Lunar Water – Hide ‘n Seek

Friedemann Freund

friedemann.t.freund@nasa.gov

SETI Institute

Carl Sagan Center

NASA Ames Research Center

San José State University

Physics Department

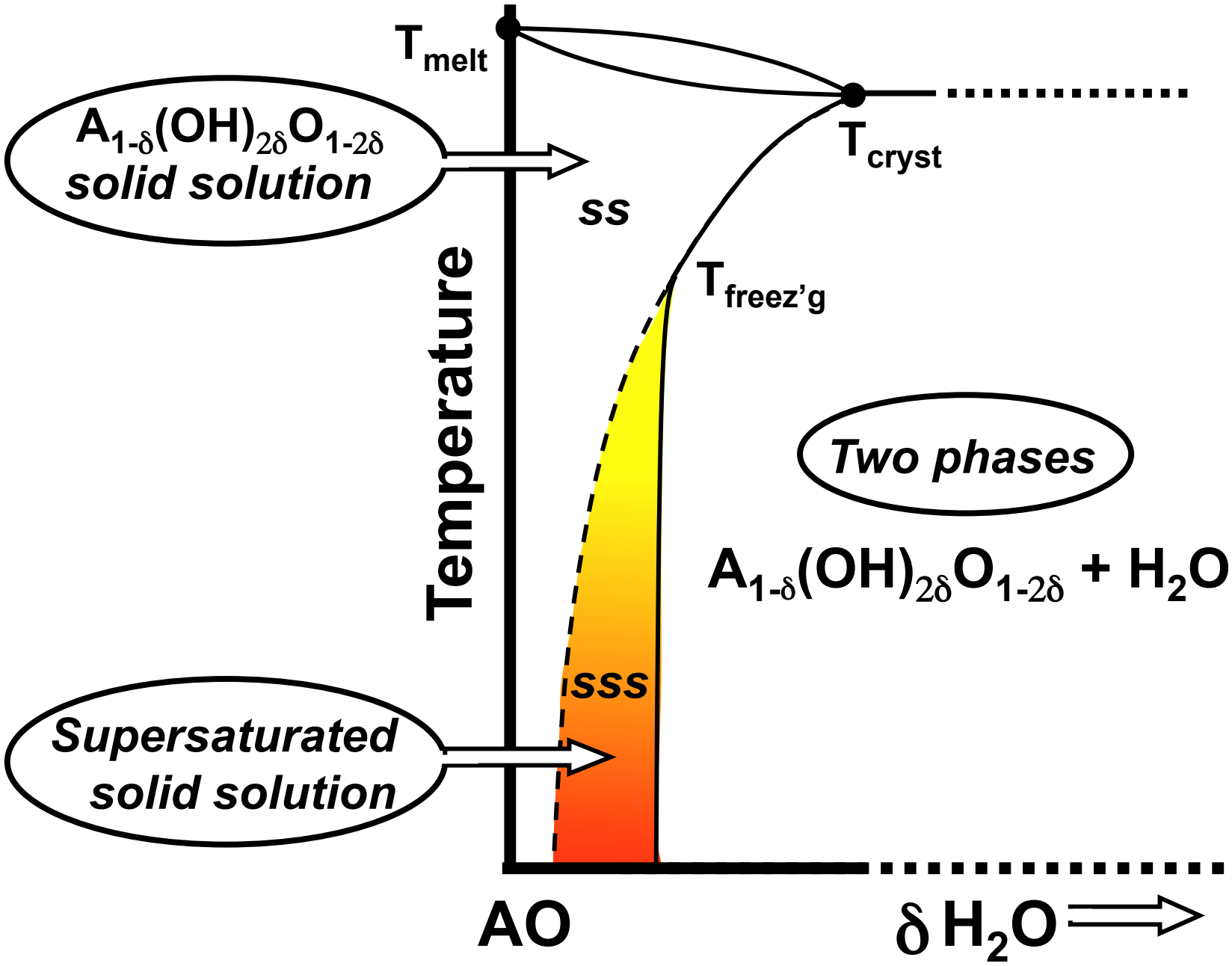
The Moon is not as dry
as you may have been told to believe

