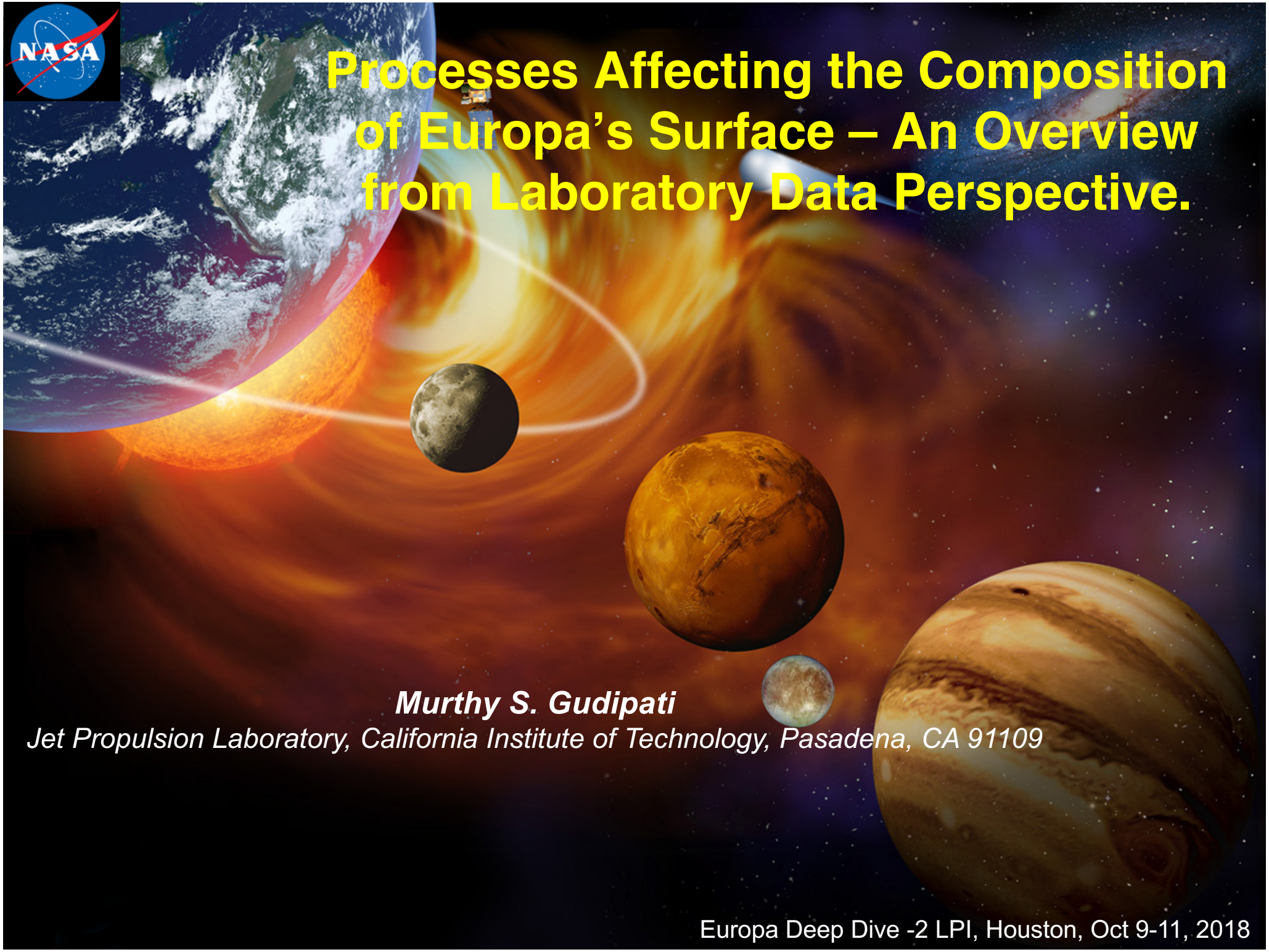


Processes Affecting the Composition of Europa's Surface – An Overview from Laboratory Data Perspective.

Murthy S. Gudipati
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

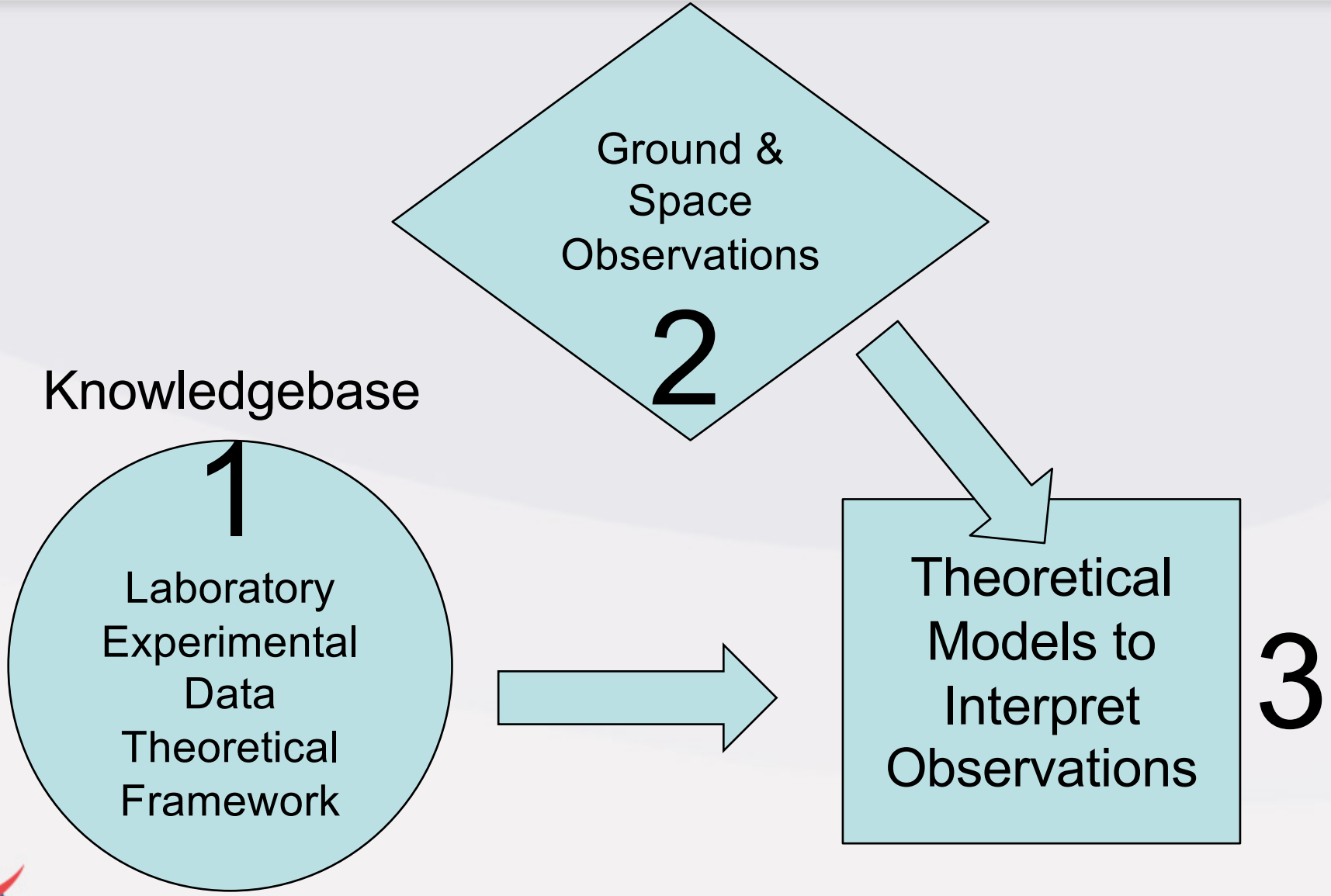
Europa Deep Dive -2 LPI, Houston, Oct 9-11, 2018

