Re-Assessment of "Water on the Moon" After LCROSS

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History of Water on the Moon

Lunar Surface subjected to impactors from meteoroids and comets along with solar wind.

Volatiles from impactors sublimate to COLD TRAPS: i.e. permanently shadowed lunar polar regions and beneath lunar rocks

Watson, Murray, and Brown, (1961) and Arnold (1979)

Sources of Lunar Water

- **Solar Wind** (Proton irradiation on silicates and/or reduction of Fe in the regolith)
- H_2O-containing **meteoroids**
- **Cometary** impacts
- **Degassing** of the lunar interior (least certain)
- **Contaminants** from space activities at the Moon (boosters impacting surface, outgassing, etc.)

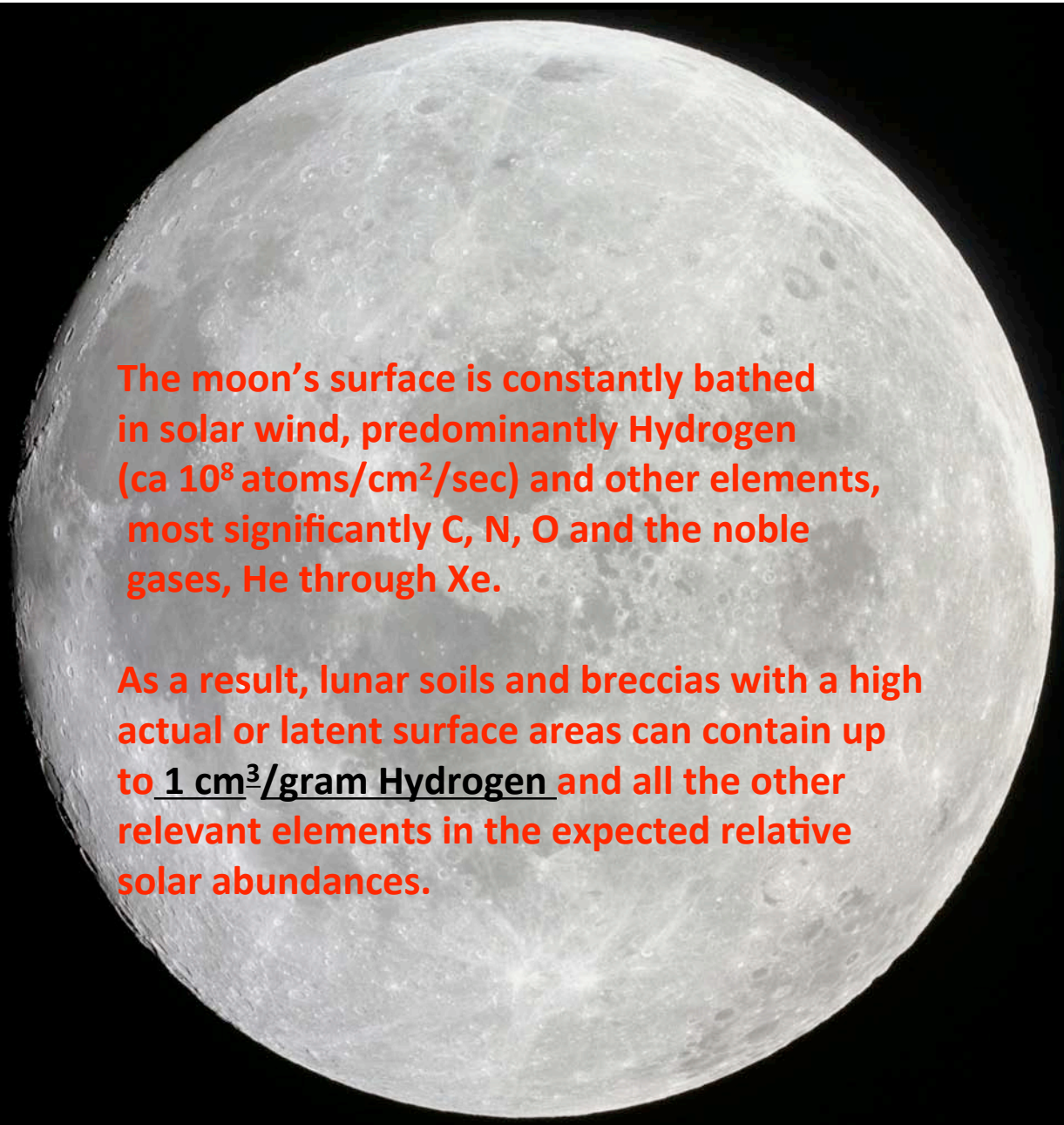
Amount of H_2O trapped at poles is estimated to be in range of 10^{16} to 10^{17} gms in trap zones or 5 to 50 g/cm^2 per unit area.

Loss Mechanisms for Lunar Water

Photodissociation -- Destroys half the molecules on their way to the cold traps or much more if strongly adsorbed molecules are exposed to solar UV for long periods

Solar Wind Removal of Species in Exosphere -- Either removed from lunar environment or implanted on surface materials

Meteoroid Bombardment -- Lunar Gardening -- and irradiation causes loss of water in upper tens of nanometer of silicates



The moon's surface is constantly bathed in solar wind, predominantly Hydrogen (ca 10^8 atoms/cm^2/sec) and other elements, most significantly C, N, O and the noble gases, He through Xe.

As a result, lunar soils and breccias with a high actual or latent surface areas can contain up to 1 cm^3/gram Hydrogen and all the other relevant elements in the expected relative solar abundances.

SOLAR WIND

History of Water on the Moon

Returned lunar samples showed hydrogen enrichment in soils and rock surfaces from solar wind

BUT

Samples from nine sites did not show large abundances of volatiles

And Remember:

NO Polar Sites have been sampled

History of Water on the Moon

Absence of lunar magmatic water detected in

lunar basalts

[abundances of <2 to 5 μgH/g]

Note: New information on water in lunar magmas suggest higher concentrations of water than originally believed BUT these new results should not come into play for current lunar ices, etc. discussions

Water formed on surfaces of lunar silicates by proton (i.e. H atoms) irradiation of the oxygen targets available.

