

Collaborators:
O. Shorttle, S. Jordan, P.B. Rimmer

Atmospheres as a Window to Rocky Planet Surfaces

Xander Byrne

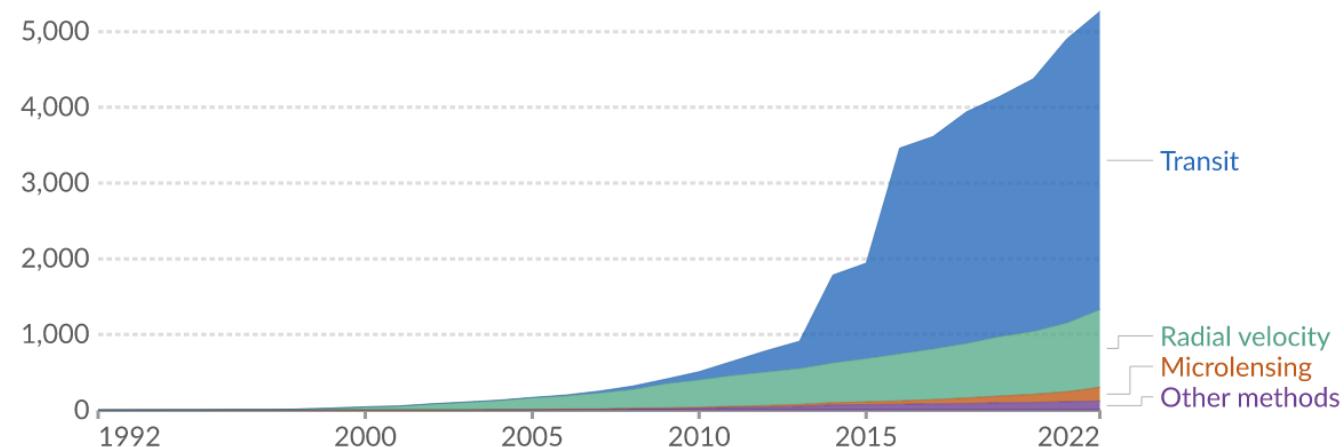
WD group, Institute of Astronomy, UK
xbyrne.github.io

The Exoplanet Revolution

Cumulative number of exoplanets discovered, by method

Our World
in Data

Cumulative number of planets discovered outside the Solar System, broken down by their first identification method: transit, radial velocity, microlensing, or other.



Data source: NASA Exoplanet Archive (2023)

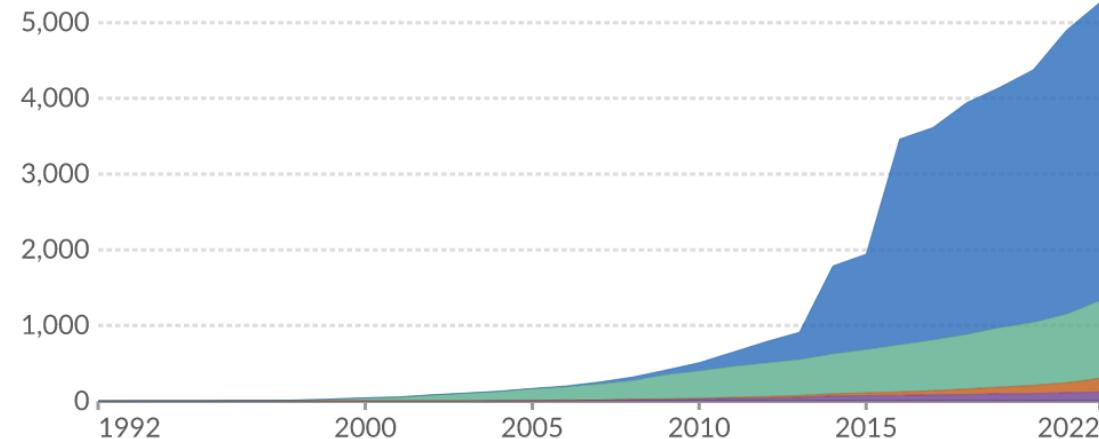
OurWorldInData.org/space-exploration-satellites | CC BY

