Laser Induced Breakdown Spectroscopy for Lunar Surface & Volatile Exploration

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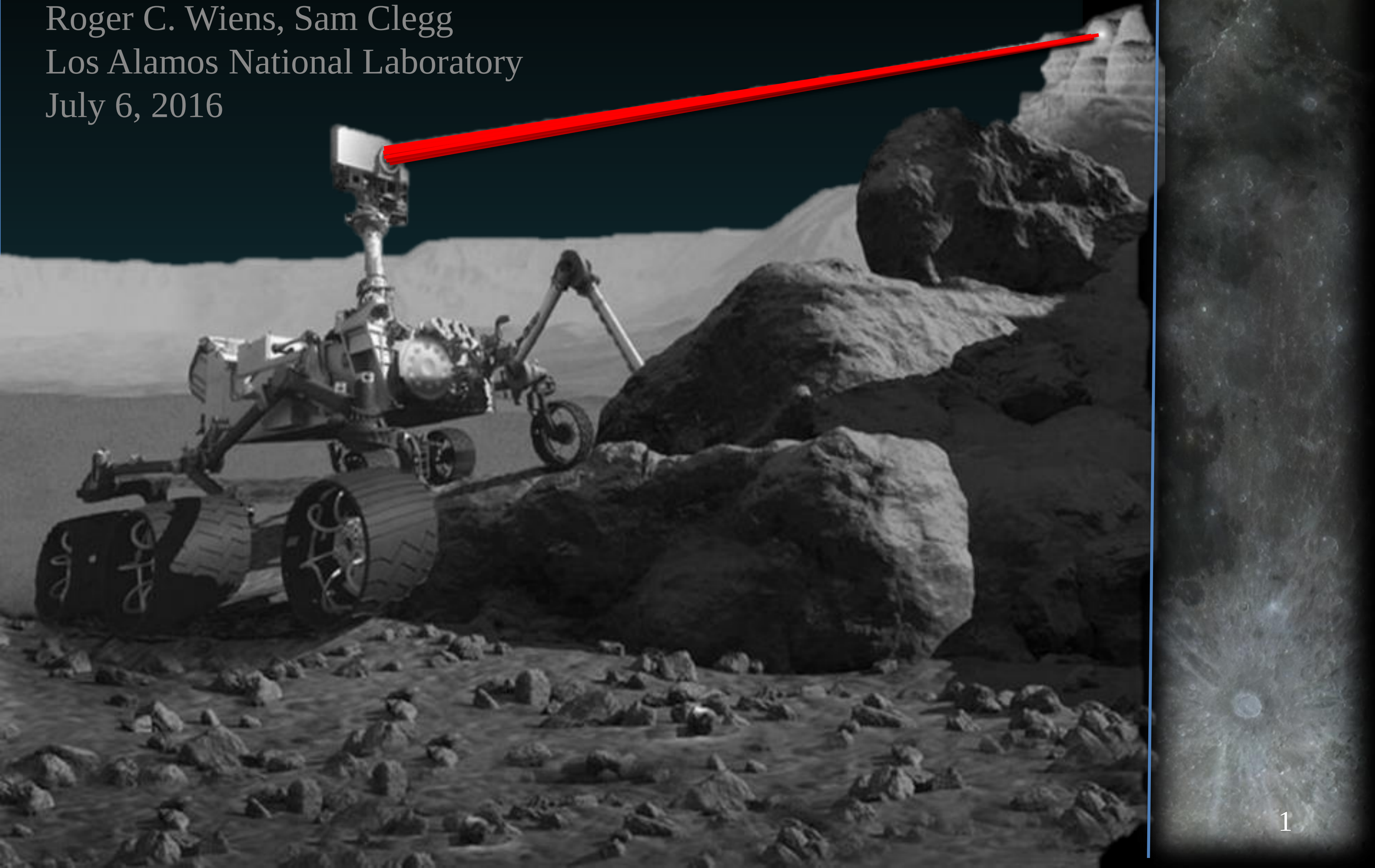
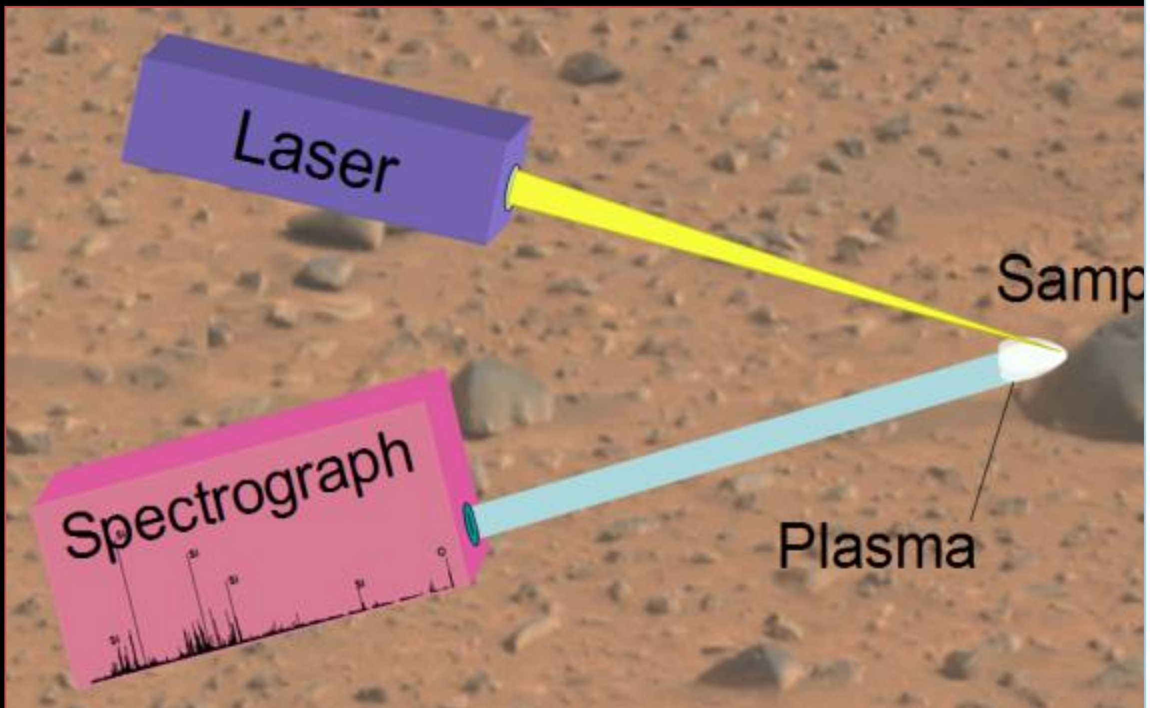


