

Surface Properties of Lunar Regolith Grains: Current Investigations and Questions for Future Missions

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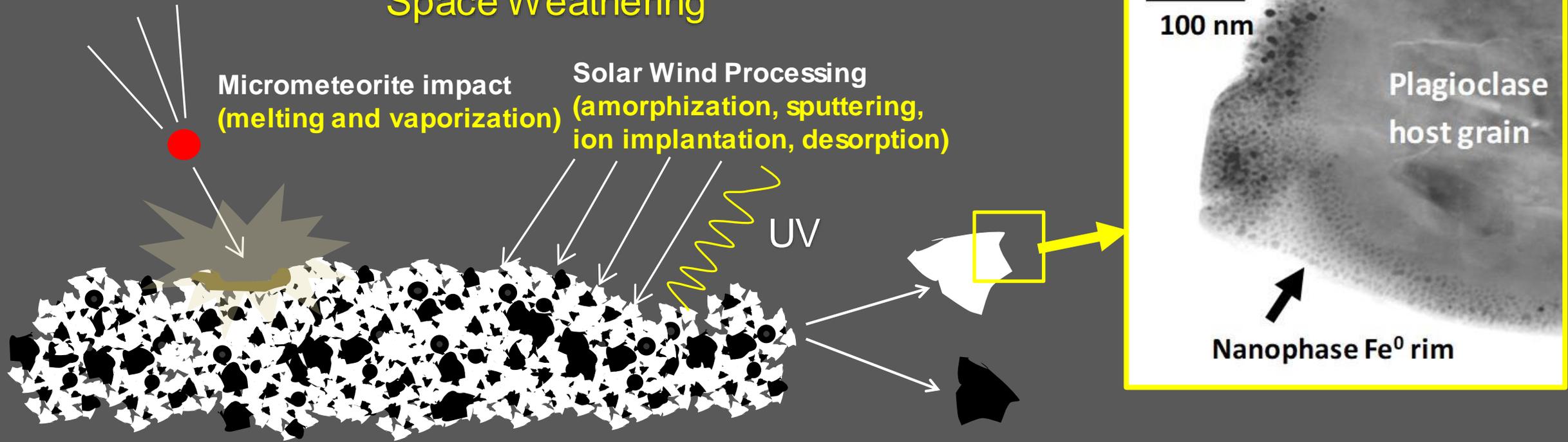
ASTROMATERIALS RESEARCH AND EXPLORATION SCIENCE
JOHNSON SPACE CENTER



Lunar Surface Science Workshop – Dust and Regolith
August 20, 2020

The Surfaces of Lunar Regolith Grains

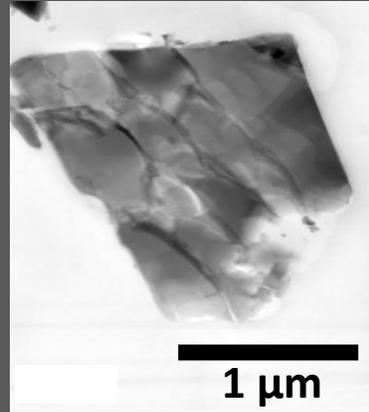
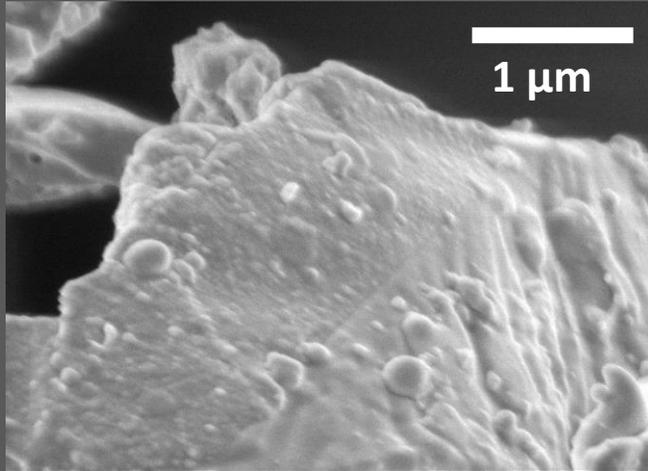
Space Weathering