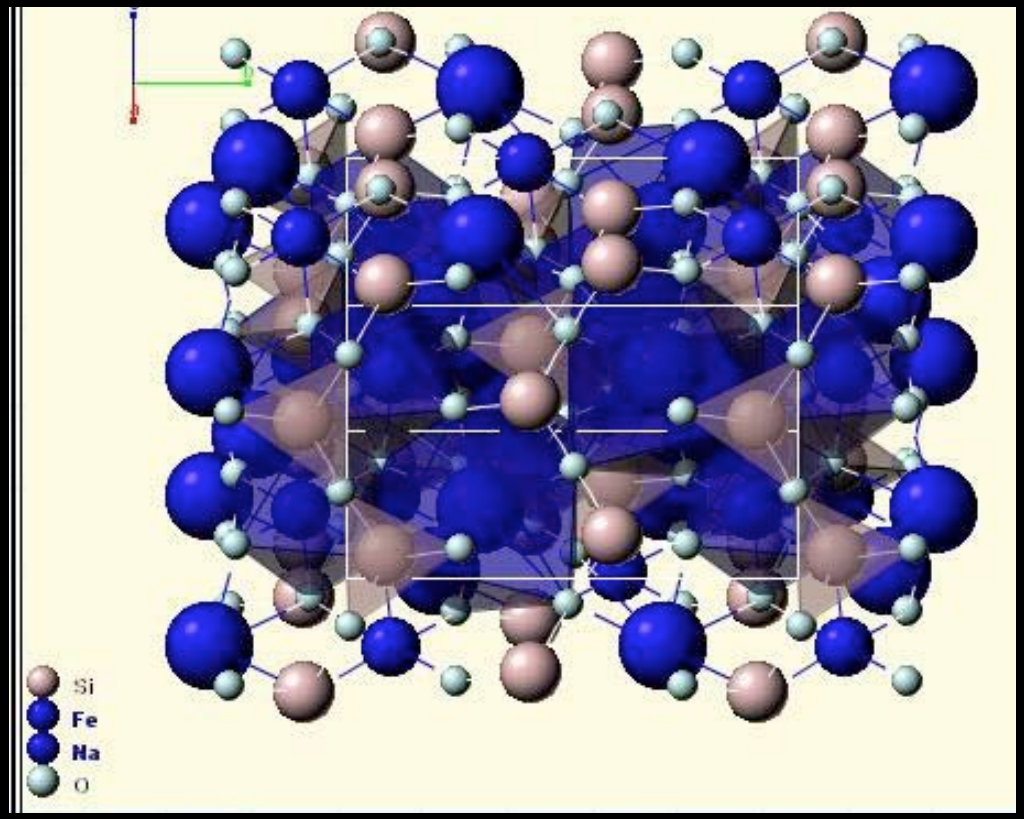
By volume the lunar silicates are around 90% oxygen –

"Big Targets" to produce H_2O

Material Surfaces Have "Dangling Bonds" The Conceptual View

Four Chemical Bonds for Atoms in interior are fully compensated.
Bonds for atoms on exterior are not, particularly on rough surfaces.
Limit to extent that bonds can distort geometry to compensate.
This renders material surfaces active sites for chemisorption & chemical reactions.

Silicate Rocks much more complex in structure, but principle still applies.



Any unsatisfied bond can be chemically reactive.

On Earth, rock surfaces become quickly neutralized because of the common presence of reactive gases such as oxygen, water, etc.

For Lunar Regolith several processes can continually create "reactive" material surfaces:

1) Impact grinding / breaking the silicate into smaller pieces;

2) Other forms of Energy input sufficient to break chemical bonds:
   a) Bombardment by energetic solar or galactic protons
   b) Strong photon (UV, X-ray) bombardment

What happens when soils are heated?

Volatile Release from Lunar Soils

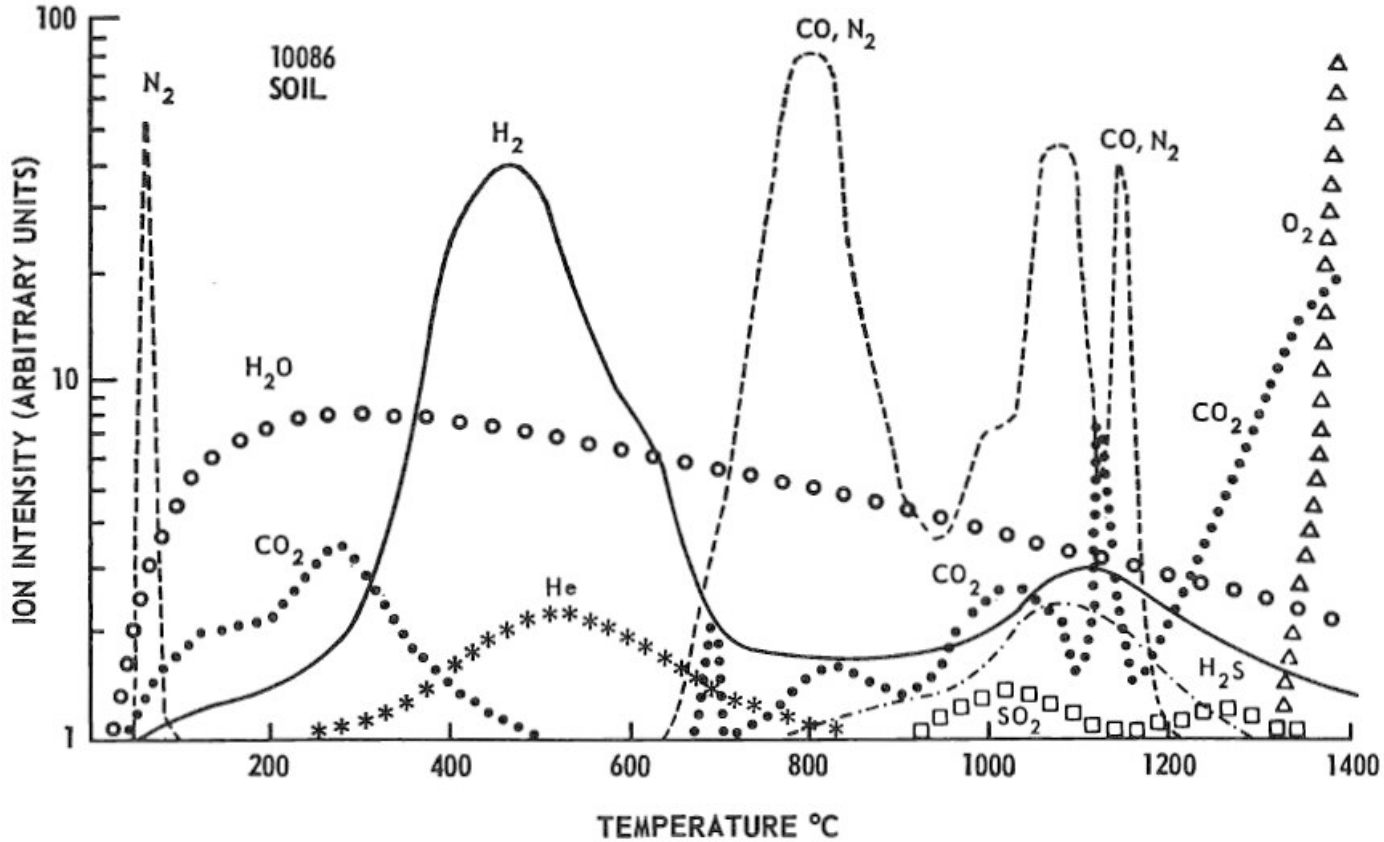
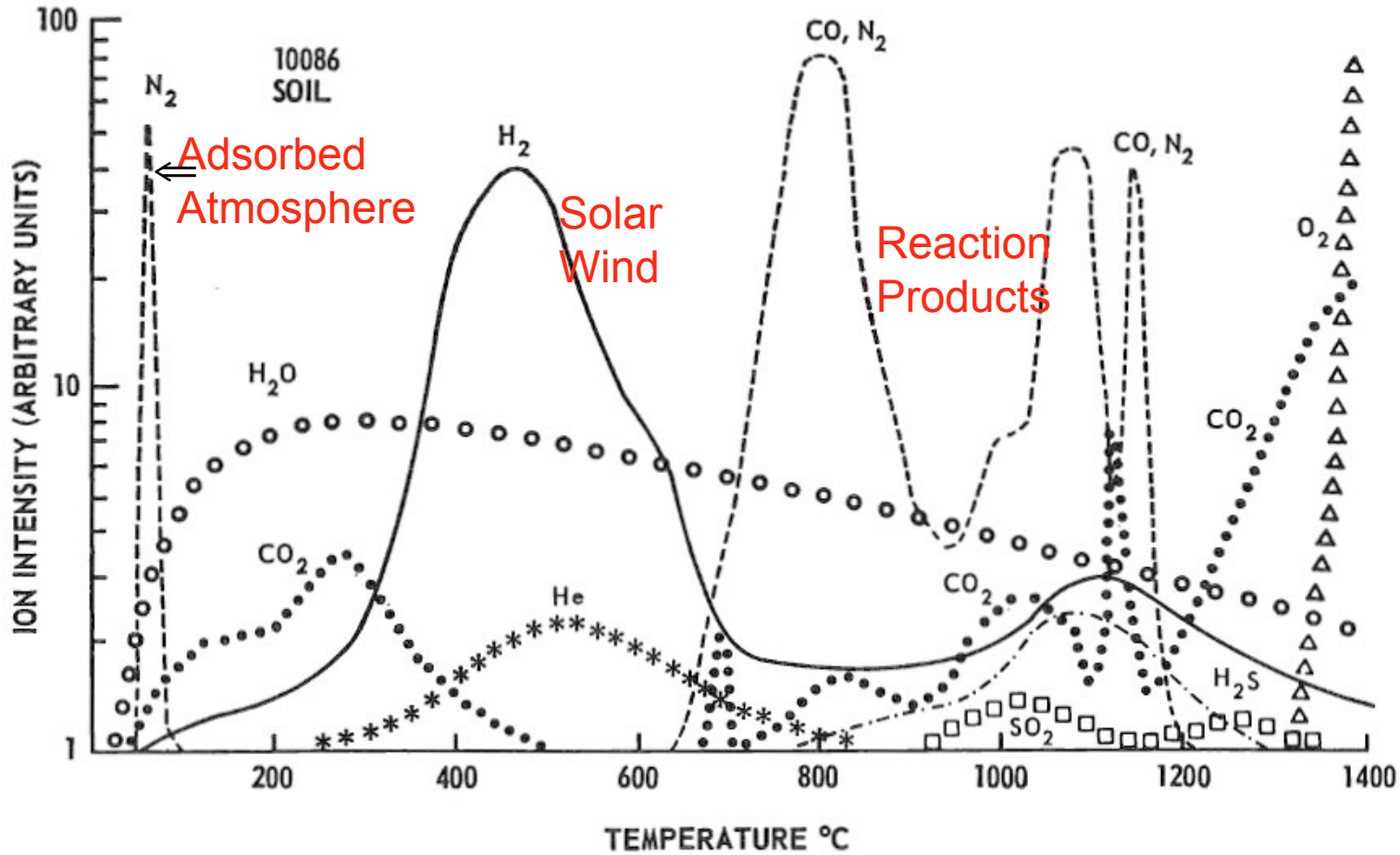


