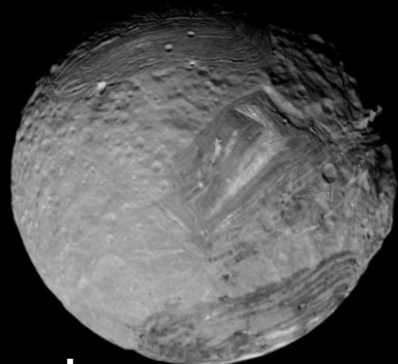


# The Uranian Moon Ariel, a Carbon Dioxide Wonderland Observed by JWST

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Miranda



Ariel



Umbriel



Titania



Oberon

# Webb Detects Carbon Oxides on Ariel, Hinting at a Hidden Ocean

- Ariel's surface is mantled by a large amount of CO<sub>2</sub> ice and minor amount of carbon monoxide ice
- CO<sub>2</sub> and CO ice are volatile on Ariel and are lost to space over time and must be replenished by some mechanism
- CO<sub>2</sub> ice might be formed by irradiation of Ariel's surface
- CO<sub>2</sub> gas might escape from Ariel's interior and condense on its surface
- If CO<sub>2</sub> escapes from Ariel's interior, then it may originate in a subsurface ocean enriched in carbon oxides, including CO and possibly carbonates (CO<sub>3</sub>)

JWST spectroscopy results better support an ocean origin for carbon oxides on Ariel



Ariel

Diameter  
~1158 km

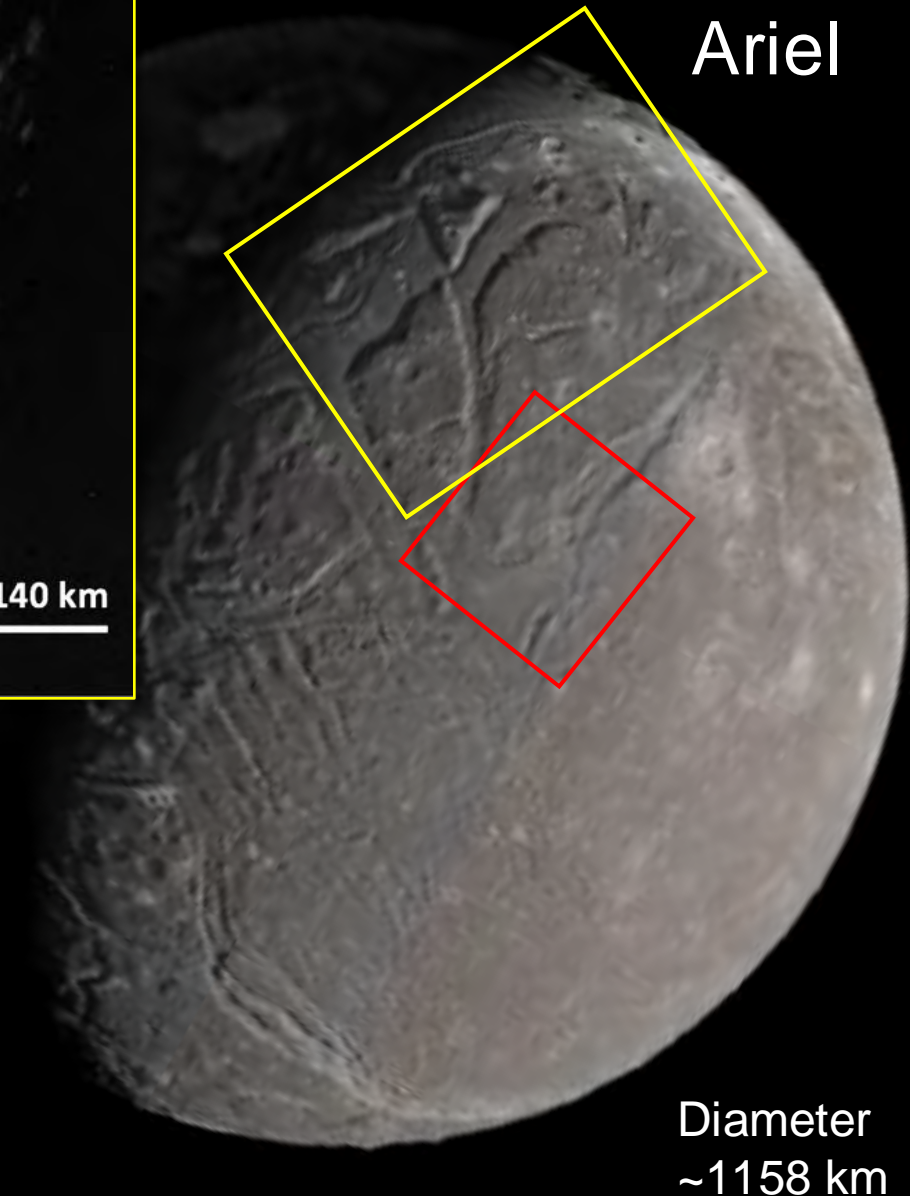
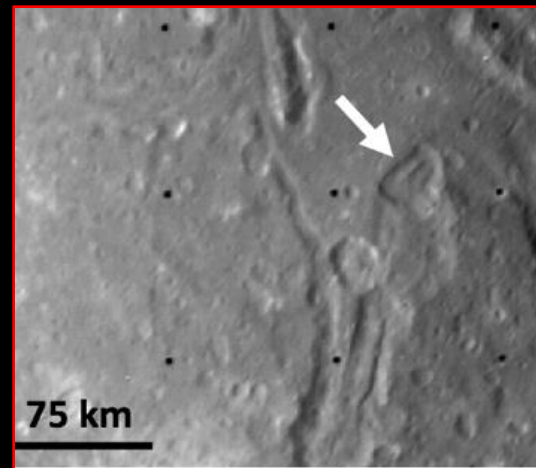
# Ariel: Resurfaced by Geologically-Recent Activity?