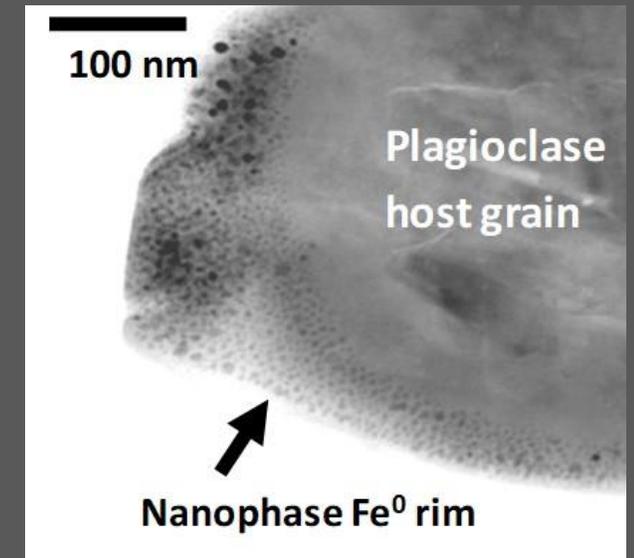
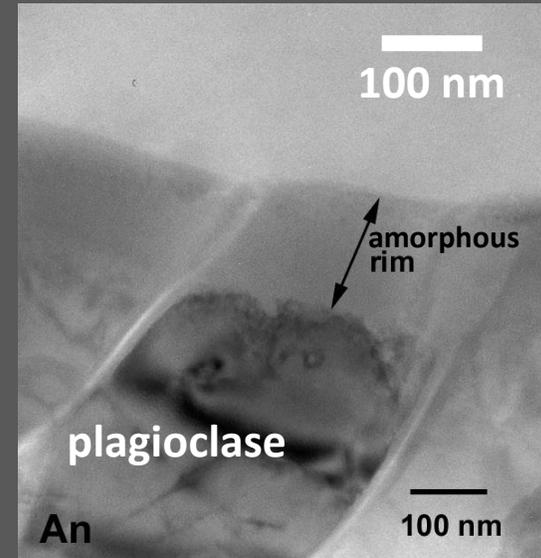
- Grain surfaces record a complex multi-stage history of lunar soil evolution
- Regolith maturity, remotely sensed optical properties, physical and chemical properties

Lunar Grain Surfaces: What We Know

Scanning Electron Microscopy (SEM)

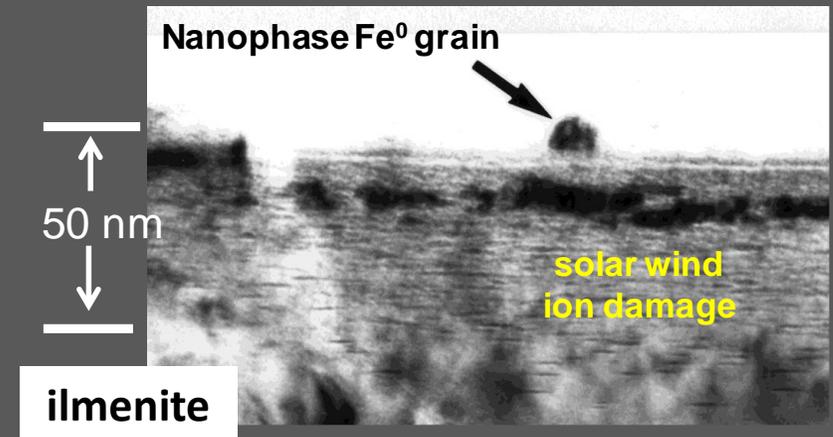


Transmission Electron Microscopy (TEM) (grain sectioning by ultramicrotomy)



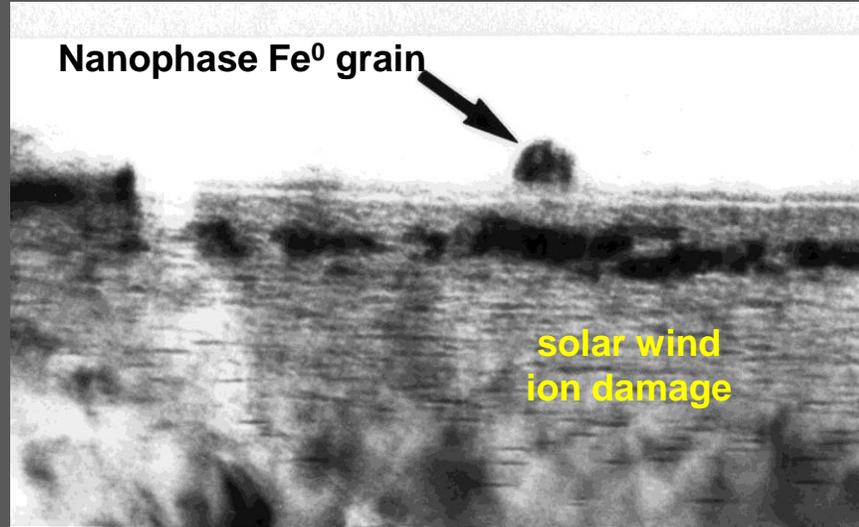
Grain surfaces at the TEM scale are combinations of:

- An “inner” layer produced by solar wind ion damage to the crystalline host grain
- An “outer” amorphous vapor deposit rich in nanophase metallic Fe.

