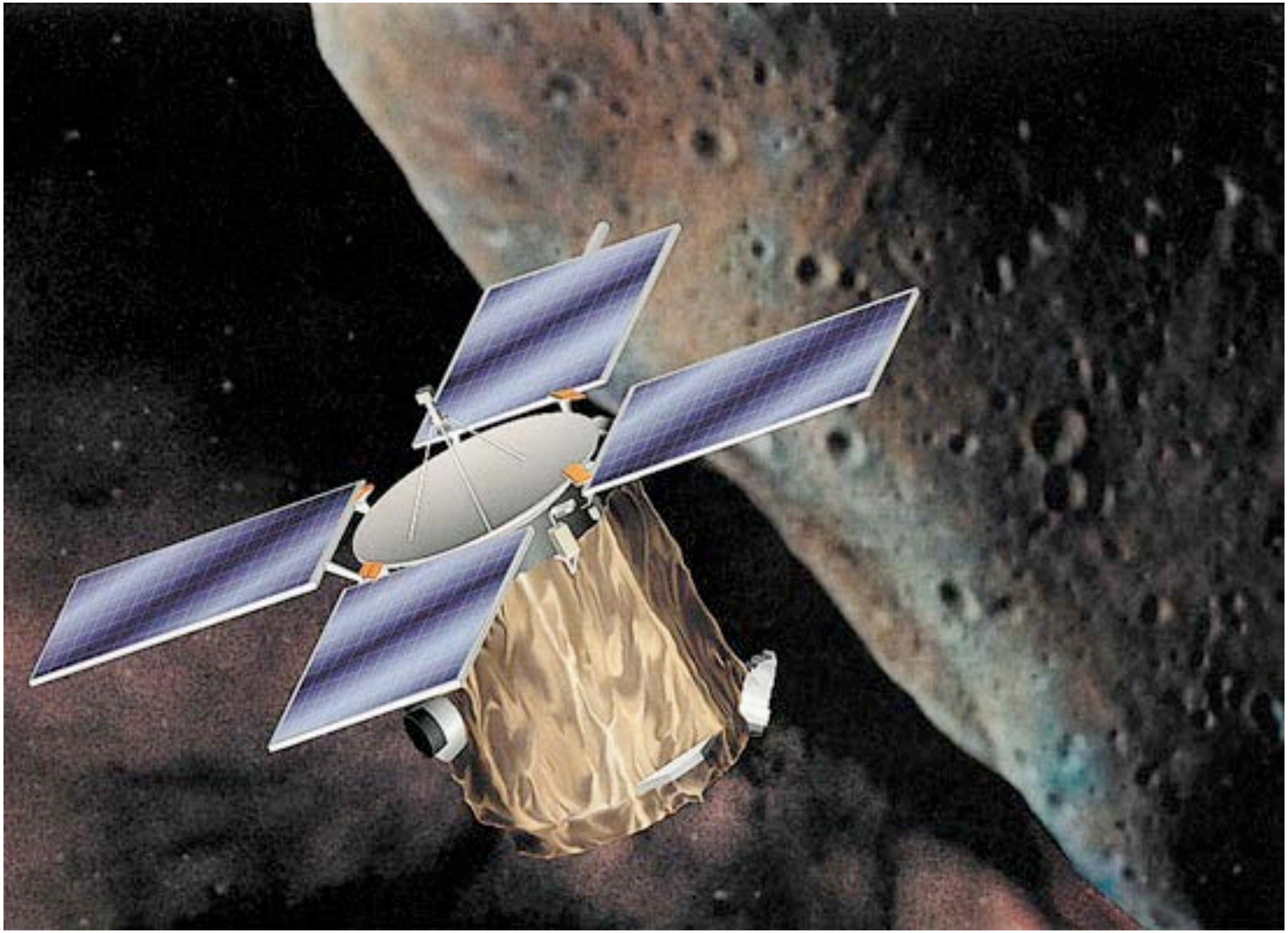
Planetary lidar: siblings of MOLA, LOLA



NEAR Laser Rangefinder (NLR) on the Near Earth Asteroid Rendezvous (NEAR) mission

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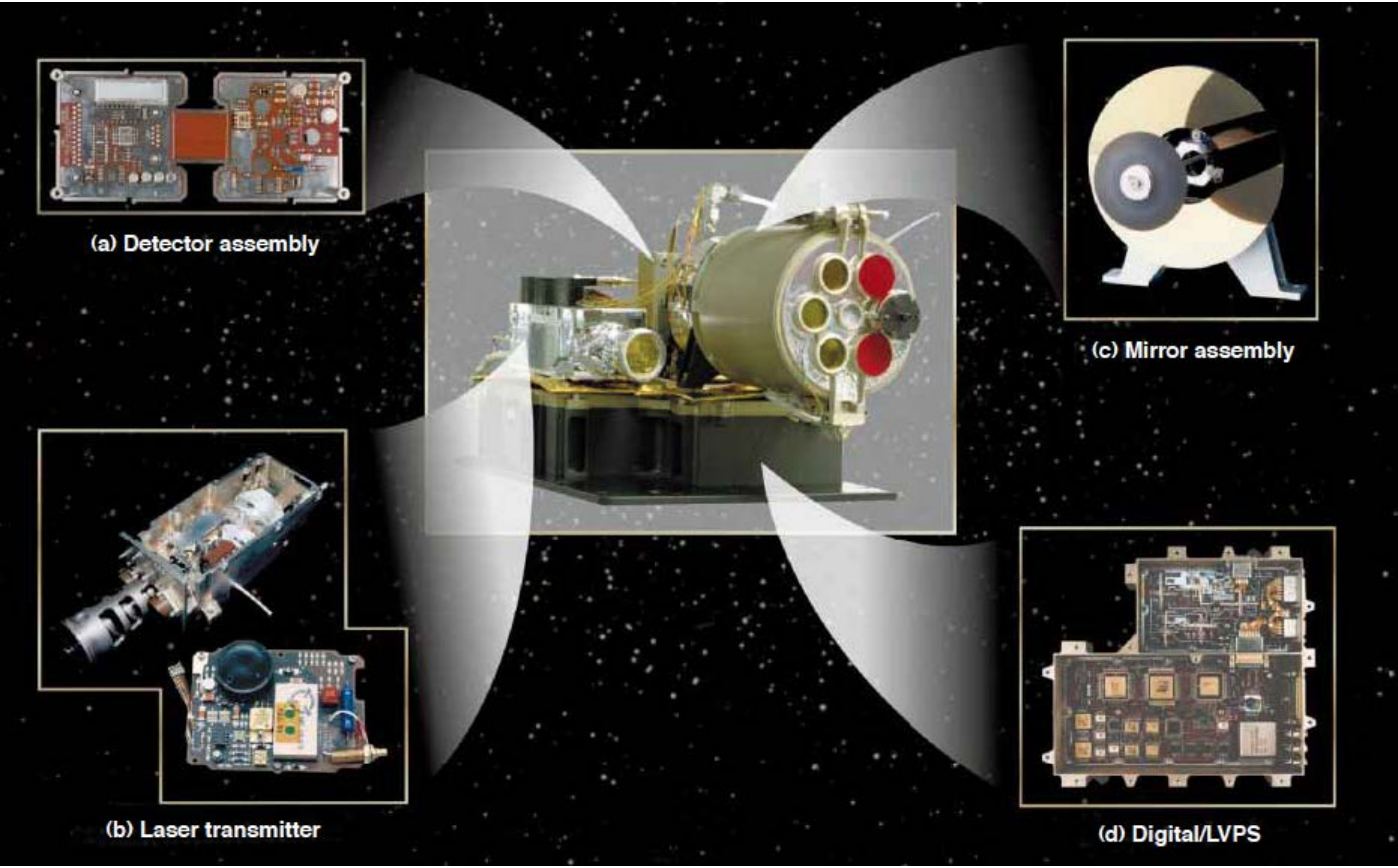
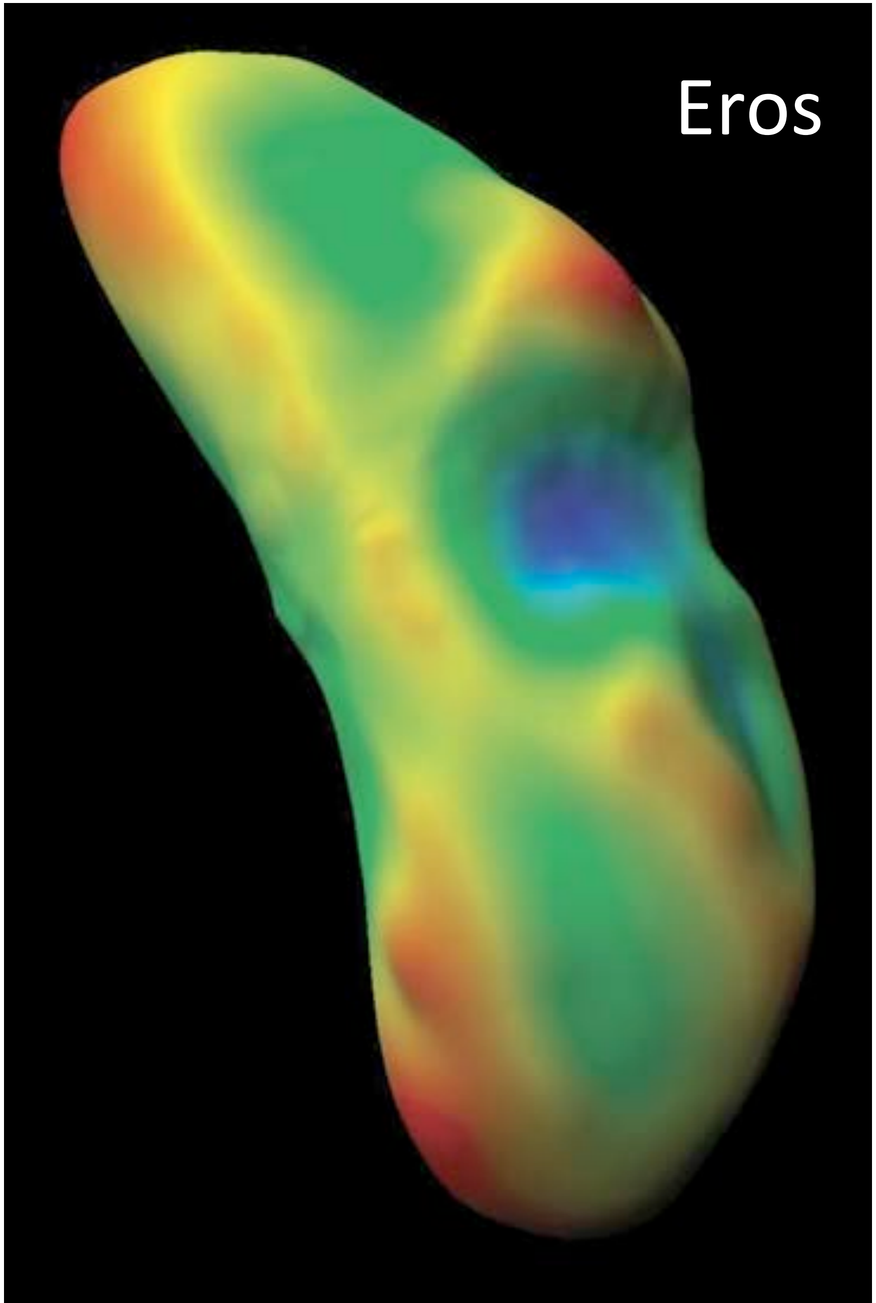
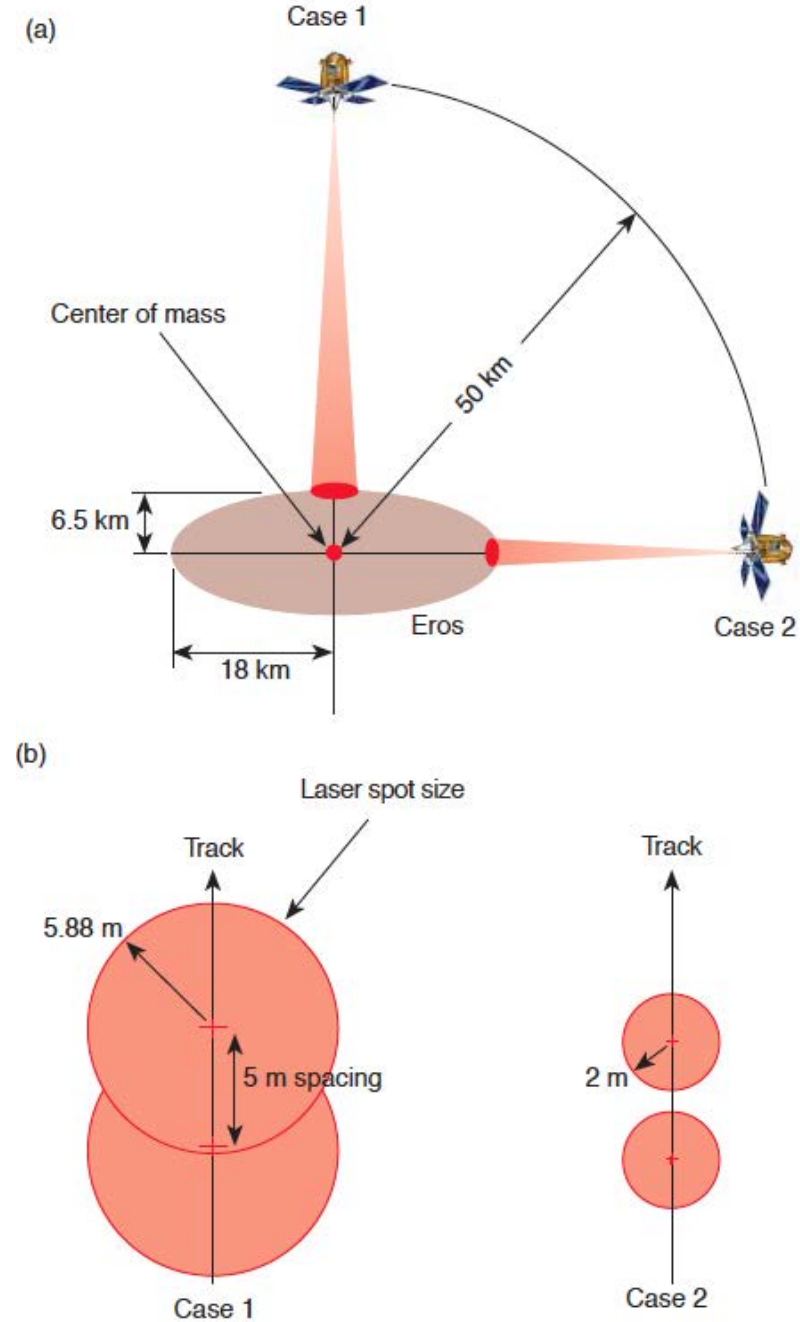
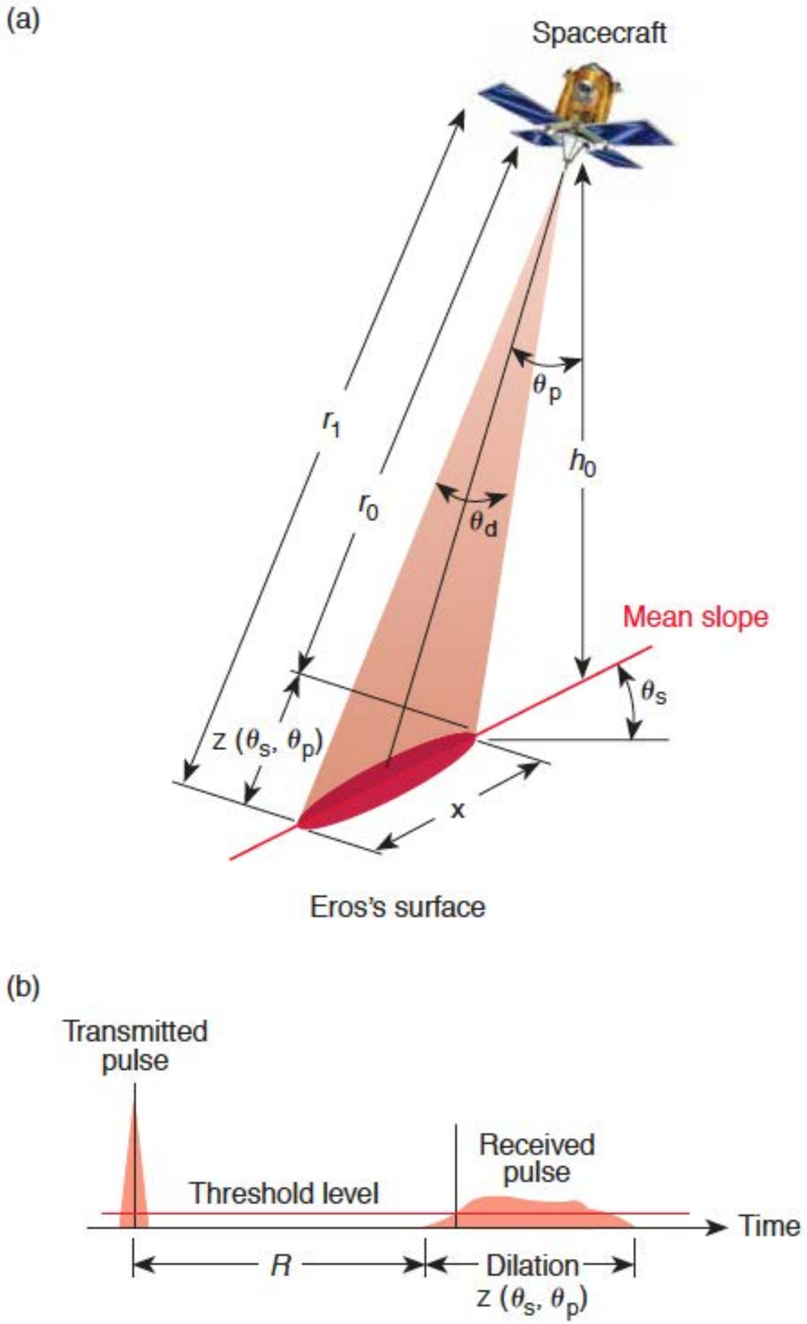