Fig. 1. Gas release pattern for Apollo 11 soil 10086,16. Sample weight 242.94 mg. Heating rate 4°C/minute.

Gibson and Johnson, LPSC 1971

Volatile Release from Lunar Soils



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Volatiles Released from Lunar Simulants

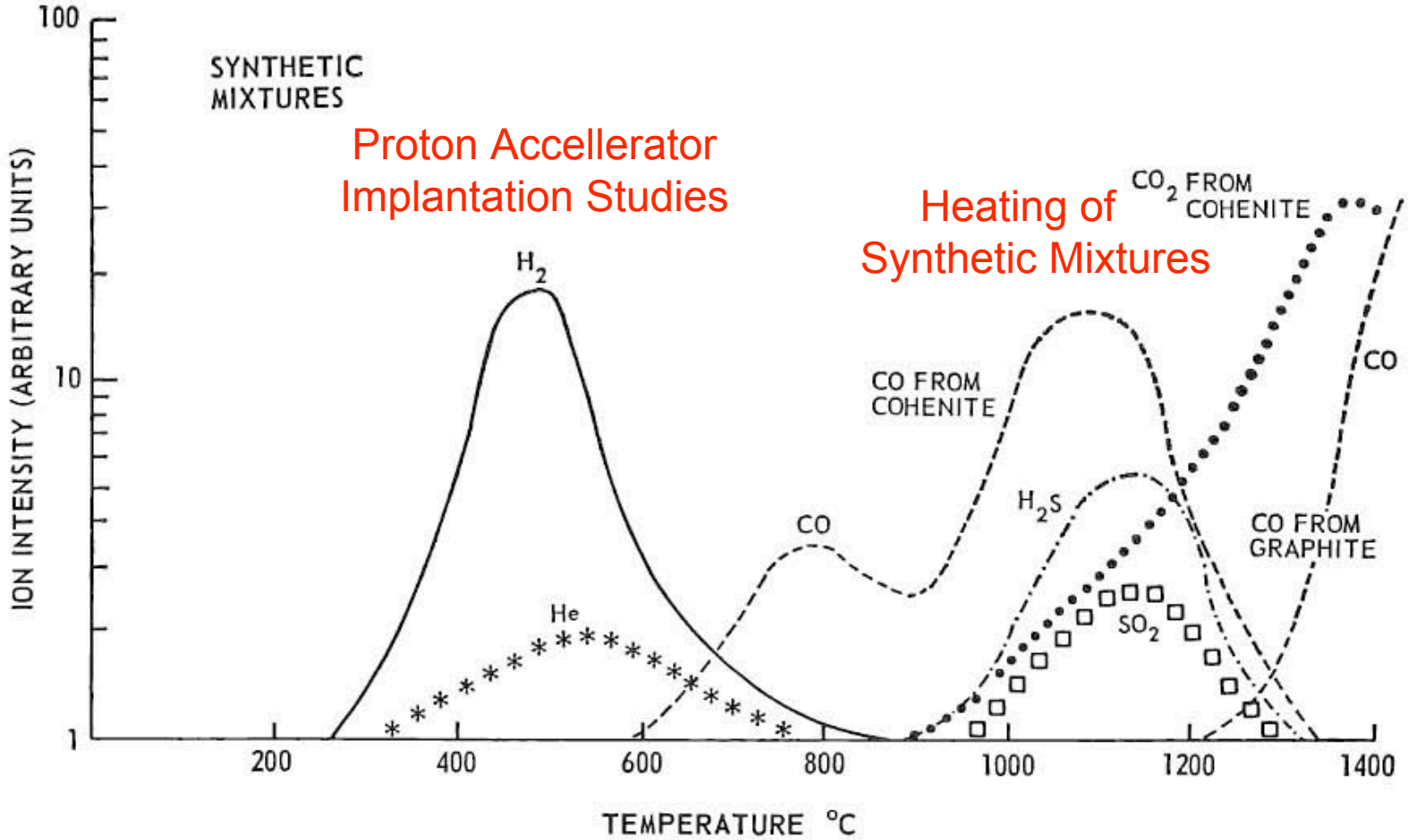


Fig. 5. Gas release patterns for synthetic lunar analogs. Matrix composed of olivine, pyroxene, and anorthite, with <5% troilite, cohenite, and graphite added. The H_2 and He release patterns are taken from LORD, 1968. The CO released below 1200°C is from the reaction of cohenite with the silicate matrix. All of the CO_2 observed is

Gibson and Johnson, LPSC, 1971

Solar Wind Species in Lunar Soils are Grain Size and Surface Area Dependent

Hydrogen and solar wind species are two to three orders of magnitude enriched in the <20 micron size fraction of lunar soils

107 to 146 μg/g H for <20 micron fraction in bulk lunar soils

Lunar Breccias have H concentrations up to 160 to 180 μg/g [gases released during formation of breccias are retained within the glasses found in samples]

Lunar Rocks typically have <2 to 5 μg/g

History of Water on the Moon

Hydrogen abundances in bulk lunar soils range from 3 to 60 μg/g

Average is 36 μg/g for 80 soils analyzed

Hydrogen concentration is directly related to maturity of soil measured by [I_s/FeO]

[Amount of fine grain metallic iron]

Immature,	Submature and	Mature Classes
11 μg/g	35 μg/g	45 μg/g

History of Water on the Moon

Unusual Samples

Lunar Cores

A-17 3 meter core: 5 to 70 μg/g

H abundances related to maturity NOT depth

Soil 61221 with Cometary Gases

H_2O, H_2, CH_4, HCN, CO_2, etc. **Adsorbed gases**

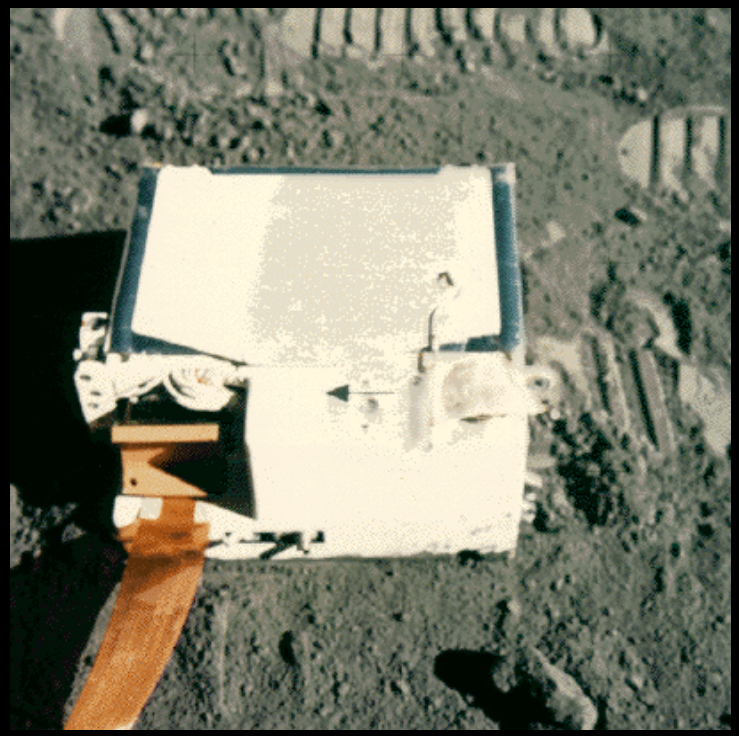
74220 Volcanic Orange Glass, **15426 Volcanic Green Glass**

Sulfur species, Zn, Cl, Br, etc. **Coatings on Surface** of spheres

Recent ion probe studies suggest water in glasses

Water increases in abundances toward interior

Apollo 17 Lunar Atmospheric Composition Experiment

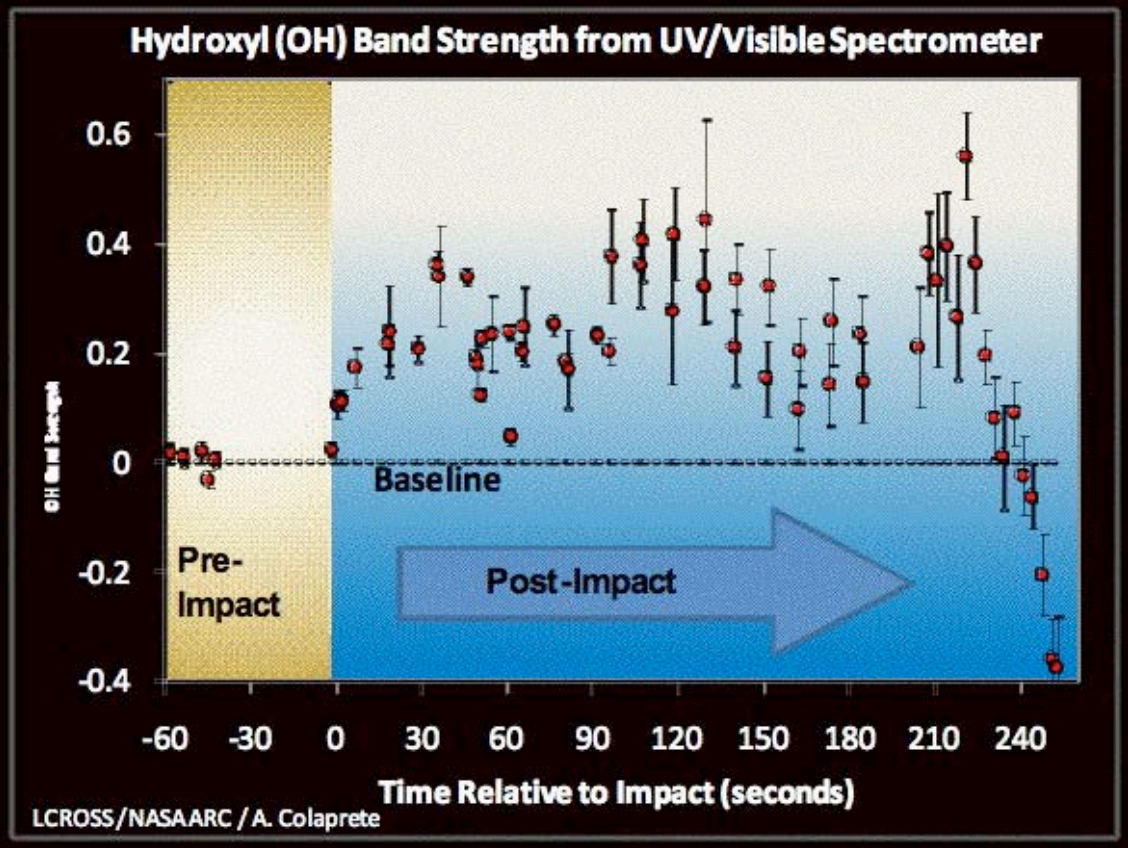


Mass spectrometer detected increased abundance of ions at masses 15, 16, 17, 18, 28, 40, 44 immediately post-dawn of the lunar day, compared with the night-detected species.

