A RESERVOIR OF WATER ON THE MOON:

Your Tennessee Valley Authority at work

Larry Taylor & Yang Liu

University of Tennessee

Andrew Ichimura & Matt Sanchez

San Francisco State

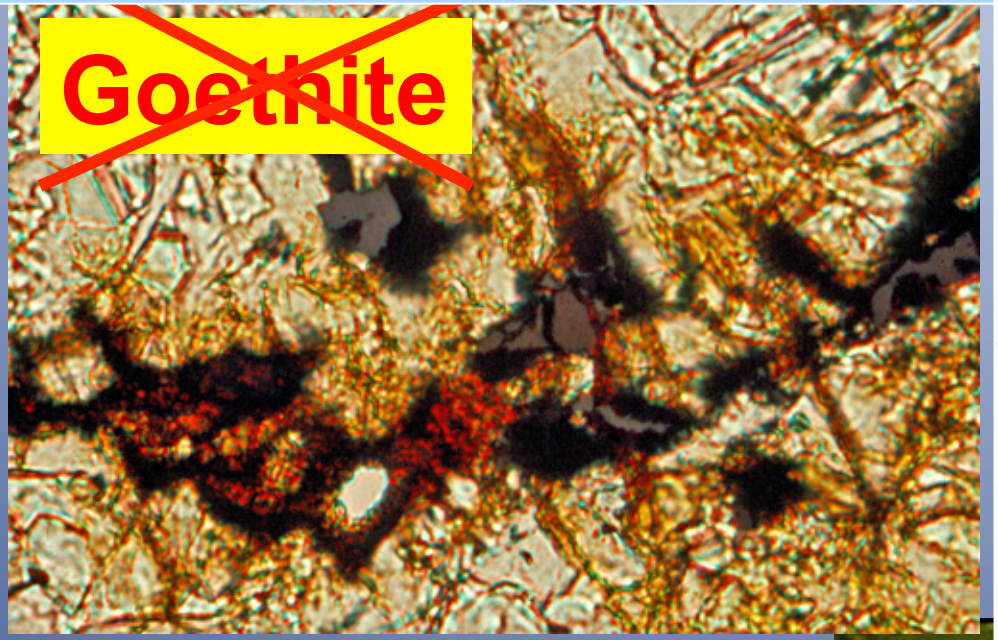
Aaron Zent

AMES Research Center

Richard Quinn

SETI Institute

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu



Selected analyses of FeO(OH) from sample 66095,80

	1	2	3	FeO(OH)
Fe_2O_3	84.0	82.1	84.7	89.9
NiO	4.94	5.42	3.18	
CoO	0.31	0.36	0.22	
MgO	---	0.42	---	
CaO	0.07	0.69	---	
SiO_2	0.10	0.22	0.14	
Subtotal	89.4	89.2	88.2	
Cl	1.47	2.81	4.57	
OH, SO_4	9.14*	7.99*	7.23*	10.1
Subtotal	10.61	10.80	11.80	

FeO(OH,Cl)

Akaganeite

Taylor et al. (1973)

Terrestrial Contamination

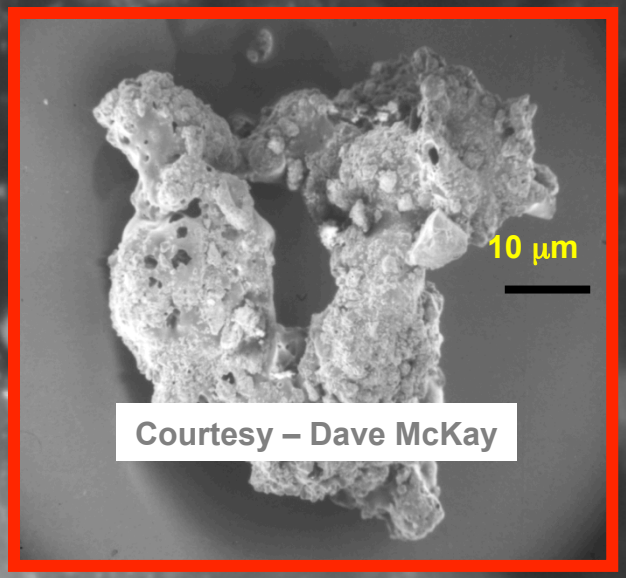
$$FeCl_2 + HOH + \tfrac{1}{2}O_2 = FeO(OH,Cl) + HCl$$

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Agglutinitic Glass

Milky Way of np-Fe^{o}

Nanophase Metallic Fe



PARADIGM

Solar-Wind Hydrogen Reduction of FeO from Impact-Produced Melted Soil

(Housley et al. 1973)