Relevance and Context of Lab Data

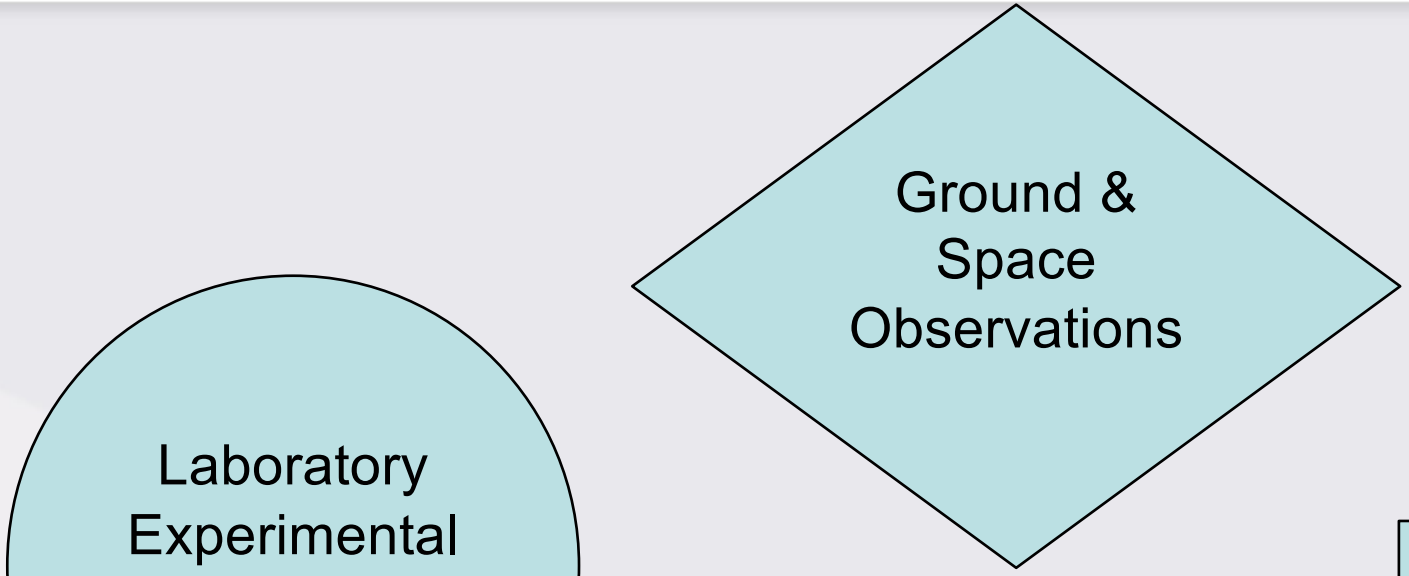
We are stuck, we need better Lab Data
Can you quickly do some experiments?

Funding? Sorry!

Space Science Interdependency Timeline



Incubation Time Scale



Laboratory
Experimental
Data
Theoretical
Framework

~5 Year

~20 Years

If we do not have the needed lab data before launch, it is too late for the prime mission