NEAR Laser Rangefinder (NLR) on the Near Earth Asteroid Rendezvous (NEAR) mission





NEAR Laser Rangefinder (NLR) on the Near Earth Asteroid Rendezvous (NEAR) mission



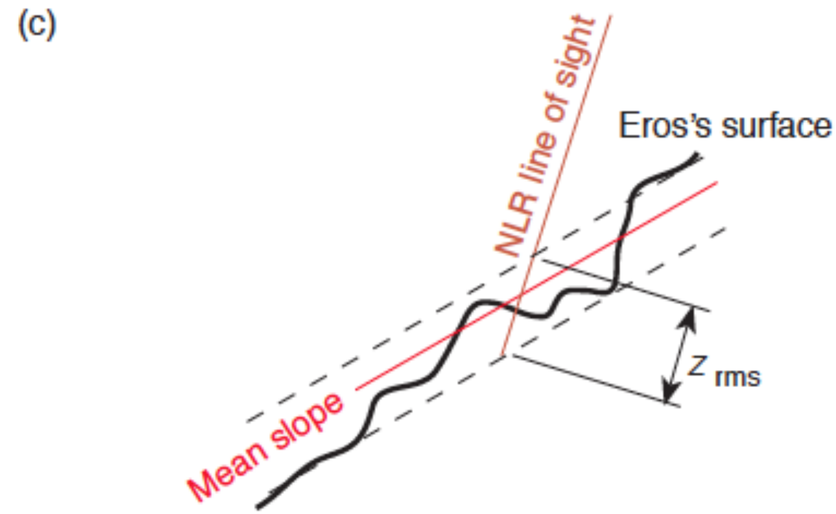
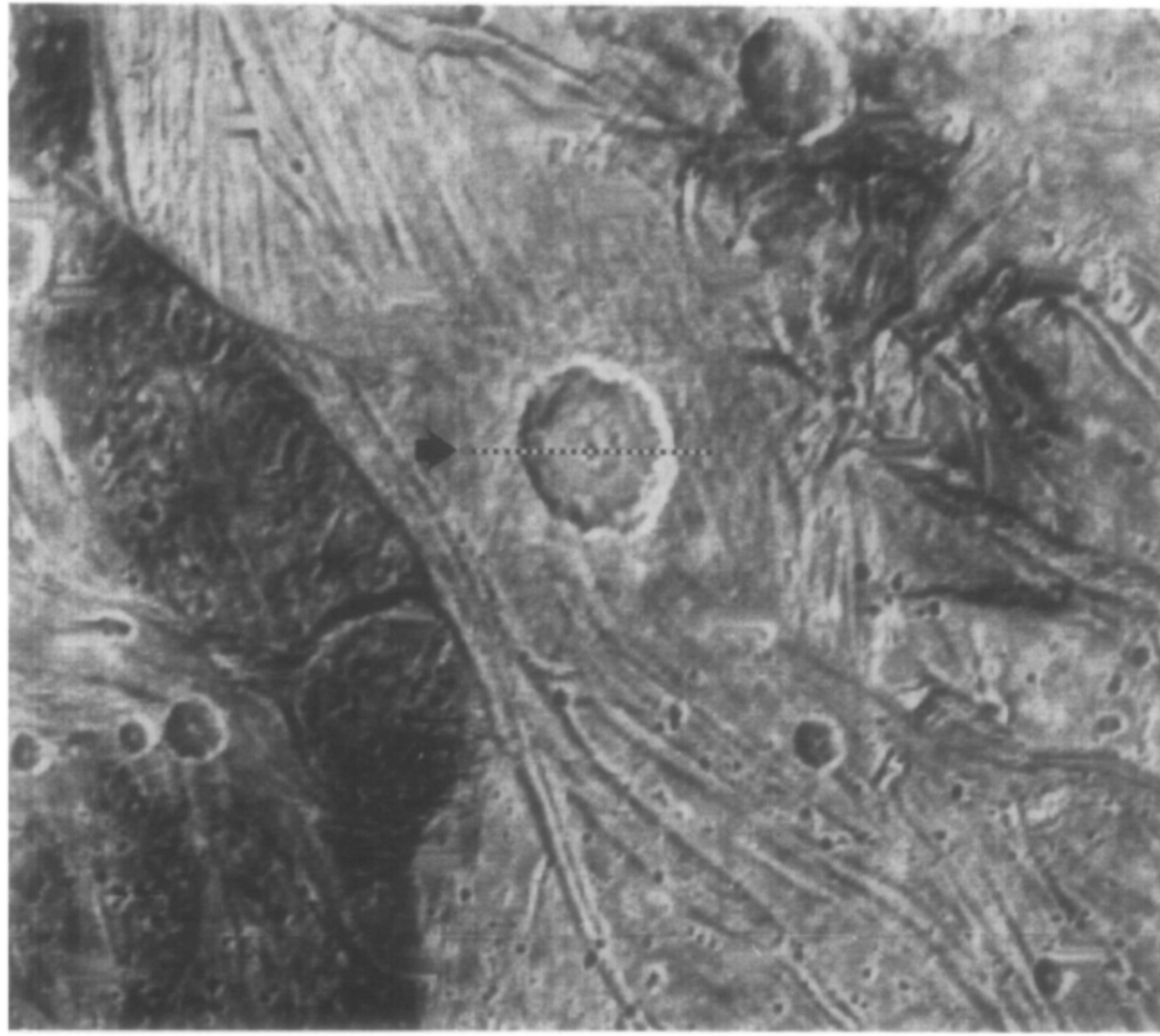


Figure 13. Diagram explaining pulse dilation occurring as the pulse interacts with the asteroid's surface. Various parameters describing the spacecraft's look angle are presented in (a), which give rise to pulse dilated returns, defined by (b). As the pulse is transmitted from the NLR, the pulse duration is relatively sharp and small, ≈15 ns. As the pulse incurs extended aspects of the surface, significant backscatter dilation starts to occur. This "distributed" return manifests itself by stretching the pulse over the finite extent of the range gate used. (c) The details associated with rough surface pulse stretching are shown. R = measured range; z_{rms} = surface roughness.