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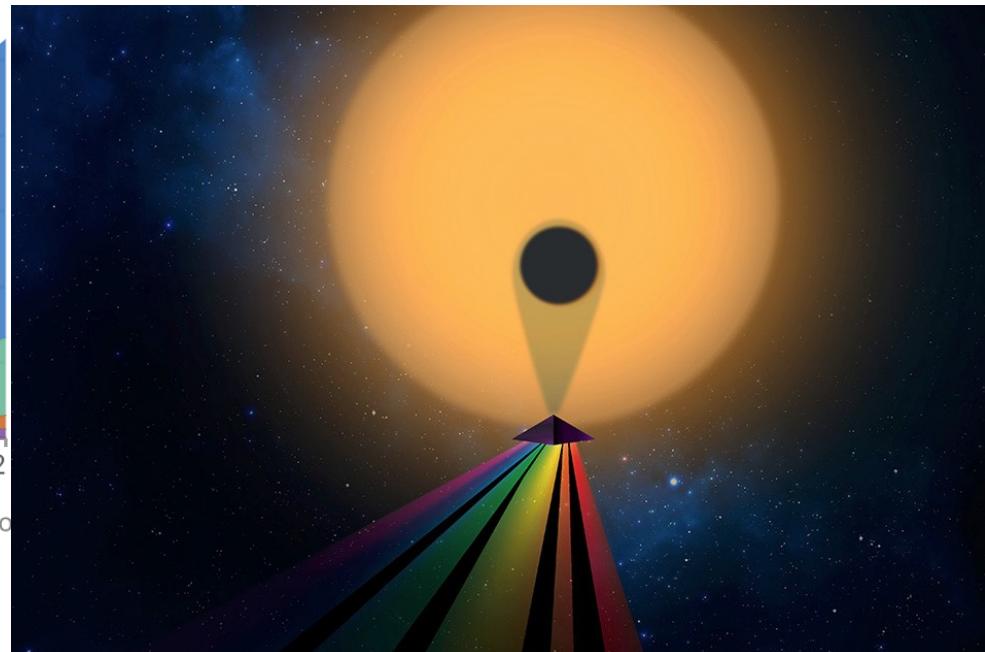
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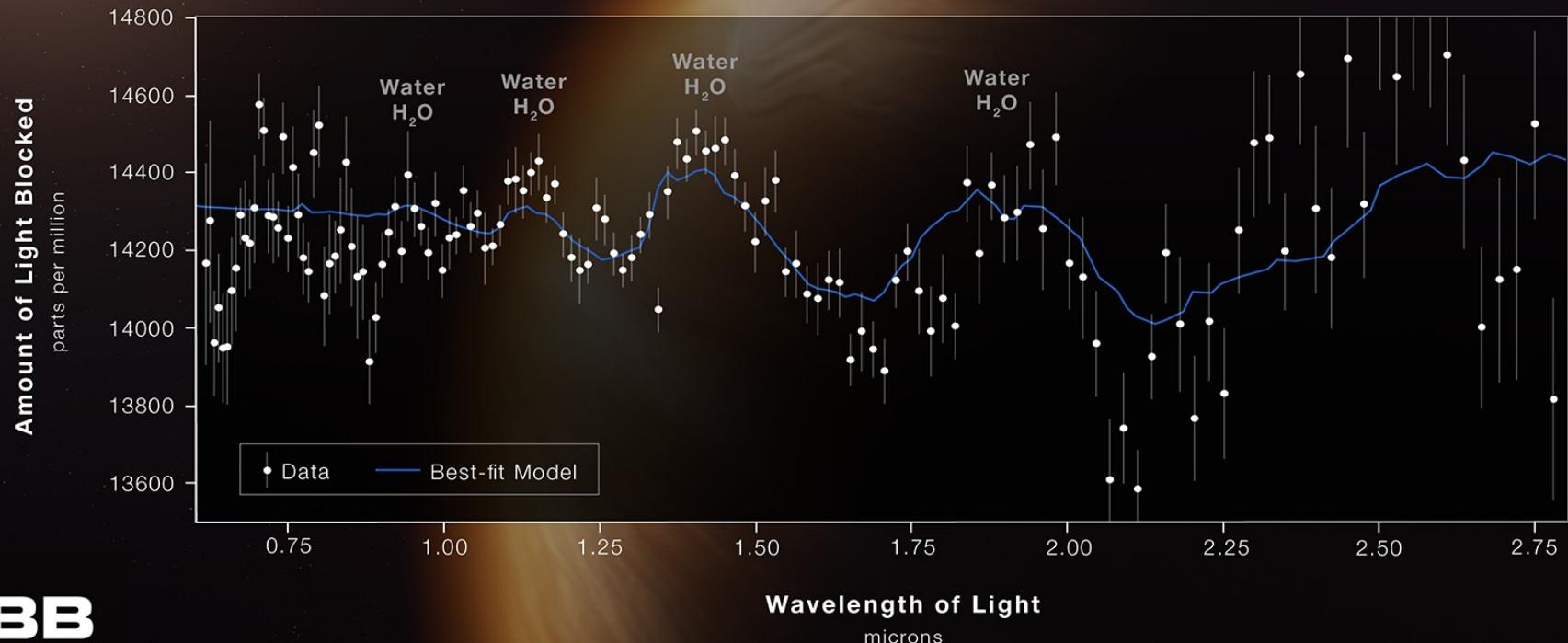
C: Christine Daniloff/MIT, Julien de Wit