Theoretical
Models to
Interpret
Observations

~10 Years

Investment ($) & Availability of Data

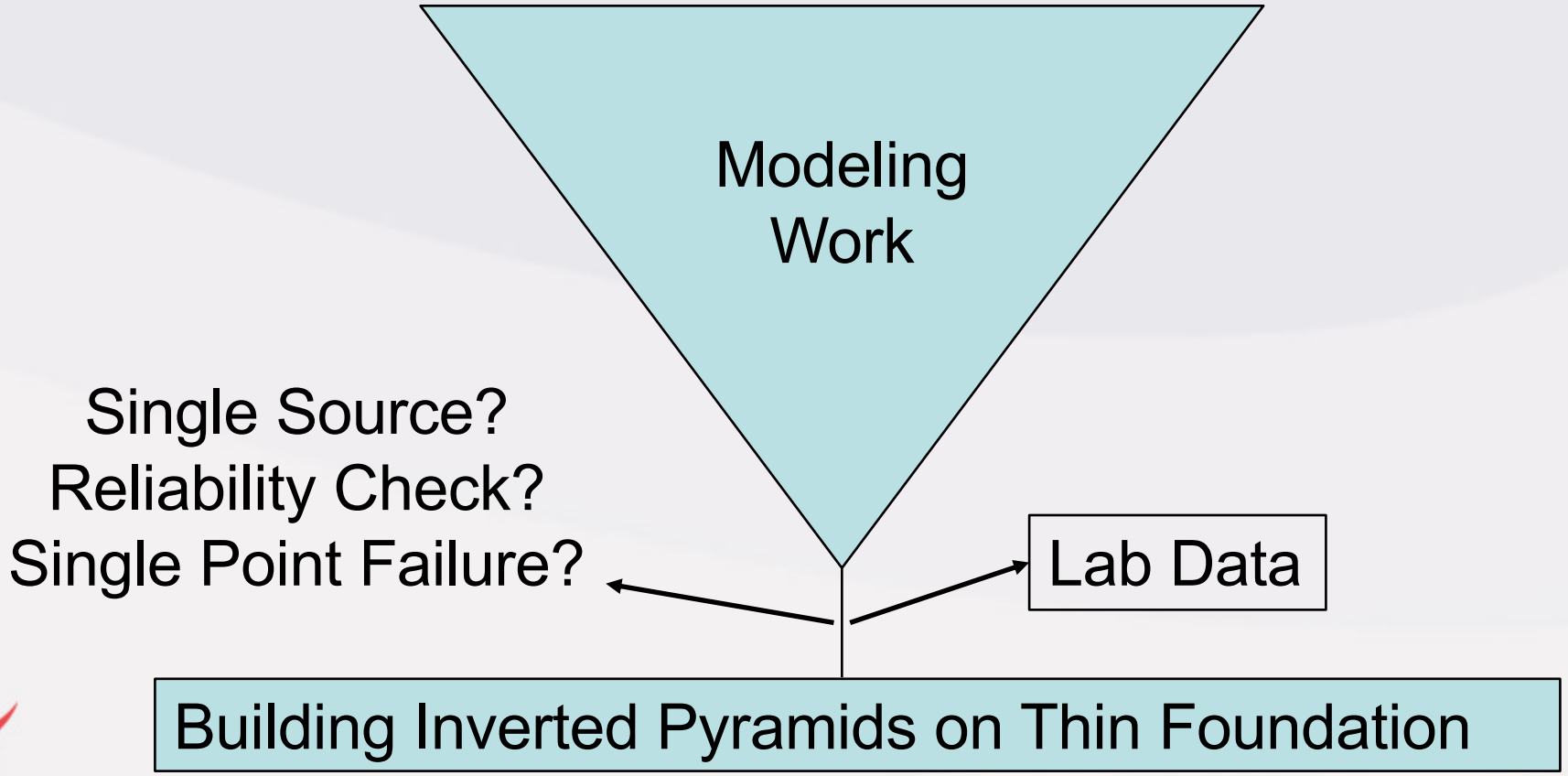
Ground & Space Observations

Lab Data

Theoretical Models to Interpret Observations

Lab Data Validation – Inverted Pyramid of Models?

- How Reliable is the Lab Data?
- What are the Errors?
- Is this a Single Source or Multiple Independent Publications?



Europa and Lab Data – Case Study

Sulfuric Acid Hydrates

Science can't be
"Because I find it believable, it must be True"

Science has to be
An Independently proven Fact

S^{+n} bombardment of H_2O Ice

S^{+n} (n=1-8) + H_2O (ice) → $H_2SO_4.xH_2O$ (sulfuric acid hydrate)