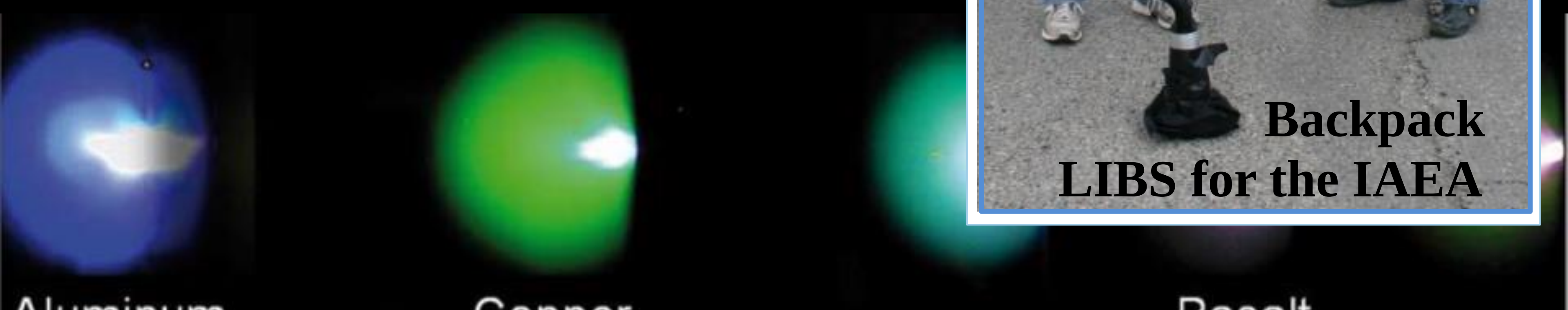
Outline

- What is LIBS?
- Does it work on the Moon?
  - LIBS in vacuum
  - Detection limits
  - Volatile observations
- What is ChemCam / SuperCam?
  - Powerful combination of elemental compositions plus active and passive mineralogy measurements (+ imaging)

Much of this presentation comes from:
Lasue J., Wiens R.C., Clegg S.M., Vaniman D.T., Joy K.H., Humphries S., Mezzacappa A., Melikechi N., McInroy R.E., and Bender S. (2012) Laser induced breakdown spectroscopy (LIBS) for lunar exploration. J. Geophys. Res. Planets, 117, E01002, doi :10.1029/2011JE003898.

Laser-Induced Breakdown Spectroscopy (LIBS)