Photoclinometry of Ganymede (Voyager)

"shape from shading"



Squyres (1981)

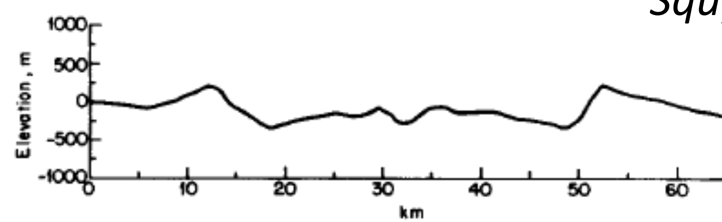
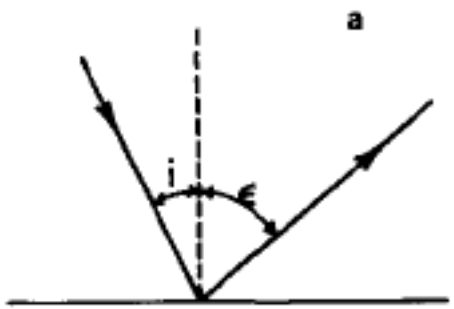
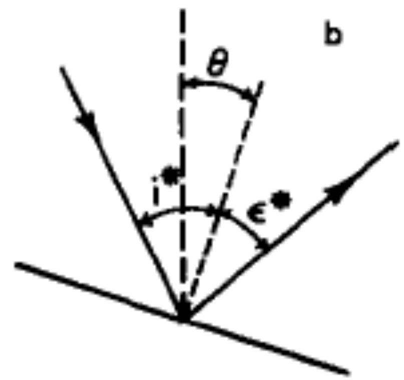


FIG. 2. Sample photoclinometric profile across an impact crater. Note the central pit with its raised rim and the floor bowed up by viscous relaxation. Vertical exaggeration is 8 : 1 ($i = 72°$, $\epsilon = 34°$, $\alpha = 39°$).

Photoclinometry





$$I = C'[\cos i/(\cos i + \cos \epsilon)]$$

$$I^* = C'[\cos i^*/(\cos i^* + \cos \epsilon^*)]$$

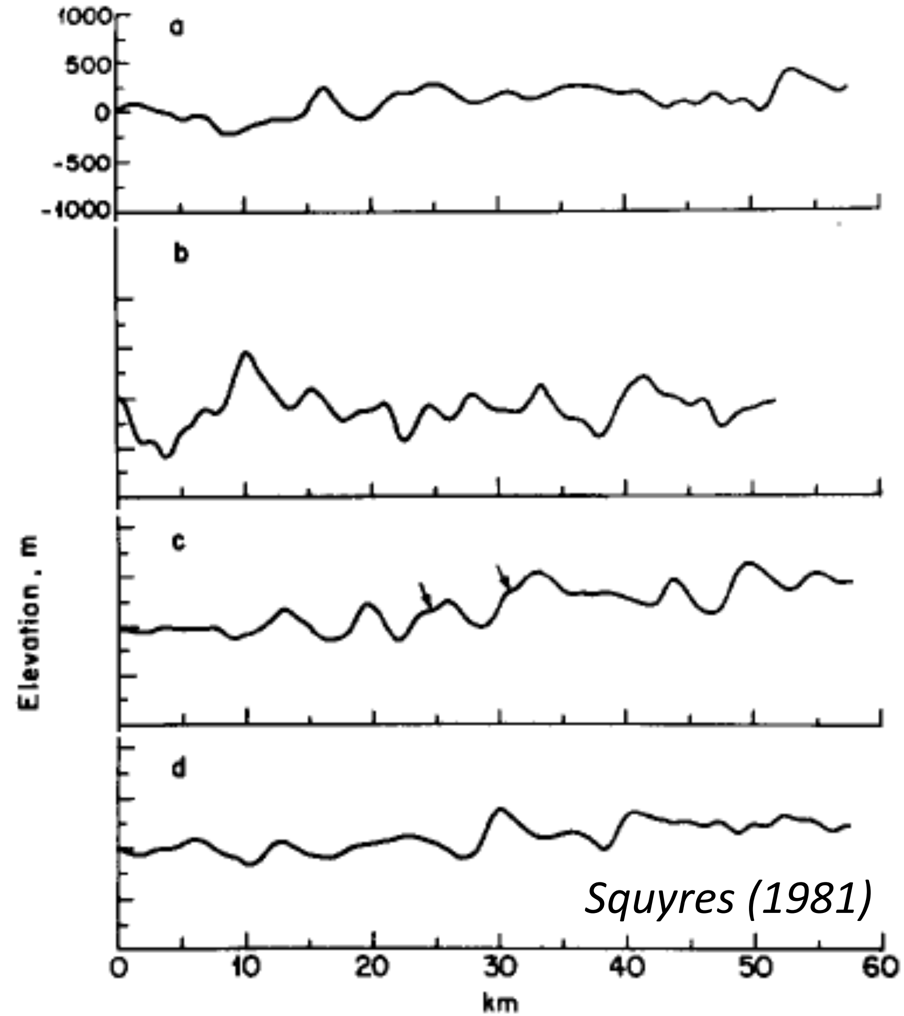
$$\theta = i^* - i = \epsilon - \epsilon^*$$

(if incident ray, emitted ray, & surface normal are coplanar)

Squyres (1981)

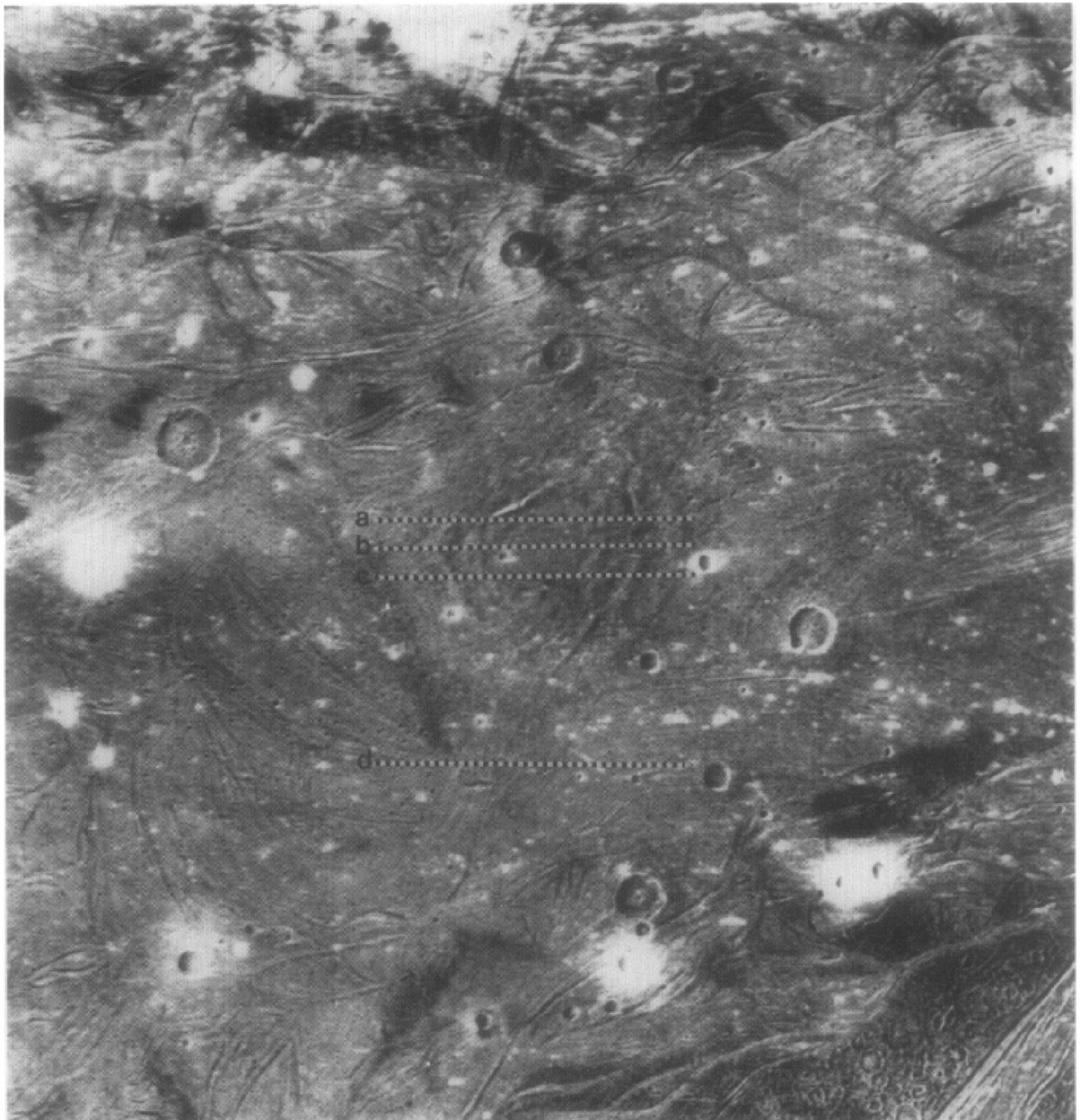
Photoclinometry of grooves on Ganymede

FIG. 3. Topographic profiles in Voyager image 660J2-001. Vertical exaggeration is 8 : 1. Arrows in (c) indicate secondary terraces occasionally observed on groove walls (i = 77°, ϵ = 49°, α = 97°).

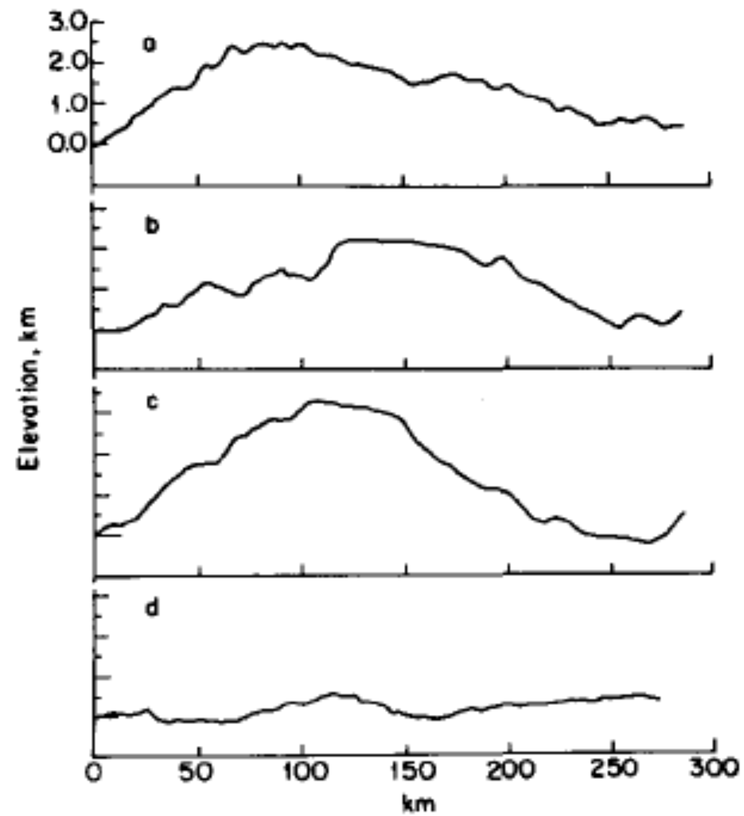


Squyres (1981)

