MARTIAN SOILS: STATISTICS, QUANTITATION, AND COMPARISONS. Hongchun Bai, Erbin Shi, Zongcheng Ling*, Shandong Key Laboratory of Optical Astronomy and Solar-Terrestrial Environment, Institute of Space Sciences, Shandong University, Weihai Shandong 264209, China (zcling@sdu.edu.cn).

Introduction: Martian surface is much covered by soils that are unconsolidated, basaltic, and global homogeneous. Martian soils have been analyzed with orbital and in situ observations. Thermal inertia, particle sizes, and elemental compositions of Martian surface were investigated with infrared observations and gamma ray spectrometer from orbit [1-3]. At Chryse Planitia, Gusev Crater, Meridiani Planum, and Gale Crater, chemical compositions of Martian soils were derived from Alpha-Particle X-ray Spectrometer (APXS) data. Those results from orbit and in situ detections deepened the understanding of soils in terms of physical properties and chemistry.

Laser-induced breakdown spectroscopy (LIBS) instruments (ChemCam, SuperCam, and MarSCode [4]) have probed plenty of soil targets at Gale Crater, Jezero crater, and Utopia Planitia. Laser spot sizes of above three payloads are submillimeter scales. Thus, LIBS can better sight into Martian fines. In this paper, we make use of the LIBS spectra over 3000 sols of MSL mission and the available spectra of Mars 2020 mission to studied soils.

Methods: Soil targets were classified as fine grained, coarse grained, pebble, soil and pebble mixture according to Wentworth scale [5]. The type "soil and pebble mixture" meaning that probed point between pebble edge and neighboring soil, and it is difficult to know soil or pebble was sampled. The number of four types of soils were counted based on the Remote Micro-Imager (RMI) [6] observations.

Elastic net is a sparse regression model, it has the capabilities of feature selection and quantitative analysis. This model was trained with three normalization methods (Norm 1, Norm 3, and StandardScaler), a series of l1_ratio, and ChemCam calibration database which includes 408 samples [7]. Training set of elastic net is four fifths LIBS datasets, testing set is one fifths LIBS spectra. 5-fold cross validation was used to optimize the α of elastic net. The model was estimated with root mean squared error of prediction (RMSEP).

Results: Statistic results of four type soils show in Fig. 1. The number of fine grained soil sampled by laser spot is 888, accounting for 58% of the total probed soil points. Coarse grained, soil and pebble mixture, and pebble have 412, 200, and 25 sampled points, respectively. Fine grained soils generally show a single peak, and pebbles often display bimodal or multi-modal distribution in the major elements density distribution maps (Fig. 2, only display Si). Difference between center peaks of soils and pebble suggests that soils are not dominate by the product originated from mechanical disruption of pebble. While the non-major peak of coarse grained soil is close to the major peak of pebble, which indicates that part physical weathering products of pebble contribute to soils.

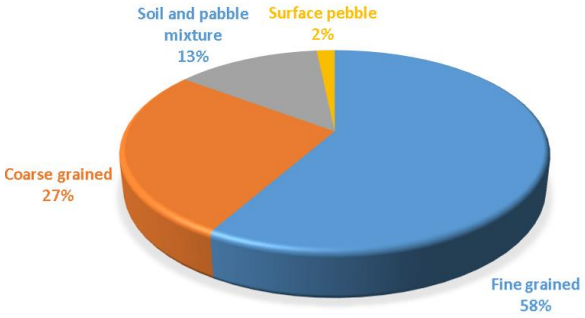

Fig. 1. Pie chart of four types soils.

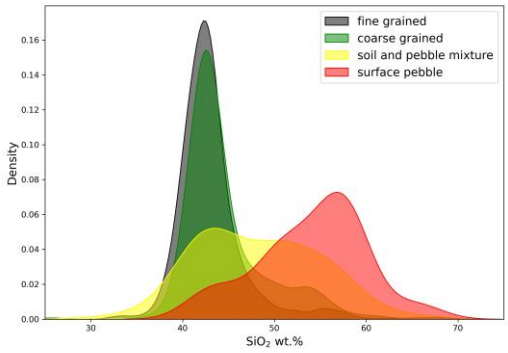

Fig. 2. Density distribution map of SiO_2 for soils

RMSEP of elastic net model for testing set is show in table 1. This result is comparable with that of the model combined ICA and PLS [7-8]. The features selected by elastic net exhibited significant emission lines belonging to a single element. Elastic net score of each major element and element concentration have a good positive correlation, such as Si (R^2 = 0.89) (Fig. 3). The score was used for studying component change of soil profile. Elastic net scores of Si change with shot number for four classes soils and ChemCam calibration target (CCCT) (Fig. 4). Elastic net scores of first shot for soil targets are close, which suggests that this score represents the chemical composition of eolian dust. Variation trends of the scores for CCCT and fine grained soil is similar and do not change with shot. However, the scores of surface pebble have significant change from first shot to sixth shot. This change indicates that there are coatings on pebble surface. The

surface coatings may be the aggregation of fine grained soil or chemical alteration products of the pebble.

Table 1. RMSEP of elastic net model for the testing set of eight major elements.