$$H_2 + FeO = Fe + H_2O$$

Pieces of minerals, rocklets, and glass welded together by shock-melt glass

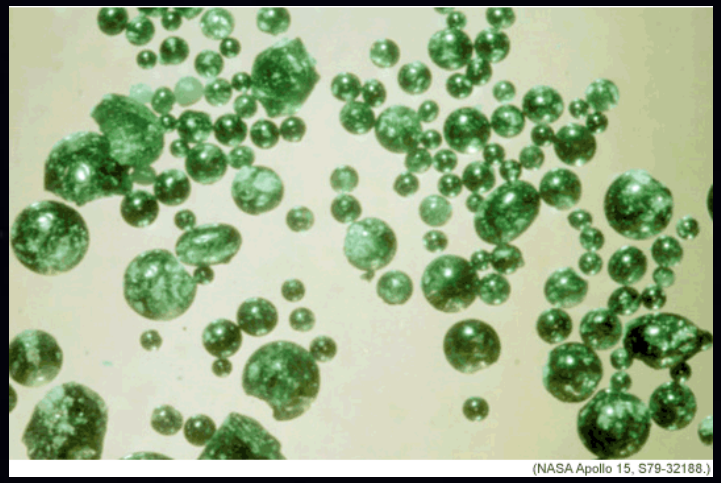
SEM - BSE

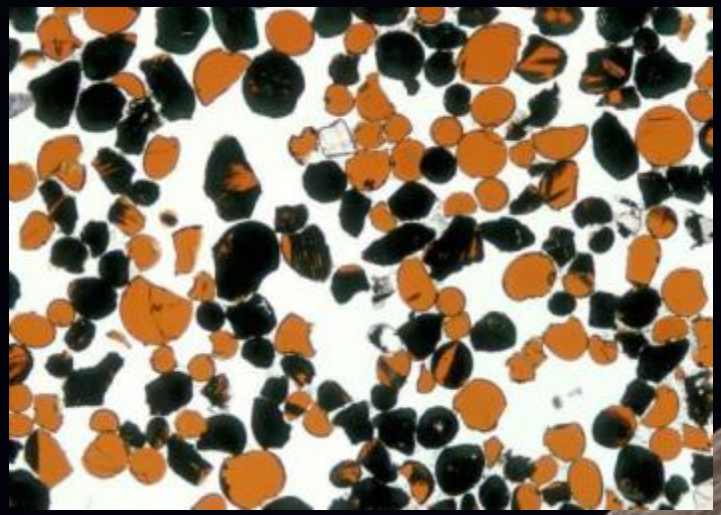
all white beads = metallic Fe

Volcanic Glasses

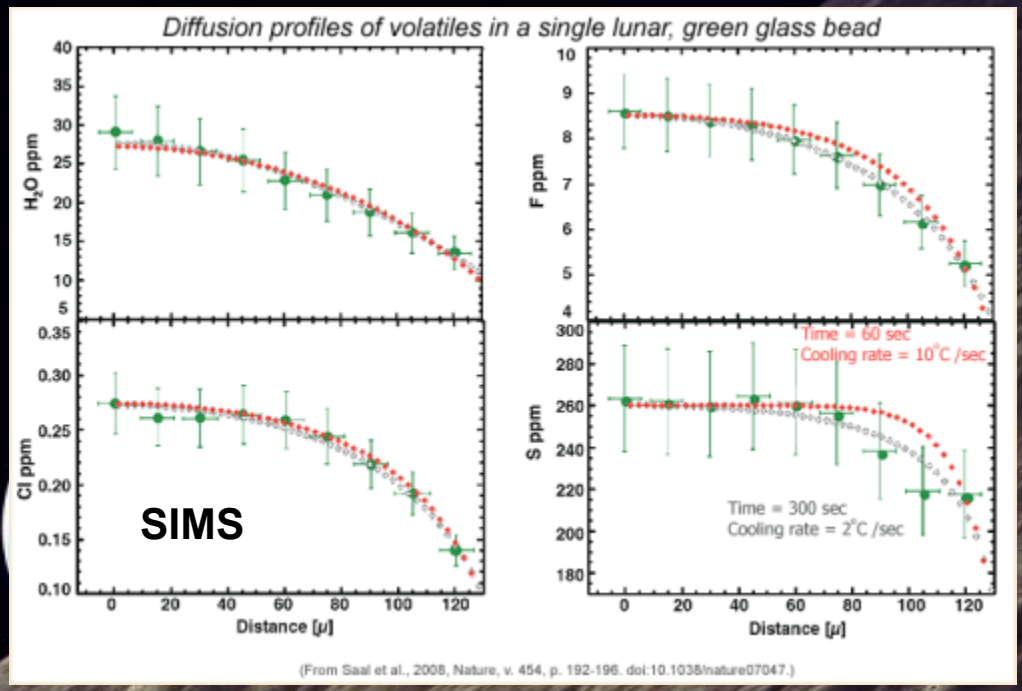

(Photo courtesy of the National Park Service.)

- Pyroclastic Glass Beads (*Saal et al. 2008*) :


(NASA Apollo 15, S79-32188.)



SIMS: 0 - 46 ppm H



(From Saal et al., 2008, Nature, v. 454, p. 192-196. doi:10.1038/nature07047.)

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Magmatic Apatite

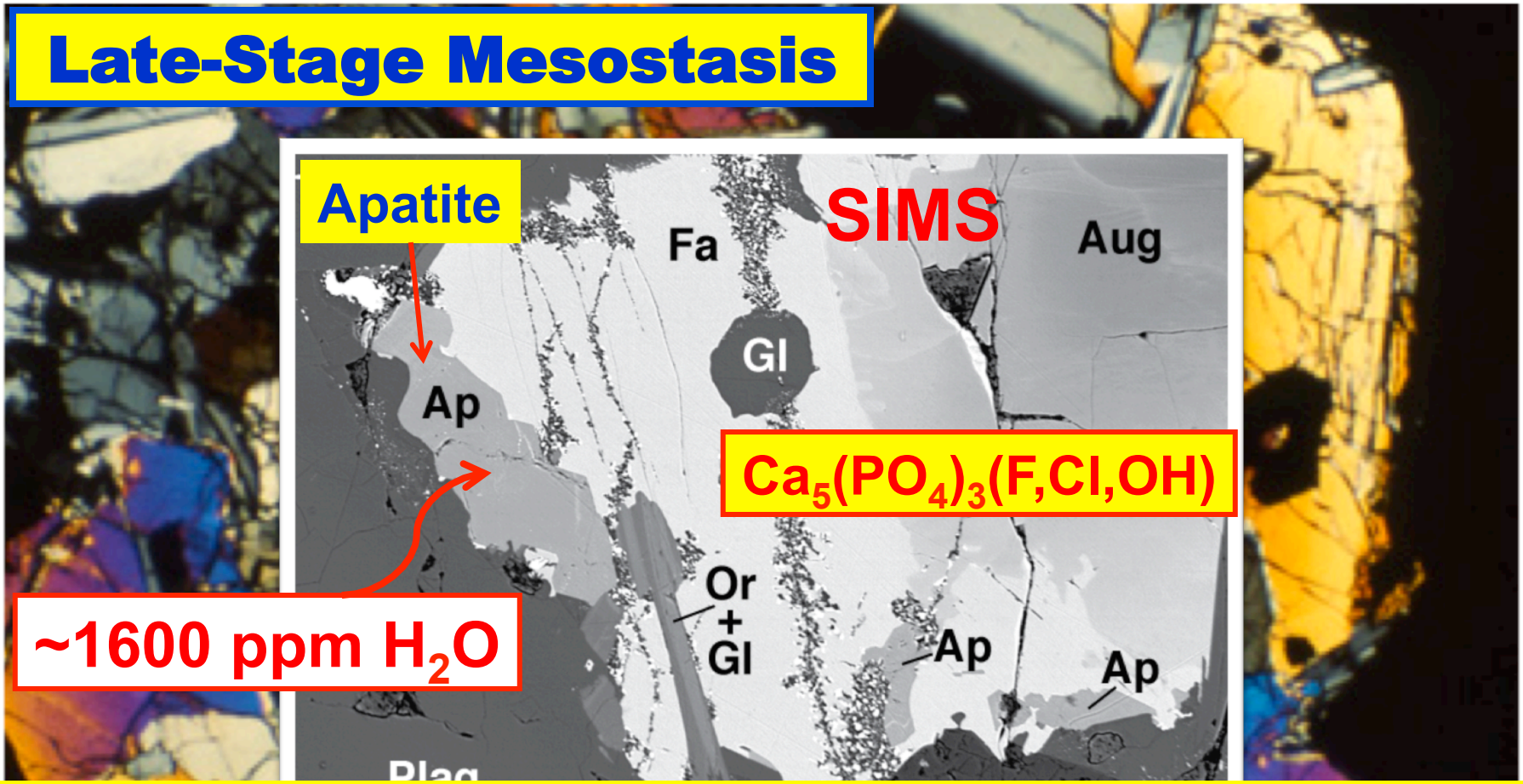
Apatite : $Ca_5(PO_4)_3(F, Cl, OH)$

- ✓ In Apollo era, deficiency in the -1 charged ion site;
- ✓ Increased interests and suspicion for water in apatite since 2008:

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

WATER IN Apollo 14 Basalt 14053

Late-Stage Mesostasis



WATER IN LUNAR MARE BASALTS: CONFIRMATION FROM APATITE IN LUNAR BASALT 14053

(2010; LPSC)

Yang Liu, J. Boyce, G. Rossman, Y. Guan, J. Eiler, & L.A. Taylor

University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Direct Confirmation

