TOOLBOX FOR RESEARCH AND EXPLORATION (TREX): THE FINE-PARTICLE SPECTRAL LIBRARY. M. D. Lane[1], J. P. Allain[2], K. S. Cahill[3], R. N. Clark[3], E. A. Cloutis[4], M. D. Dyar[3,5], J. Helbert[6], A. R. Hendrix[3], G. Holsclaw[7], M. Osterloo[7], N. Pearson[3], D. W. Savin[8], and the TREX team, [1]Fibernetics LLC (Lititz, PA, lane@fibergyro.com), [2]University of Illinois at Urbana-Champaign (Urbana, IL), [3]Planetary Science Institute, (Tucson, AZ), [4]University of Winnipeg (Winnipeg, Canada), [5]Mount Holyoke (South Hadley, MA), [6]DLR (Berlin, Germany), [7]University of Colorado (Boulder, CO), [8]Columbia University (New York, NY).

Introduction: The Toolbox for Research and Exploration (TREX) is a NASA SSERVI (Solar System Exploration Research Virtual Institute) node. TREX (trex.psi.edu) aims to decrease risk to future missions, specifically to the Moon, the Martian moons, and near-Earth asteroids, by improving mission success and assuring the safety of astronauts, their instruments, and spacecraft. TREX studies will focus on characteristics of the fine grains that cover the surfaces of these target bodies – their spectral characteristics and the potential resources (such as H_2O) they may harbor. TREX studies are organized into four Themes (lab studies, Moon studies, small bodies studies, and field work). In this presentation, we focus on Theme 1: lab studies and the development of a comprehensive spectral library.

Samples for Spectral Library: The development of a spectral library for TREX will focus on ***fine-grained (<10 µm)*** planetary materials measured over *ultraviolet, visible/near-infrared, and mid-infrared (UV-VNIR-MIR*) under environmental conditions that mimic the surfaces of the airless targets *(in vacuum, when possible, and at various temperatures)* (Table 1). Here we present the terrestrial (Table 2), lunar and meteorite (Table 3) samples (for end-members, mineral mixtures, and select mineral-ice mixtures) to be measured by collaborating laboratories (Table 4).

Table 1. Surface temperature ranges of TREX targets.

Target Body	Surface T	Refs
Moon	-181 to +123 ºC	[1]
Near Earth Asteroids	-153 to +300 ºC*	[2]
Phobos & Diemos	-144 to +27 ºC	[3]

*Hotter near the Sun for the ~0.5 % of NEOs that go within 0.2 AU.

Table 2. Terrestrial minerals to be measured.

MINERALS:	Ilmenite
Forsterite Globe SSERVI*	Pyrite
Forsterite SC SSERVI*	Palygorskite (PFI-1)
Bytownite SSERVI*	CaS (oldhamite)
Labradorite SSERVI*	Hectorite (SHCa-1
Diopside SSERVI*	Na-montmorillonite (SWy-3)
Augite SSERVI*	Ca-montmorillonite (STx-1b)
Albite (AL-I)	Kaolinite (KGa-1b)
Anorthite (Anorthosite AN-G)	Serpentine (UB-N)
Fayalite	Biotite Mica-Mg
Pigeonite	Zinnwaldite (ZW-C)
Enstatite	Fe metal <10 um
Hematite <5 um	Graphite 7-11 um
Hematite 3 nm	Amorphous C

*Samples being used by several SSERVI teams for cross-SSERVI collaborations & science linkages [4,5].

Table 3. Meteorite types and lunar samples to be measured.

METEORITES:	EL	**LUNAR*:**
Aubrite	EL6	Anorthite
C2	H3	KREEP basalt
C4	H4	Low-Ti basalt
CI1	H5	Anorthositic gabbro
CM2	H6	High-Ti basalt
CO3	Howardite	Soil (61211,92)
CO4	L3	Soil (67461,25)
CV3	L4	Soil (67481,31)
CV4	L5	Soil (61141,56)
Diogenite	L6	Soil (62231,91)
EH5	Eucrite	

*For the lunar samples, we will attempt to measure similar samples to [6] and [7] to compare results.

Spectral Measurements: We will make spectral measurements of the samples at multiple labs (Table 4) with unique and overlapping capabilities to derive a robust set of cross-calibrated laboratory spectra.

Table 4. TREX laboratories.