Looks nice, believable, plausible, but not proven until 2012

Radiolytic Sulfur Cycle – Sulfuric Acid Hydrate

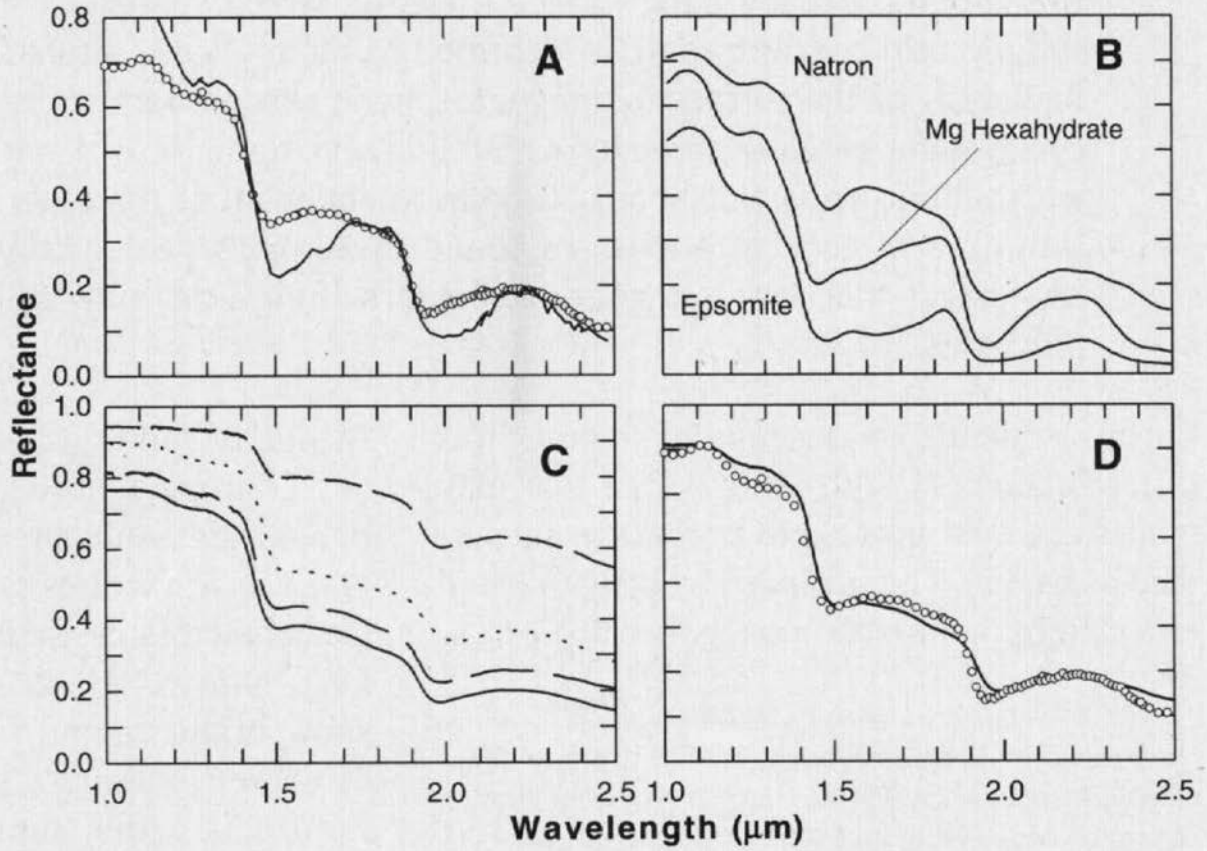


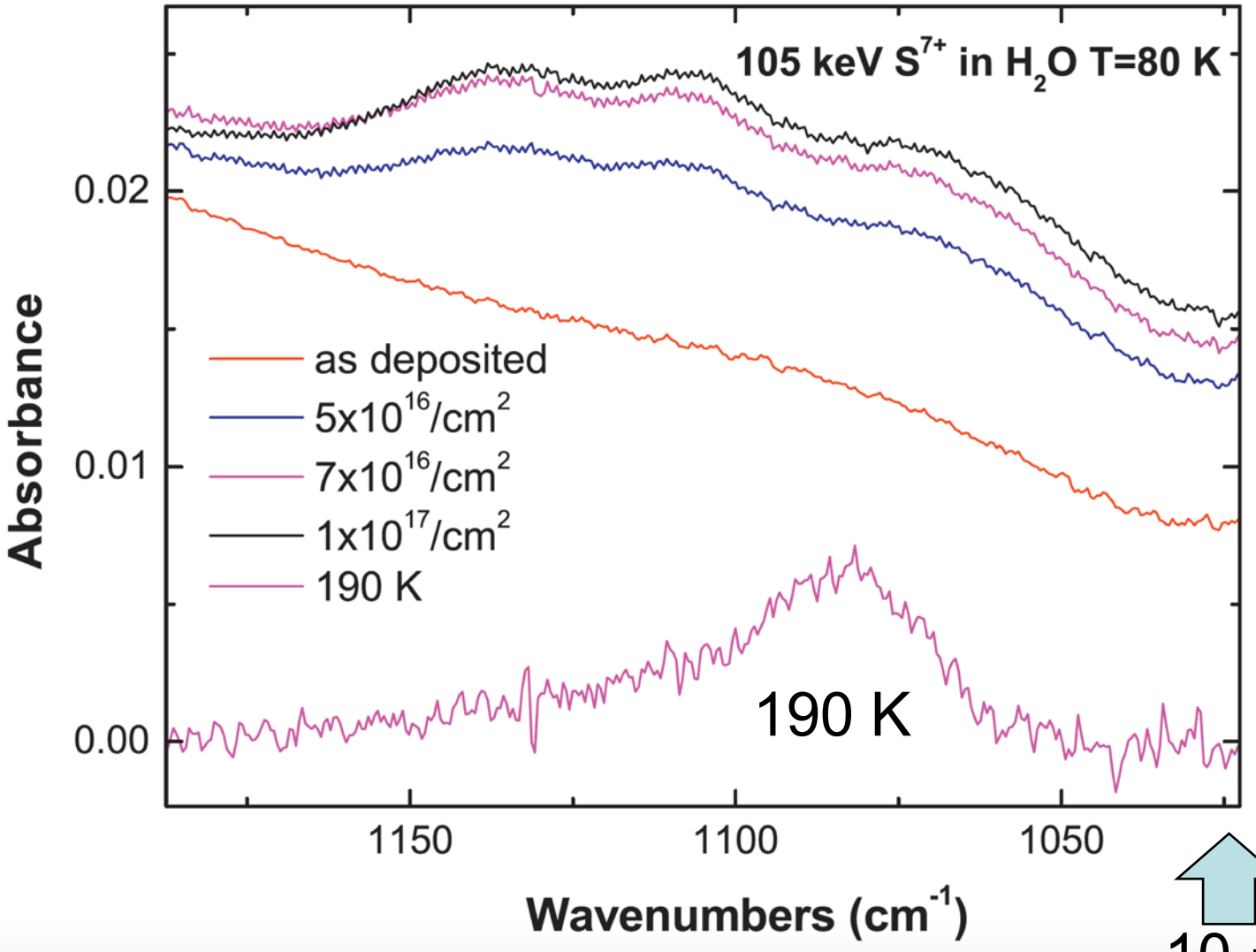
Fig. 1. IR reflectance spectra of Europa and candidate surface materials. (**A**) NIMS Europa end-member spectra. Ice abundance is much greater than hydrate (solid line), and hydrate abundance is much greater than ice (line with circles). (**B**) Evaporite salt minerals (*12*). (**C**) Spectra of $H_2SO_4 \cdot nH_2O$ for various n, grain size (d), and temperature (T): $n = 8$, $d = 5$ μm, and $T = 80$ K, offset vertically by 0.10 (short-dashed line); $n = 8$, $d = 50$ μm, and $T = 80$ K, offset vertically by 0.05 (long-dashed line); $n = 8$, $d = 50$ μm, and $T = 140$ K (solid line); and $n = 6.5$, $d = 50$ μm, and $T = 80$ K (dotted line). (**D**) Comparison of Europa's hydrate spectrum [line with circles, from (A)] and $H_2SO_4 \cdot 8H_2O$ at $T = 140$ K and $d = 50$ μm, normalized at 1.1 μm [solid line, from (C)].

No Spectral Proof until Today

S^{+7} into H_2O MID-IR

not 1-2.5 μm region!