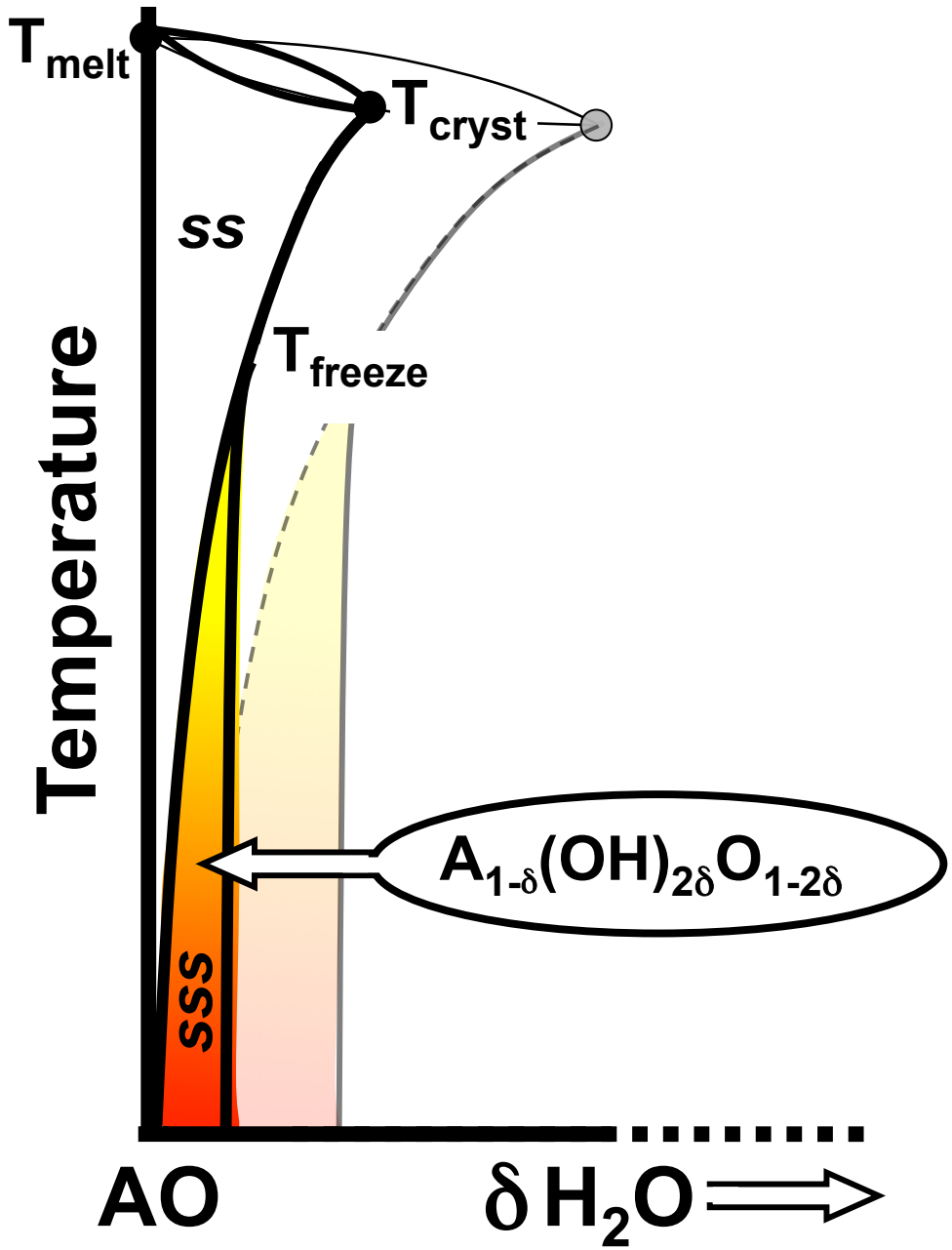
I'm not talking about the water
tugged away in permanently shaded craters at the poles

- **I'm talking about the rest of the moon**
- **…which looks so very barren**
- **…which has little or no hydroxyl-bearing minerals**
- **…which seems not to have even traces of hydroxyls in its nominally anhydrous minerals**

Moon's Origin

- …formed out of ejecta circling the Earth
- …reasonable to assume outgassing
- …unreasonable to assume **total** outgassing


T_{melt}
$A_{1-\delta}(OH)_{2\delta}O_{1-2\delta}$
solid solution
ss
T_{cryst}
$T_{freez'g}$
Temperature
Two phases
$A_{1-\delta}(OH)_{2\delta}O_{1-2\delta} + H_2O$
sss
Supersaturated
solid solution
AO
δH_2O


T melt
T cryst
ss
T freeze
Temperature
A1-δ(OH)2δO1-2δ
SSS
AO
δ H2O

$$O_3Si^{/O\backslash}SiO_3 + H_2O \Leftrightarrow O_3Si^{/OH}_{HO/}SiO_3$$

It is never possible to totally degas a melt/magma, even when ejected into the vacuum of space.

Hence, lunar rocks must contain residual Si-OH.

Why don't they?

