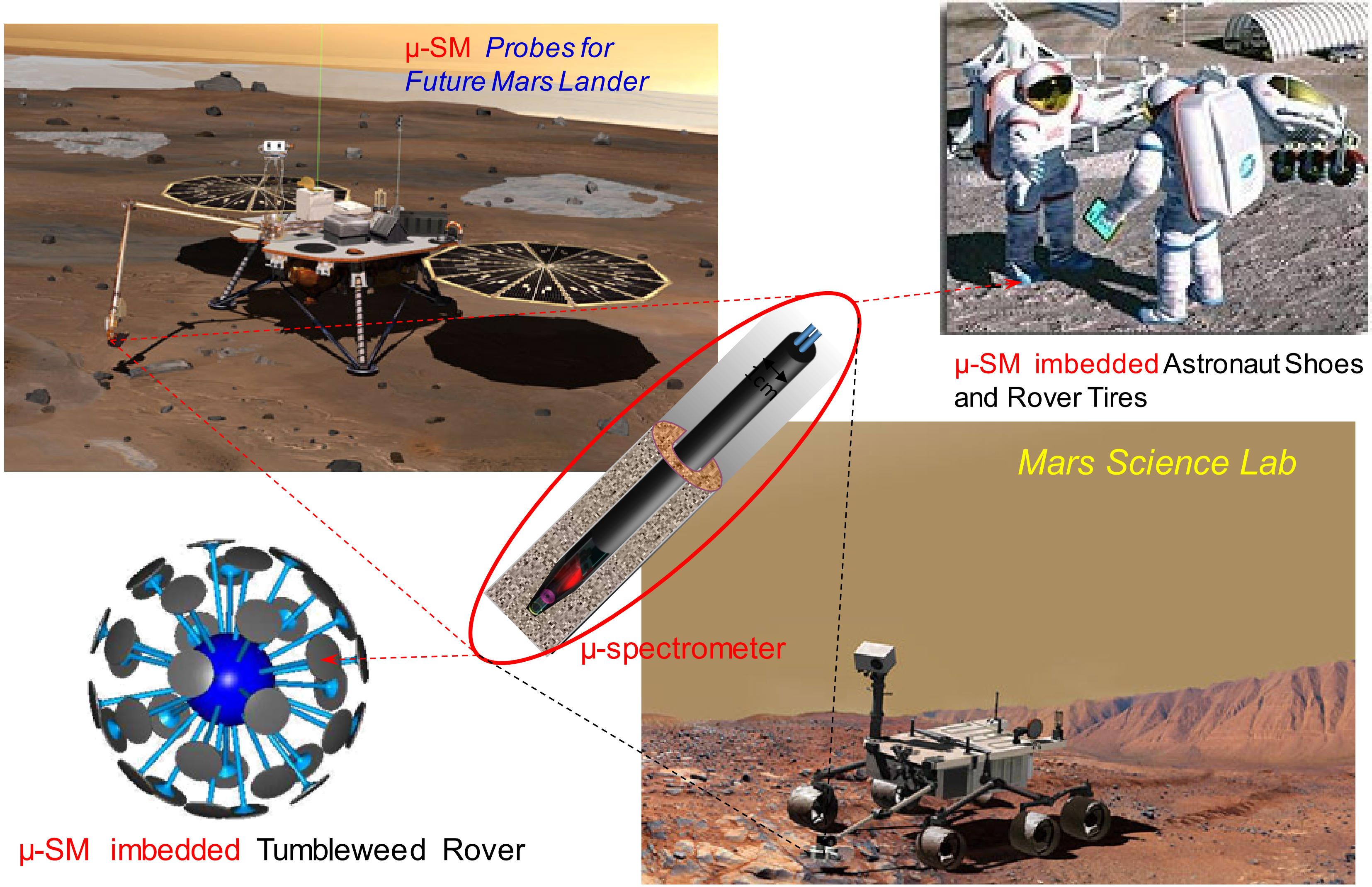
Images credit: NASA

Asteroid Soil Assay by Bullet μ-Spectrometer



Images credit: NASA

μ-Spectrometer for Lunar & Mars Exploration



Concluding Remarks

- Applications of micro-spectrometer bullets include mineral mapping on the Moon and Mars, especially hillsides and deepened bottom floor of craters.
- Laboratory prototype was fully developed and tested for dopamine samples.
- Bullet type micro-spectrometer and deployment gun were designed for space applications.
- Based on the spectral data of the minerals of interest, line and pixel densities of the micro-spectrometer will be tailored for measurement accuracy and clarity.
- Device components, such as avalanche photo-diode, burst-mode LED, cylindrical super-capacitor, and telemetry device require further development for enhanced and versatile performance of bullet shape micro-spectrometers.