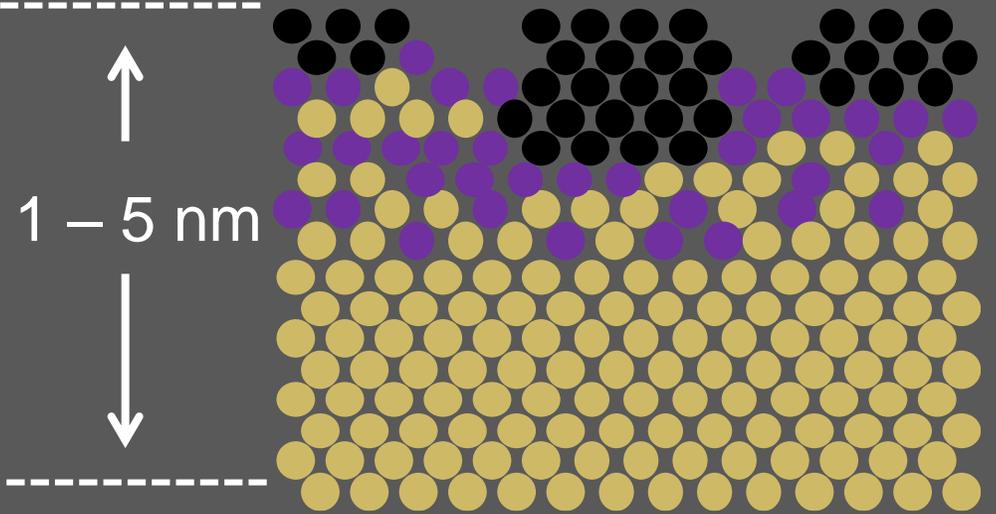


The Next Level: TEM-Scale “Surface” to True Surface Science

TEM – ilmenite grain rim



Surface Science



Why extend to the true surface scale?

- “The atomic face to space” – controls how lunar grains interact with the lunar space environment, e.g. surface charging, exosphere, day/night effects, volatiles, water and ices
- Records history of grain interactions with space environment, e.g., composition of condensed volatiles in volcanic eruption clouds
- For human and robotic exploration systems, may control factors such as grain adhesion, toxicity