The Exoplanet Revolution

HOT GAS GIANT EXOPLANET WASP-96 b

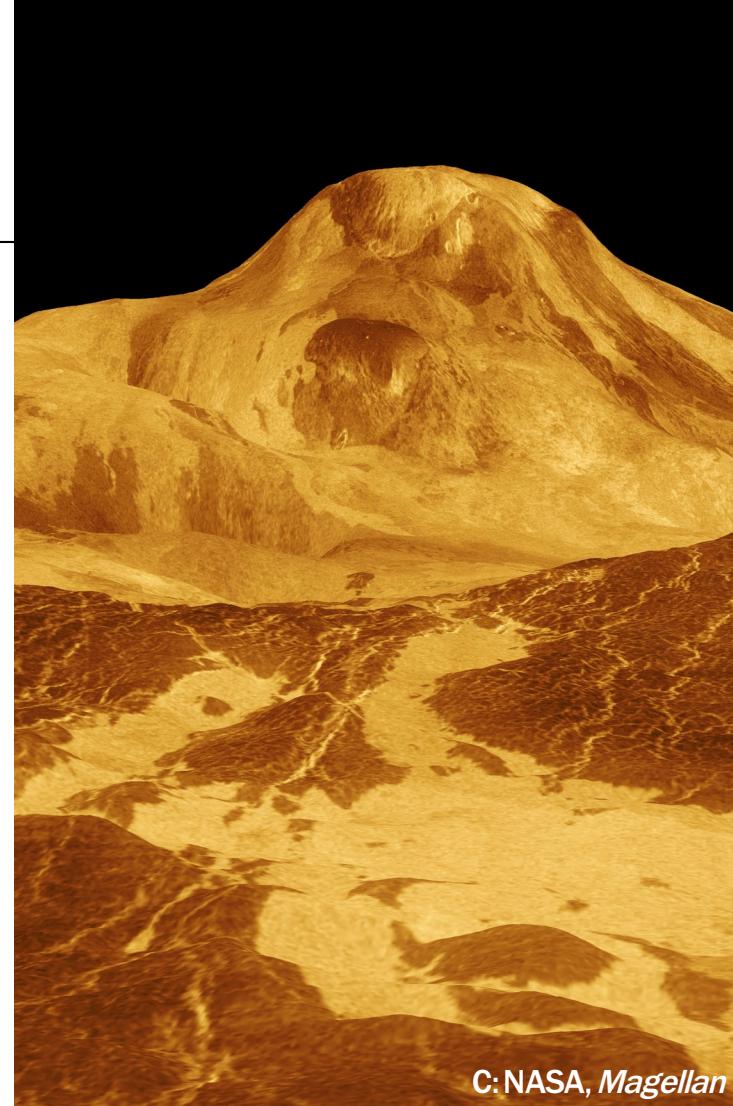
ATMOSPHERE COMPOSITION

NIRISS | Single-Object Slitless Spectroscopy



Rocky Exoplanet Surfaces

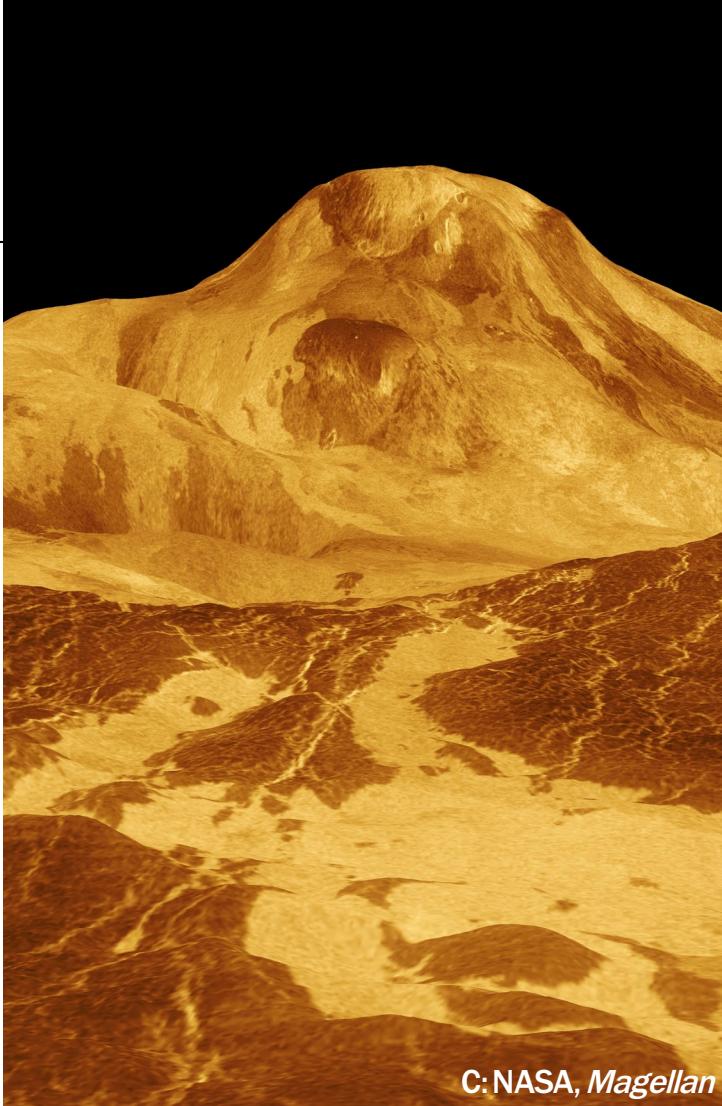
- After atmospheres, the next step is characterising mineralogy