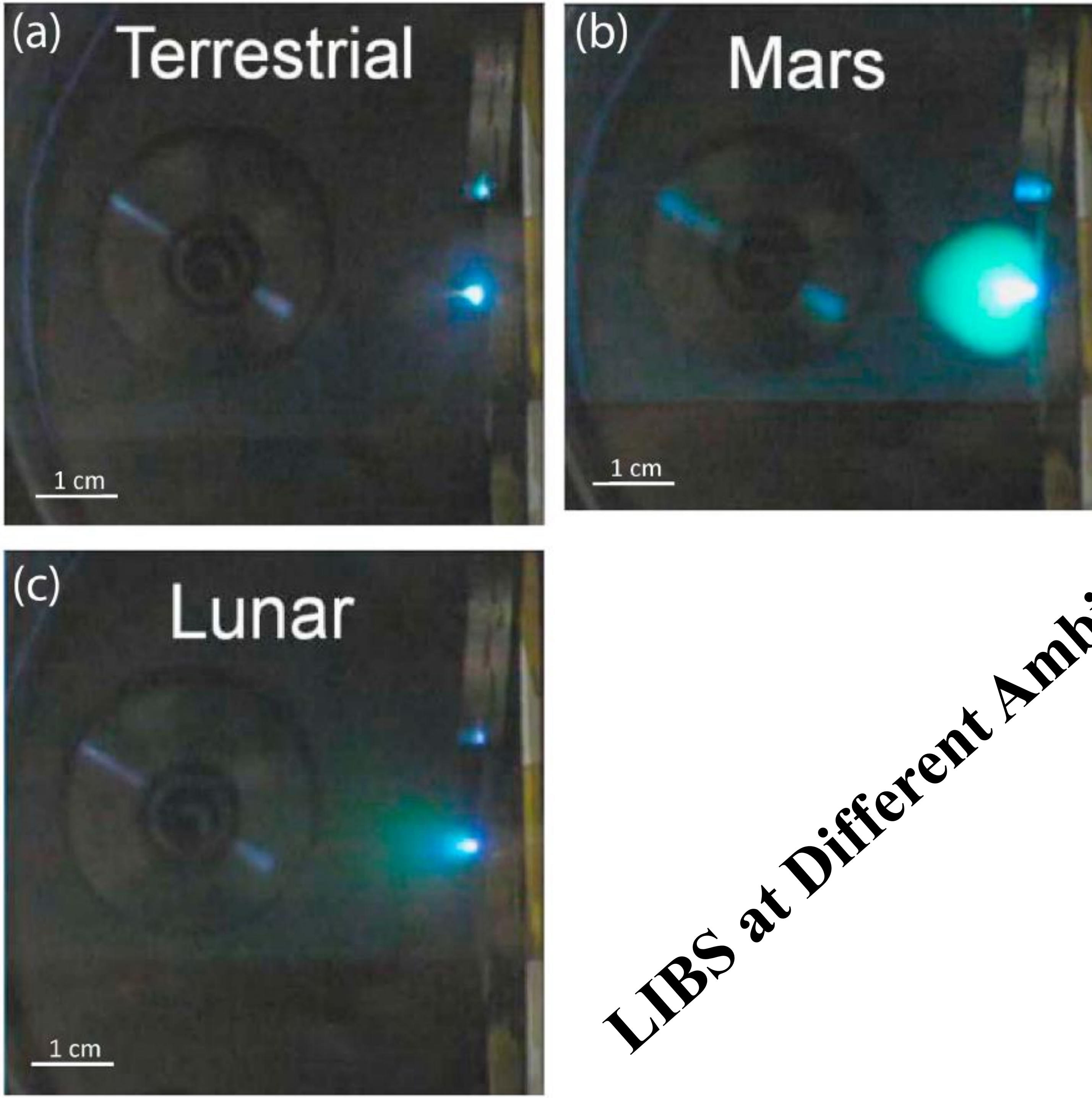




Sirven et al., JAAS

LIBS

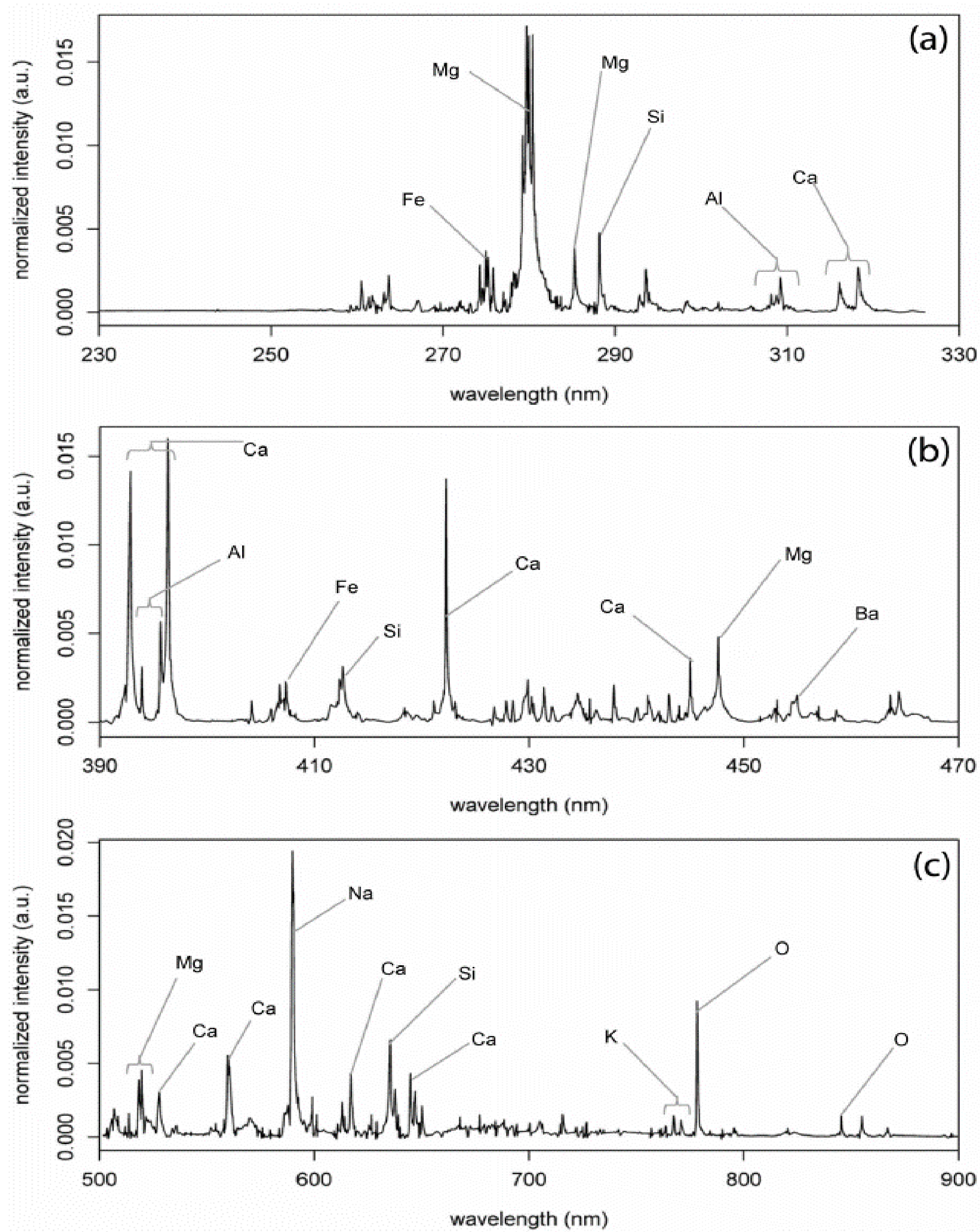
- Uses a focused, pulsed laser to ablate a small amount of the target material in the form of a luminous plasma.
  - Laser energy density > 10 MW/mm^2
- Optical emission lines are observed representing the elements present in the target.
- Intensities are calibrated to produce quantitative compositions.
- Repetitive laser pulses remove dust and profile into the rock or soil.
  - Depths to ~1 mm in rock and 1 cm in soil allow compositional gradients to be determined.