Widespread evidence for tectonic resurfacing and possible cryovolcanism ( $\sim 1$  km/pixel) (e.g., Schenk, 1991; Beddingfield and Cartwright, 2021; Beddingfield et al., 2022, Under Review)

Regions as young as 0.8 Ga ( $-0.5/+1.8$  Ga) (Kirchoff et al., 2022)

Younger chasma floors do not have age estimates, nor do overprinting “medial grooves” (Beddingfield et al., Under Review)

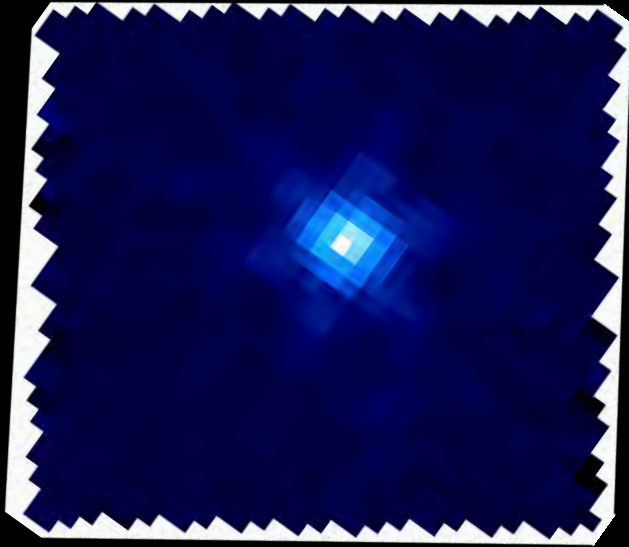
Likely youngest regions on Ariel do not have age estimates



# JWST Observes Uranus

**JWST:** 6.5 m space telescope collecting NIR-MIR data with no atmospheric contamination

NIRSpec IFU spectral cube (G395M) of Ariel (9/6/23)