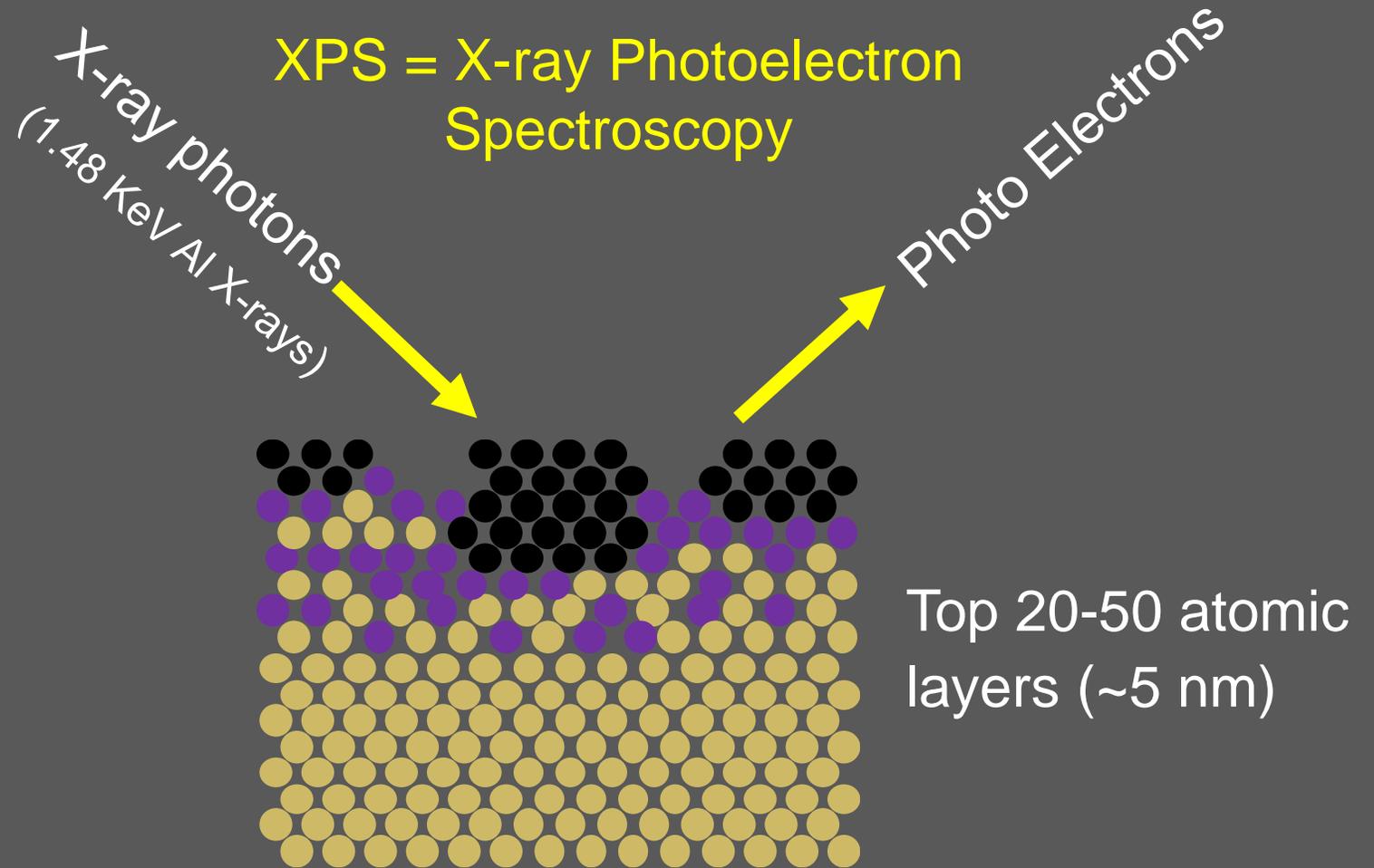
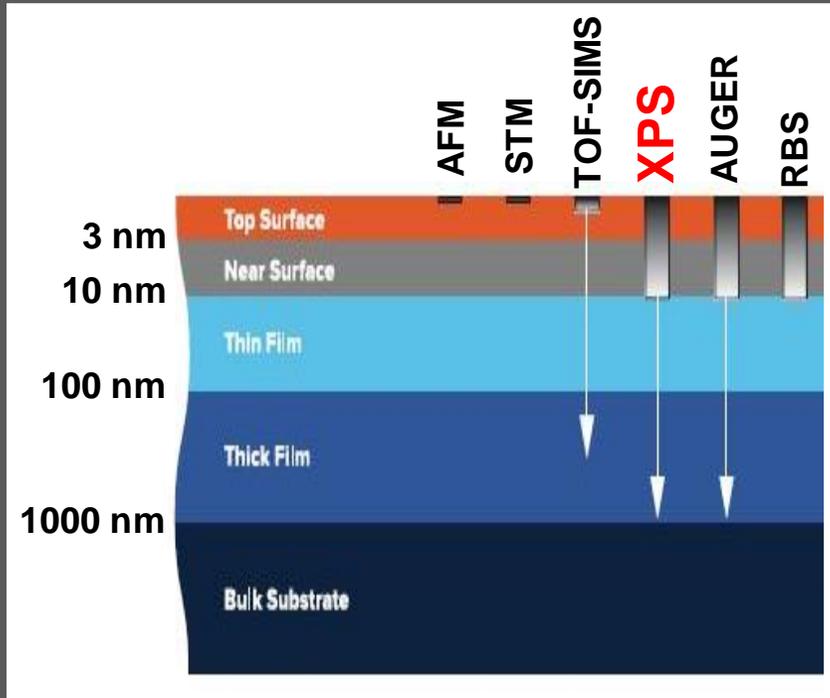
Doing True Surface Science Studies To Support Lunar Science and Exploration Objectives

Top 2 Questions:

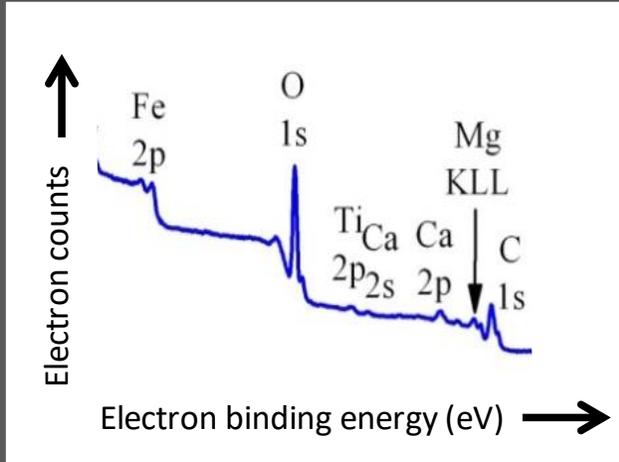
1. How do we design science systems and procedures to collect and return regolith grains with their outer surfaces in as pristine a state as possible (“don’t muss the face to space”)?
2. In evaluating factors such as surface adhesion and chemical activities relative to engineering systems, does perfect surface pristinity affect the fidelity of engineering tests (“what makes lunar grains stick?”)