Photoclinometry of an unusual (subtle!) dome on Ganymede



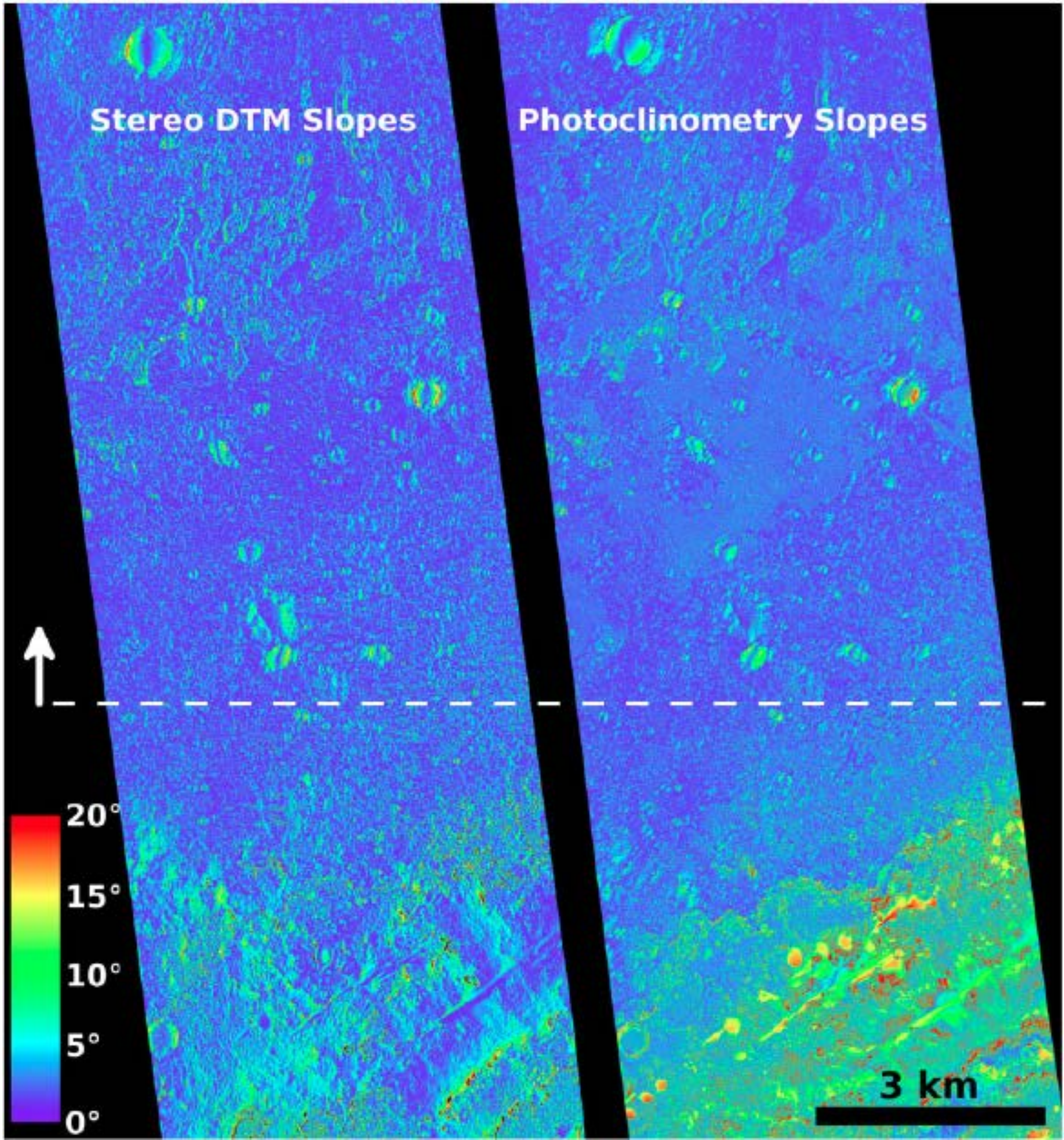
See anything in this image that makes you worry about using photoclinometry?



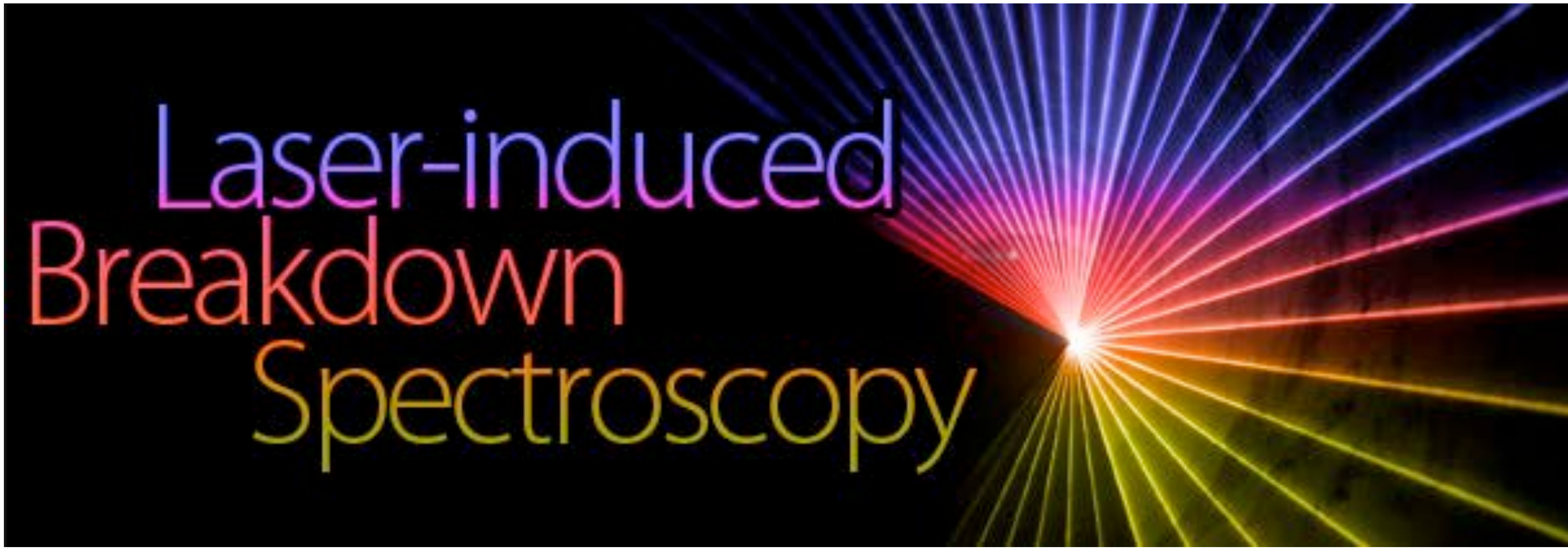
Squyres (1981)

Slopes in Gale crater

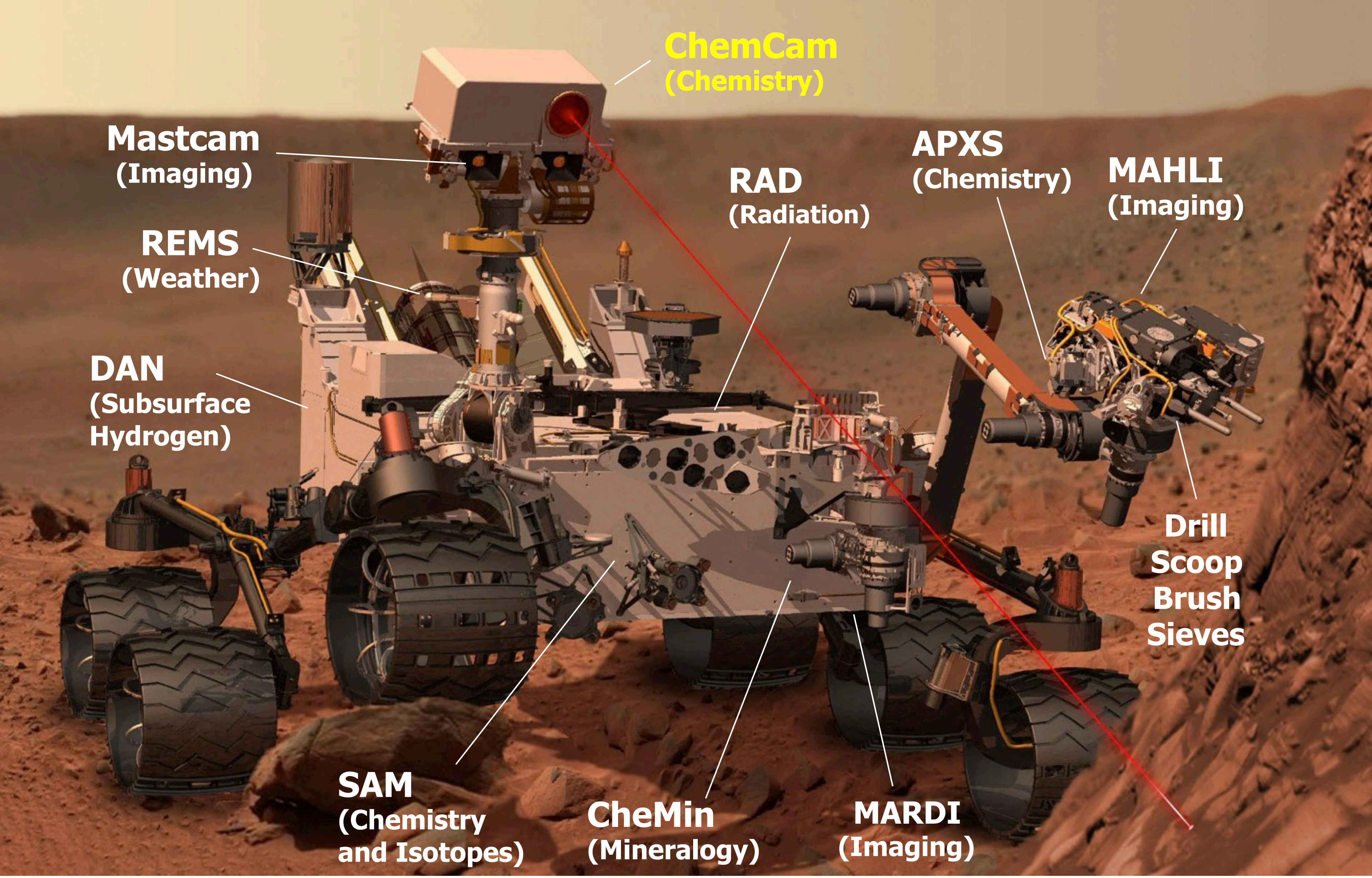
Very good agreement in dusty landing ellipse



Beyer & Kirk (2012)