C: NASA, Magellan

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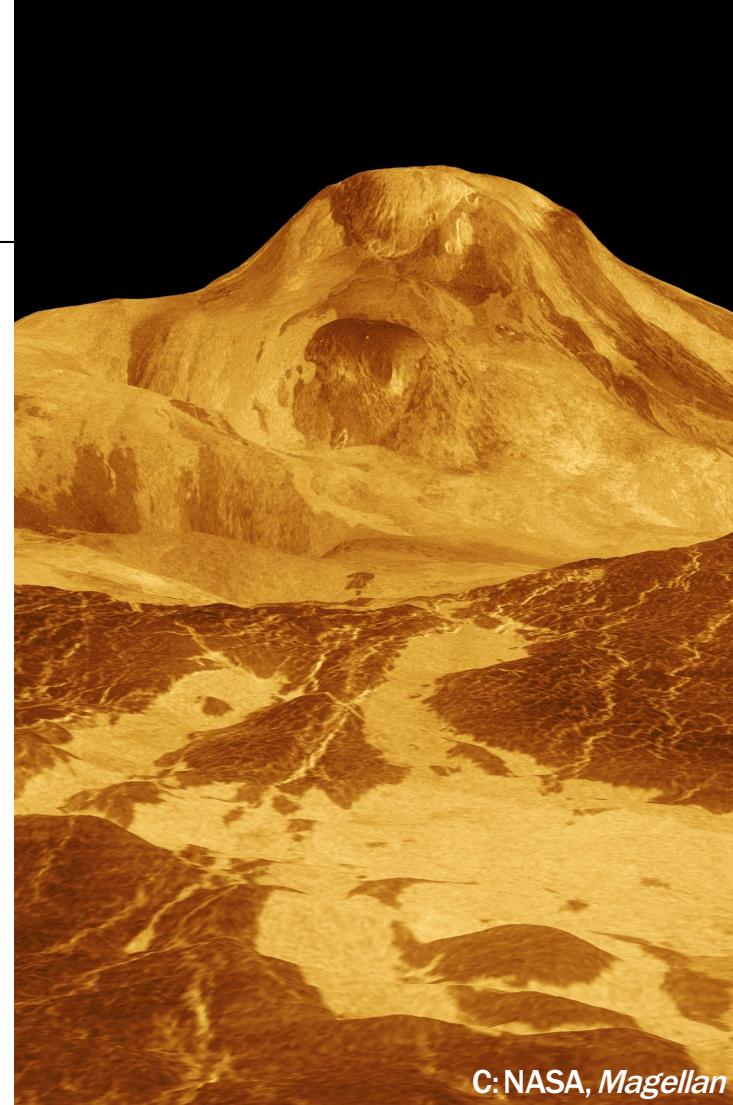
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- Could inform planet formation models
 - e.g. differentiation
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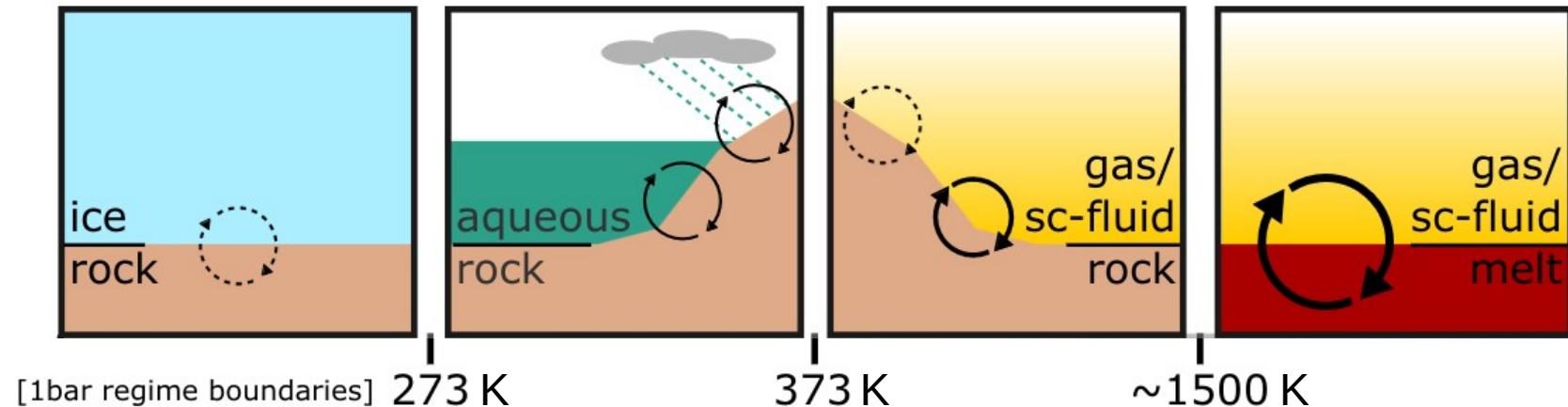
Rocky Exoplanet Surfaces

- After atmospheres, the next step is characterising mineralogy
- Could inform planet formation models
 - e.g. differentiation
- Influence on habitability
- But not directly observable, unlike atm.
 - => Need to link surface to atmosphere