Detected volatiles are similar to LCROSS's observed species.

Impact temperatures associated with the LCROSS impact were ~500°K similar to those needed to release low-temperature adsorbed volatiles from lunar samples.

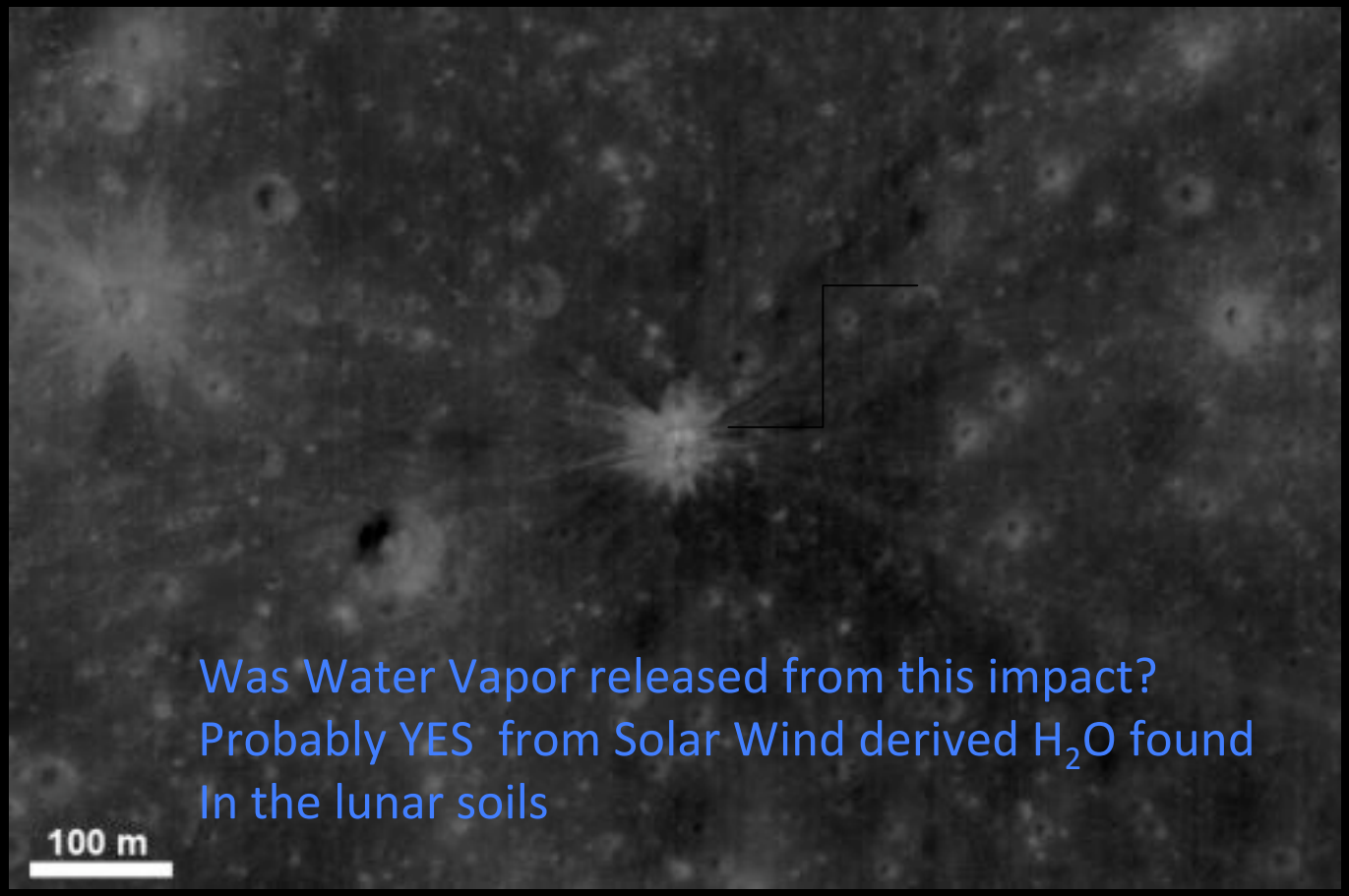
Hydroxyl Release Upon Impact



Question: Could this be SOLAR WIND Derived Hydroxyl produced from Solar Wind Hydrogen and NOT from water ice?

CONTROLLED EQUATORIAL IMPACT COULD ANSWER QUESTION

Apollo 14 Upper Stage Impact Crater



Was Water Vapor released from this impact?
Probably YES from Solar Wind derived H_2O found
In the lunar soils