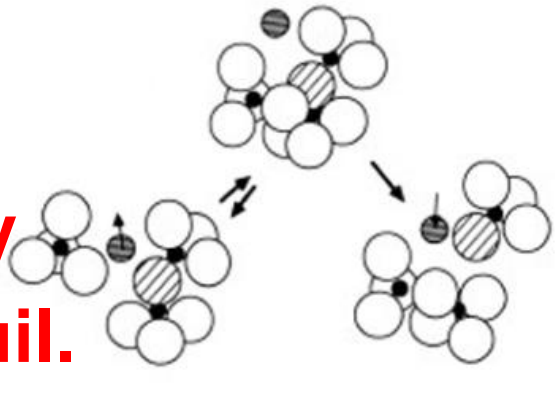
- Greenwood, Taylor, et al., 2010, LPSC;
  Greenwood, Taylor, et al., 2011 Nature
  up to 6000 ppm
  Up to 1.2 wt% OH in apatite
- McCubbin et al., 2010, PNAS; thin sections
  220 ± 40 ~7000 ± 1100 ppm
- Liu, Taylor, et al., LPSC, 2010
  Boyce, Taylor, et al., LPSC, 2011
  Boyce, Taylor, et al., Nature, 2010
  ~1600 ± 125 ppm

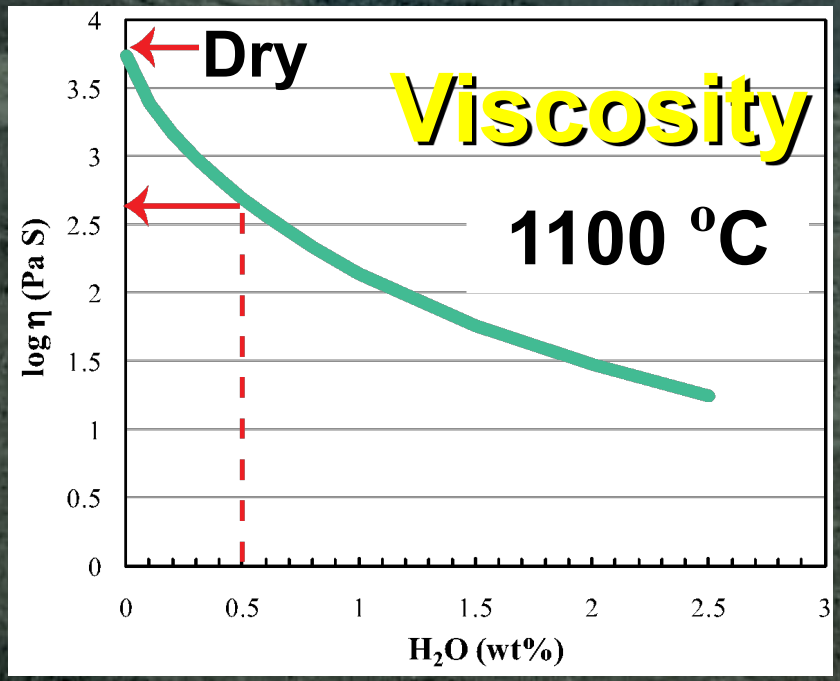
Implications:
Effects on Basaltic Melts

Density

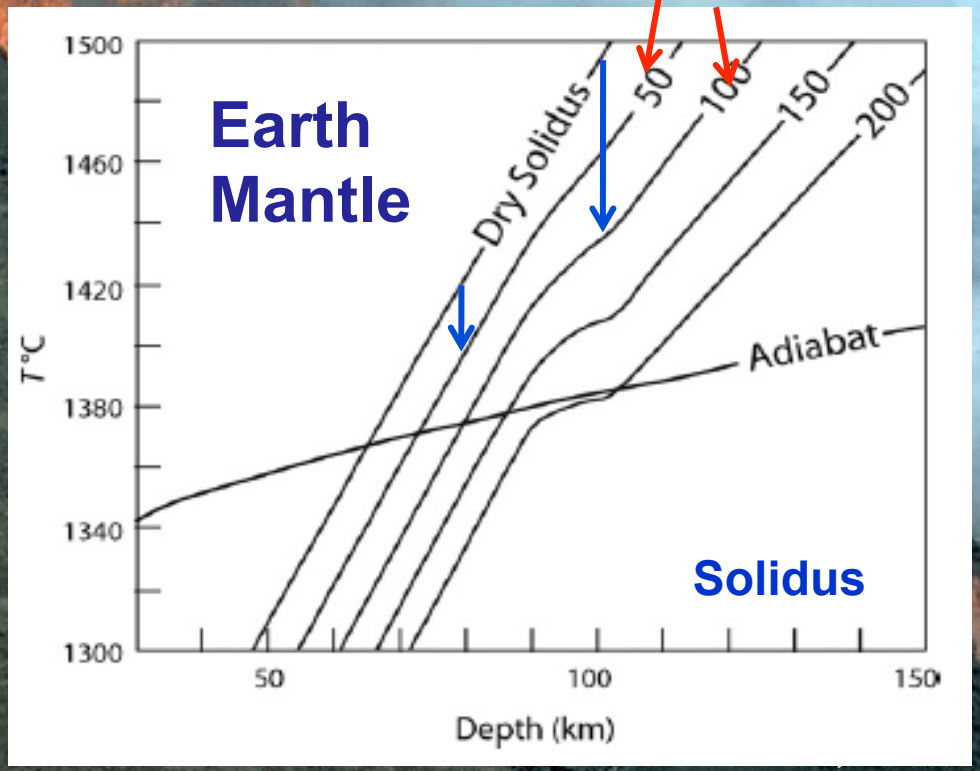
Viscosity

Phase Equil.