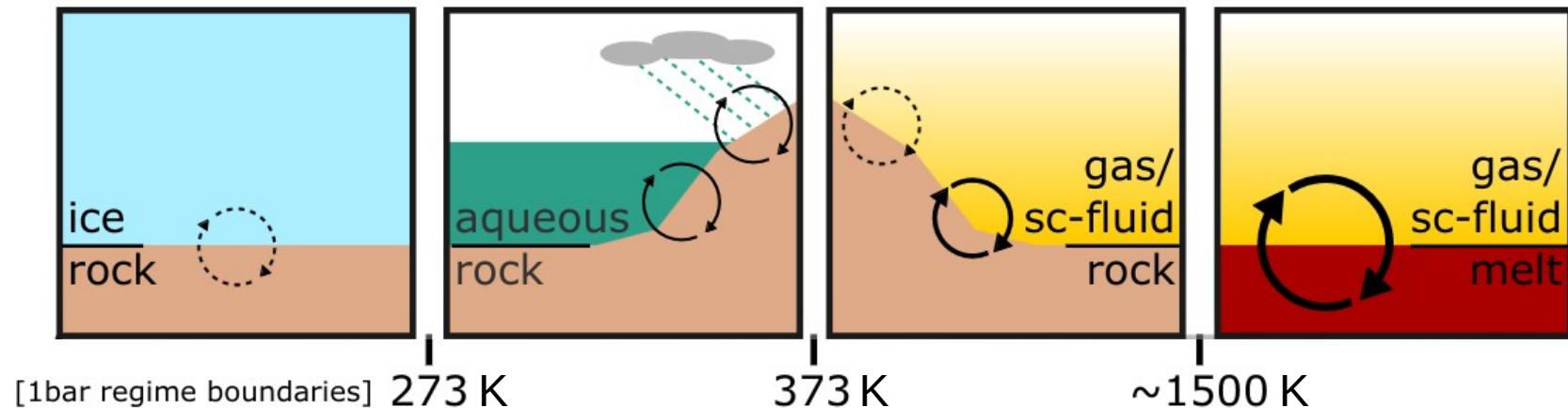


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How do surfaces and atmospheres interact?

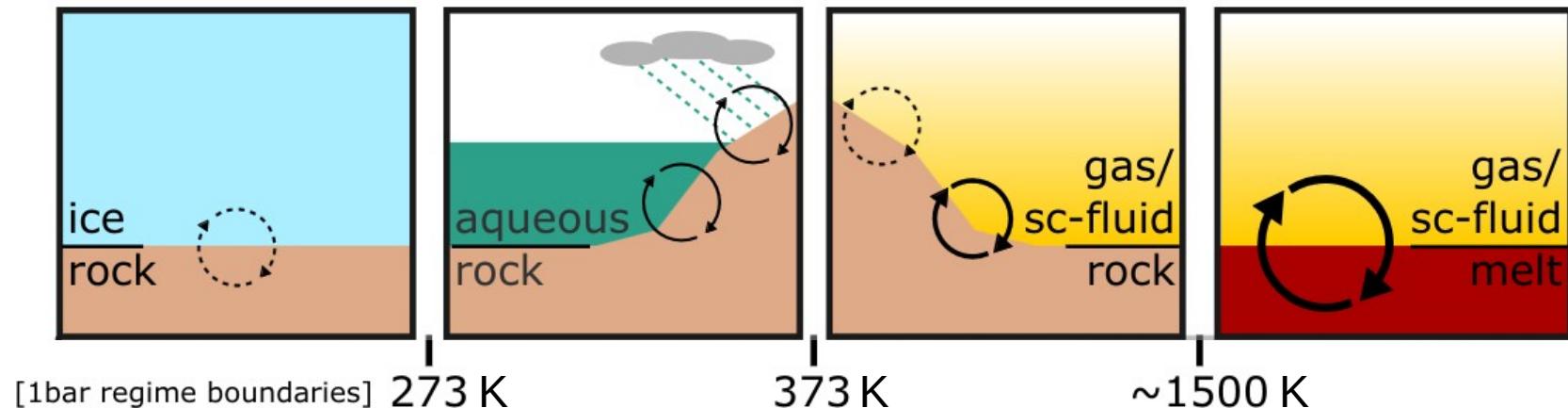


How do surfaces and atmospheres interact?



Solid-solid:
V. slow!