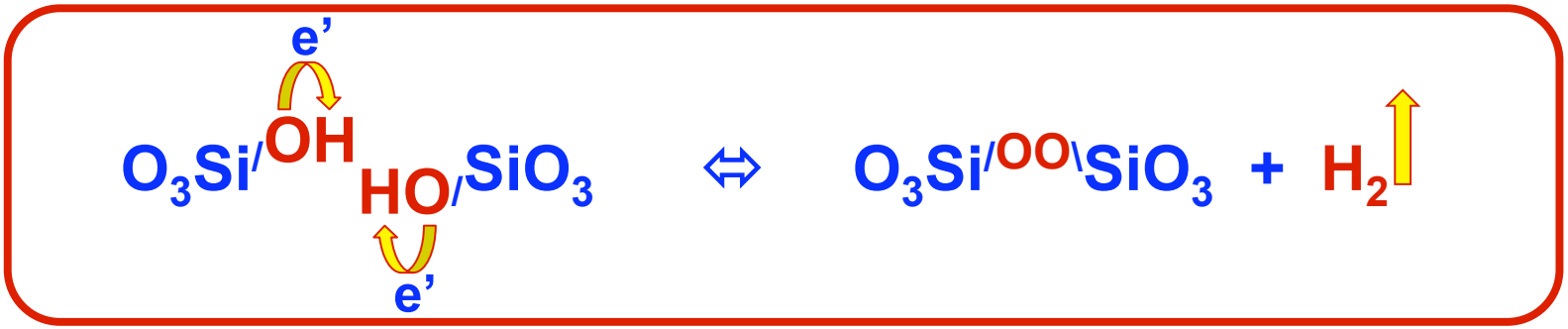
…because…

$$O_3Si^{/OH}_{HO/}SiO_3 \Leftrightarrow O_3Si^{/OO\backslash}_{H_2}SiO_3$$

Redox conversion of hydroxyl pairs into peroxy plus H_2

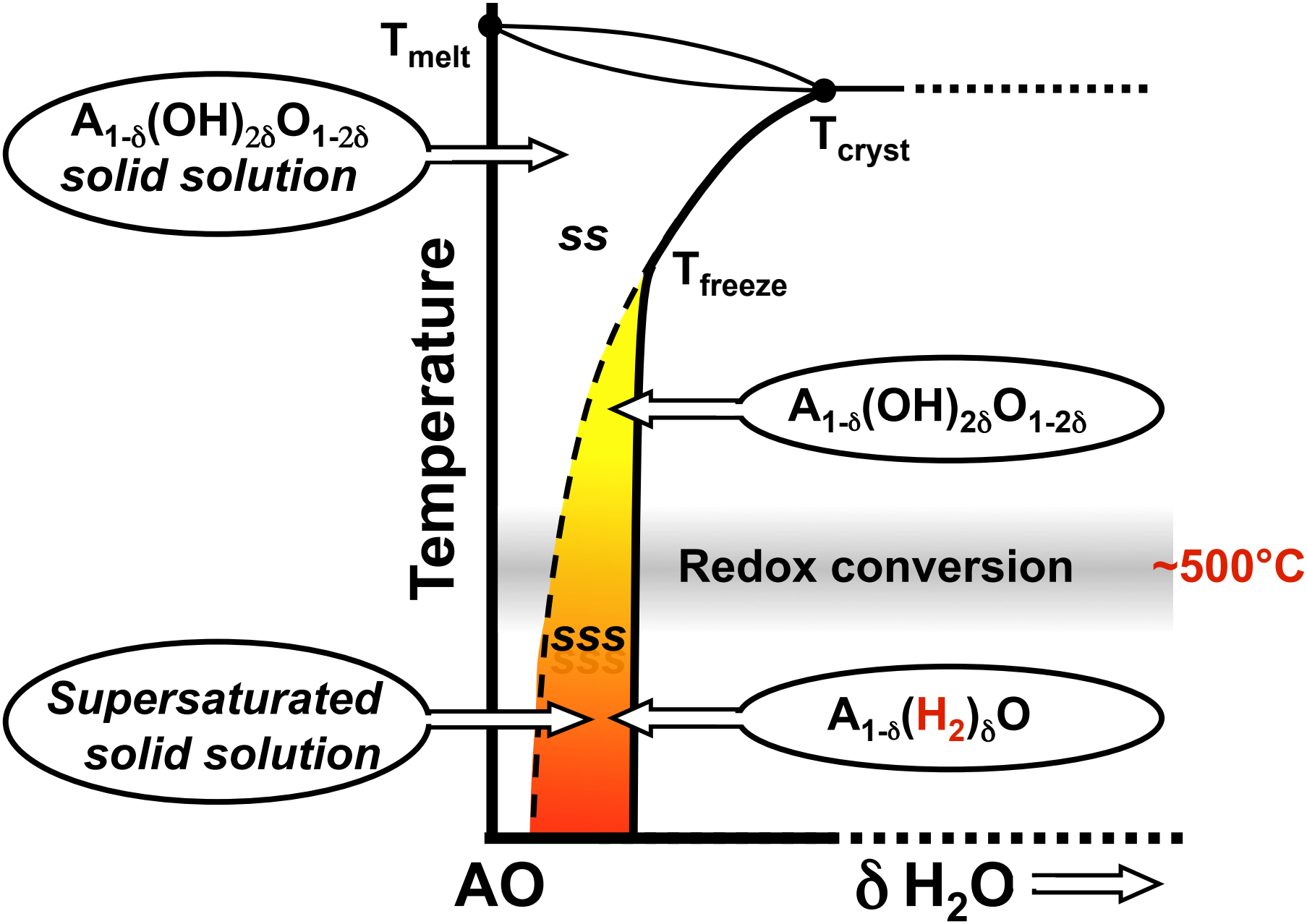
It takes place during cooling through the 600-400°C window