Surface Science

A diverse set of approaches and laboratory techniques for investigating the chemical and physical state of solid surfaces.



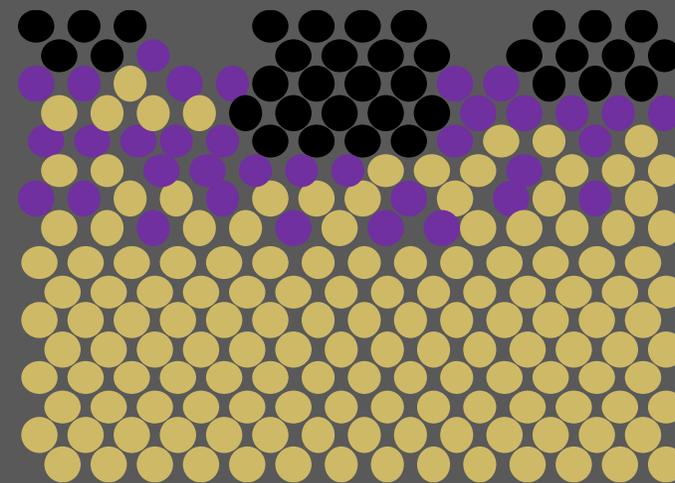
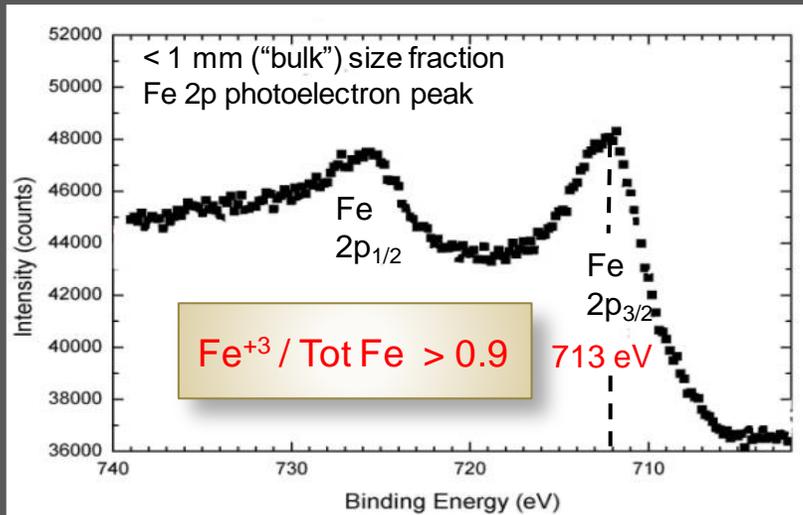
XPS : Chemical Composition / Oxidation State Analysis at Surface "Monolayer" Scale



XPS = X-ray Photoelectron Spectroscopy

X-ray photons (1.48 KeV Al X-rays) →

Photo Electrons ←



XPS Analysis of Lunar Regolith Grains

- A fairly active area of research in post-Apollo decade
- First discovery of “Fe surface enrichment”, metallic?

Proc. Lunar Sci. Conf. 7th (1976), p. 881–889.
Printed in the United States of America

ESCA studies of the surface chemistry of lunar fines

R. M. HOUSLEY and R. W. GRANT

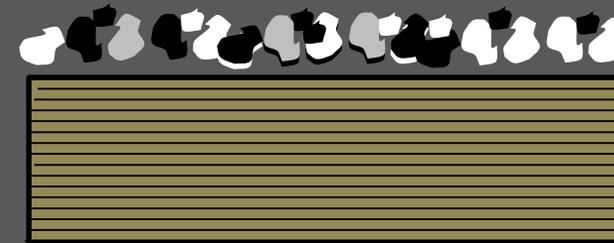
Rockwell International, Science Center, Thousand Oaks, California 91360

Abstract—We present an ESCA analysis based on the use of a synthetic lunar glass standard that allows us to determine the surface composition of lunar samples with an accuracy that appears to be better than 10% of the amount present for all major elements except Ti. With this analysis we have found that, on the average, grain surfaces in the lunar fines samples 10084 and 15301 are strongly enriched in Si, moderately enriched in Fe, moderately depleted in Al and Ca, and strongly depleted in Mg. This pattern could not be produced by the deposition of any expected meteoritic vapor. Neither could it be produced by simple inverse mass dependent element loss during sputtering. We suggest that at least part of the pattern may be a simple consequence of agglutinate glass formation in the fines since there is some evidence that Si can become enriched on the surface of silicate melts. Our results do not support the strong enrichments in Fe on grain surfaces reported from Auger studies.