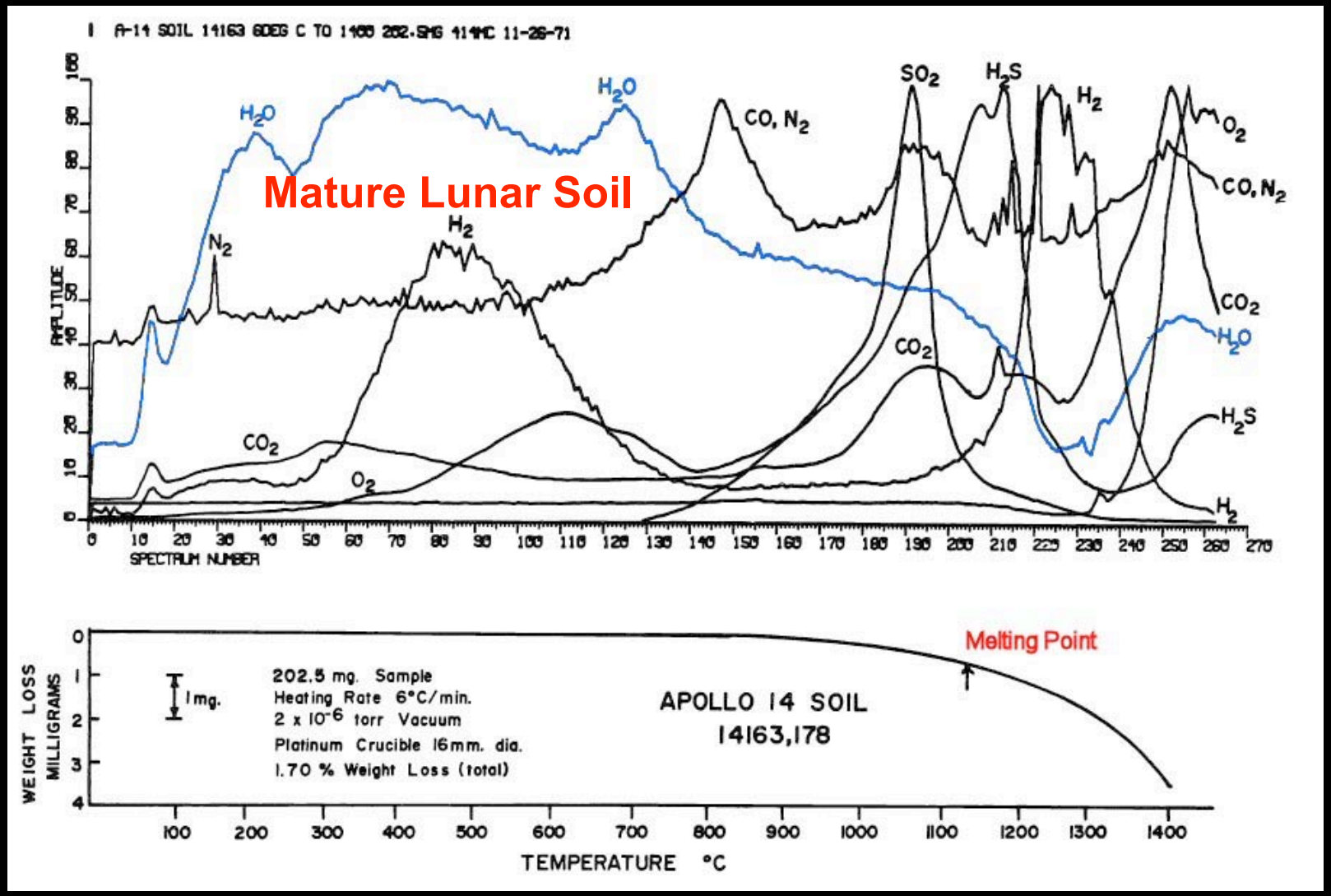
Conclusions

Because of the wide variety of volatiles present within lunar regolith materials and before any interpretation of polar volatiles seen by the LCROSS mission can be properly made, information available within the returned sample collection must be considered.

The volatiles seen by the LRO/LCROSS mission are identical to volatile species observed in "ordinary lunar equatorial regolith materials".

Until the control experiment of having an impactor strike an equatorial site is carried out, CAUTION must be taken when interpreting the "polar water" observations from the LCROSS mission.

Volatiles Released from Lunar Soils

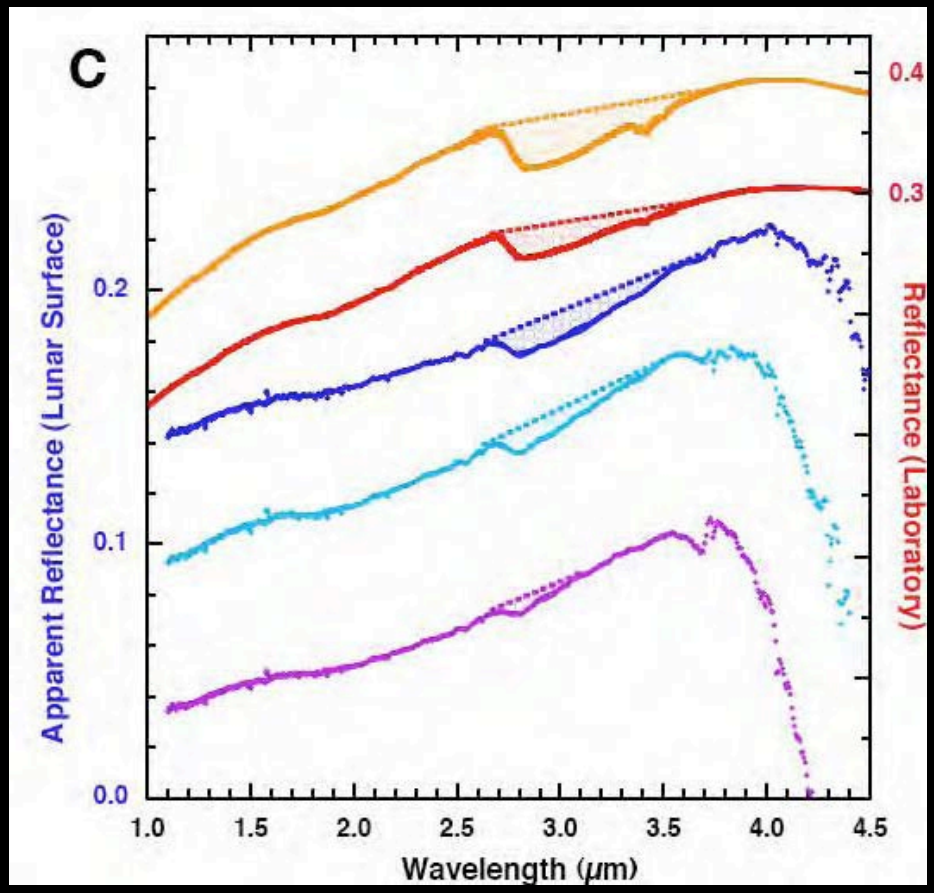


Gibson and Moore, LPSC, 1971

Solar Wind Hydrogen may make lunar water: Interaction of solar H with active surfaces to form O-H (and H_2O?) that neutralize surfaces.