LIBS at Different Ambient Pressures

LIBS Lunar Analog Spectra

- Lunar soil simulant JSC-1
- In ‘lunar vacuum’
- Distance = 1.5 m
- Laser energy 17 mJ
- Shows all major elements and some trace elements
- Non-optimized



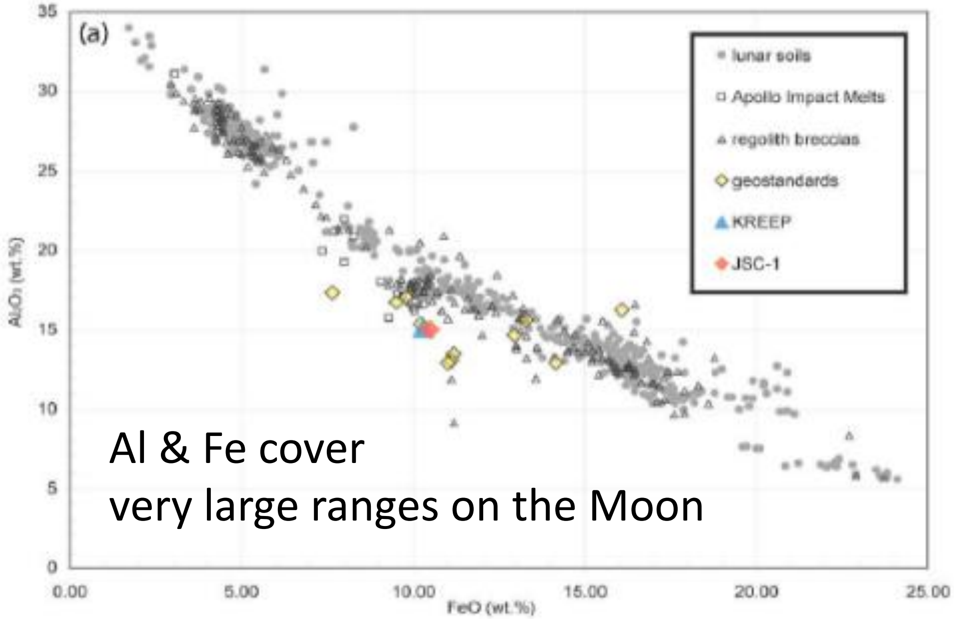
Los Alamos

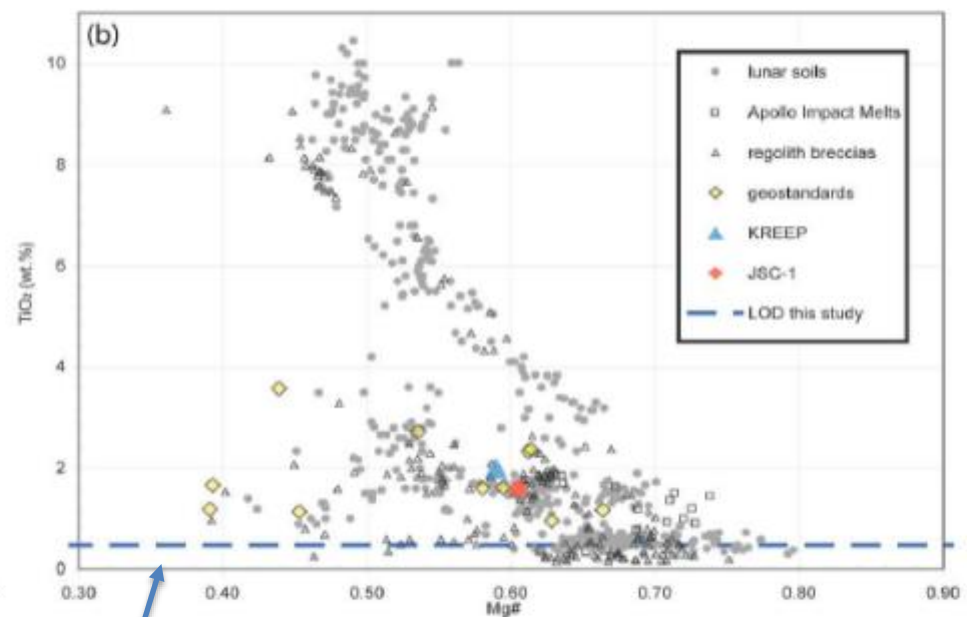
Accuracies of Major Elements

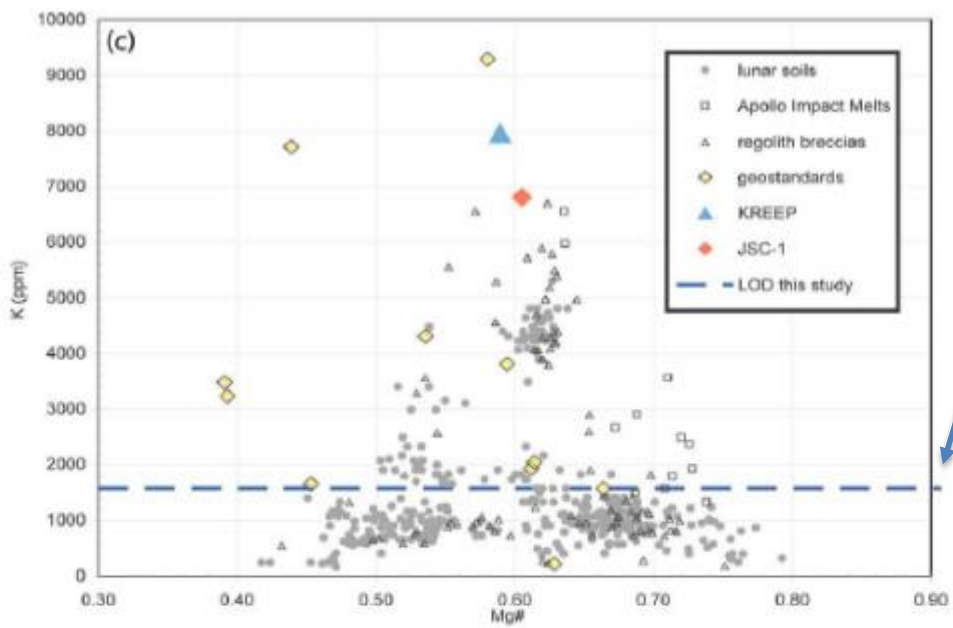
	Error Predictions										
	SiO_2	FeO	Al_2O_3	MnO	MgO	CaO	Na_2O	TiO_2	K (ppm)	Ni (ppm)	Mg #
Med REP (%)	1.55	10.3	6.97	8.83	13.61	13.16	20.77	21.84	113.04	76.84	10.21
RMSEP (wt %)	0.78	1.18	1.03	0.02	0.9	1.15	0.61	0.43	1705	39.7	0.05

- Relative error of prediction (in %)