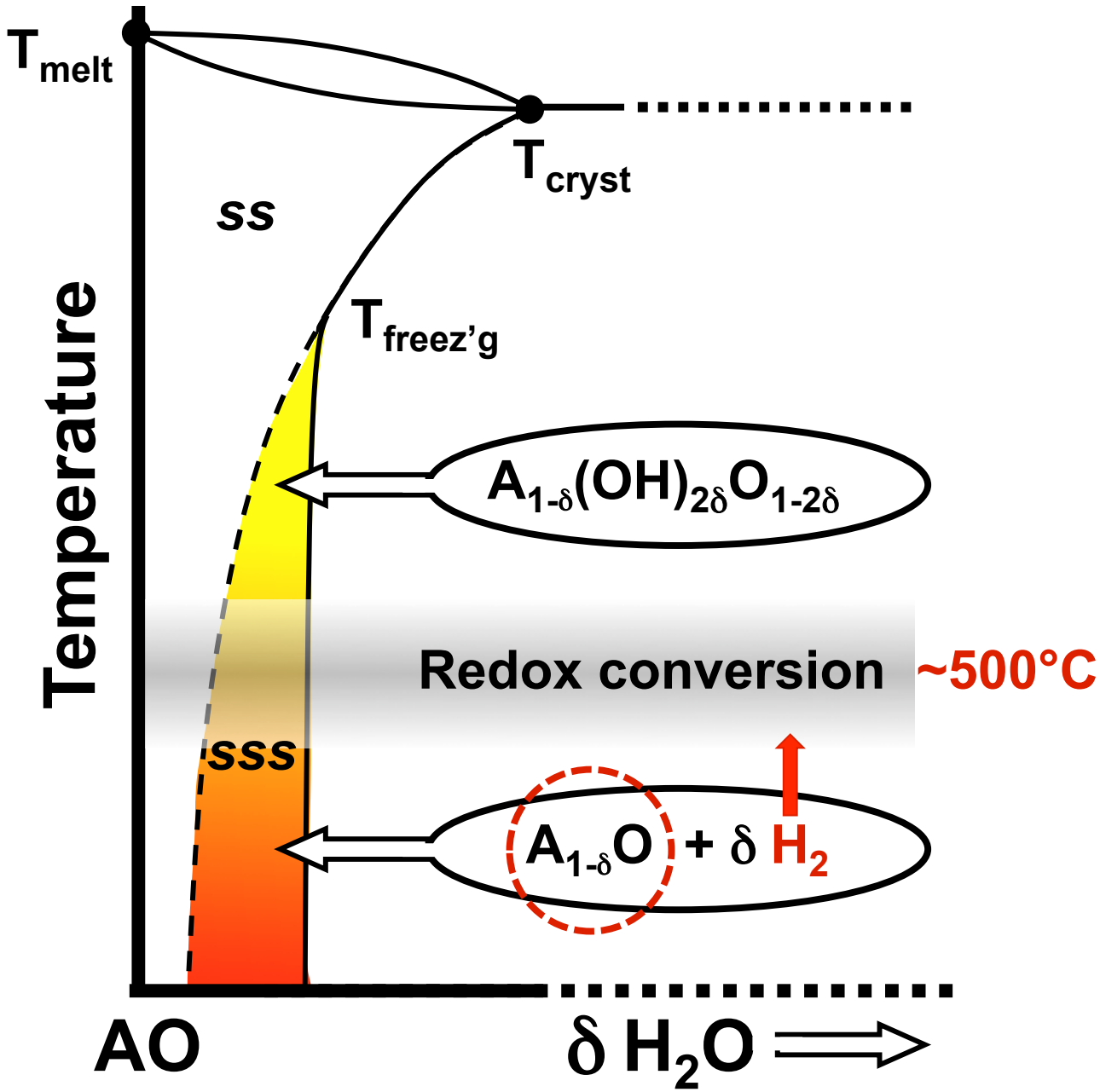
…but H_2 is diffusively mobile…



Redox conversion of hydroxyl pairs into peroxy plus H_2.

When H_2 diffuses out, peroxy stay behind.


T melt
T cryst
T freeze
A1-δ(OH)2δO1-2δ solid solution
ss
Temperature
A1-δ(OH)2δO1-2δ
Redox conversion
~500°C
sss
Supersaturated solid solution
A1-δ(H2)δO
AO
δ H2O


T melt
T cryst
ss
T freez'g
Temperature
A1-δ(OH)2δO1-2δ
Redox conversion
~500°C
sss
A1-δO + δ H2
AO
δ H2O

Metastable Peroxy Defects

If $\delta << 1$, $\mathbf{A_{1-\delta}O \sim AO_{1+\delta}}$

Excess oxygen in the form of peroxy.

≈

If we want to learn about "water" in lunar rocks,
it's wrong to look for OH^-
it's wrong to even look of H

We have to look for the presence of peroxy.

Redox conversion of hydroxyl pairs into peroxy plus H_2.

When H_2 diffuses out, peroxy stay behind.

- First published for MgO in 1976