Elements	Si	Ti	Al	Fe	Mg	Ca	Na	K
RMSEP	3.94	0.35	1.79	1.88	1.12	1.29	0.49	0.49

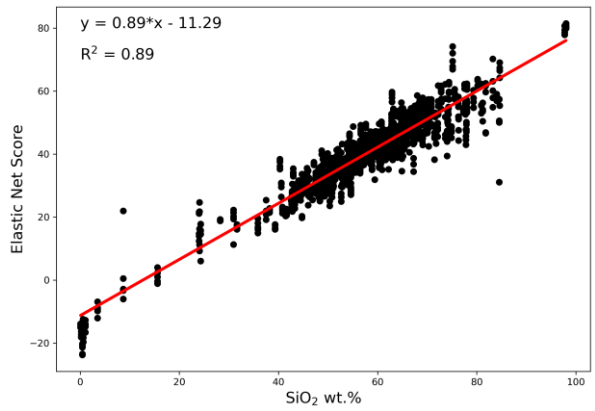

Fig. 3. Relationship between SiO_2 concentrations and elastic net scores.

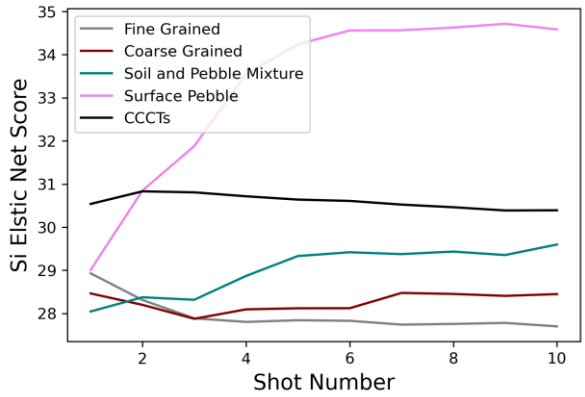

Fig. 4. Elastic net scores of different targets change with shot number.

Martian soils have been probed at several landing site, and the total alkali and silica of those region shown in Fig. 5. The ellipses are the 2 sigma confidence ellipses for different type soils, and the points and ellipse for individual type soil were displayed with same color. Average value of alkali and SiO_2 for Ares Vallis (studied by Pathfinder), Gusev Crater ((studied by Spirit), Meridiani Planum (studied by Opportunity) are close, and they are located within the 2 sigma confidence ellipses of the gale crater soils sampled by APXS. At Gale crater, the Na+K and Si are higher in coarse grained soils than fine grained soils. This difference is difficult to observe when soils were detected by orbiter or APXS. The ellipse of the Jezero crater soils sampled by SuperCam has inconsistent direction of distribution with other confidence ellipses, which may imply the soils at Jezero crater experienced more complex geological processes.

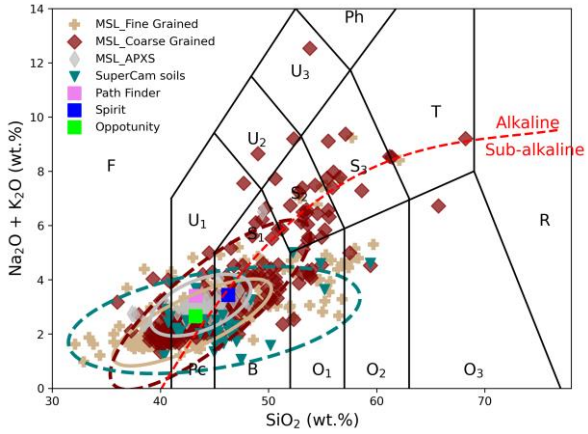

Fig. 5. TAS diagram of the soils probed as five landing site on Martian surface. The ellipses are the 2 sigma confidence ellipses for different type soils, and the points and ellipse for individual type soil were displayed with same color.

Summary: LIBS payload can probe soils at submillimeter scale. Gale crater soils sampled by ChemCam were classified into four classes based on their granular sizes. And more than half are fine grained soils. The performance of elastic net employed to quantify Martian targets is well. The elastic net score of each major element and element concentration have a good positive correlation. Elastic net scores suggest that fine grained soil is homogeneous within the depth ablated by 10 pulses, and that coatings of pebble and underlying materials have different chemical compositions. The compositions of soils at five landing sites are generally homogeneous. However, the elemental compositions of different grained soils are different.

Acknowledgments: This work is supported by the funds from the National Natural Science Foundation of China (U1931211, 11941001, 41972322). We also thank the Pre-research project on Civil Aerospace Technologies No. D020102 funded by China National Space Administration (CNSA), and the Natural Science Foundation of Shandong Province (ZR2019MD008).

References: [1] Boynton W. et al., (2007) *JGR*,112. [2] Edgett K. S. and Christensen P. R., (1991) *JGR*, 96, 22765-22776. [3] Mellon M. T. et al., (2000) *Icarus*, 148, 437-455. [4] W. Xu, X et al., (2021) *SSR*, 217. [5] Wentworth C. K. (1922) *Geology*, 30, 377-392. [6] Le Mou ic S. et al., (2015) *Icarus*, 249, 93-107. [7] Clegg S. M. et al., (2017) *SAB*, 129, 64-85. [8] Anderson R. B. et al., (2017) *SAB*, 129, 49-57.