Titania

Miranda

Oberon

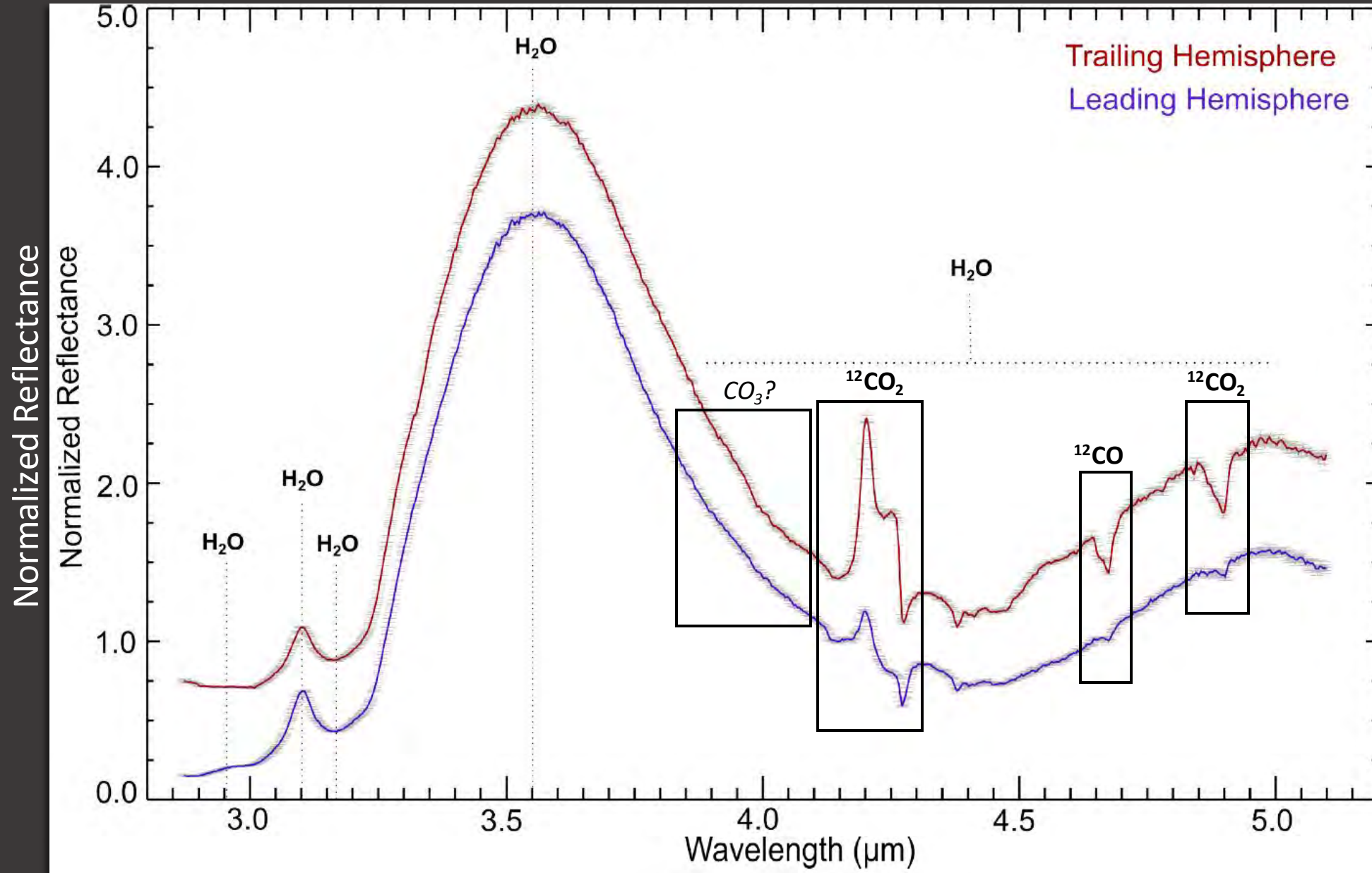
Umbriel

Ariel

# Combining NASA IRTF and JWST Observations of Ariel

Grand average IRTF  
(1 – 2.5  $\mu\text{m}$ ) and  
JWST (2.9 – 5.1  
 $\mu\text{m}$ ) spectra

Large amount of  
 $\text{CO}_2$  and possible  
presence of  
carbonates ( $\text{CO}_3$ )  
consistent with  
geologic origin