- Root mean square error product (in wt. %)
- Based on calibration model of 12 standards
  - Compared to > 400 standards used for ChemCam on Mars

Limits of Detection Compared to Lunar Abundances

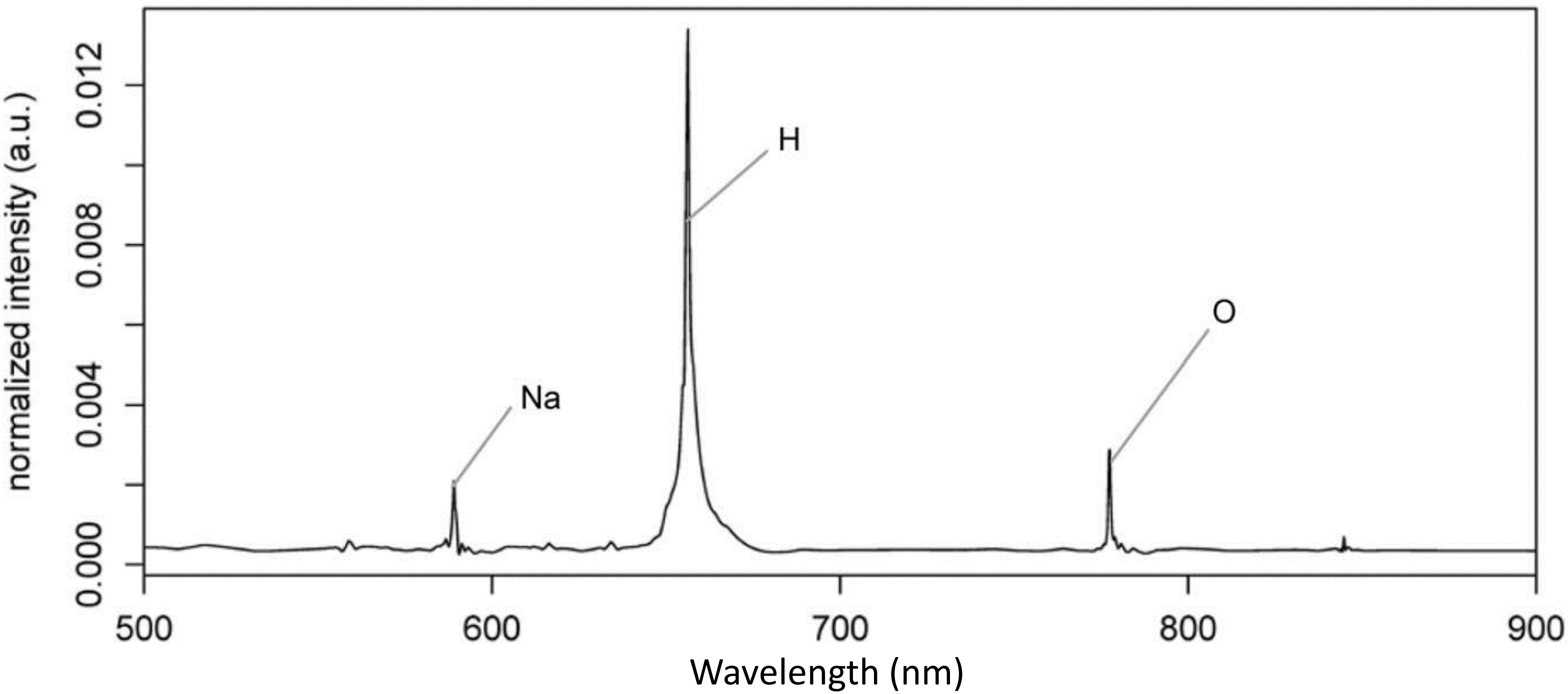






Limits of detection. Some low-K soils and breccias would pose a challenge for this set of commercial spectrometers

Water Ice Observations

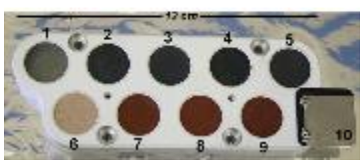


- Partial spectrum of lunar soil simulant JSC-1 mixed with ~25% H_2O ice under vacuum, interrogated with 50 mJ laser pulse at a distance of 3 m. A very strong hydrogen peak is seen.

What is ChemCam?