Active Remote Sensing of Elemental Chemistry



Curiosity’s Science Payload

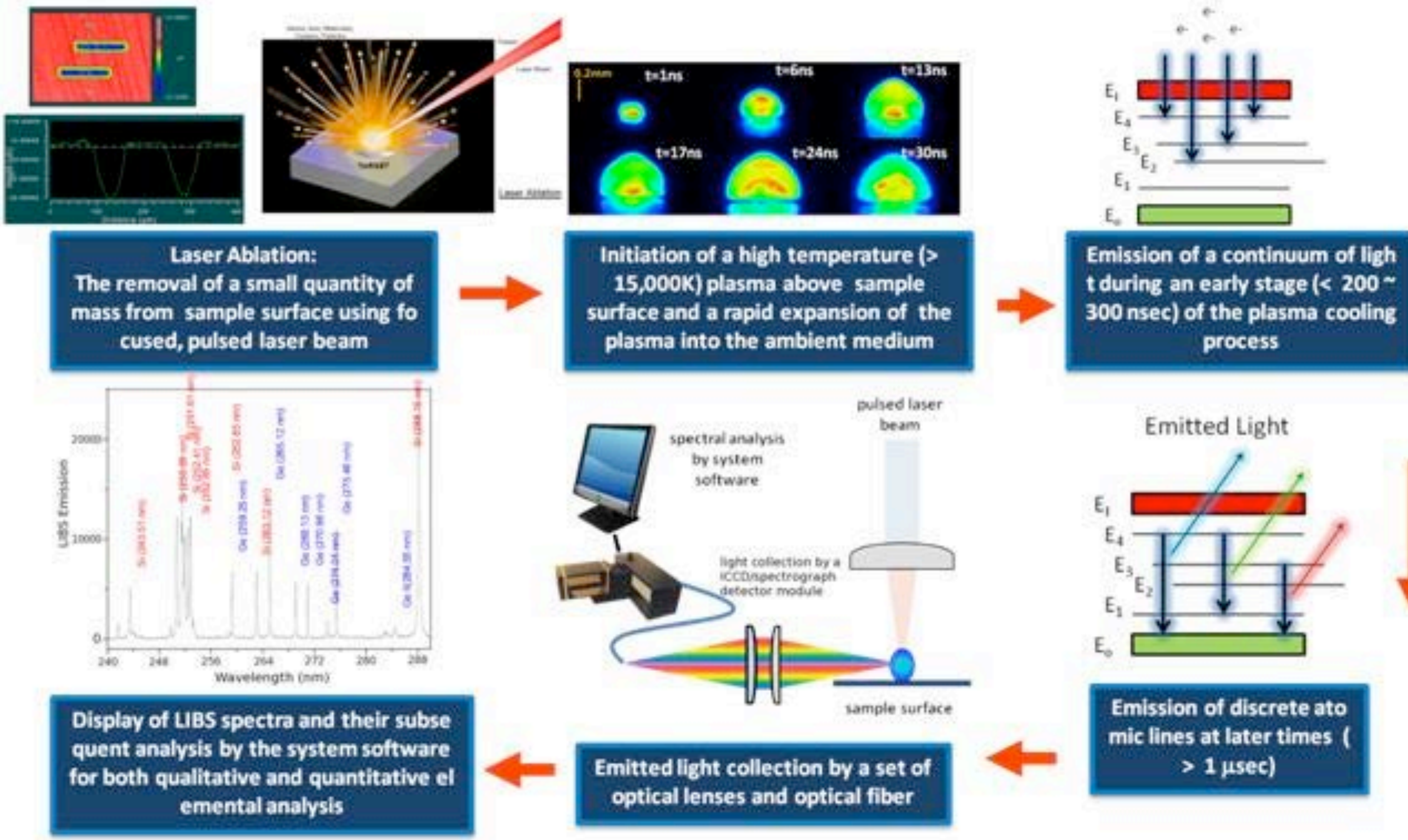
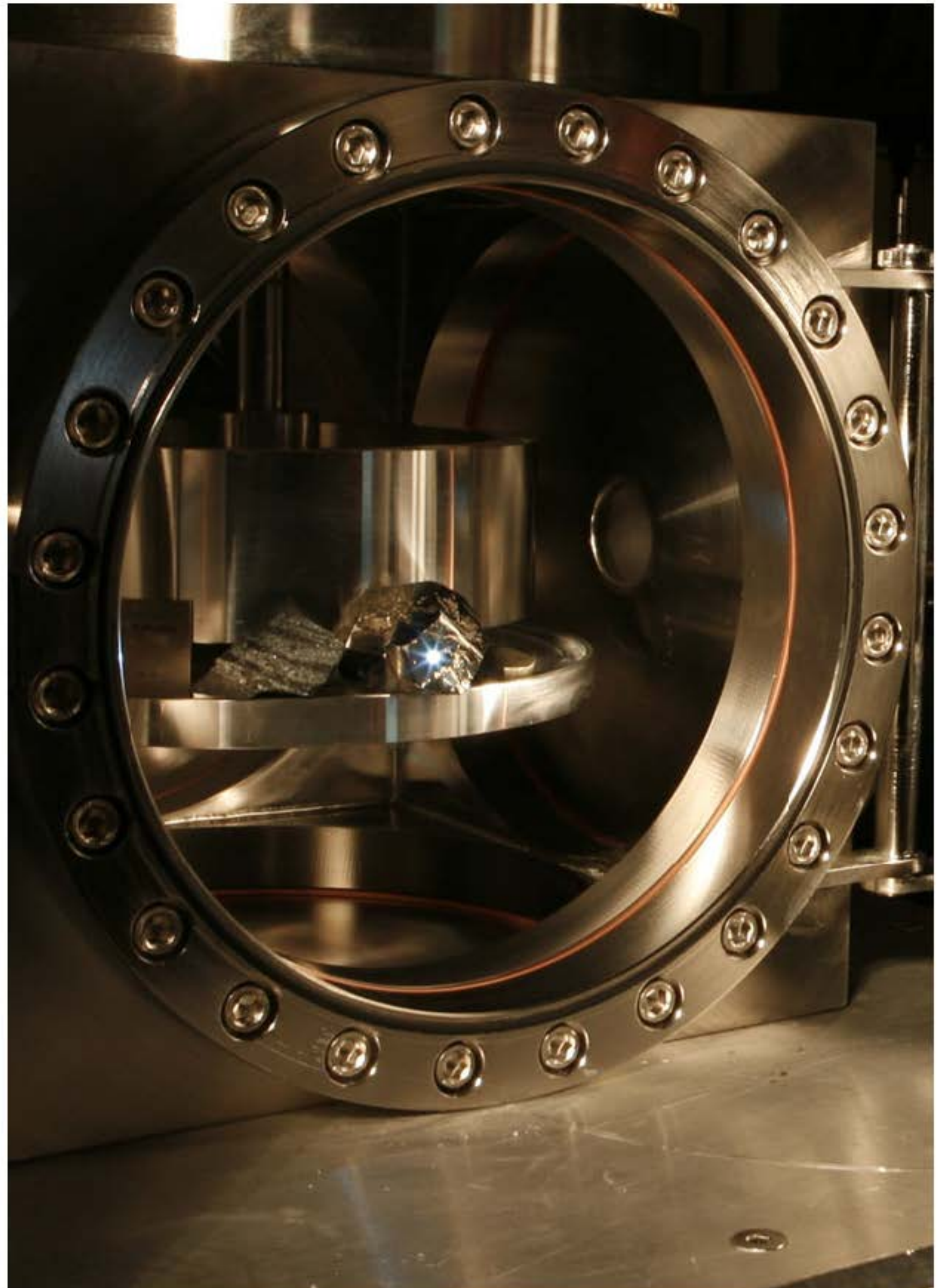

Laser Ablation:
The removal of a small quantity of mass from sample surface using fo cused, pulsed laser beam
t=1ns
t=6ns
t=13ns
t=17ns
t=24ns
t=30ns
Initiation of a high temperature (> 15,000K) plasma above sample surface and a rapid expansion of the plasma into the ambient medium
Emission of a continuum of ligh t during an early stage (< 200 ~ 300 nsec) of the plasma cooling process
Emitted Light
Emission of discrete ato mic lines at later times (> 1 μsec)
pulsed laser beam
spectral analysis by system software
light collection by a ICCD/spectrograph detector module
sample surface
Emitted light collection by a set of optical lenses and optical fiber
LIBS Emission
Wavelength (nm)
Display of LIBS spectra and their subse quent analysis by the system software for both qualitative and quantitative el emental analysis

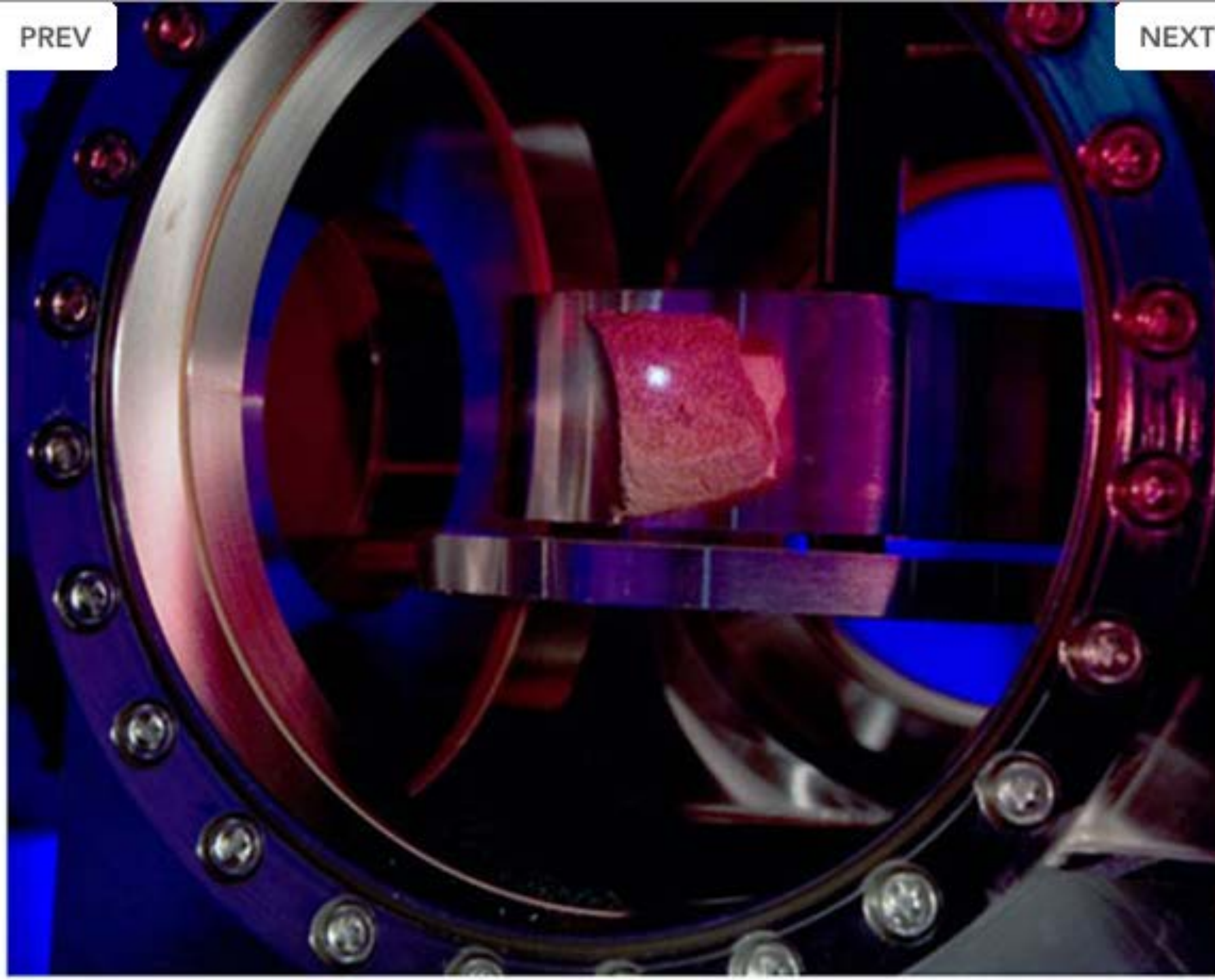
Fig. 1 A ball of plasma erupts on the surface of a 3 cm diameter iron pyrite crystal in the Mars calibration chamber approximately 3 m from the ChemCam instrument. The plasma in this image was produced in air; plasmas under Mars pressure are brighter and larger



Wiens et al. (2012)

PREV

NEXT



LIBS plasma under Mars conditions | This is what it is all about: a tiny spark of light created by a focus laser beam! For each laser shot, a few nano-grams (billionths of grams) of Martian rocks is vaporized at very high temperature (~9000°C). A tiny cloud of plasma is created, which radiates in all directions. This light will have to be captured by the ChemCam telescope and send to the spectrographs for analysis. The light decomposition as a function of wavelength will tell us about the chemical composition of the target. The test is being done here on a natural target placed inside a chamber that reproduces Mars atmosphere and pressure.