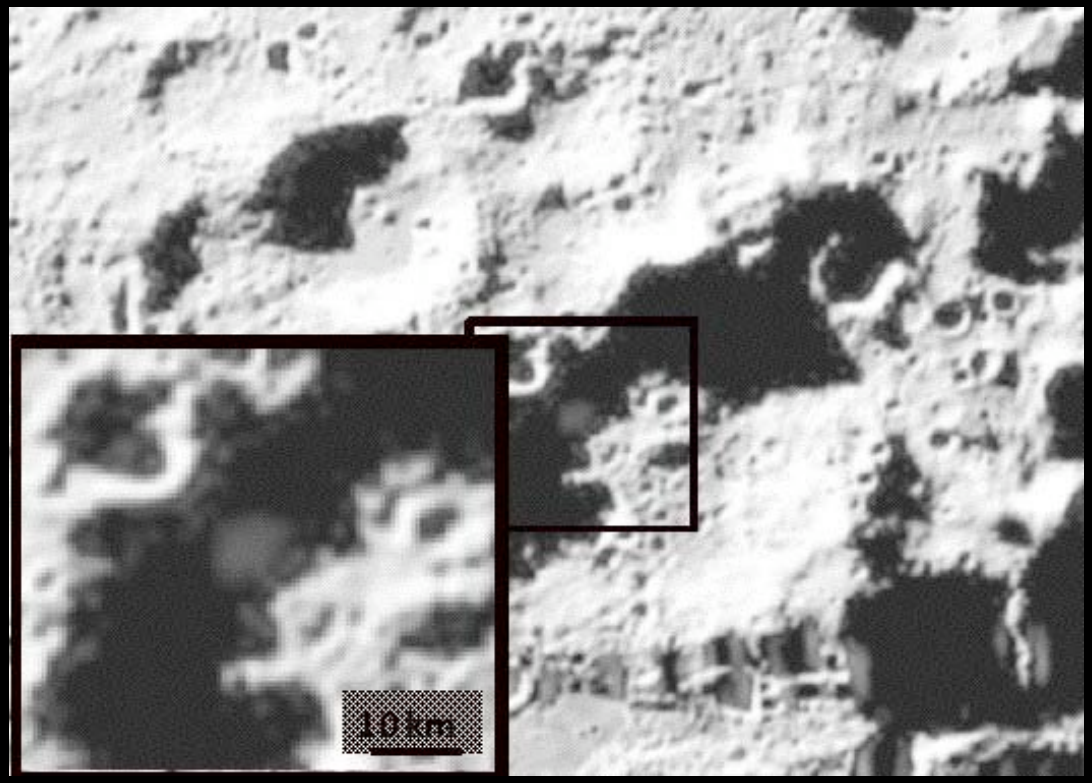
Likely source of some detected lunar O-H bonds.

Deep Impact June 2009 Lunar Fly-by
(Sunshine et al. 2009)
O-H adsorption at 2.8 microns