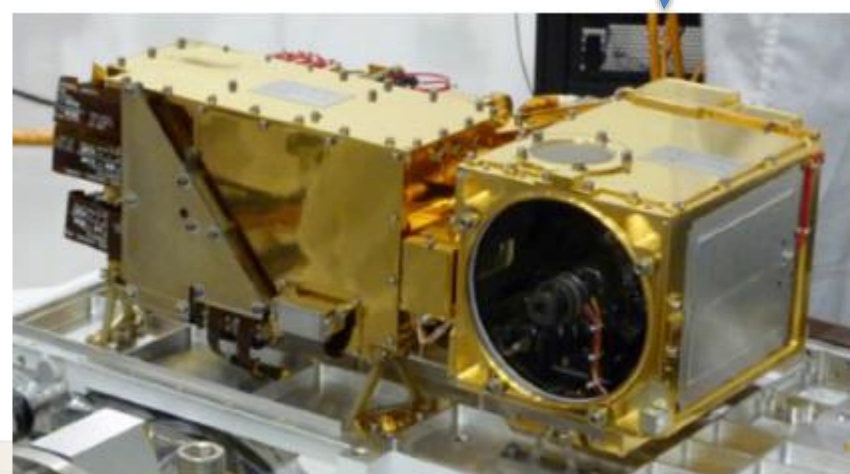
- ChemCam is a combined remote LIBS + hi-res imager operating on Mars since 2012
- >350,000 spectra of ~12,000 observation points
- > 10,000 images
- Laser & telescope on rover mast, spectrometers in rover body
- Joint French-US instrument
- Mass = 10 kg

Calibration Targets



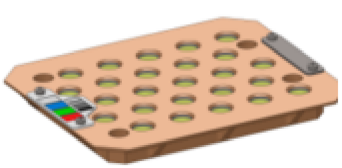
Body Unit

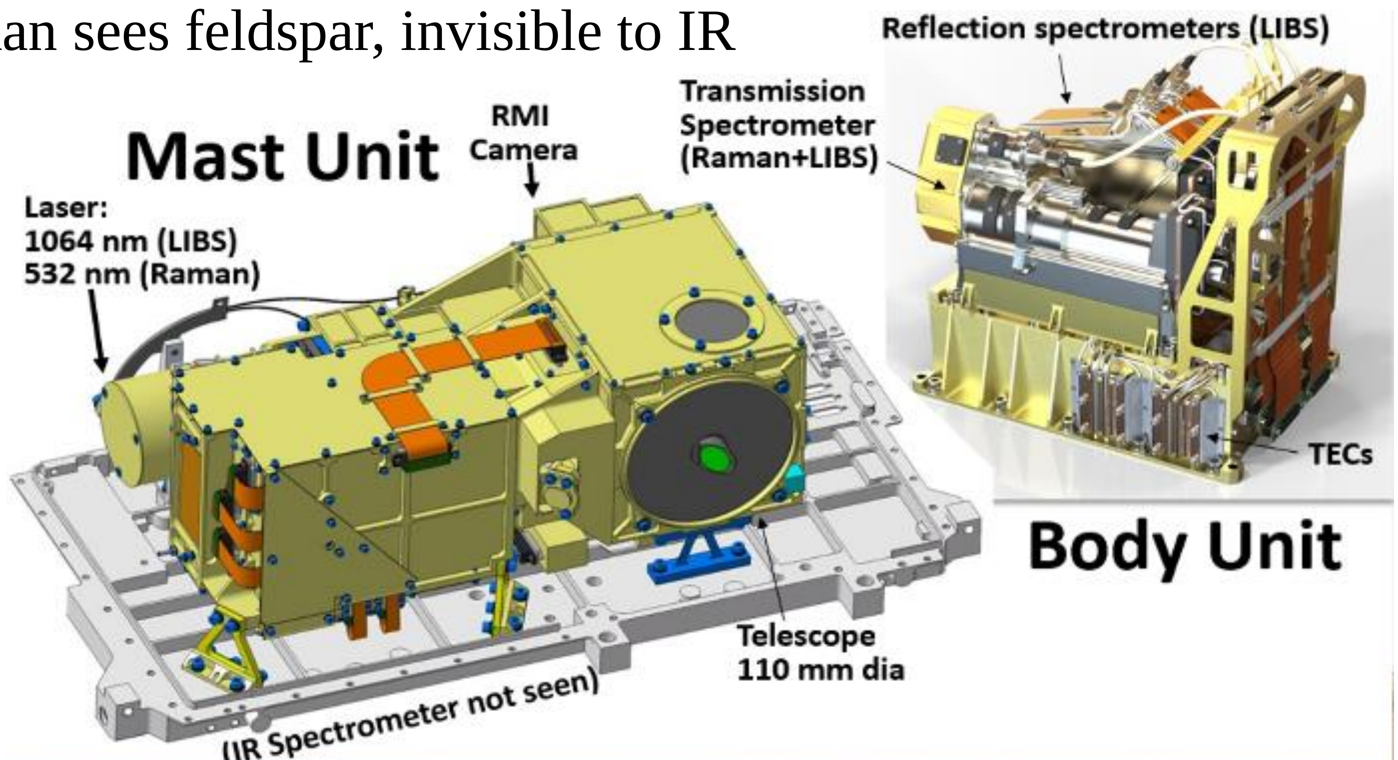
Mast Unit



What is SuperCam?