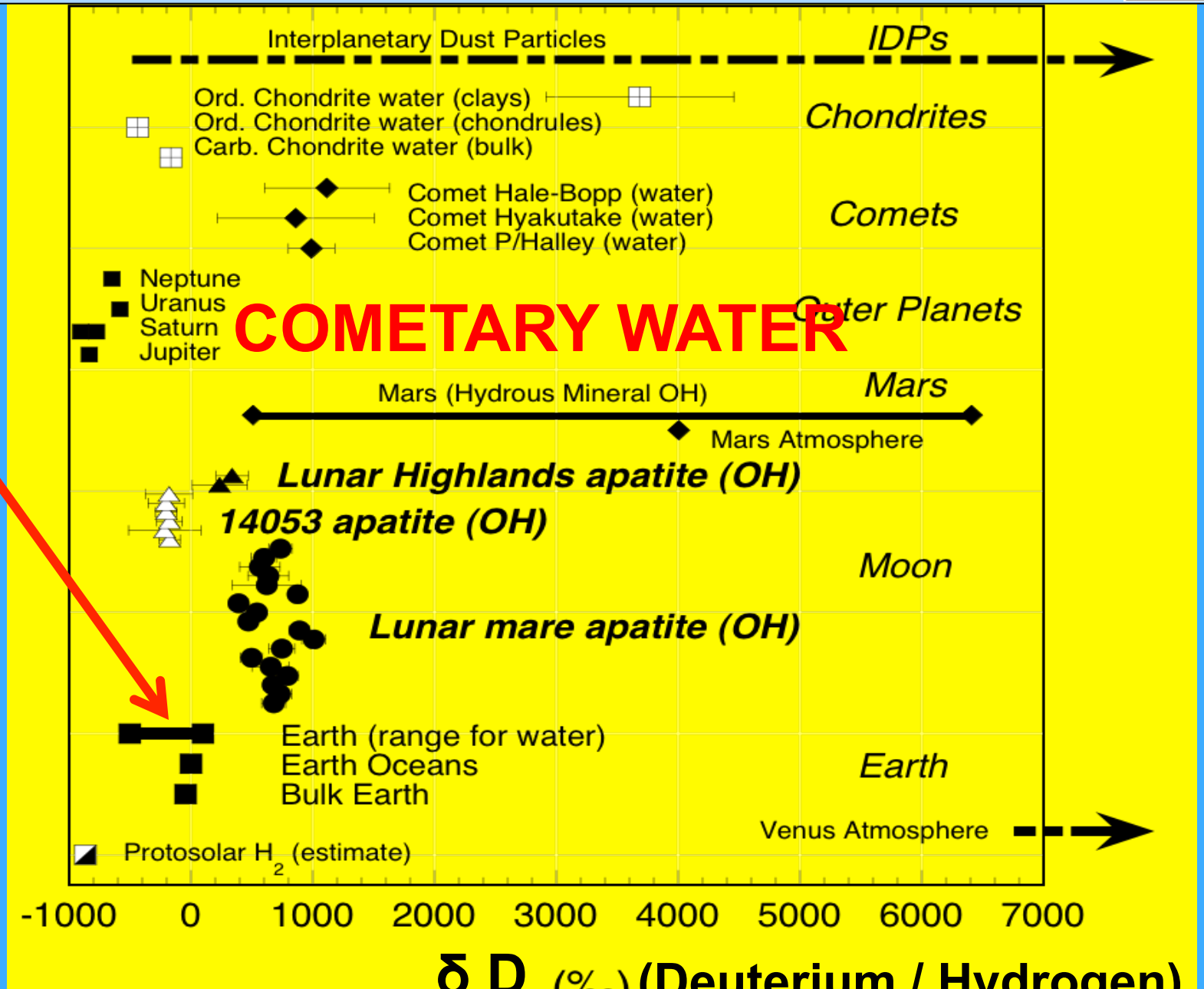




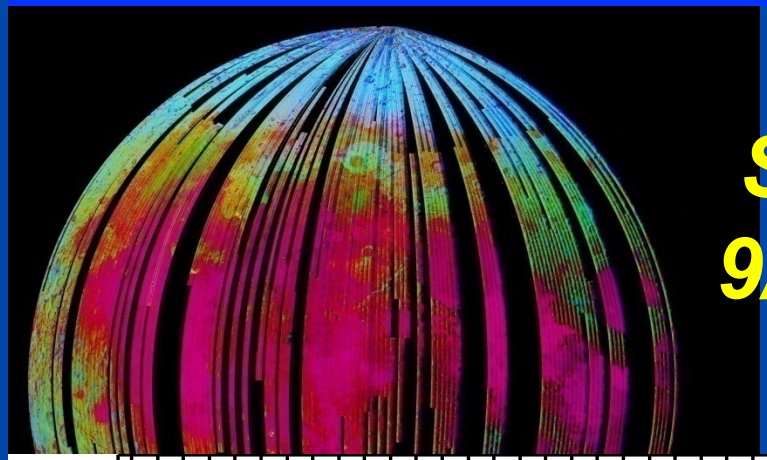
H2O (ppm) in mantle



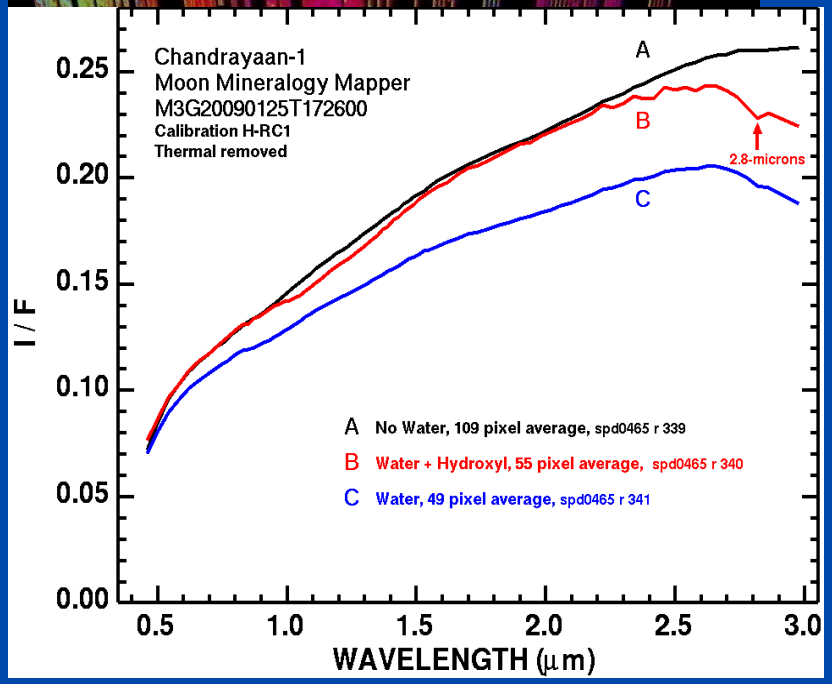
University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu