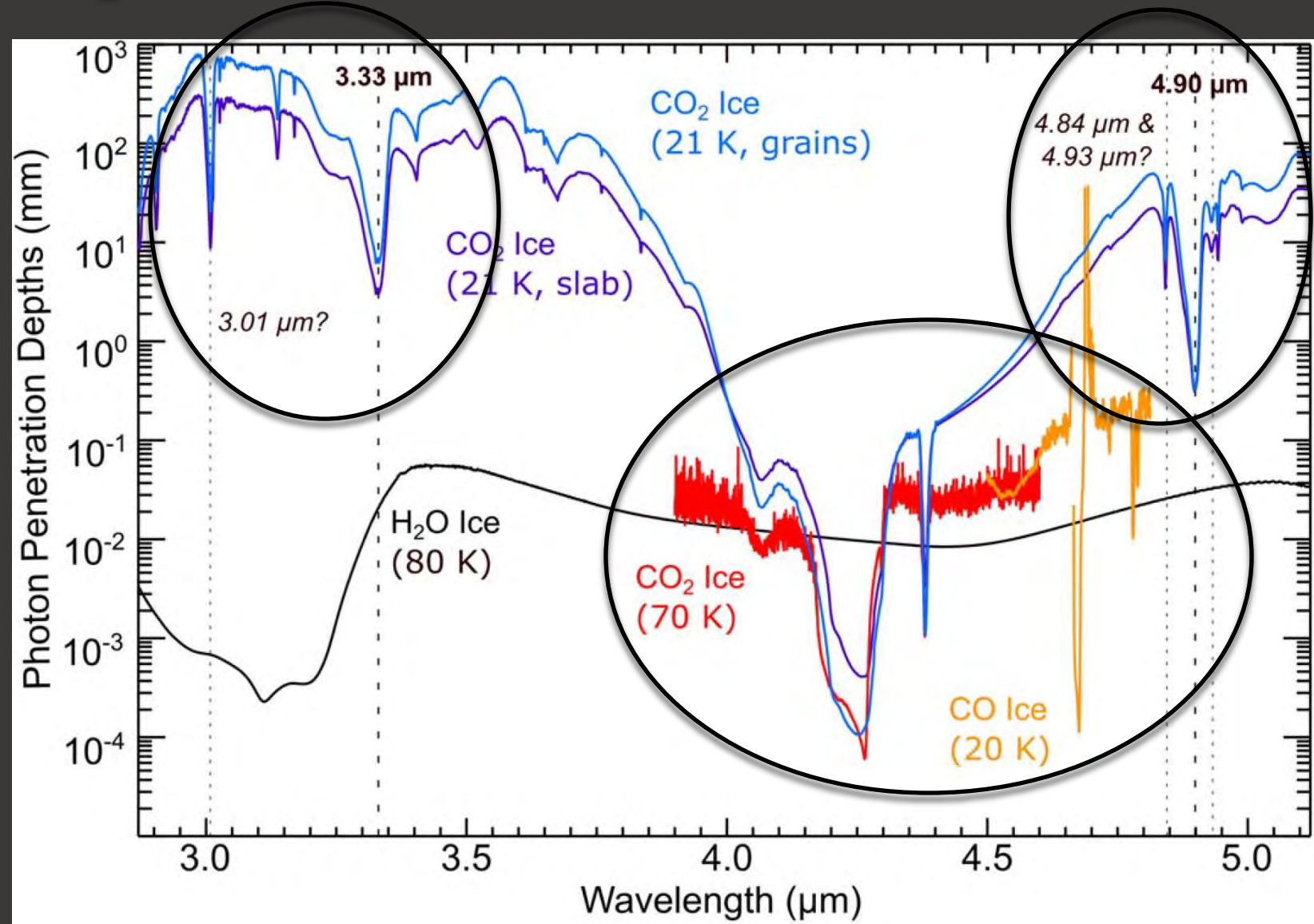


# Ariel's Concentrated CO<sub>2</sub> Ice Deposits

CO<sub>2</sub> and CO ices absorb strongly and persist when mixed with H<sub>2</sub>O ice

Weaker CO<sub>2</sub> ice features only exhibited by 'pure' and layers of CO<sub>2</sub> > 10 mm in thickness