http://www.msl-chemcam.com

http://www.msl-chemcam.com

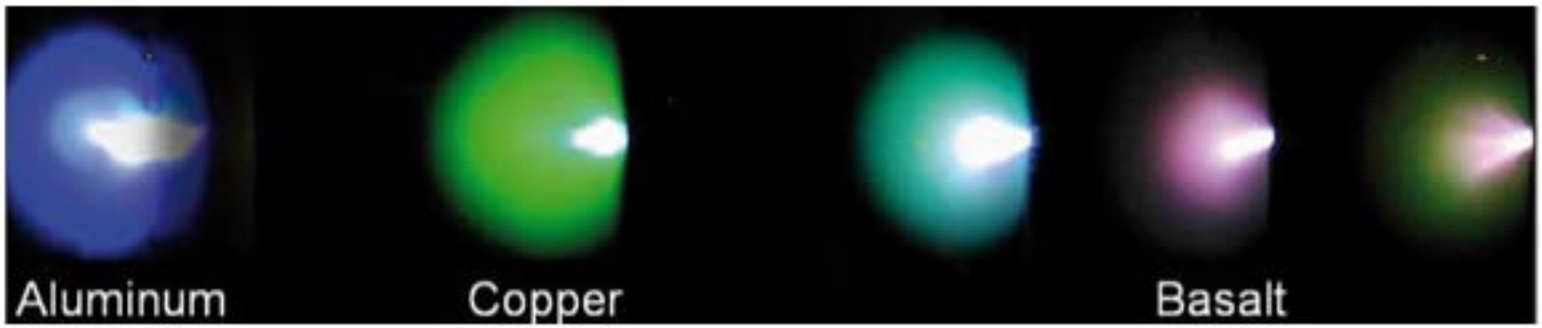


Figure 2. Different elements, such as aluminum and copper, and rock types like basalt, give off their own color of light when zapped by a laser. Credit: Sirven et al., JAAS

http://www.msl-chemcam.com

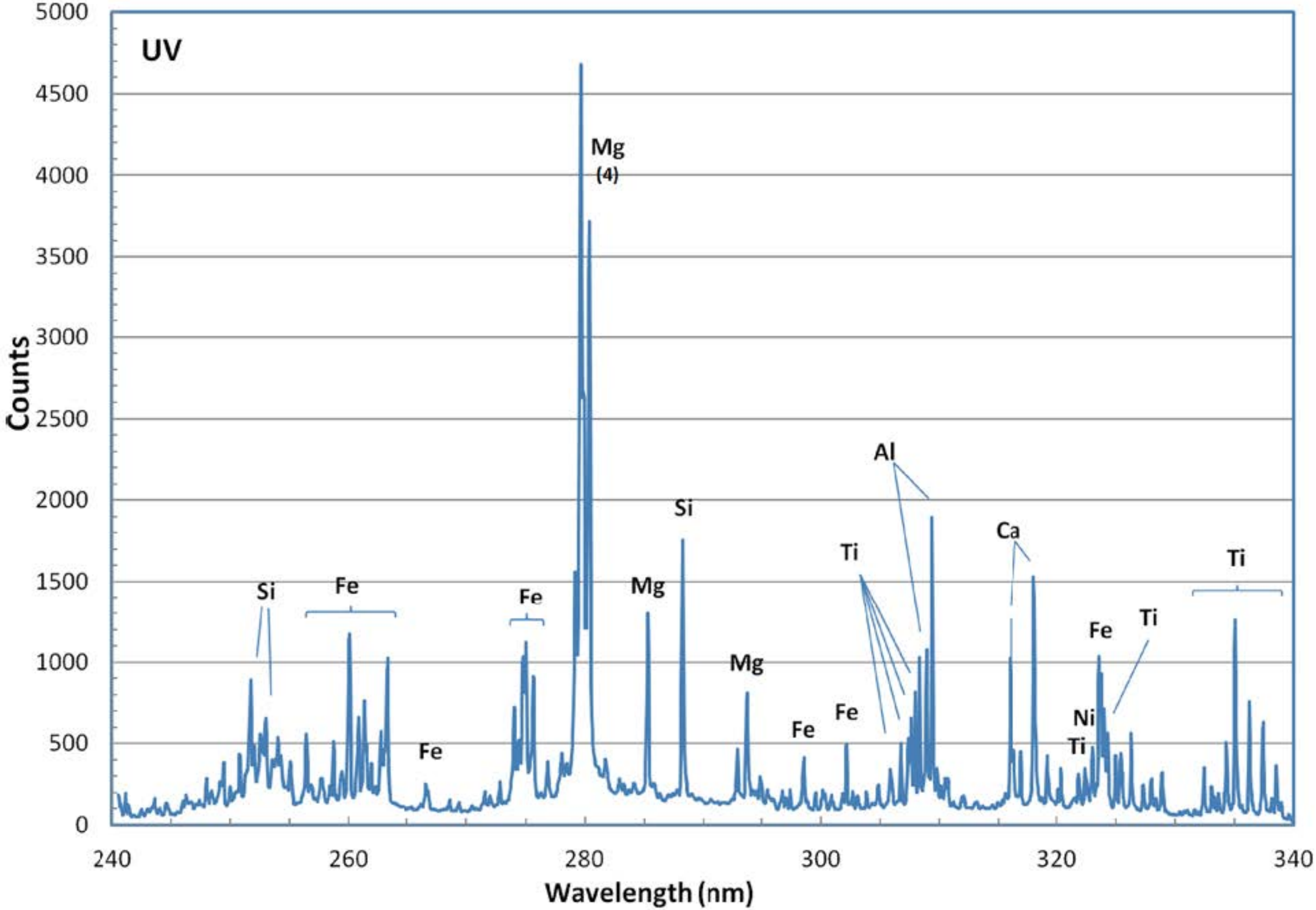
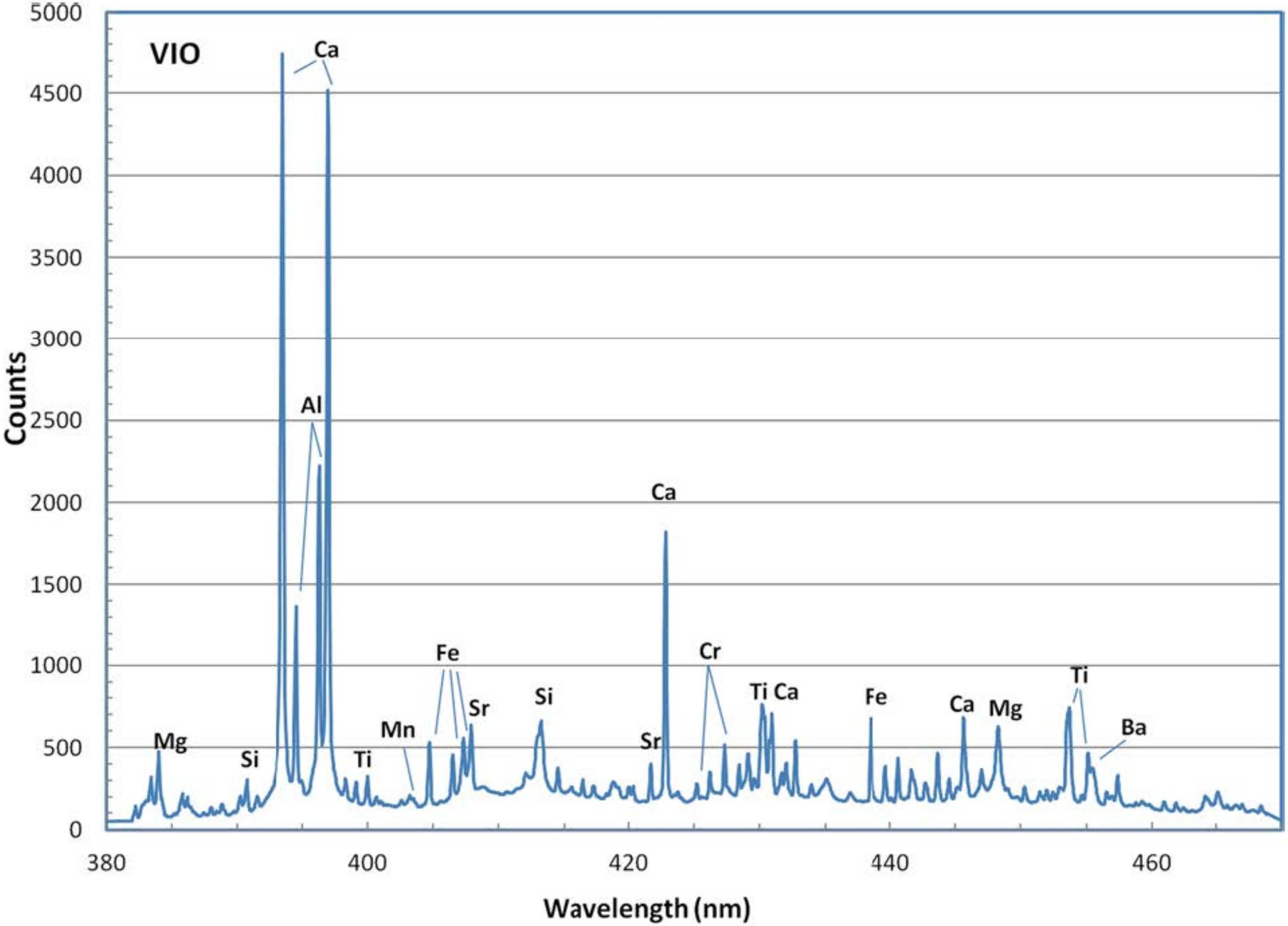


Fig. 25 LIBS spectrum of BT-2 basalt standard at a distance of 3.0 m, showing the VNIR (*top*), violet (*middle*), and UV (*bottom*) spectral ranges. Major peaks are labeled. A non-laser dark spectrum was subtracted, but the continuum was not removed

Wiens et al. (2012)



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Wiens et al. (2012)

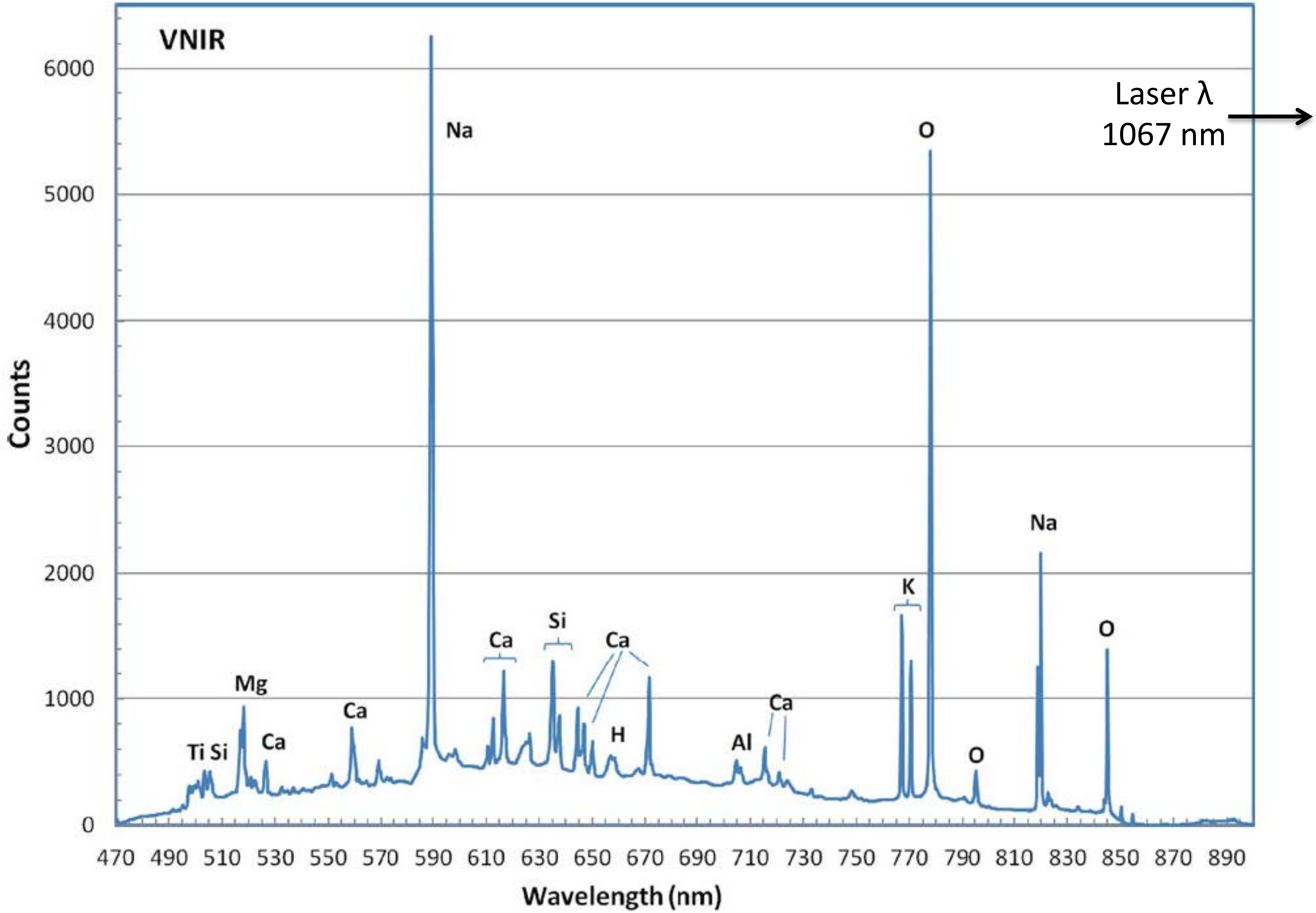
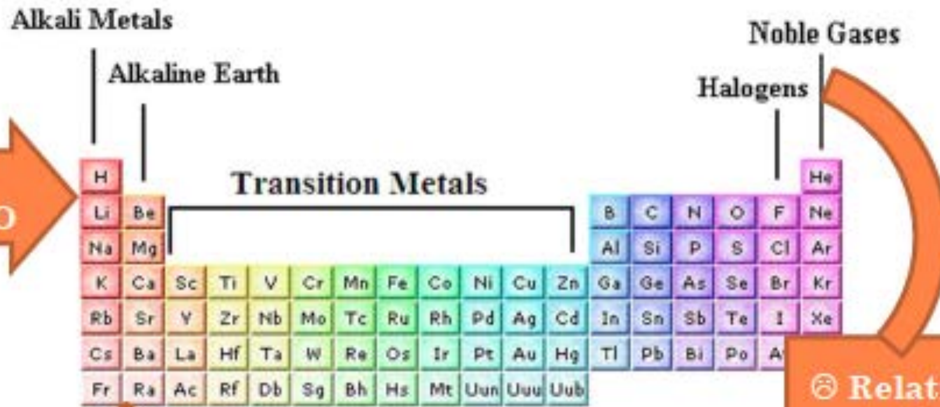