FIRST Evidence for Water ON the Moon



Science 9/24/2009



- Pieters et al. 2009
- Clark et al. 2009
- Sunshine et al. 2009

Solar-Wind Protons
React with "Dangling" Oxygen Bonds = OH^-

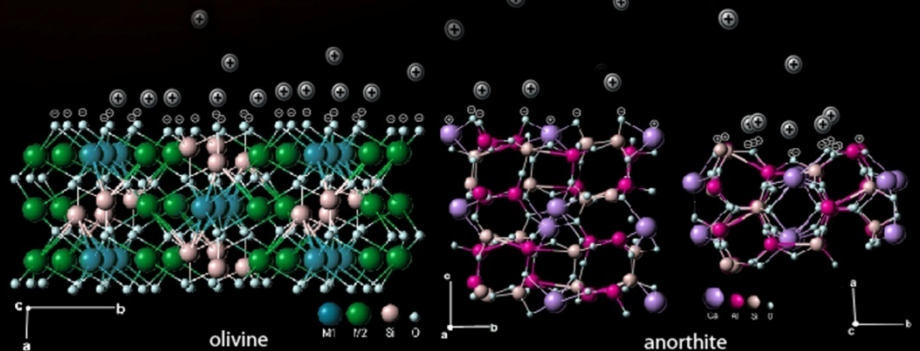
$O^{--} + H^+ = OH^-$

$H^+ + OH^- = HOH$

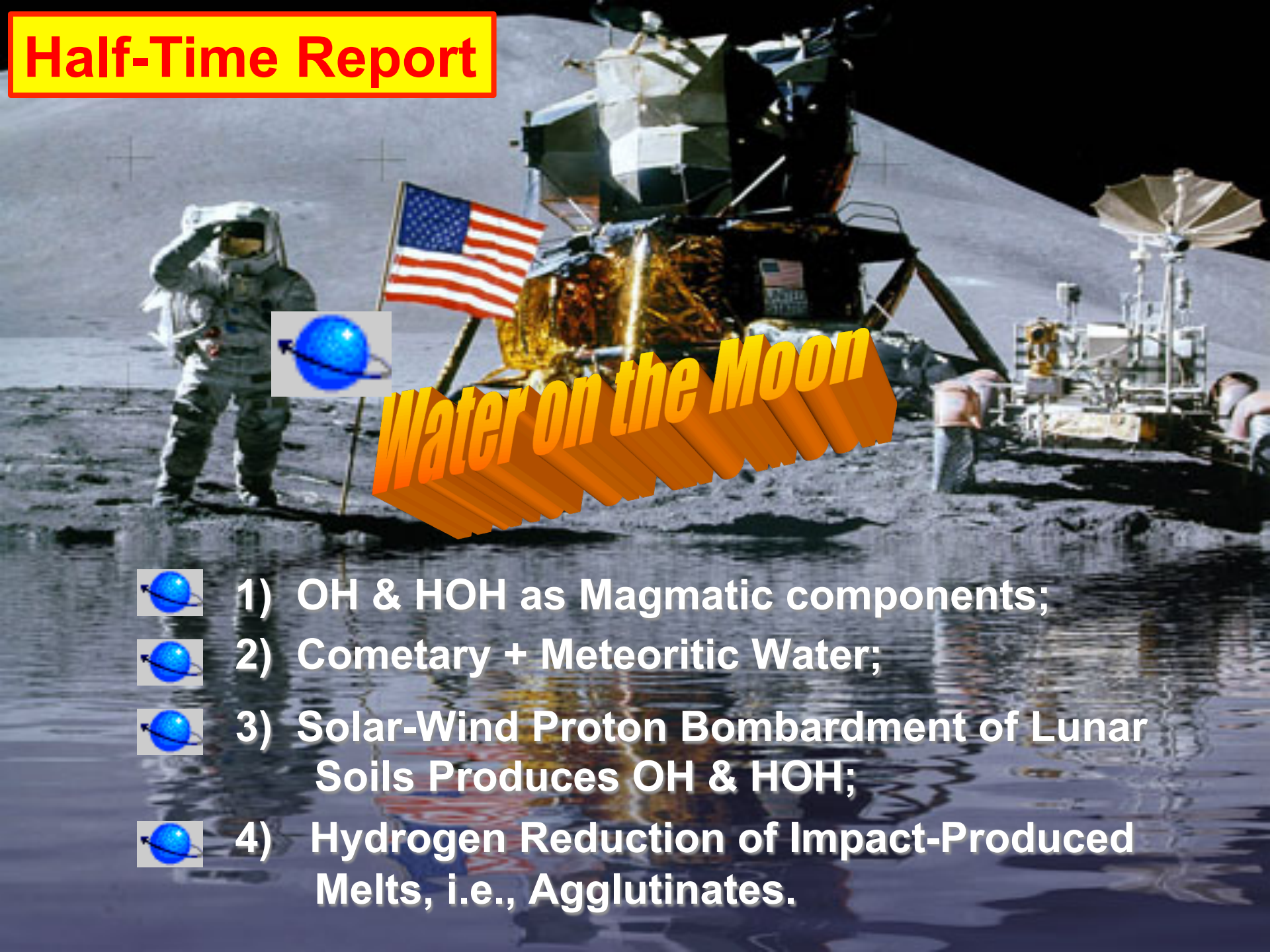
SPACE DEW

EXOGENIC

MICRO-METEORITE IMPACTS CREATE CRUSHING & SHATTERING THAT LEAVE "Dangling Bonds"!!