Thick CO<sub>2</sub> layer more consistent with geologic origin



# Exploring CO Ice on Ariel

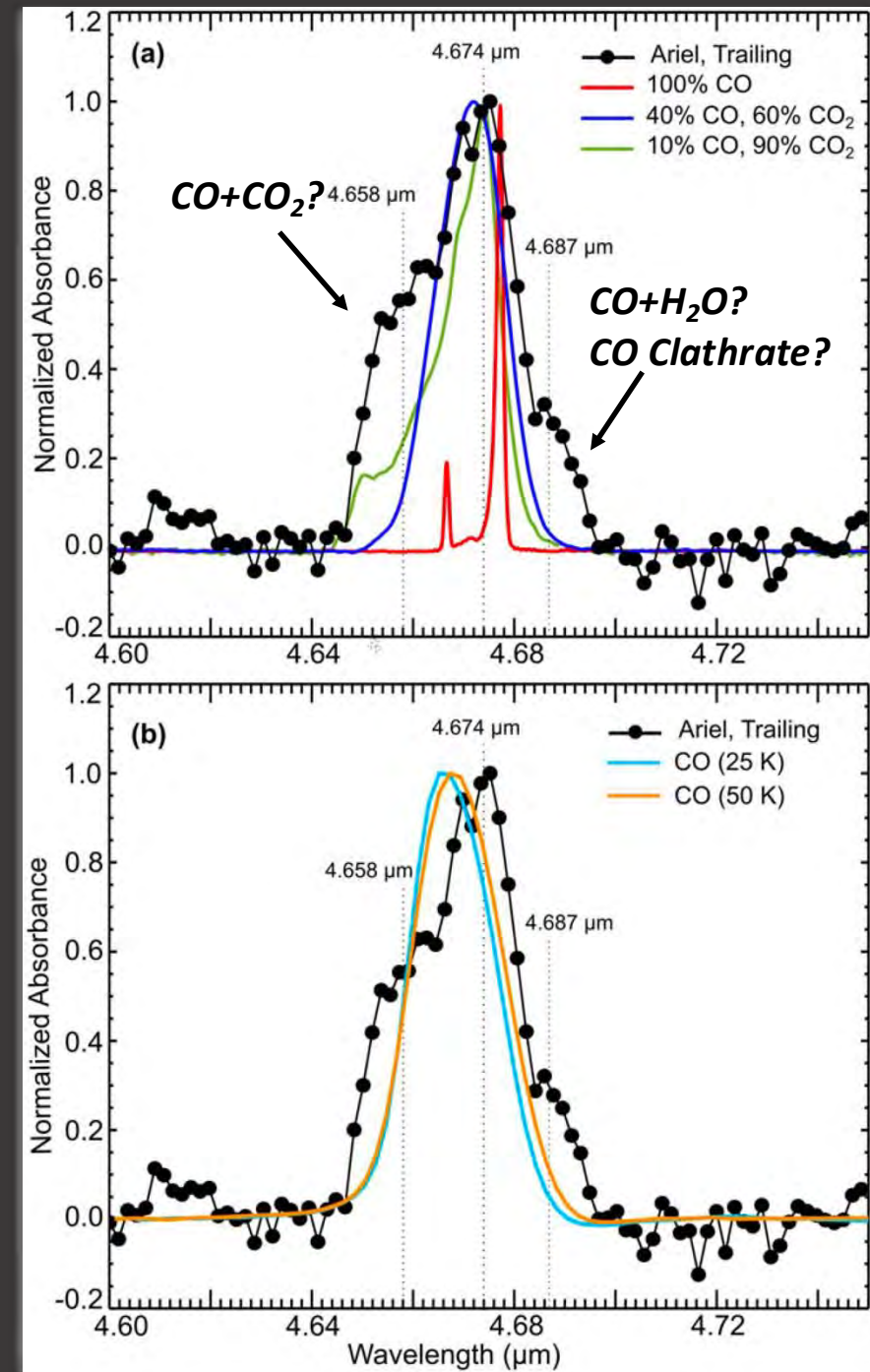