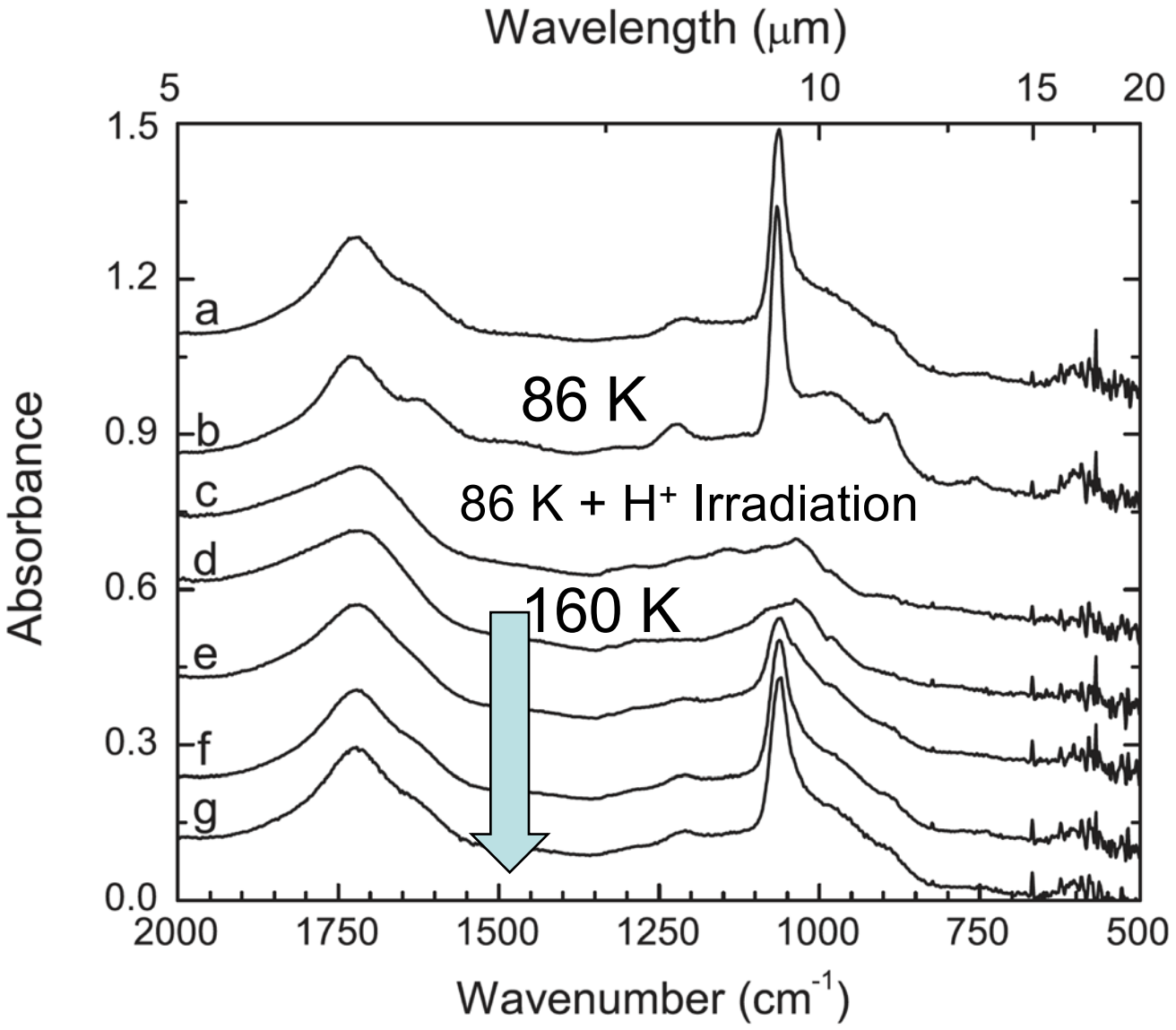
Ding et al., Icarus 226 (2013) 860–864



Radiation Effect on Sulfuric Acid Hydrate

$H_2SO_4.4H_2O$ Destroyed Under Radiation Regenerated Thermally At 160 K

Loeffler & Hudson, Icarus 219 (2012) 561–566

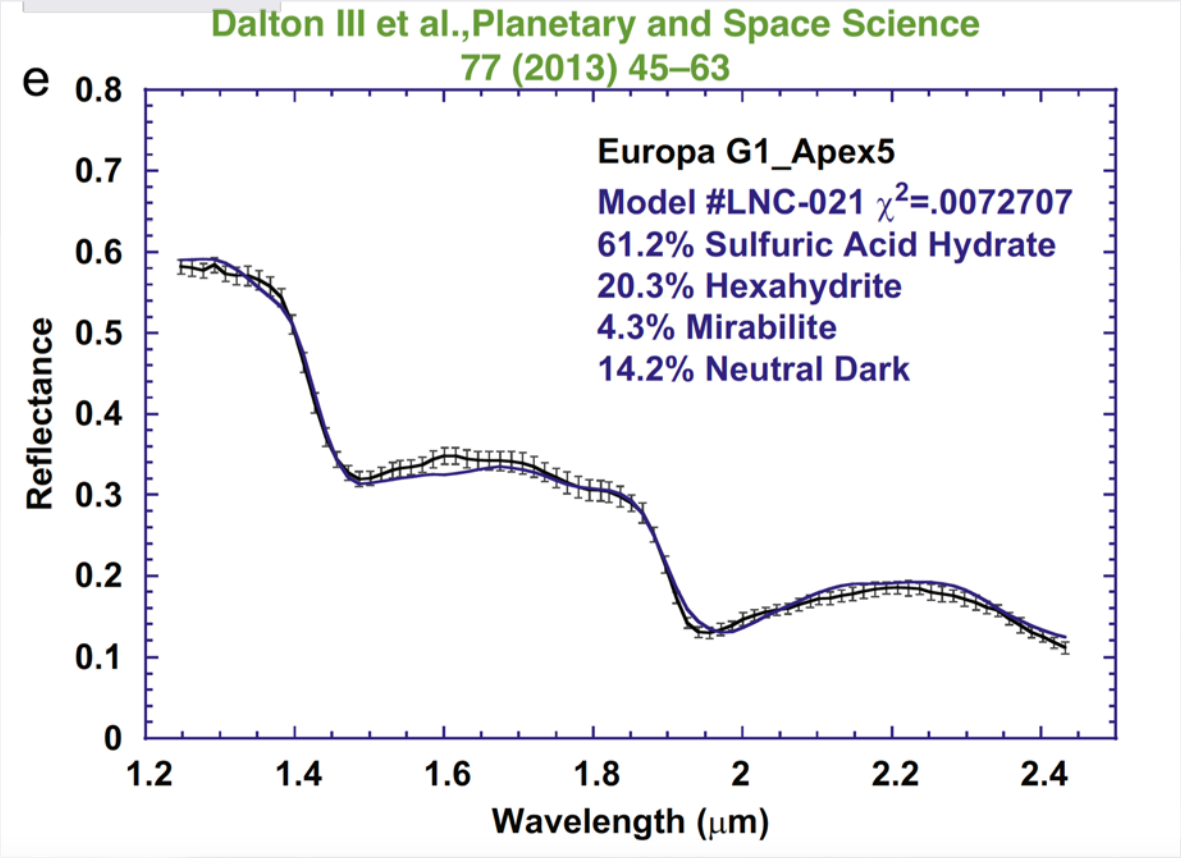


Moral of the Story of Sulfuric Acid Hydrates on Europa

Sulfuric Acid Hydrates – May be there, perhaps very likely
BUT NOT PROVEN
Spectroscopically in the 1-2.5 μm region
That S^{+n} bombardment on H_2O-Ice produces them!

Radiation Effect On the 1-2.5 μm Region are NOT KNOWN

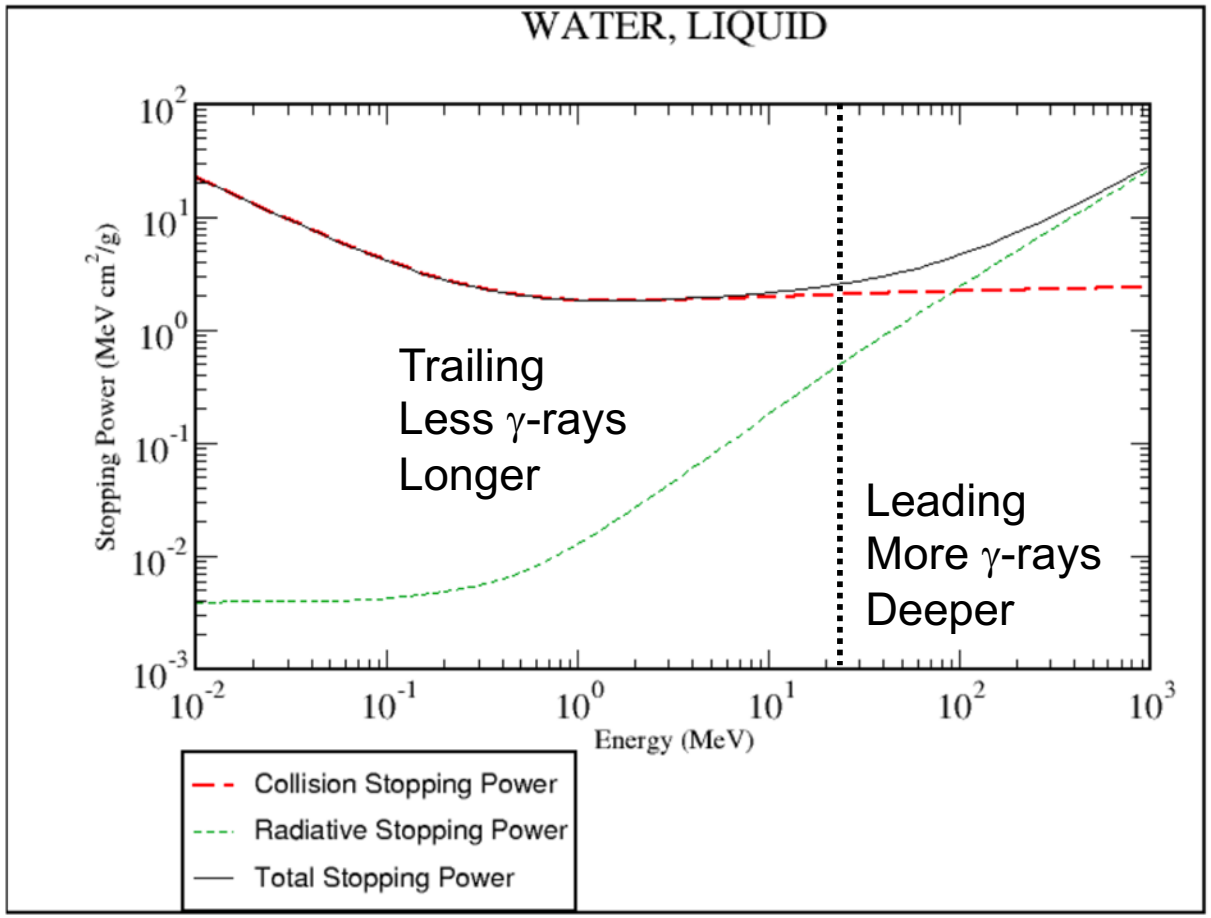
Where are other S^{+n} radiation products?