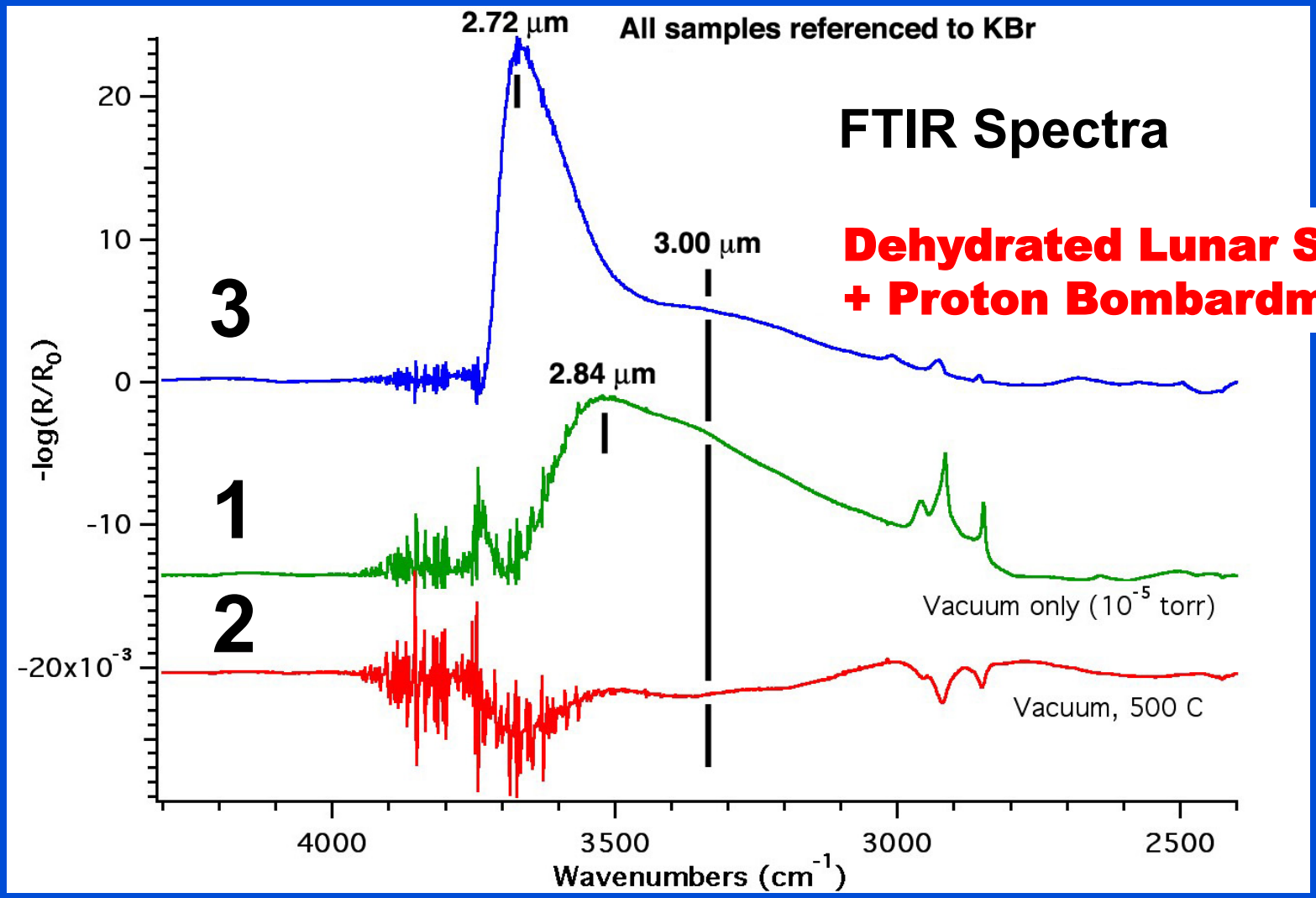


Half-Time Report



Water on the Moon

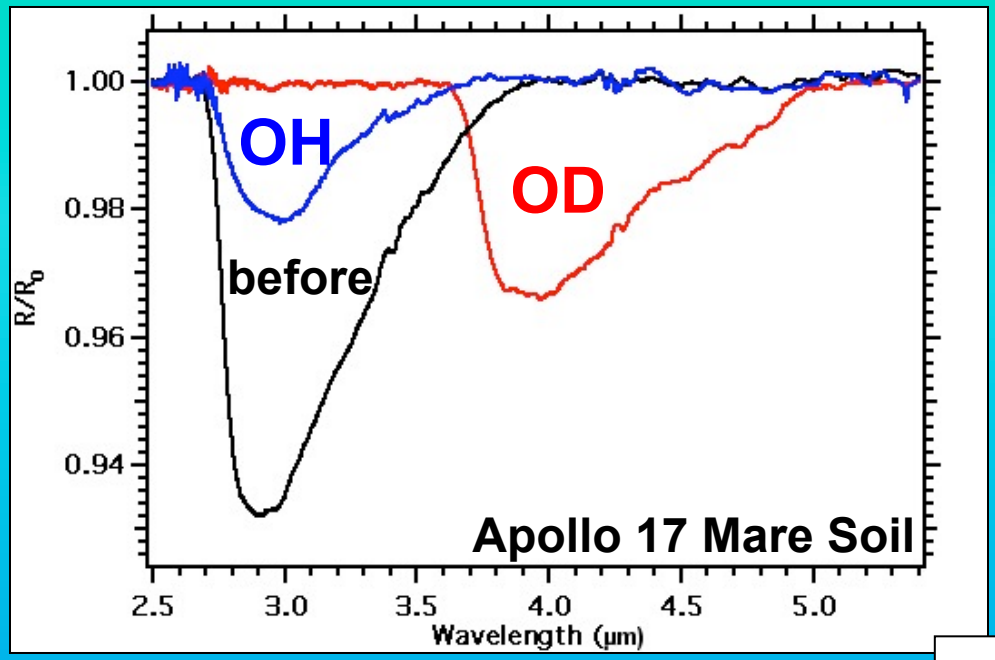
1) OH & HOH as Magmatic components;
2) Cometary + Meteoritic Water;
3) Solar-Wind Proton Bombardment of Lunar Soils Produces OH & HOH;
4) Hydrogen Reduction of Impact-Produced Melts, i.e., Agglutinates.



Zent, Ishimura, Quinn, & Taylor

LPSC (2010)

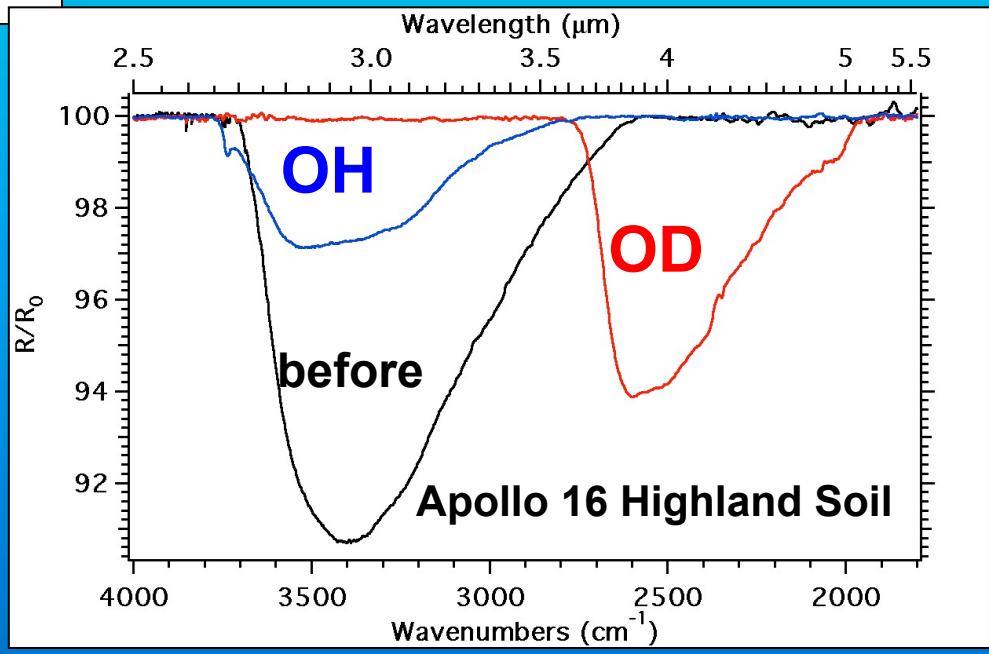
Deuterium Implantation Creates OD^- Groups



Ishimura, Zent, Quinn, Sanchez, & Taylor

Earth & Planetary Sciences Letters 2012 (in press)

"Origin OH and HOH in Soils on Airless Bodies"

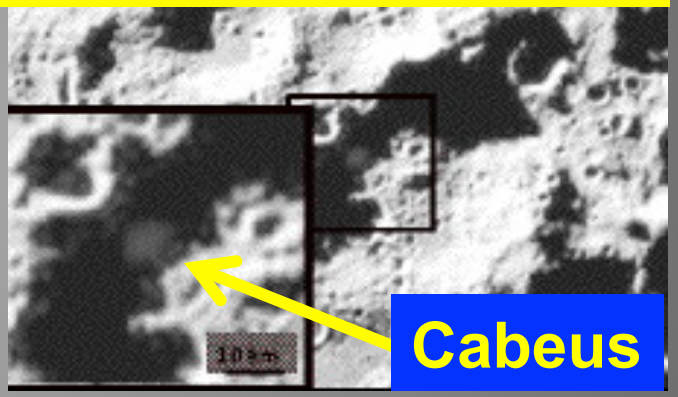


More Solar-Wind Water ???

LCROSS (October, 2009)

(Lunar CRater Observation and Sensing Satellite)