Fig. 25 LIBS spectrum of BT-2 basalt standard at a distance of 3.0 m, showing the VNIR (*top*), violet (*middle*), and UV (*bottom*) spectral ranges. Major peaks are labeled. A non-laser dark spectrum was subtracted, but the continuum was not removed

Wiens et al. (2012)

Introduction to LIBS

☺ Light elements:
H, Li, Be, B, C, N, and O



☹ Relatively insensitive to these elements, including S, Cl, and F.

However, ChemCam can still detect sulfur at the several percent level, as expected for many materials on Mars.

☺ Most sensitive to the alkalis particularly low detection limits (e.g., < 100 ppm) for Li, Sr, and Ba.

- **Overall, LIBS is sensitive to nearly all elements**

Table 2 Requirements for detection limits, precision and accuracy for most elements that can be detected by remote LIBS on Mars. All percentages are relative errors

Elements	Detection limits	Precision & accuracy
Major		
O, Na, Mg, Al	1 %	±10 %
Si, K, Ca, Fe		
Minor and trace		
S, F, Cl, C	5 %	±20 %
H, N, Ti	1–2 %	
Be, P, Cr, Mn, Ni, Cu	1000 ppm	
Zn, Rb, As, Cd, Pb, Cs		
Li, Sr, Ba	100 ppm	

Maurice et al. (2012)

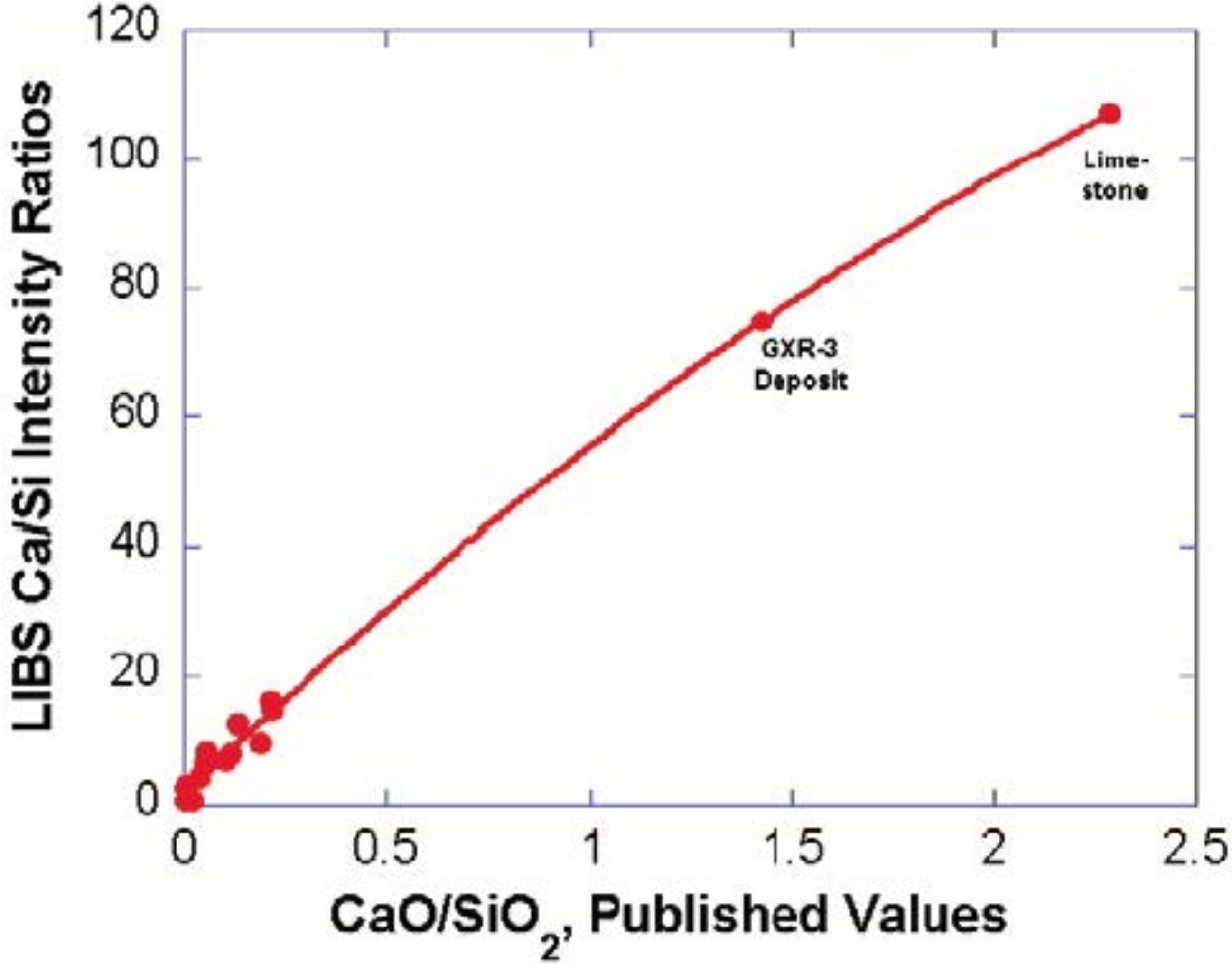
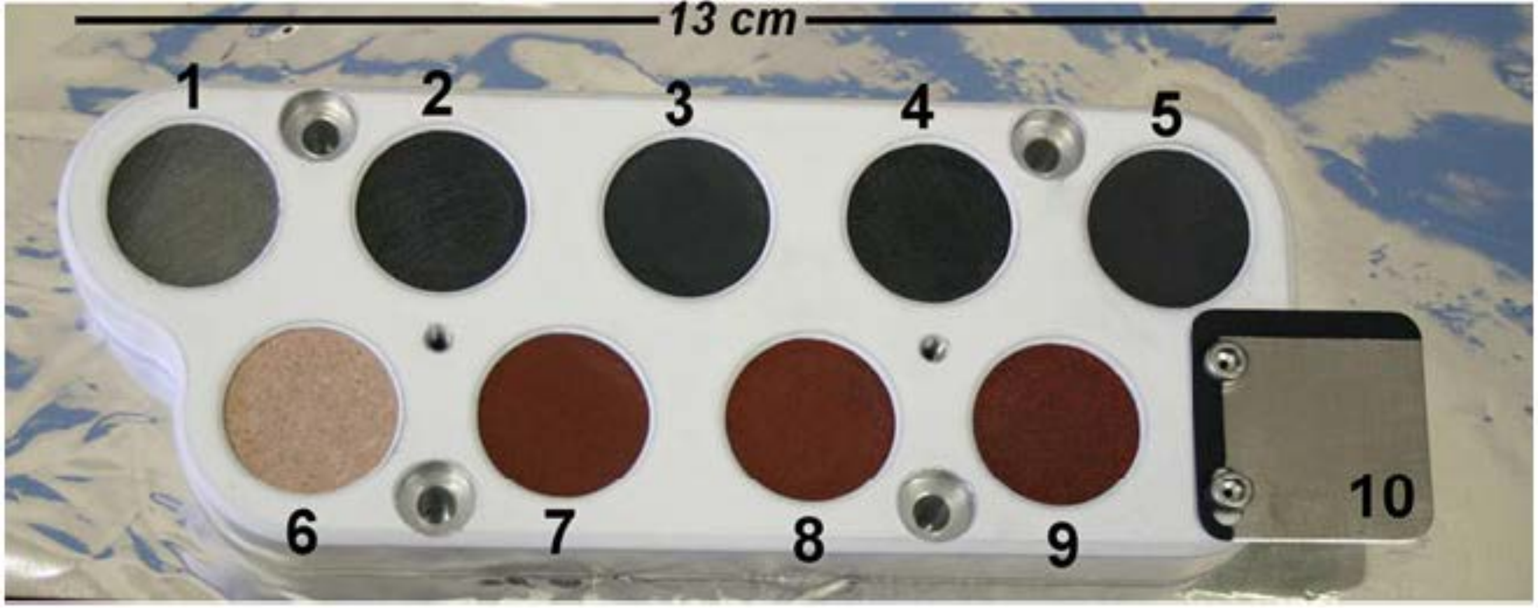


Figure 5. LIBS calibration curve for Ca/Si. Data were taken in the laboratory using rock powder standards of known composition compiled by *Govindaraju* [1994]. The curve is a quadratic fit to the data with a correlation coefficient of 0.998.