Electron Penetration Depths – Case Study II

Except our Preliminary Laboratory Studies,
NO DATA on Electron Penetration Depths into Europa Ice Analogs
ALL the Models use Liquid Water Data

>1 MeV electrons
Collisional stopping
Constant at 2.5 MeV/cm
Radiative stopping
Increases



More in the talk of
Bryana Henderson

Moral of the Story

- Longer Exchange Time Scales – Deeper Radiation Damage
- We need a handle on the Interior-Surface Exchange Time Scales for Different Geologically Distinct Features/Regions.
- Laboratory Data for Electron Penetration Depths and Organic Damages need to be conducted on Europa Ice Analogs.

O_2 on Galilean Satellites – Case Study III

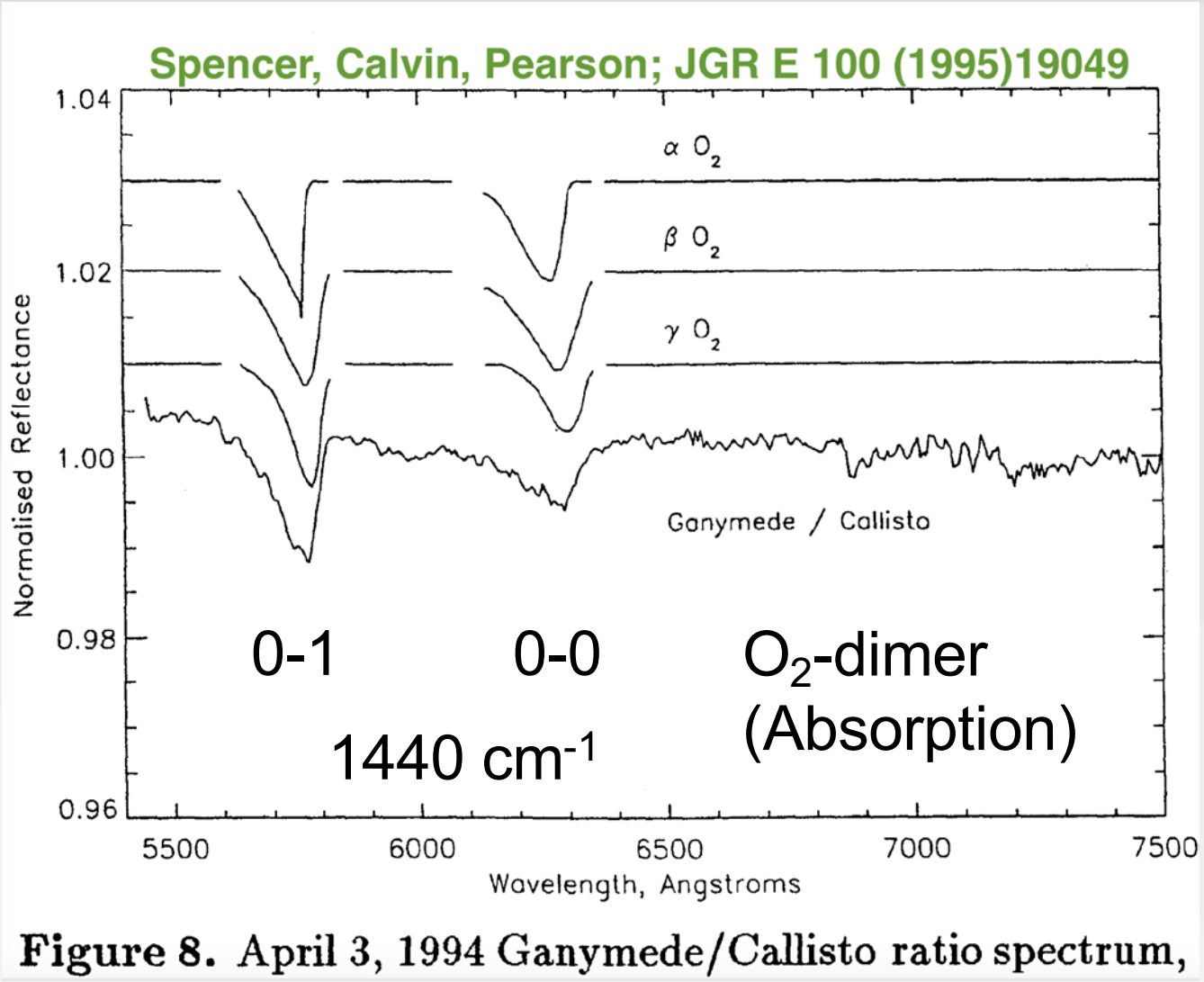
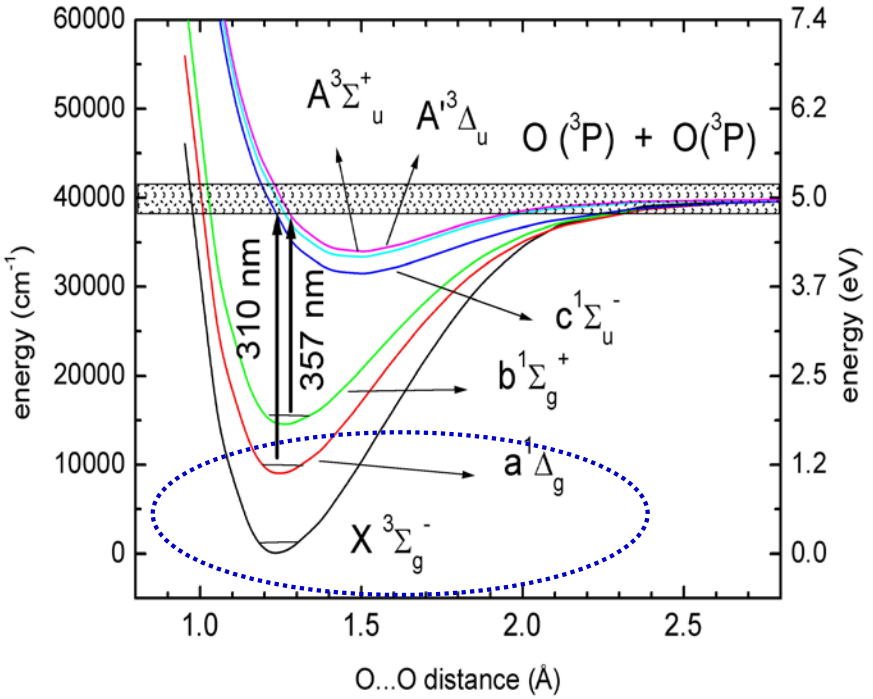
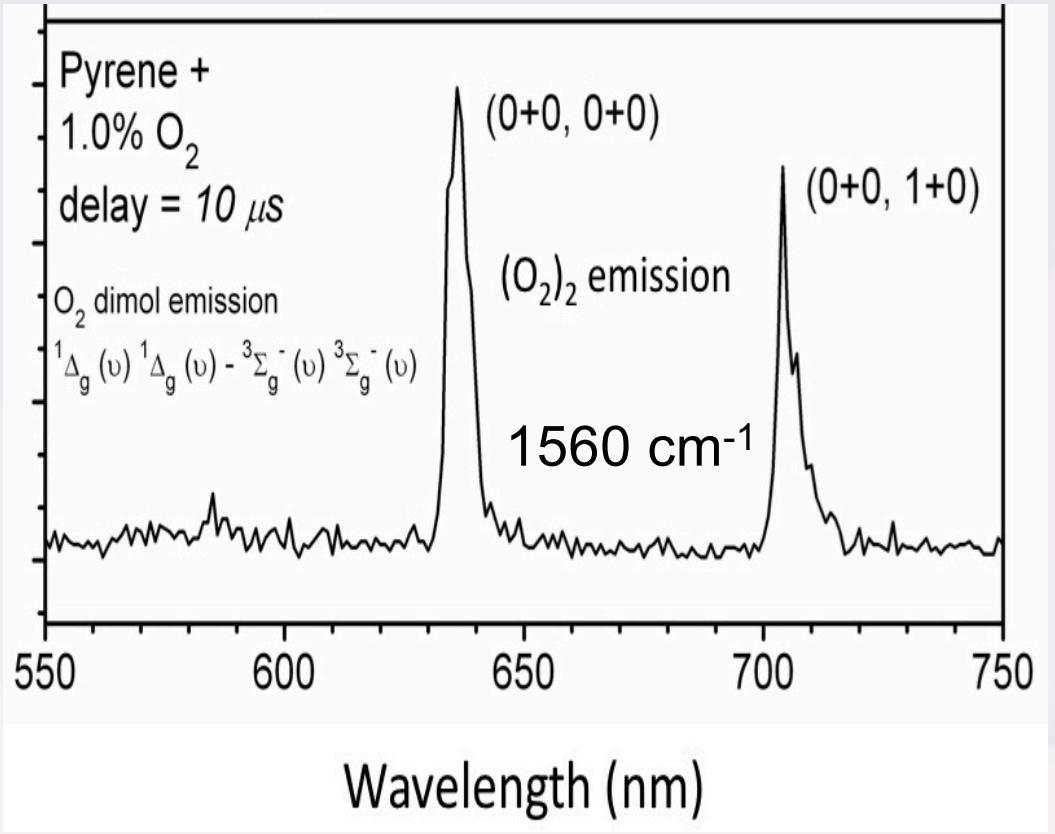