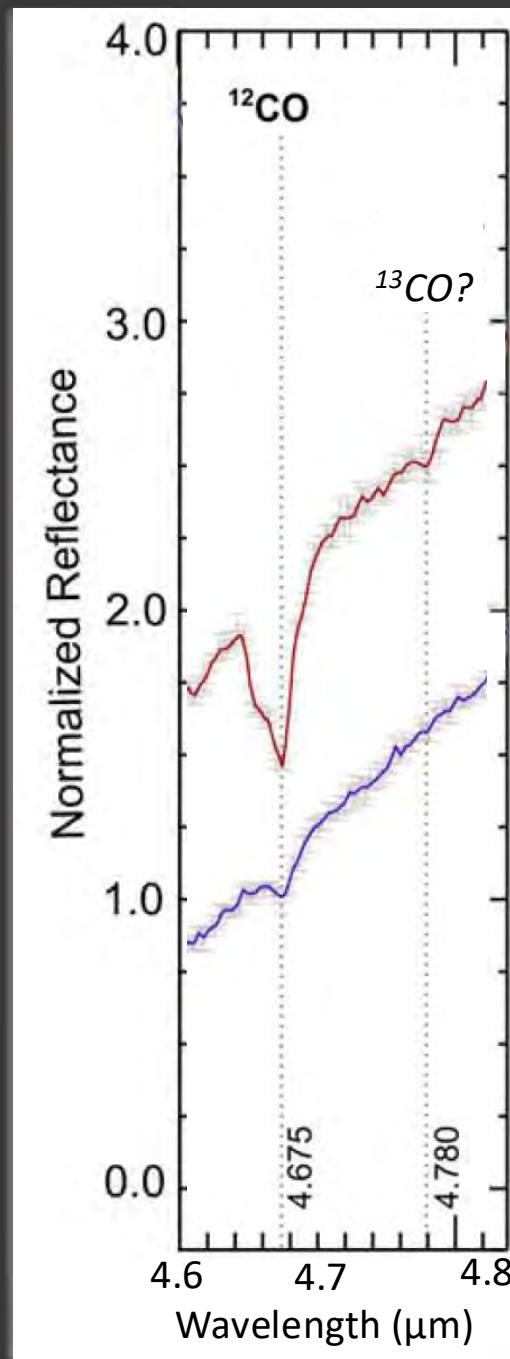
Ariel's  $^{12}\text{CO}$  ice feature significantly stronger on its trailing hemisphere