Lab*	**Meas-urement**	**Wave-length**	**P,T**
DLR PSL	Reflect.	0.18 - 20 um	0.7 mbar; ambient T
	Emission	3 – 20 um	Purged air; 30-200C
	Reflect.	0.7 – 300 um	0.7 mbar; ambient T
	Emission	0.7 – 300 um	0.7 mbar; 50-300C
Mount Holyoke	Raman	3 - 33 um	Ambient
	Mossbau.	14.4 KeV	Ambient
PSI	Reflect.	0.11 – 0.22 um	<mbar; 77K
	Reflect.	0.18 – 0.88 um	77 – 490K; <mbar to 1.5 bar
	Reflect.	0.35 to 2.5	77 – 490K; <mbar

		um	to 1.5 bar
	Reflect. (future)	1.5 to 50+ um	77 – 490K; <mbar to 1.5 bar
Univ. Winnipeg	Reflect.	0.16 – 0.4 um	Ambient
	Reflect.	0.35 – 2.5 um	Ambient
	Reflect. (future)	1.6 – 20 um	<mbar; ambient T
LASP	Reflect.	0.12 to 0.6 um	<mbar P; 90K for ices
Univ. Illinois	Refl.; Irradia-tion	0.35 – 2.5 um	<mbar P; 77-900K
NASA-JSC	Impact sims	n/a	n/a

*DLR PSL (German Aerospace Center's Planetary Spectroscopy Lab); PSI (Planetary Science Inst.); LASP (Univ. of Colorado's Lab for Atmospheric and Space Physics); JSC (Johnson Space Center). NOTE: Additional UV-MIR measurements will be made at the Johns Hopkins Applied Physics Lab in collaboration with the VORTICES SSERVI project.

Ultraviolet (UV): Lab UV spectra are relatively uncommon, and fine particles have not been studied. The TREX team will obtain UV spectra that will enable diagnostic bands to be identified for various materials to allow this spectral range to be better utilized for the study of planetary bodies. Previous far-UV measurements (120-200 nm) [6,8] revealed spectral features (predominantly due to charge transfer) that could be applied to UV data sets from the Hubble Space Telescope, Lunar Reconnaissance Orbiter, Cassini, Rosetta, and future spacecraft.

Visible/Near-infrared (VNIR): Spectra in this range are dominated by charge transfers (some overtones). Fine-grained materials typically exhibit brighter reflectance and shallower bands in the VNIR region than coarser-grained samples. UV to NIR data can also exhibit the effects of particle size due to Mie and Rayleigh scattering and Rayleigh absorption [9,10].

Exposure of our samples to thermal processing will allow us to determine how VNIR spectra are affected by elevated temperatures for various minerals. At VNIR wavelengths, temperature effects can cause changes in sample color and spectral slope. These thermal-processing effects are irreversible, at least for sulfides [11]. In a study by [12], their thermal gradients were controlled carefully and negated, but changes in sample temperatures still affected their VNIR spectra.

Mid-infrared (MIR): MIR spectra are dominated by fundamental vibrational modes (some overtones). For fine-particulate, high-porosity samples, the MIR region also exhibits volume-scattering features [13,14]. Furthermore, MIR spectra (for fine-grained materials) behave differently under vacuum conditions versus ambient (e.g., 1 atm) due to the lack of interstitial gases [15]. Conduction of heat is minimized and fine particulates develop intense thermal gradients [e.g., 12,16,17], effectively shifting the Christiansen Frequency to shorter wavelengths (higher wavenumbers) and decreasing the transparency features [see 15,17]. Temperature can also affect MIR spectra [18,19] because increased temperature can cause structural expansion of the crystal lattice, thus changing the spectral bands. Due to the difference in spectra between those obtained under ambient conditions from those obtained under vacuum, typical 1-atm laboratory spectra are decreasingly useful for determining mineralogy on airless bodies, especially for fine-particulate surfaces.

Additional Spectral Analyses and Other Labwork: Our samples also will be analyzed using Mössbauer and MIR Raman spectroscopy at Mt. Holyoke College. Other labs involved with TREX are at the Univ. of Illinois (irradiation studies) and NASA-Johnson Space Center (impact simulations). Involvement of these latter two labs will be described in [20].

Support of Other TREX Themes: The UV, VNIR, MIR, Raman, and Mössbauer spectra generated through the Theme 1 efforts will be archived publicly and utilized by other TREX Themes [20,21,22]. These spectra, with additional modeling, will be used to identify regolith mineralogy, particle size, mineral abundances, volatile abundances, thermal attributes, and space weathering effects on our target bodies.

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