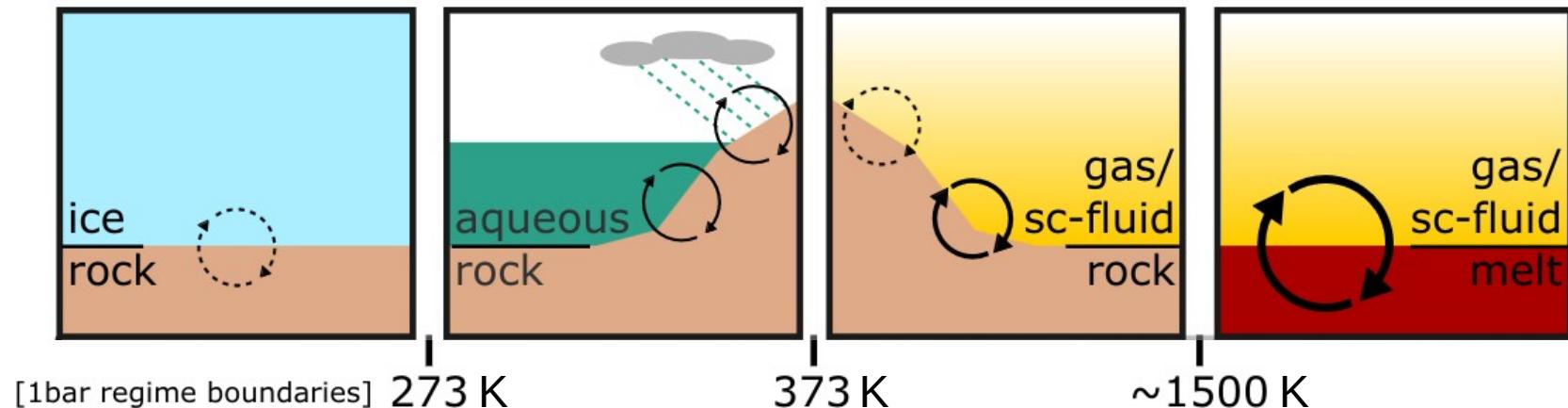
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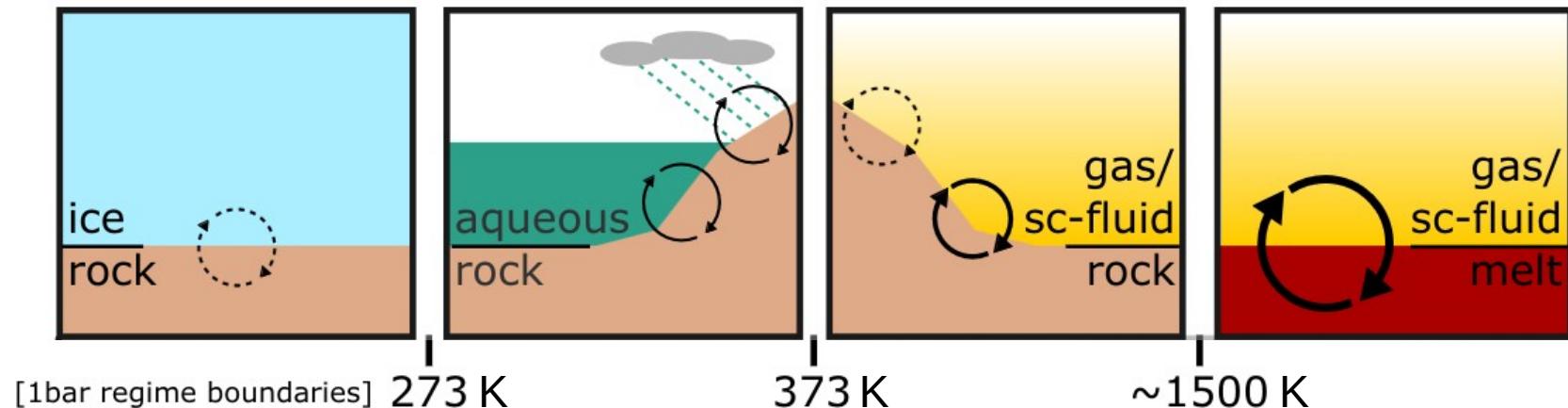


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**Gas-melt
mass transfer:**
V. difficult!

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Solid-solid:
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**Thermochemical
Equilibrium?...**