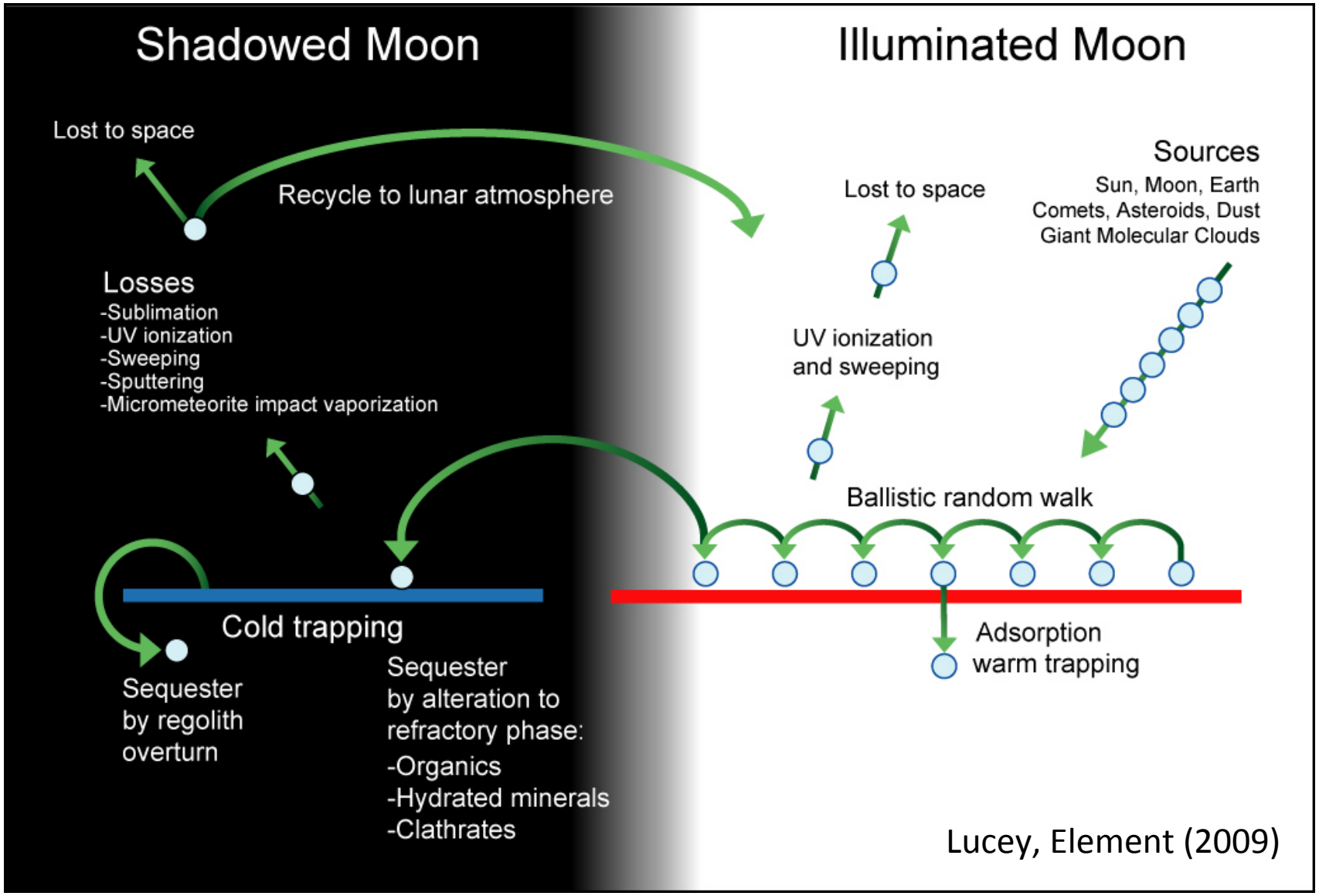
Permently Shadowed Crater
T = 25-40 K



Water – ICE; 100 kg
Organics (ammonia, methane, etc)

Cometary & ??

Schematic of the lunar volatile transport system



Lucey, Element (2009)

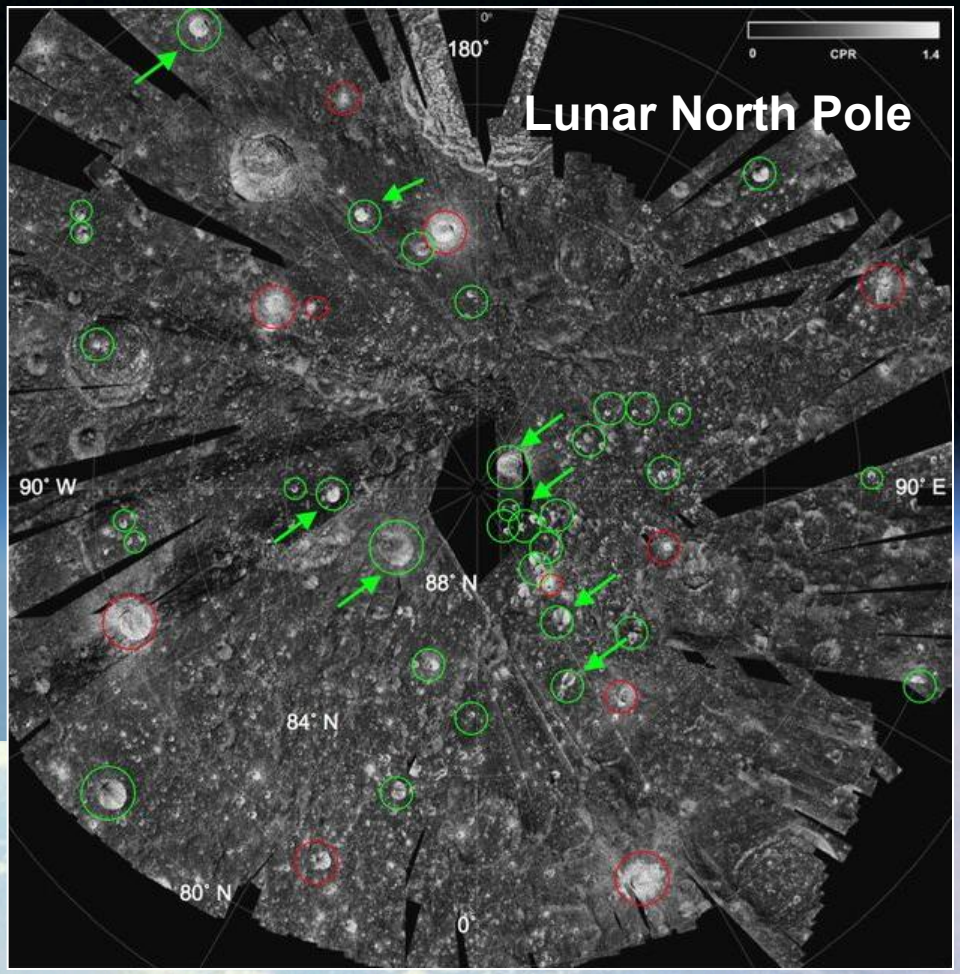
University of Tennessee, Planetary Geosciences Institute
Larry Taylor, lataylor@utk.edu

Surface Ice

Spudis & Team

Mini-SAR on Chandrayaan-1
(SAR: Synthetic Aperture Radar)