Wiens et al. (2002)



Wiens et al. (2012)

Table 5 LIBS calibration targets on board the rover

Number	Name	Description
1[a]	Macusanite	Natural obsidian glass from the Andes Mountain Range, South America
2	Norite	Synthetic glass; potential analog of the Noachian crust
3	Picrite	Synthetic glass; analog of abundant composition on the martian surface (e.g., McSween et al. 2006)
4	Shergottite	Synthetic glass; Mars meteorite-like; resembles Bounce rock Meridiani Planum (e.g., Zipfel et al. 2011)
5	Graphite	Graphite rod, included for identification of C emission lines
6	KGa-2med-S	Ceramic; CMS kaolinite standard mixed with basalt and anhydrite
7	NAu-2lo-S	Ceramic; CMS nontronite standard mixed with basalt and a low ratio of anhydrite
8	NAu-2med-S	Ceramic; CMS nontronite standard mixed with basalt and a medium ratio of anhydrite
9	NAu-2hi-S	Ceramic; CMS nontronite standard mixed with basalt and a high ratio of anhydrite
10	Ti plate	6-4 titanium alloy; to be used for wavelength calibration and diagnostic LIBS tests

Vaniman et al. (2012)

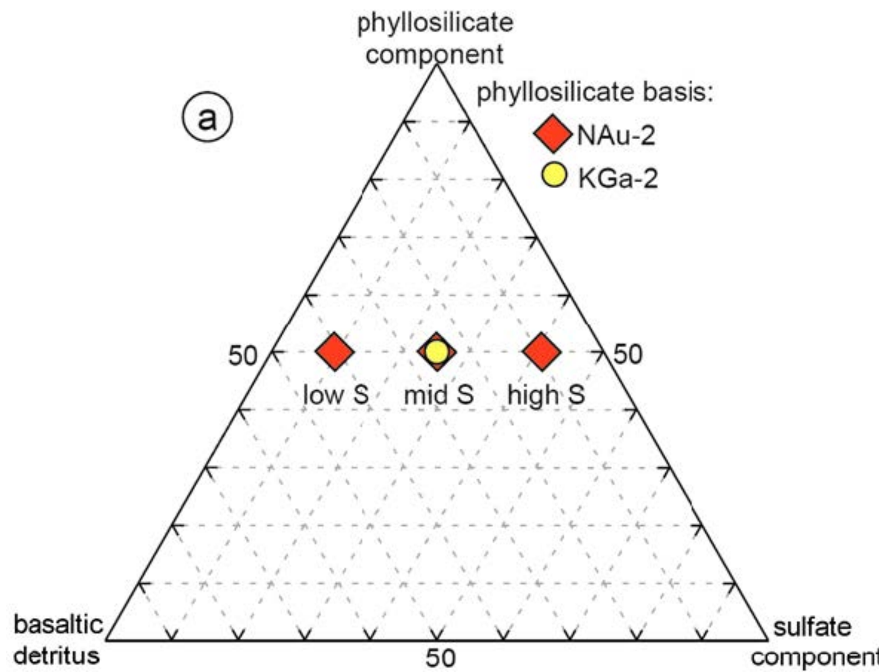
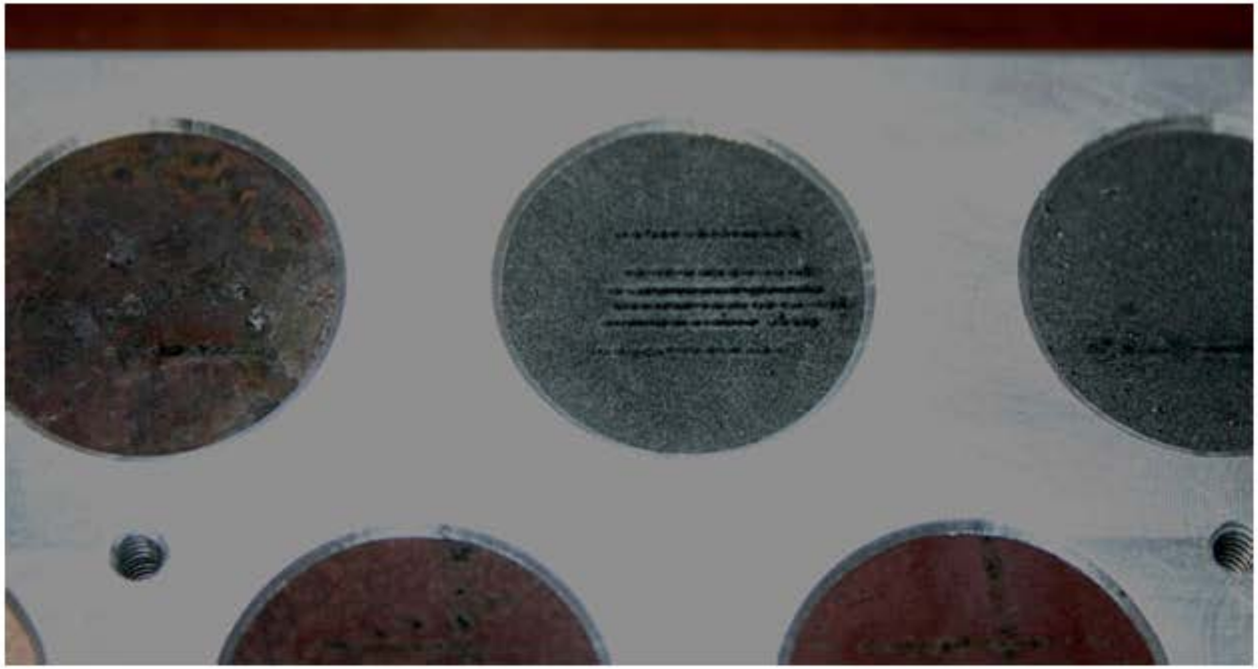
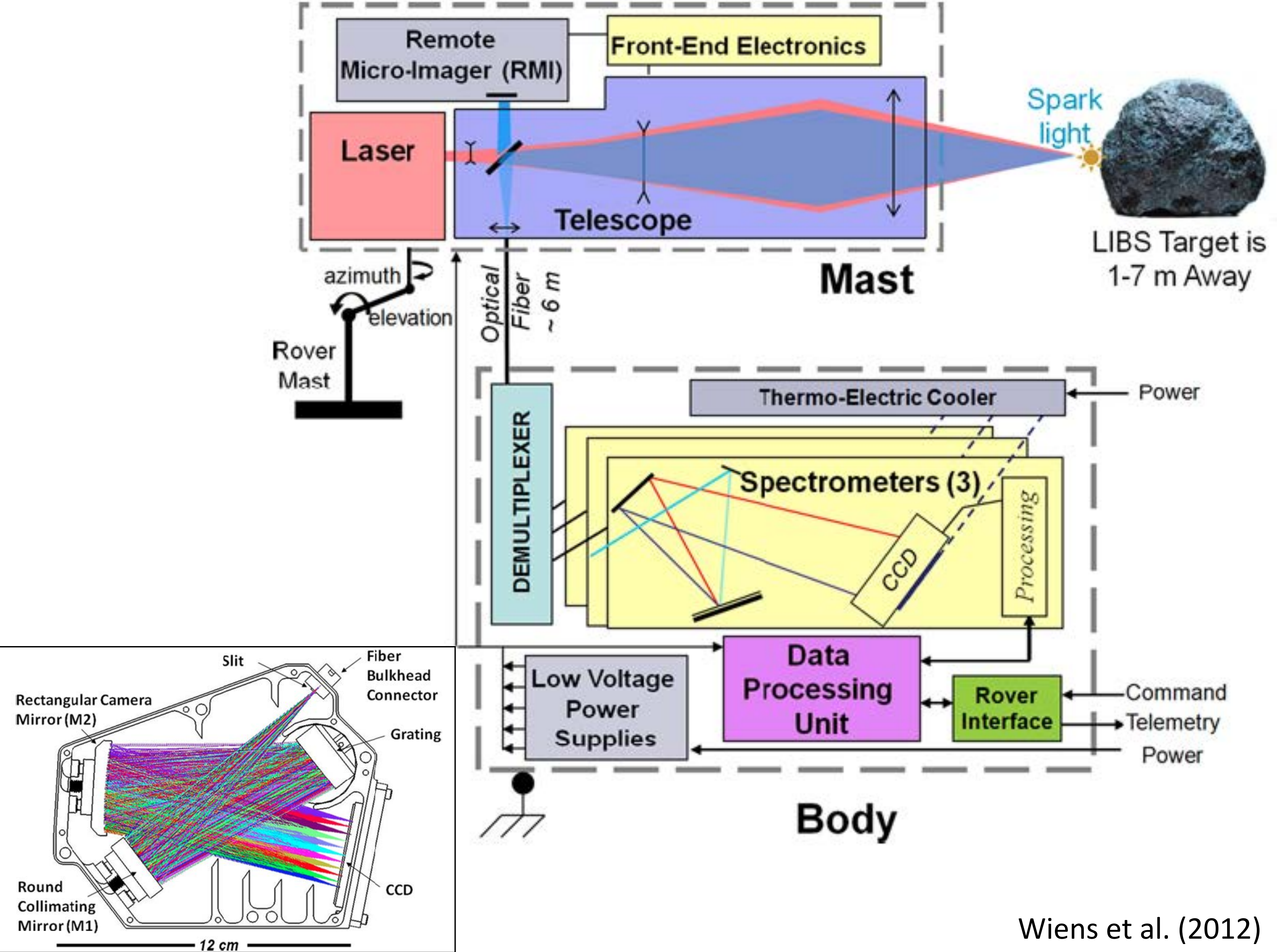


Fig. 13 Engineering model shergottite calibration target (*center of image*) after 15,000 laser pulses as part of the sample consumption test

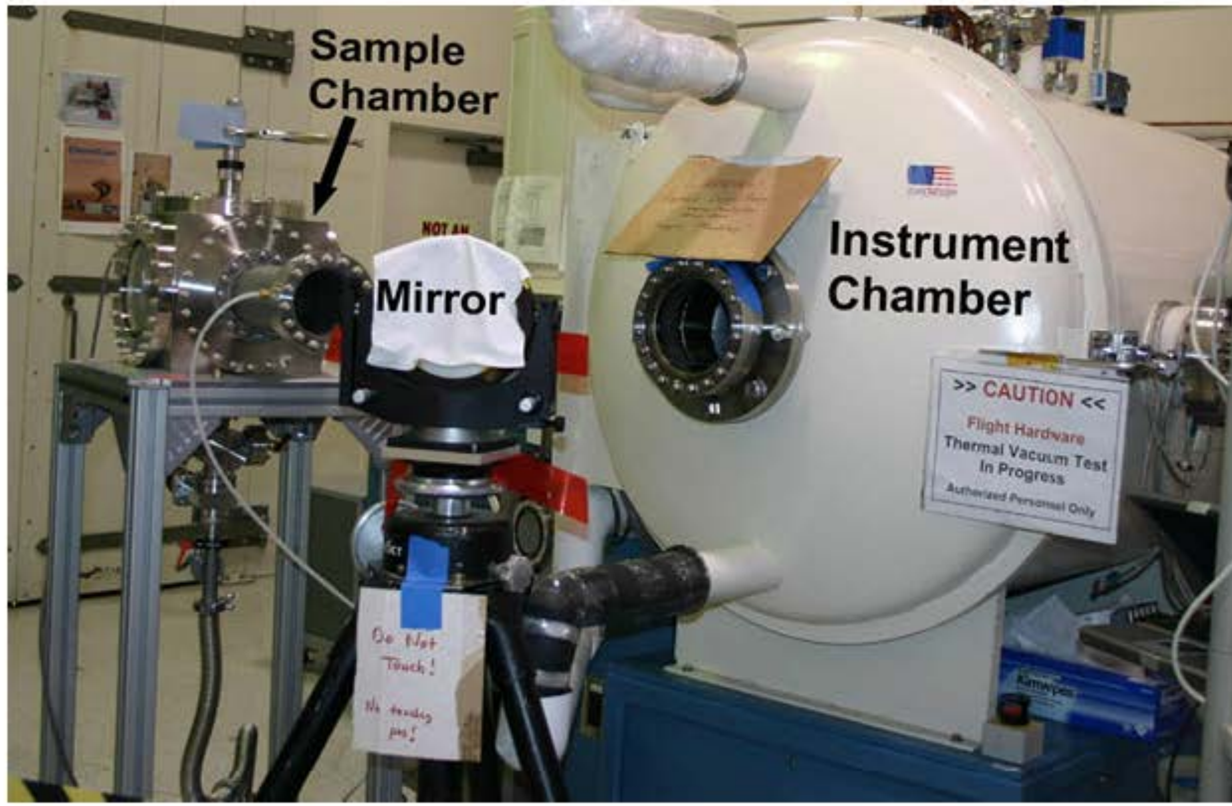


Wiens et al. (2012)



Wiens et al. (2012)

Fig. 23 Experimental set-up for ChemCam LIBS thermal vacuum tests. The instrument is in the large white thermal chamber to the right, a turning mirror is in the foreground, and the sample chamber is to the left, providing an instrument-to-sample distance of 1.5 m. For tests with more distant sample positions the sample chamber was moved back, into the adjoining room



Wiens et al. (2012)