XPS = X-ray Photoelectron Spectroscopy

X-ray photons
(1.48 KeV Al X-rays)

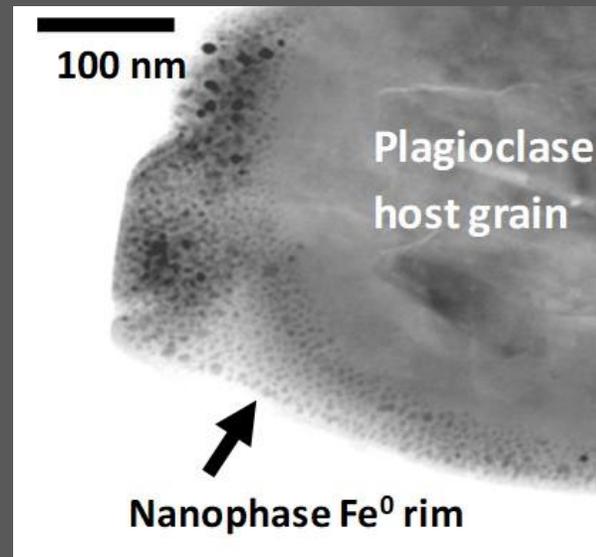
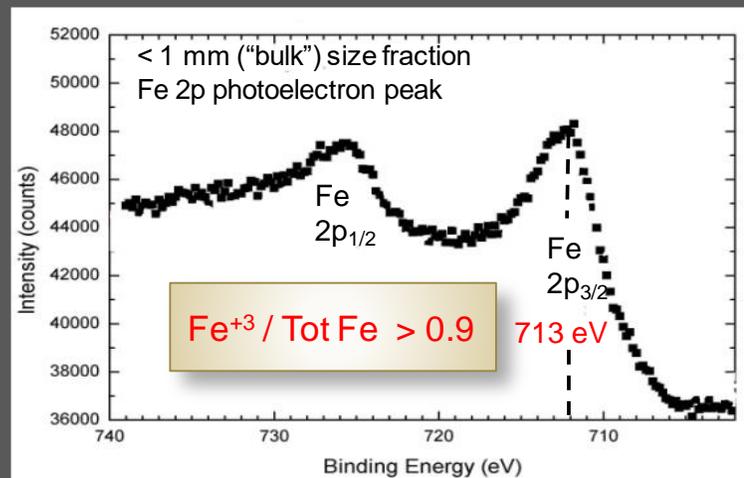
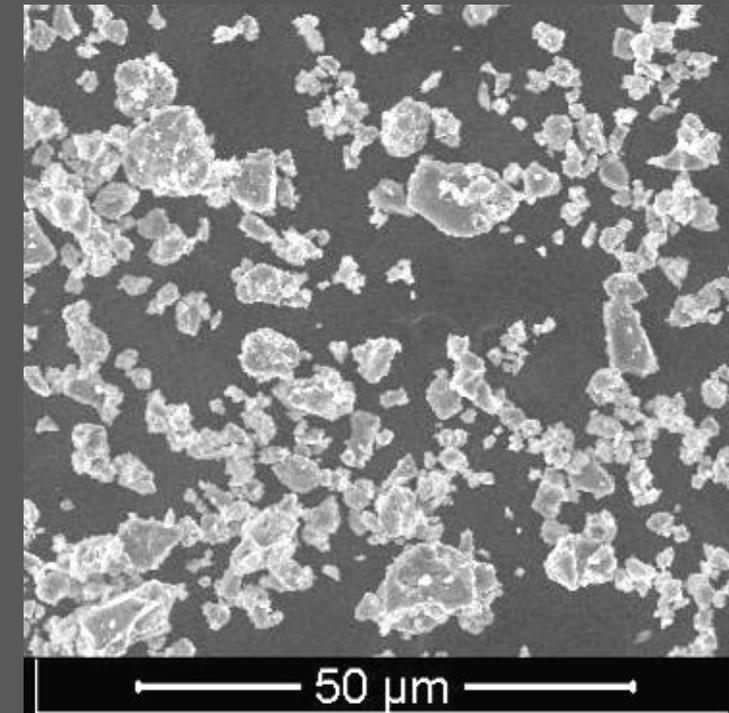
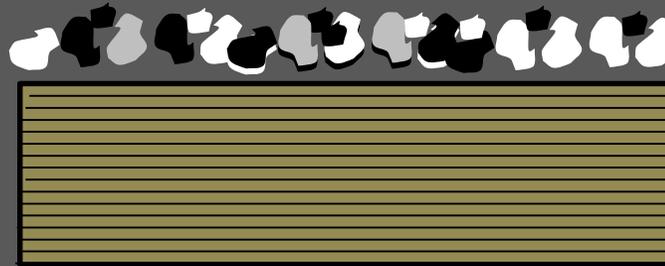
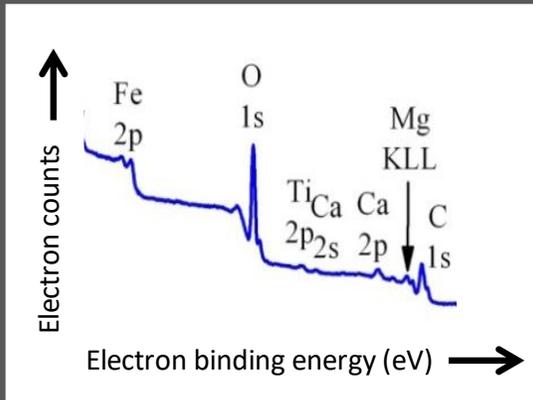
Photo Electrons