Figure 8. April 3, 1994 Ganymede/Callisto ratio spectrum,

O_2-Dimol Emission

X-state vibrational spacing (emission): 1556 cm^{-1}
a-state vibrational spacing (absorption)1446 cm^{-1}

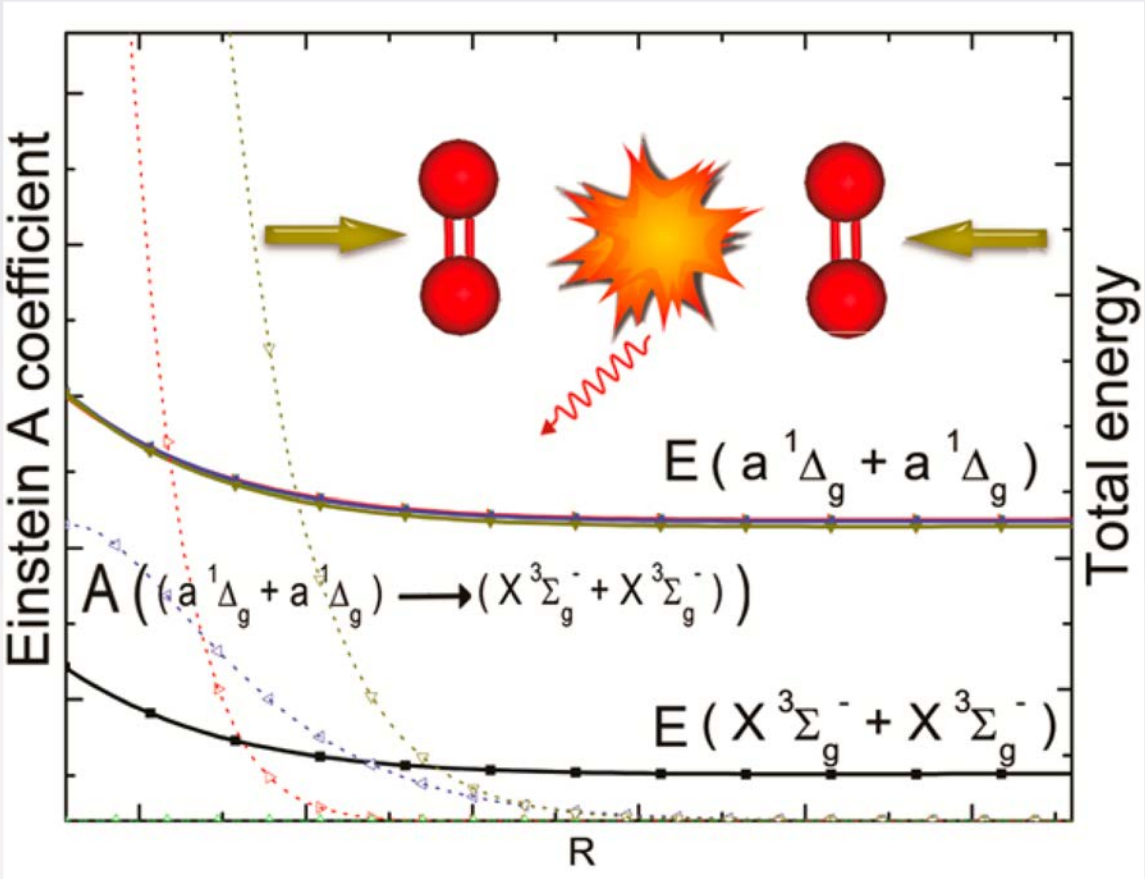




R. Wagner & M.S. Gudipati (unpublished)
R. Wagner (Ph.D. Thesis)

O_2-Dimol (dimer) Abs/Emission Well Established

O2-Dimer absorption/emission is also observed in the GAS-PHASE



Tajti et al., J. Phys. Chem. Lett. 2017, 8, 3356–3361

My Hypothesis:

It is most likely that O_2 is radiolytically produced at centimeters to meters depth on Europa, Ganymede, and Calisto

AND

Percolated to the top surface, during which process, form O2-bubbles (dimers and above)

Moral of the Story

Spencer, Calvin, and Pearson did an excellent job!