Potential  $^{13}\text{CO}$  ice feature

Ariel's  $^{12}\text{CO}$  ice feature not consistent with 'pure' CO ice measured in the lab nor CO generated by irradiation of  $\text{CO}_2$  ice

CO ice on Ariel more consistent with  $\text{CO}+\text{CO}_2$  mixtures

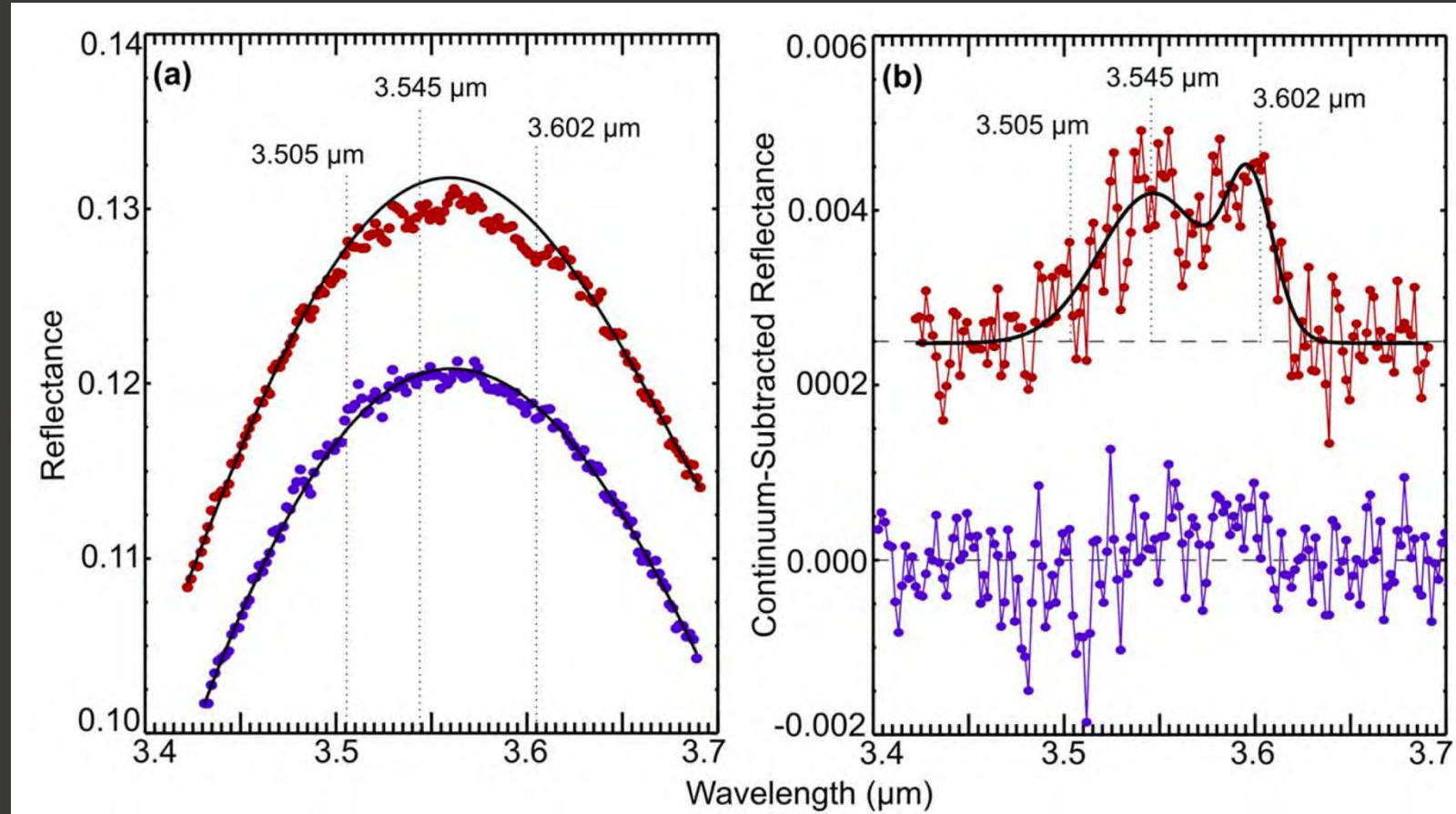
Possible presence of CO mixed with  $\text{H}_2\text{O}$  and/or CO clathrates support geologic origin



# No Evidence for Hydrogen Peroxide on Ariel

3.505  $\mu\text{m}$   $\text{H}_2\text{O}_2$  features on Europa, Ganymede, and Charon likely result from irradiation of  $\text{H}_2\text{O}$  ice, possibly mixed with  $\text{CO}_2$

Ariel's weak 3.545 and 3.602  $\mu\text{m}$  features may result from formaldehyde ( $\text{H}_2\text{CO}$ ), formic acid, ( $\text{H}_2\text{CO}_2$ ) or other species



Radiation environment at Ariel somewhat quiescent, and/or topmost layer of  $\text{CO}_2$  ice reduces irradiation of  $\text{H}_2\text{O}$  ice