bulk lunar soil

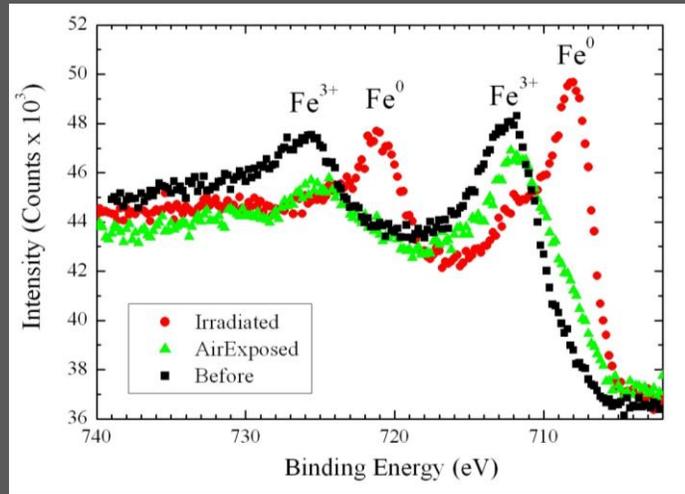
Contemporary XPS and In-Situ Ion Irradiation Study of Bulk Lunar Soil 10084

- 10084 is a “mature” lunar mare soil
- “Sprinkle coated” dry sieved <20 μm grain on freshly cleaved pyrolytic graphite

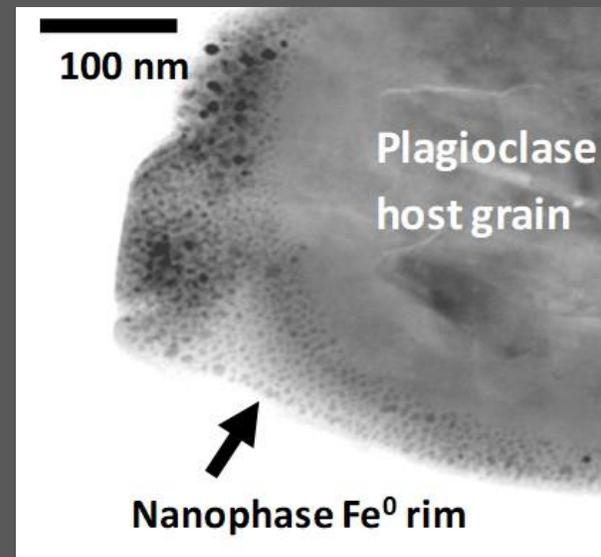
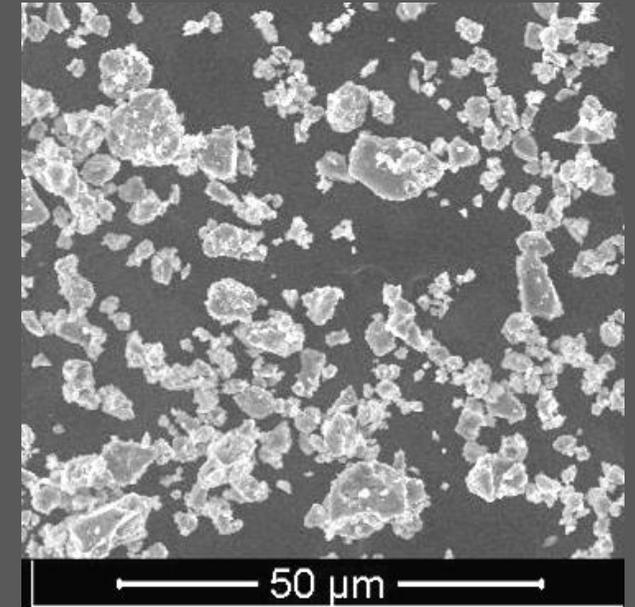
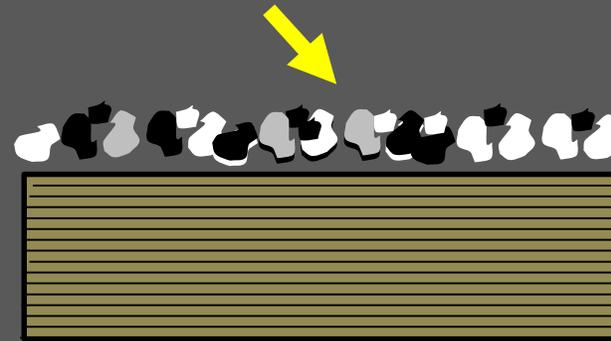