- =ChemCam plus remote Raman and VISIR spectroscopy
- Being built for Mars 2020, mass = 10 kg
- Elemental composition + mineralogy is powerful combination
- Raman + VISIR highly complementary
  - Different types of minerals are observed by the two
    - E.g., Raman sees feldspar, invisible to IR





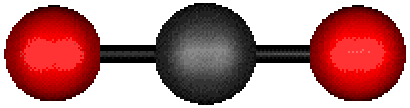
Raman and Infrared Spectroscopy

- **Raman Active Modes:** change in induced dipole moment of molecule

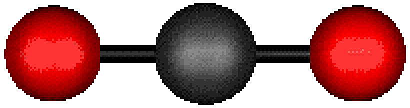
  Induced dipole moment (P): $P = \alpha E$

  Polarizability (α): Charges in a molecule separated under the influence of an external field (E)

- **IR Active Modes:** Change in the permanent dipole moment of the molecule $M = \mu E$



Symmetric Stretch
Raman Active
IR Inactive



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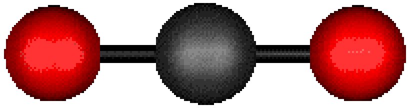
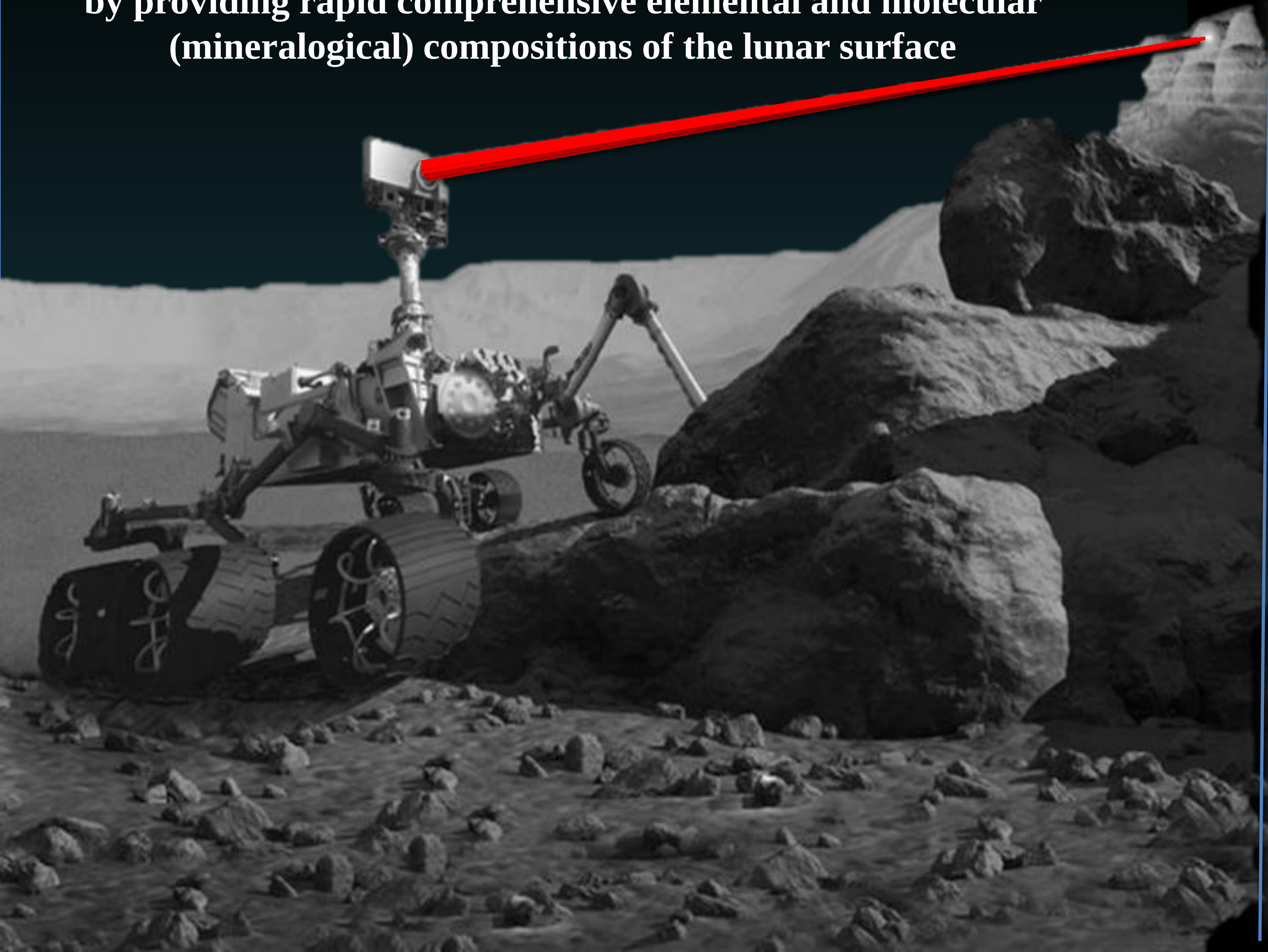