**Gas-melt
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Thermochemical Equilibrium

- All chemical reactions that can happen, do happen
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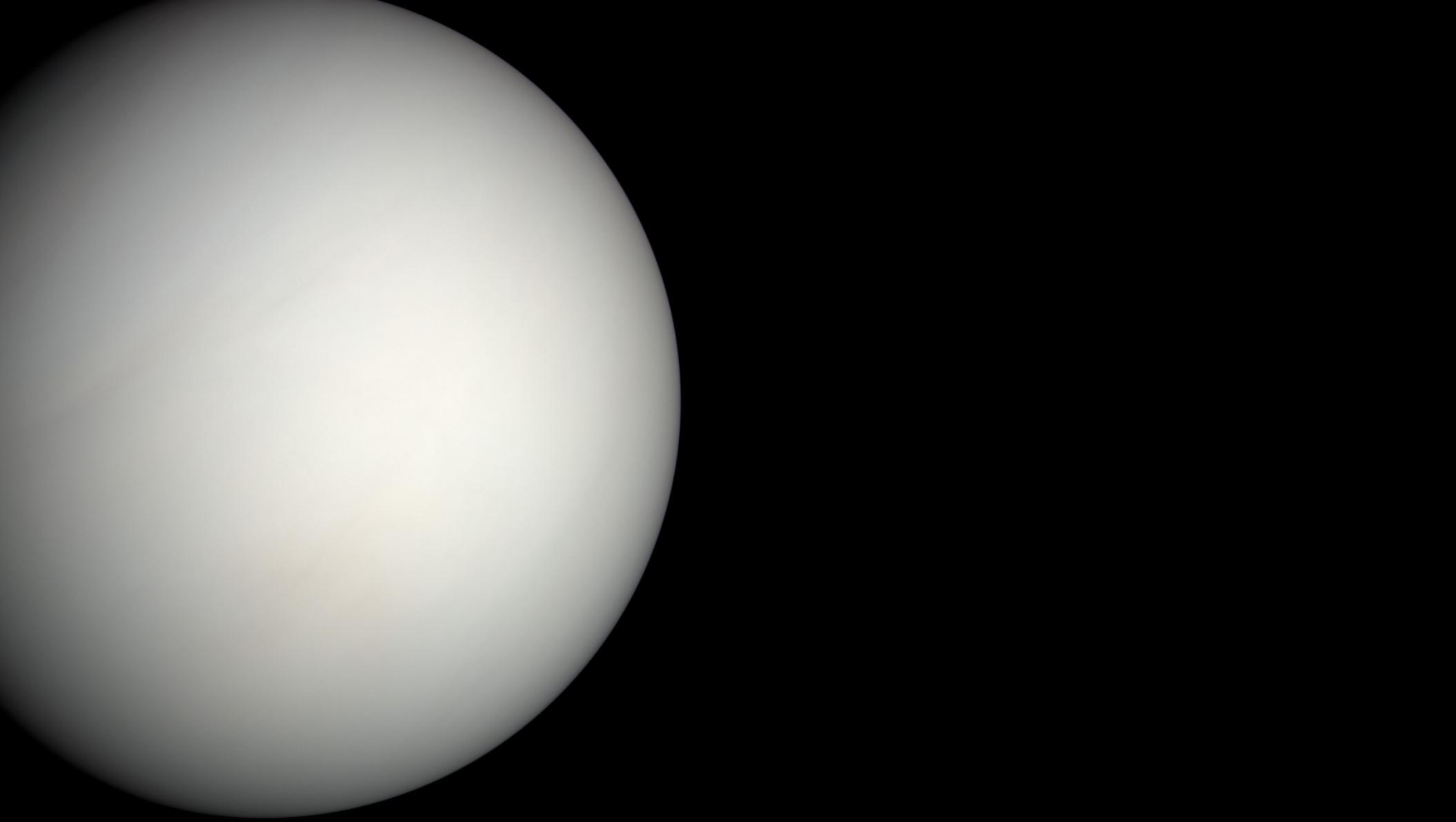
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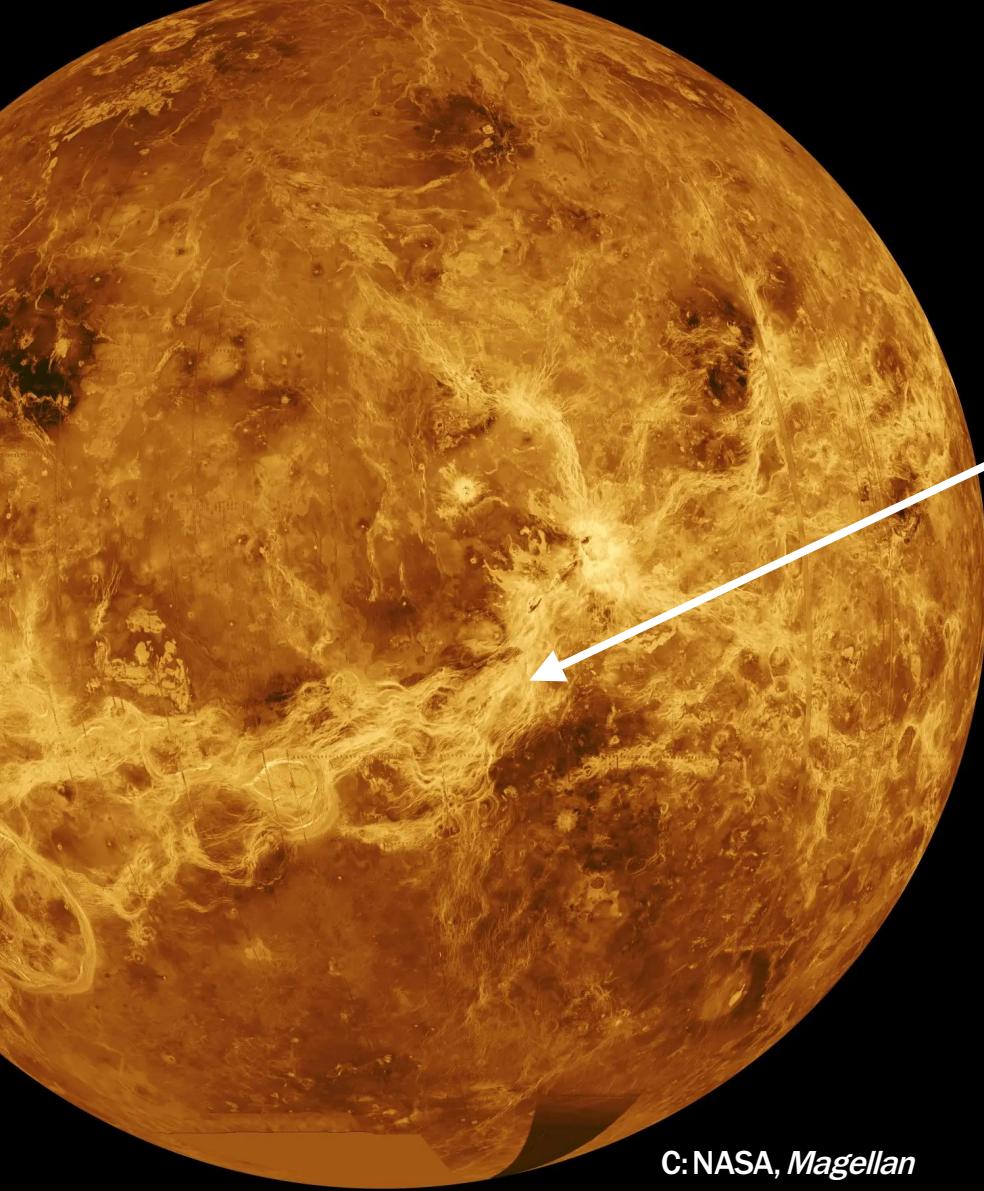