- Confirmed for MgO in 1982/1983
- Proposed for silicates in 1986/1987
- Further substantiated in 1989
- Still further substantiated in 1993/1994
- Broadly applied to Earth materials in 2002/2003
- **Today we can apply it to lunar rocks**

Many Testable Consequences

In the lab (with Apollo rock samples):

- Use Hall Effect measurements
- Use dielectric polarization measurements
- Look for oxidizing reactions

On the moon:

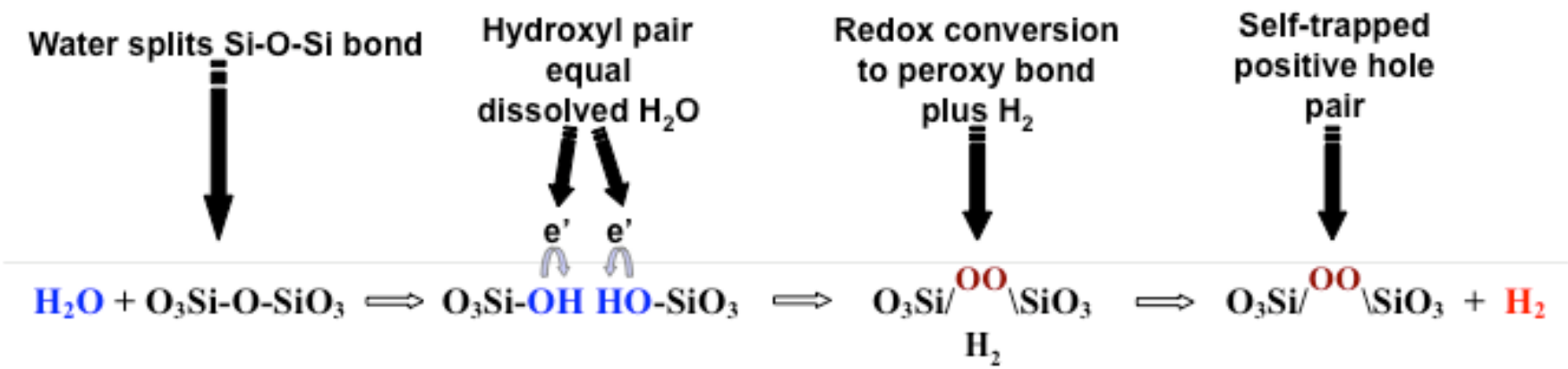
- Look for UV-induced surface charging
- Look for electrostatic dust levitation (LADEE)
- Look for H_2O emitted at the morning terminator
- Look for narrow IR emission bands at $\leq 930\ cm^{-1}$
- Look for terminator changes in radar reflectivity

Thank You

Universally true

for nominally anhydrous minerals and the rocks, which contain them

Redox Conversion of "Water" into H_2 plus O



Friedemann Freund NASA ARC
SGE/SETI/SJSU