Bend
Raman Inactive
IR Active

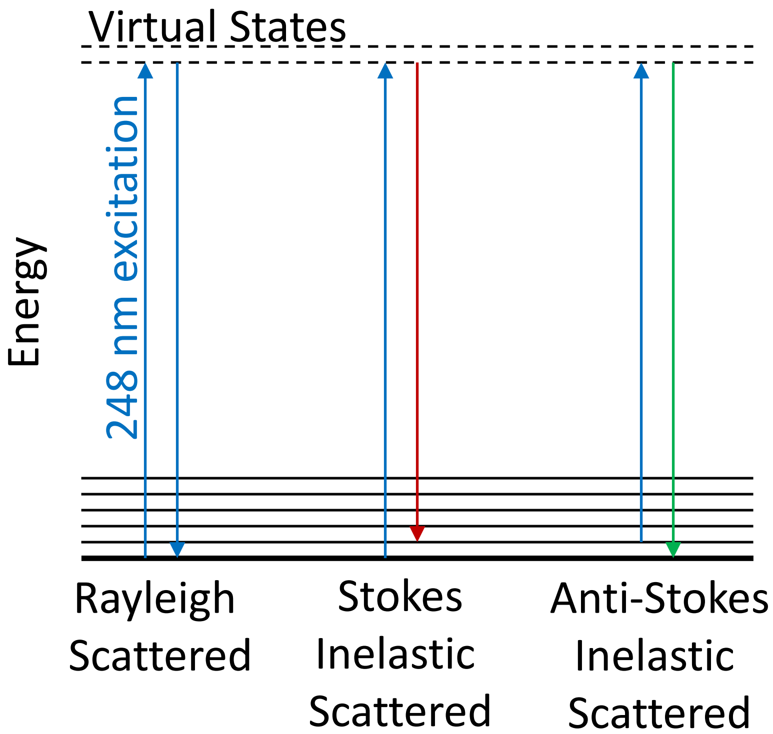
A SuperCam-like instrument would revolutionize lunar exploration

by providing rapid comprehensive elemental and molecular (mineralogical) compositions of the lunar surface



Backup

Fundamental Raman Scattering



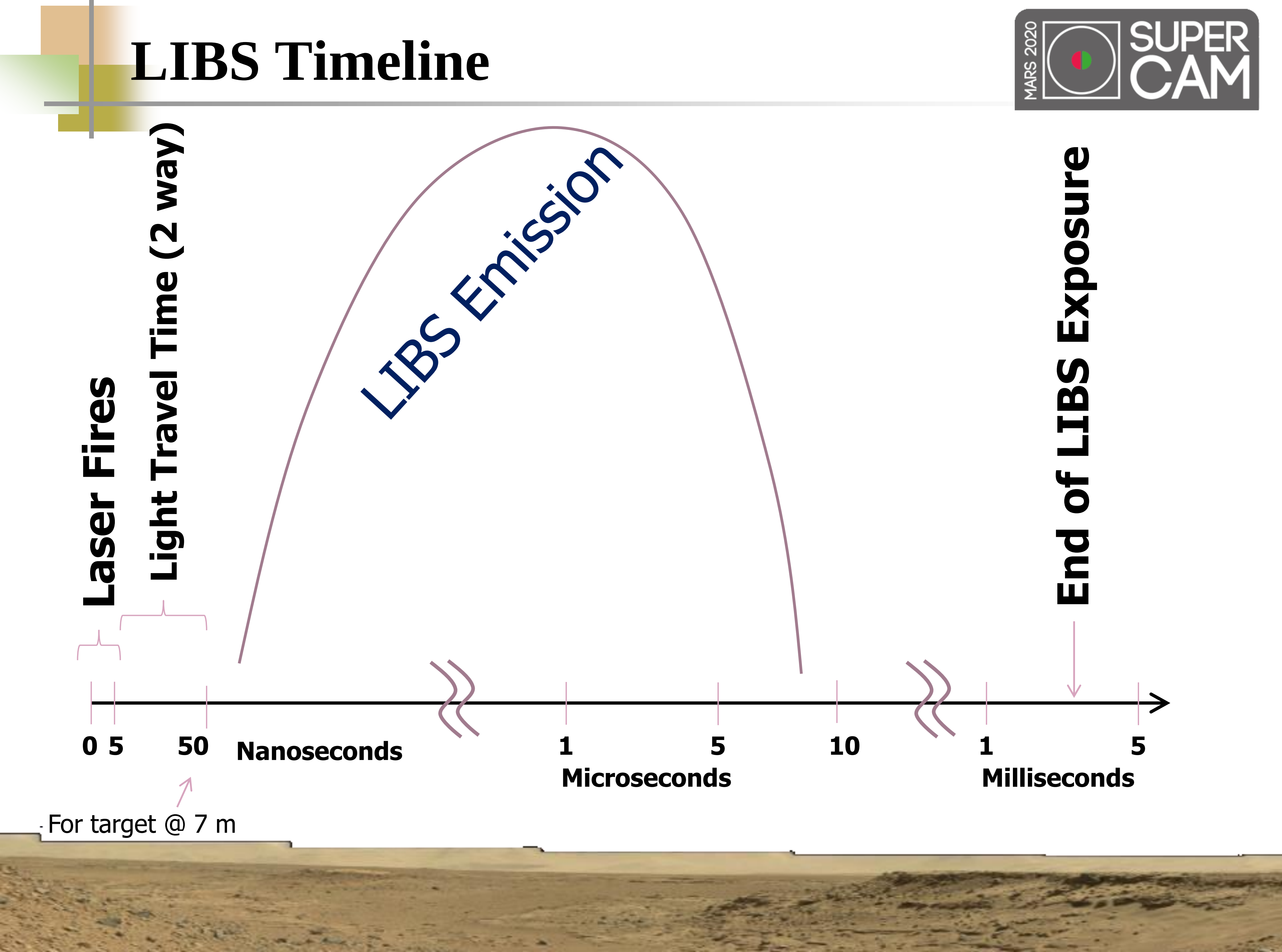
Virtual State

- a quasi-excited, intermediate state that arises from the polarization of the molecule in an external electric field
  - not a real energy level
- scattering occurs on the time scale of a nuclear motion, ~10^{-13} sec

Raman Scattering

- The molecular electric field oscillates at the frequency of the passing wave
- Molecular polarizability can induce dipole.
  - if polarizability is constant, scattering is elastic (Rayleigh) scattering
  - if polarizability is not constant, inelastic (Raman) scattering is allowed
- Raman signal lifetime ~ laser pulse width

LIBS Timeline



Raman / Time-Resolved Fluorescence Timeline