- Surface Ice
- 40 craters, north Pole
- space shuttle/day for 2000 yrs

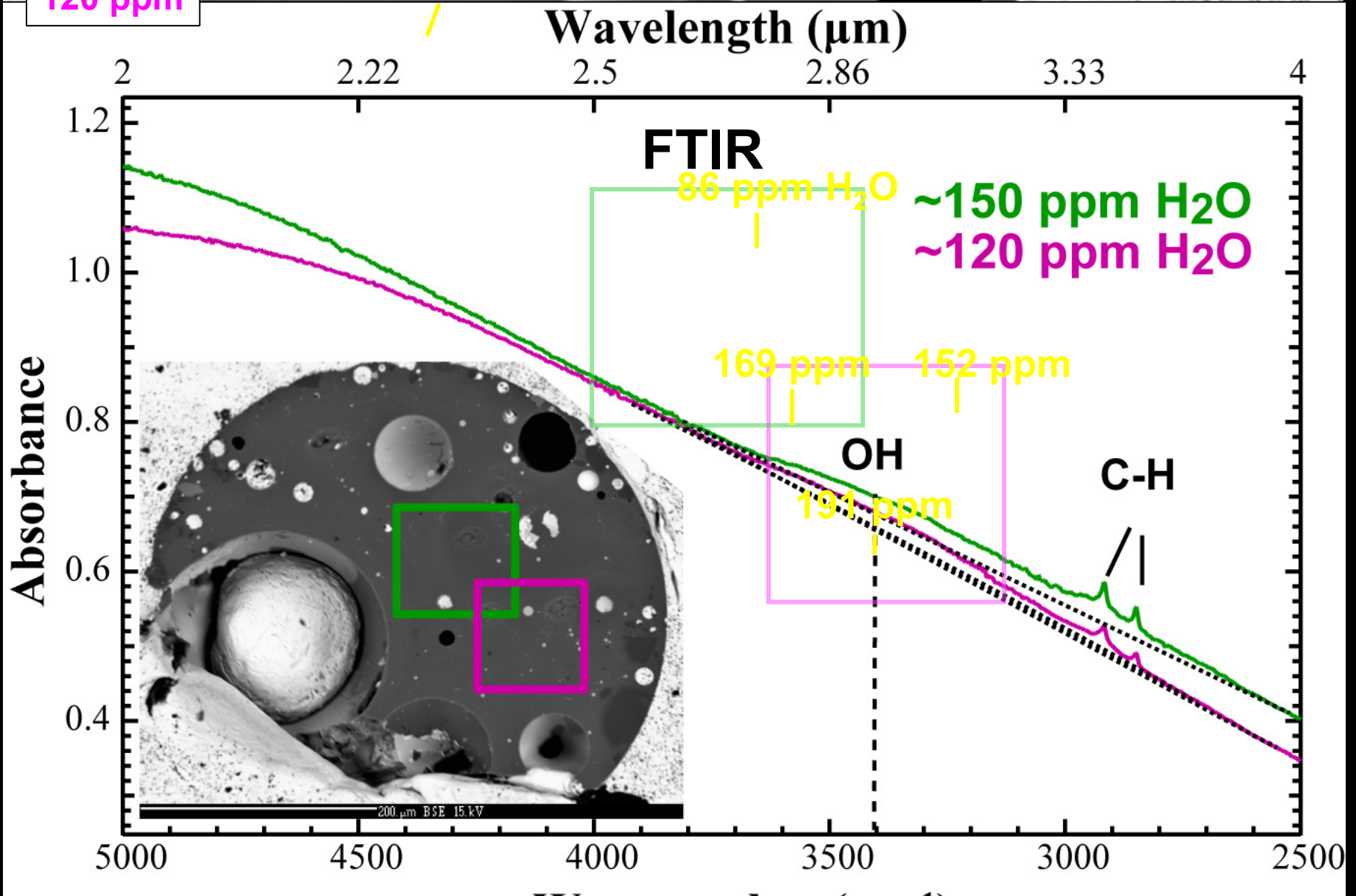


600 x 10^6 metric tons

70051 Agglutinitic Glass

FTIR
150 ppm
120 ppm

SIMS
159 ppm



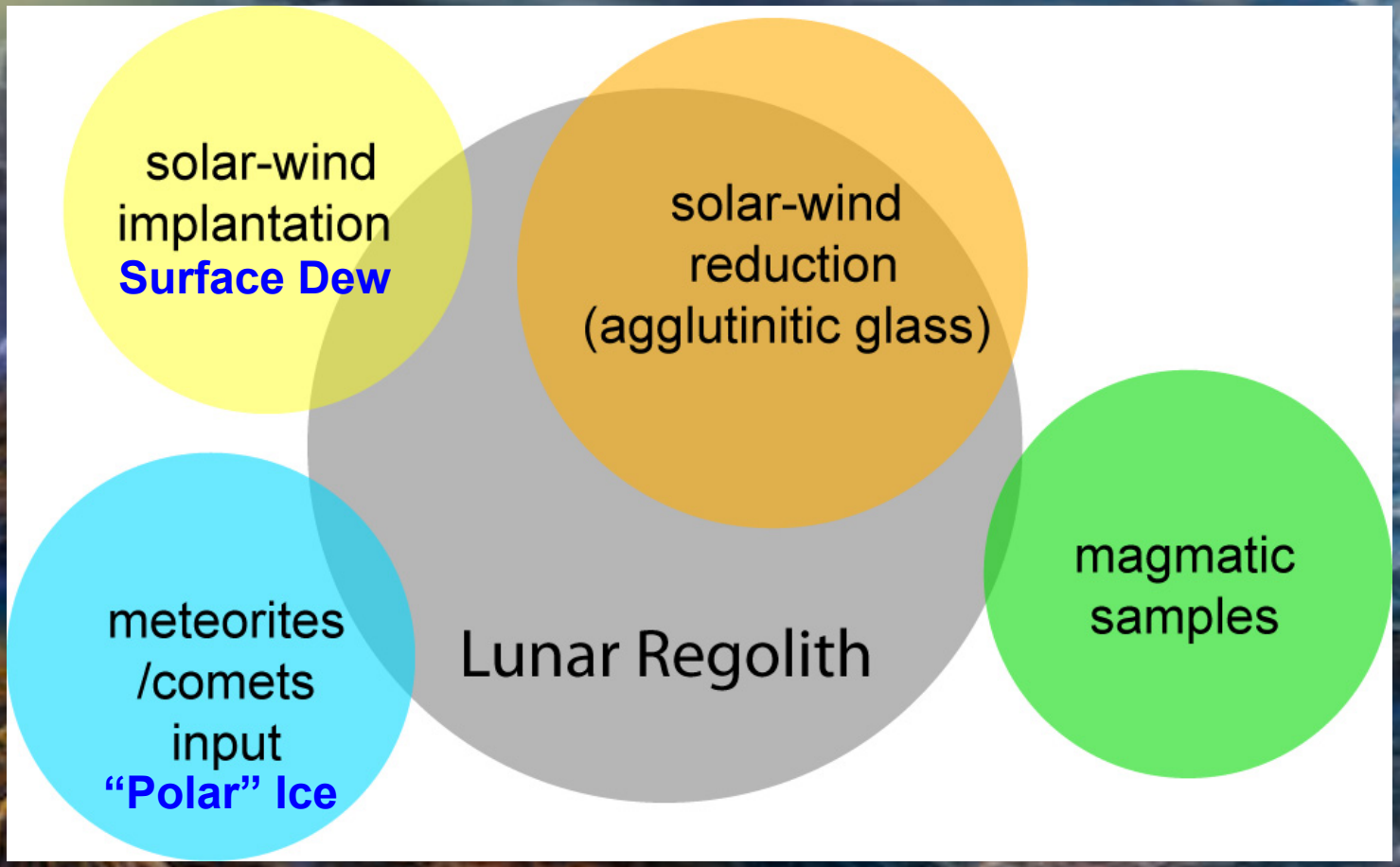
Direct Measurement of OH in Lunar Soils

Yang Liu, Y. Guan, Y. Zhang, G. Rossman, J. Eiler, & L.A. Taylor

Nature Geosci. (in press)

Reservoirs of OH on the Moon

Agglutinates = ~50% of Mature Lunar Soils
(e.g., Papike et al., 1982)



Water on the Moon

- "Not Your Grandpa's Moon"
- 4 – 5 – 6 Sources of Lunar Water
- Both Exogenic and Endogenic
- Impacts on Concepts of Planetary Evolution & Space Weathering

OUR YOUTH Of TODAY

Return

To the

MOON!

Cheaper !

Faster !

Better !

(Mike Griffin)