O_2-dimer absorption in Galilean Moons is a fact!

What could be there in the ice: O_2-dimer (a minimum aggregate required, but could me more clusters)

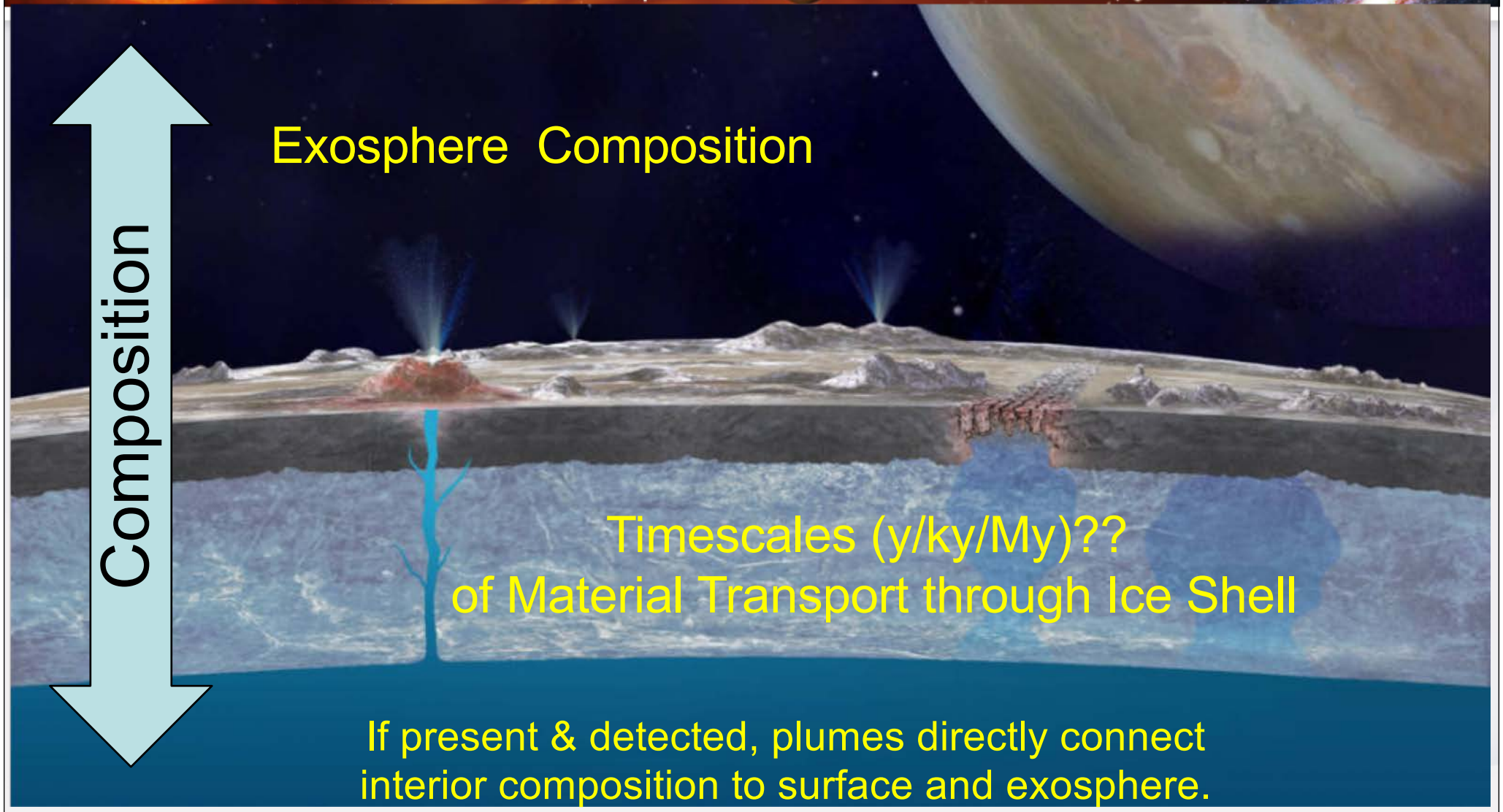
Mechanism of $(O_2)_{n\geq 2}$ through radiolysis in ice is yet to be established in the Laboratory Experiments!

Assessment of Europa's Composition
Future Needs (Laboratory and Modeling)

Key Composition Questions

- What are the Non-Ice Components?
- What is the effect of Radiation on Ice/Non-Ice?
- What are the Surface-to-Interior Material Exchange Processes (Plumes, Upwelling, Cryovolcanism, etc)? What are their Rates?
- What is the refreshing rate of the top 1-2 m of Europa's surface materials?
- How does Surface Composition effect the Exosphere?
- What is the Depth-vs-Concentration of Composition?
- How can we translate Surface Composition into the Interior?
- What is the effect of Amorphous vs. Crystalline Ice on Composition?

Composition



Plumes may originate from liquid ocean or iceshell.

Material Inventory

Molecules and Materials on Europa
(Thermal and Radiation Equilibrium Chemistry)

Chemical Inventory

H_2O
H_2O_2
OH?
O?
O_2?
O_3?
SO_x?
$MgSO_4$?
NaCl?
$H_2SO_4.xH_2O$
CO_2?
Carbonates?
Organics?
Inorganics (other than Salts)?
Fe and other metals?
FeS?

Mixing Ratio?

Biomarkers?
Color Carriers?
TBD…

Physical Mixing of Salts, Minerals, Organics, and Ice?
OR Intimate Mixing?
If so, Crystalline Water Ice expels majority of molecules!

Accuracy of Chemical Identification
- Spectroscopy vs. Color
- Tentative vs. Positive Identification

Conclusions

- Evaluate the Source of Input Data to Your Models (You Need to know the source of your Food)!
- Partnership among “Observers/Modelers/Experimentalists”
- Laboratory Data under “Simulated Europa Environment” is Sparse.
- Come up with “Critical Lab Work needed” to better Model Europa’s Composition!

Thank You

JPL and NASA for Funding
Ice Spectroscopy Lab Team (Past and Present)