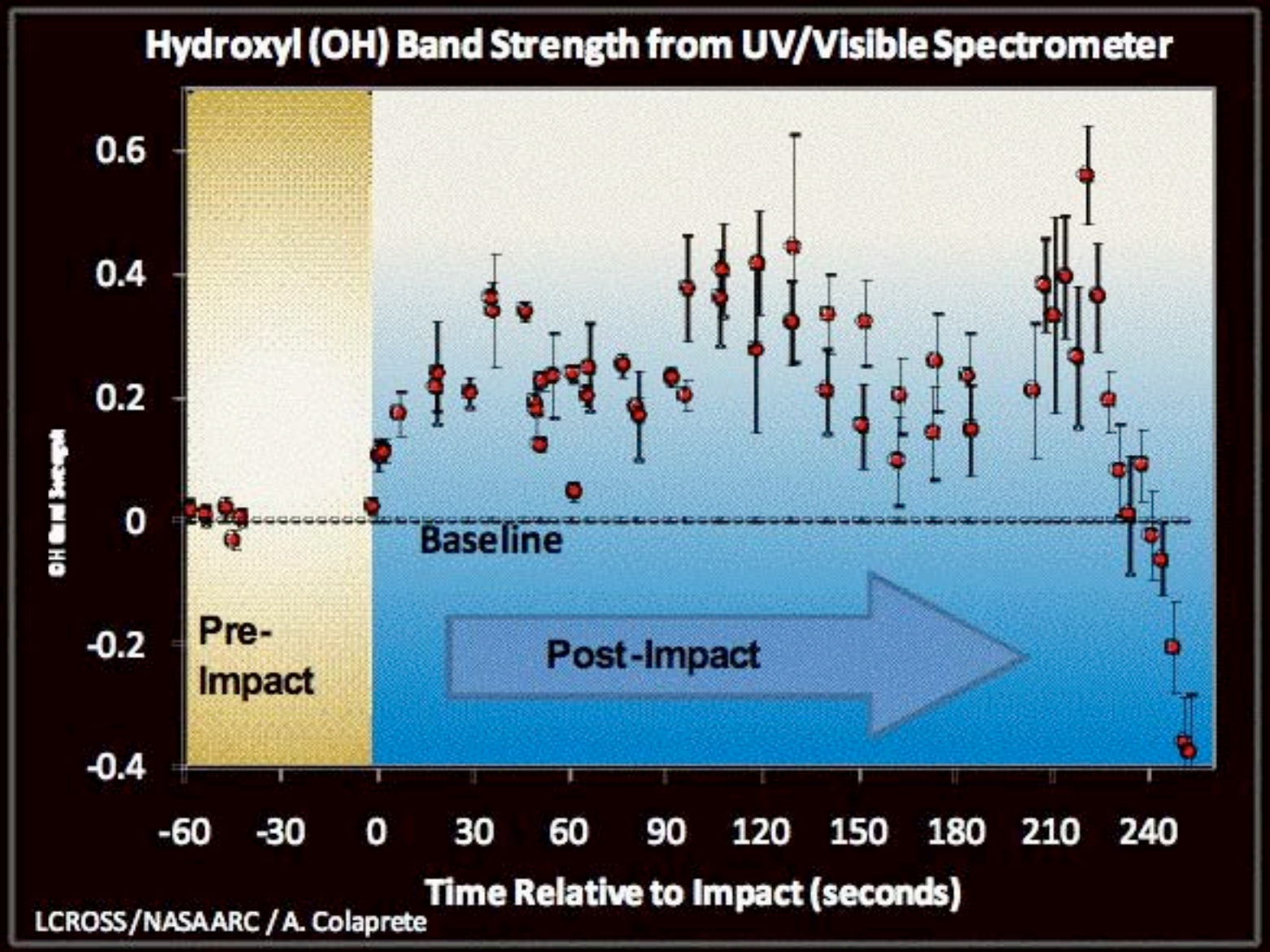


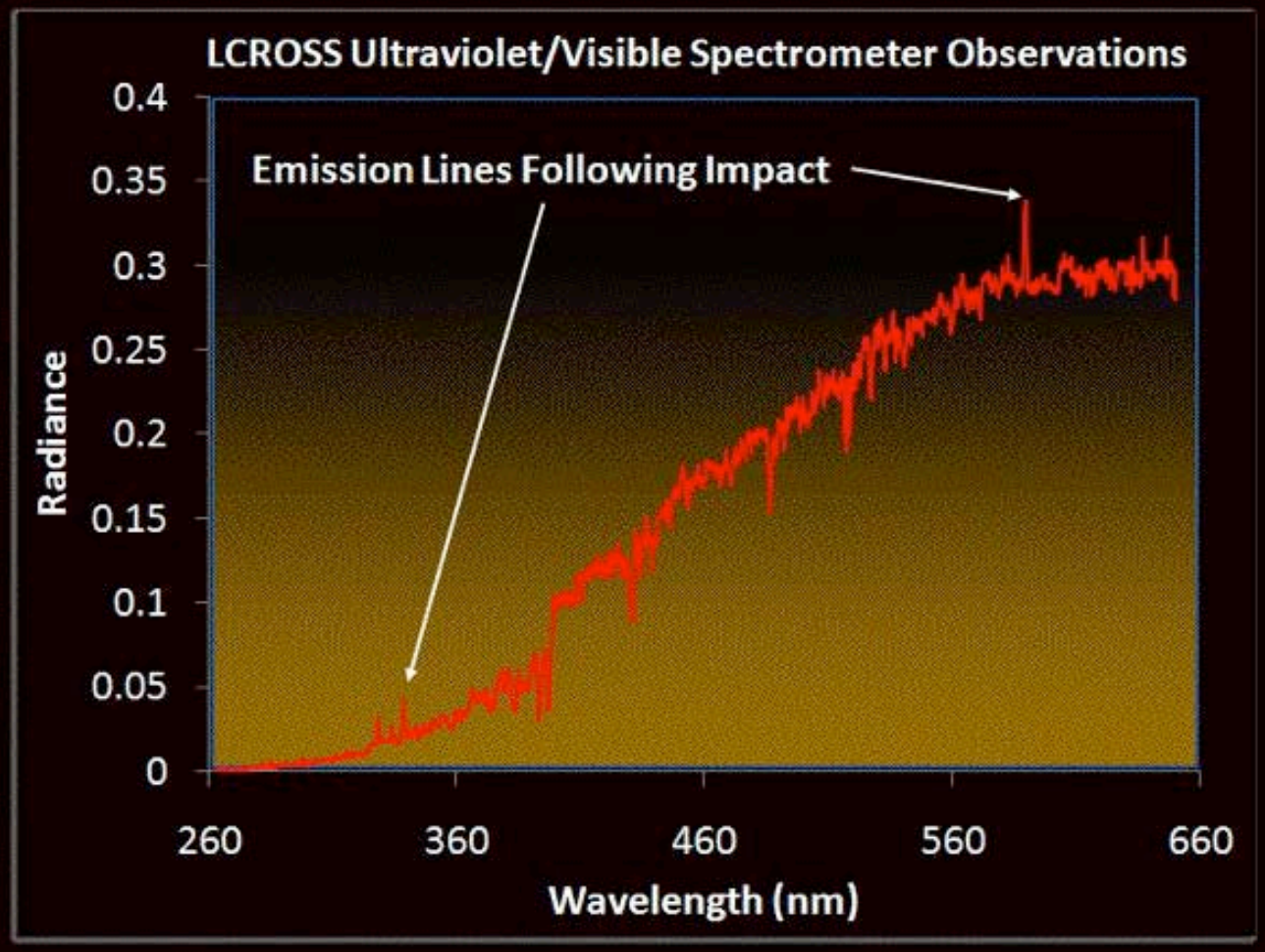
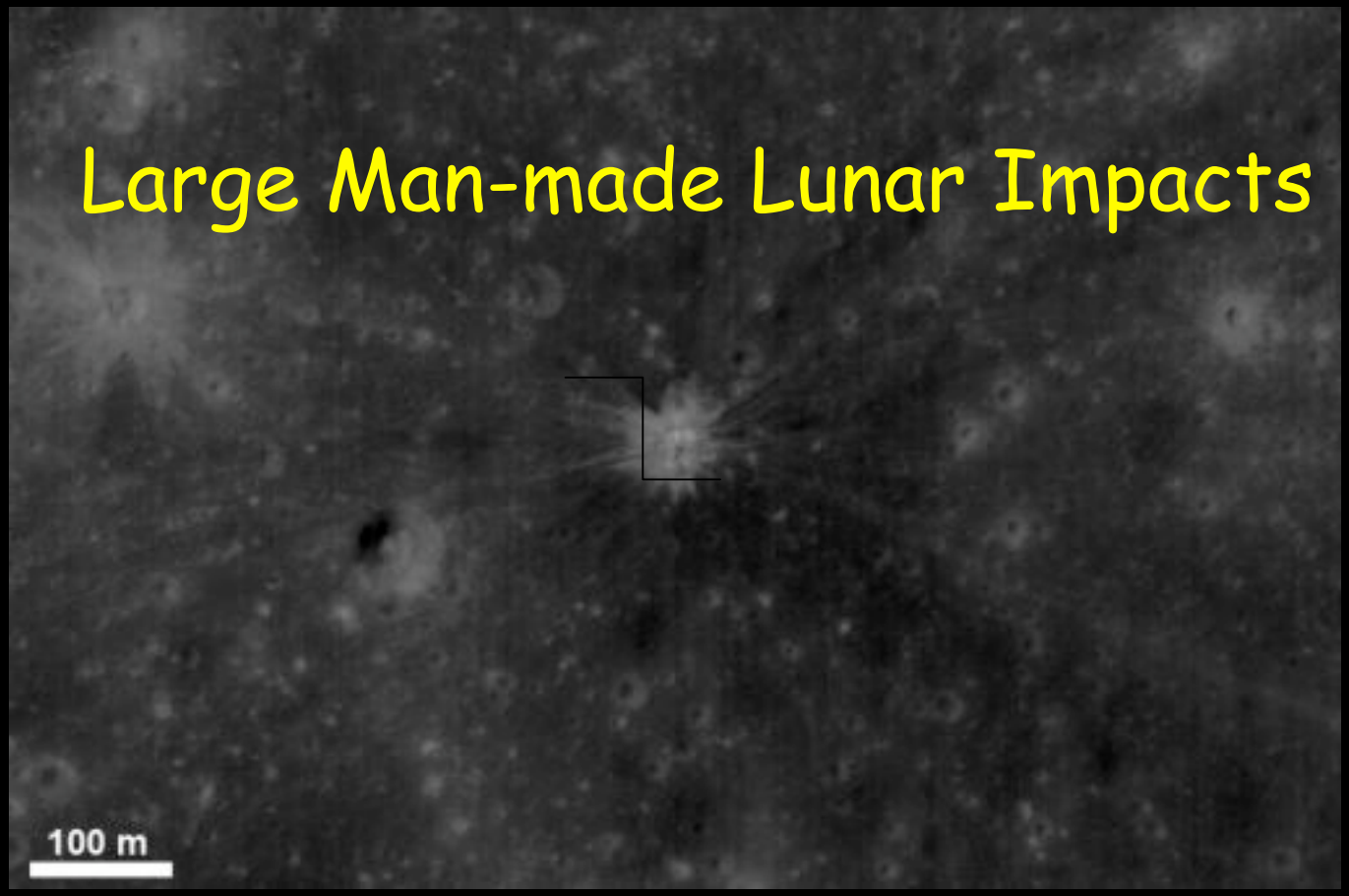
M3 Team on Chandrayaan-1
(Pieters et al., 2009)
blue is O-H adsorption

LCROSS Impact at Lunar Polar Site



Hydroxyl Release Upon Impact




LCROSS Ultraviolet/Visible Spectrometer Observations
Emission Lines Following Impact
Radiance
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
260
360
460
560
660
Wavelength (nm)

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