# Is Ariel Closer to a Relict or Active Ocean World?

**Ceres**

*~939 km*



*CO<sub>3</sub>-rich  
Salt  
Deposits*

**Ariel**

*~1158 km*



*Mantled  
with CO<sub>2</sub>  
& CO Ices*

**Enceladus**

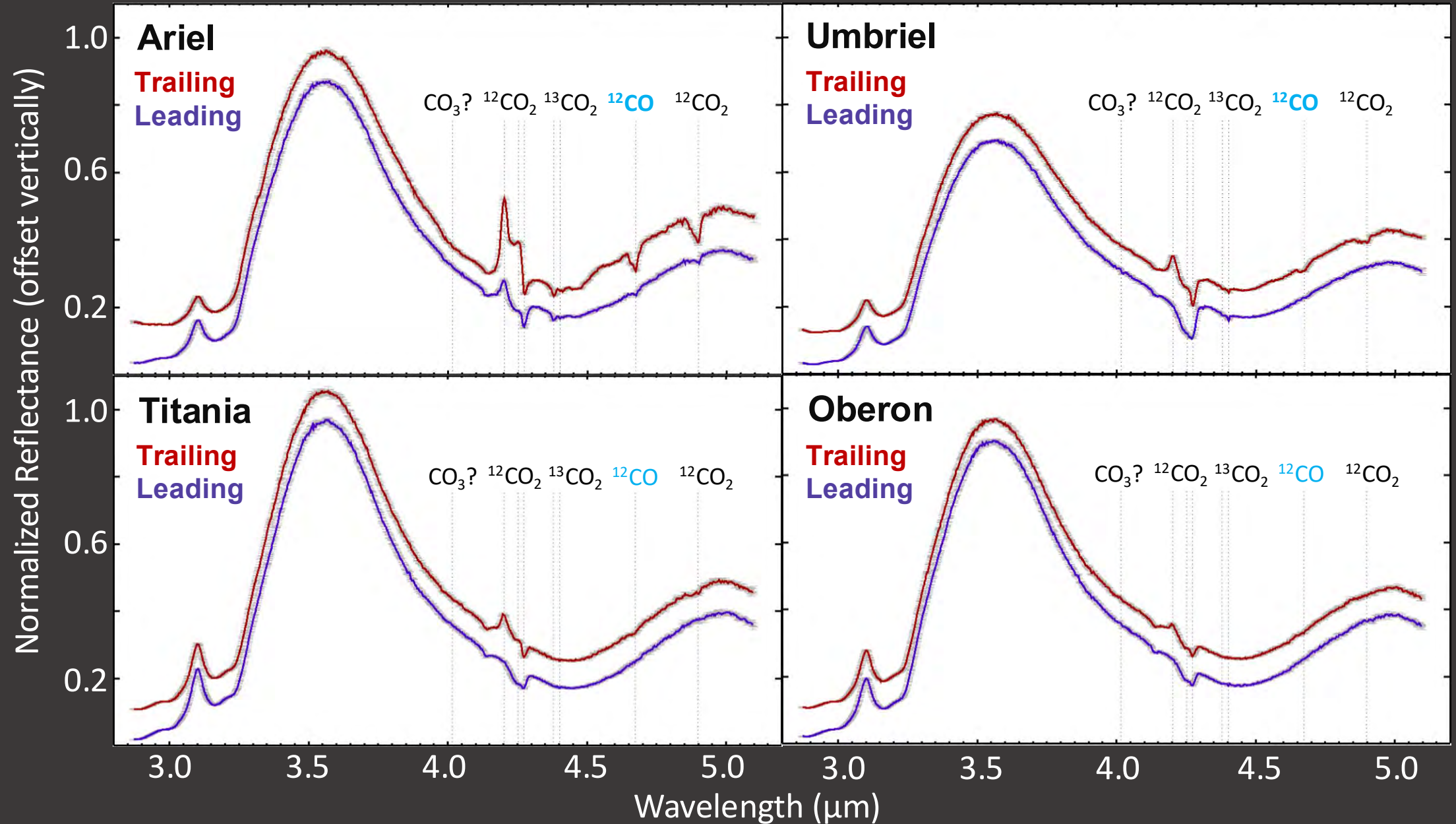
*~505 km*

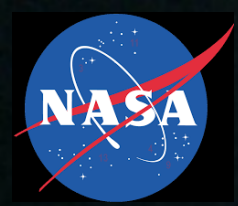


*Plume  
has CO<sub>2</sub>  
& CO gas*

Could carbon oxides be sourced from Ariel's interior, possibly associated with a 'soda' ocean (active now or in the recent past)?

# Future Work: JWST Observations of Umbriel, Titania, & Oberon





# Acknowledgments



*Cartwright et al. (2024), ApJ Letters.*  
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