In-Situ Ion Irradiation Under UHV Conditions with 4 keV He⁺ ions

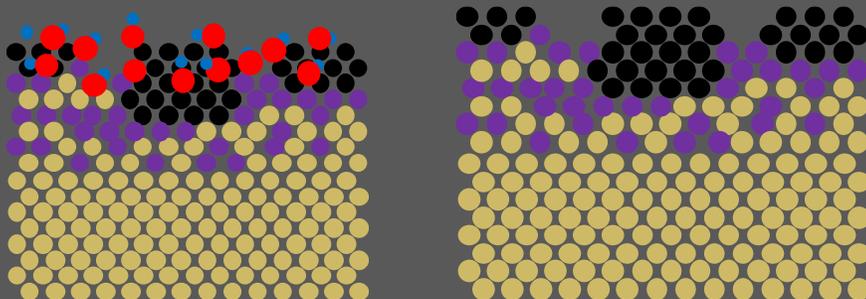
- Combine XPS with in-situ ion irradiation with 4 keV He⁺ (“solar wind”)
- High resolution Fe 2p spectrum scans before, after irradiation and after air exposure



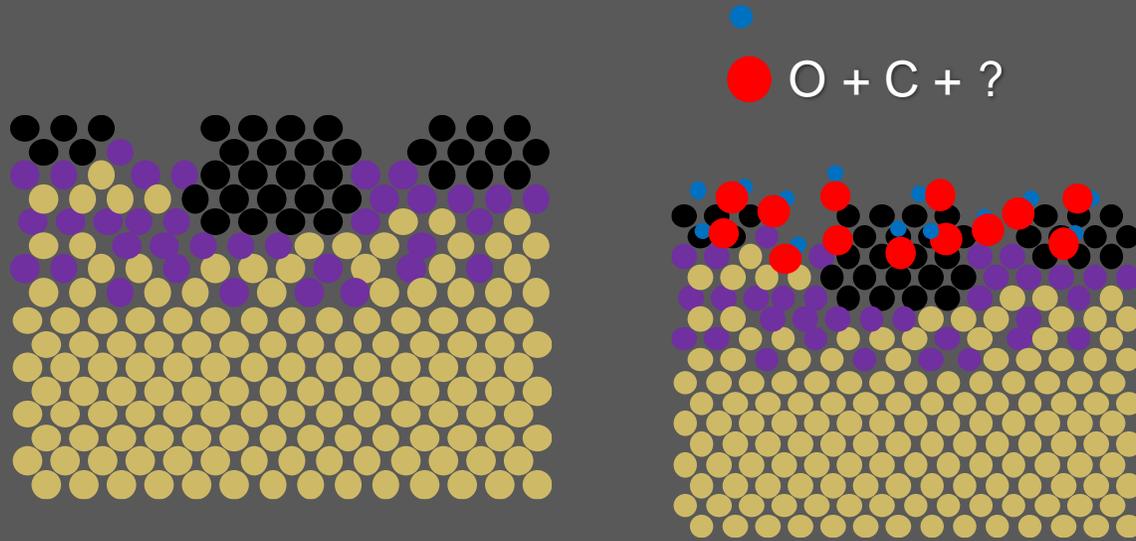
4 keV He⁺



● O + C + ?



What does this tell us?



- Chemical and physical adsorption of volatile species is **RELENTLESS** at monolayer scale
- Presents a challenge to determining the surface chemistry of **regolith grains as they occur “with their face to space” on the lunar surface.**
- Returning samples with “pristine” surfaces for analysis may be simple or unexpectedly challenging