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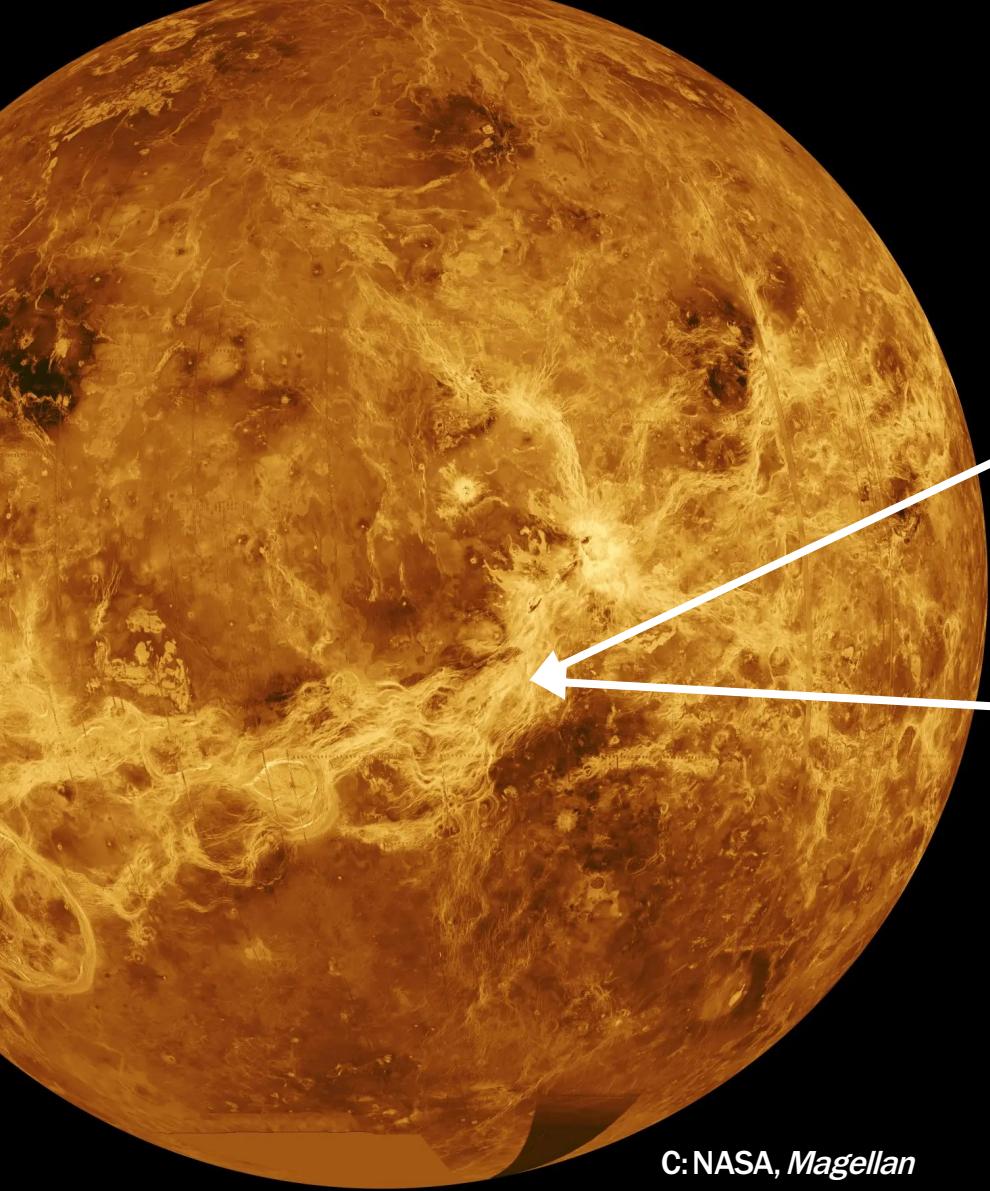
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 - $p, T, \{n_i\} \Rightarrow$ Abundances of mineral and gas species
- Is there a planet where thermochemical equilibrium operates?







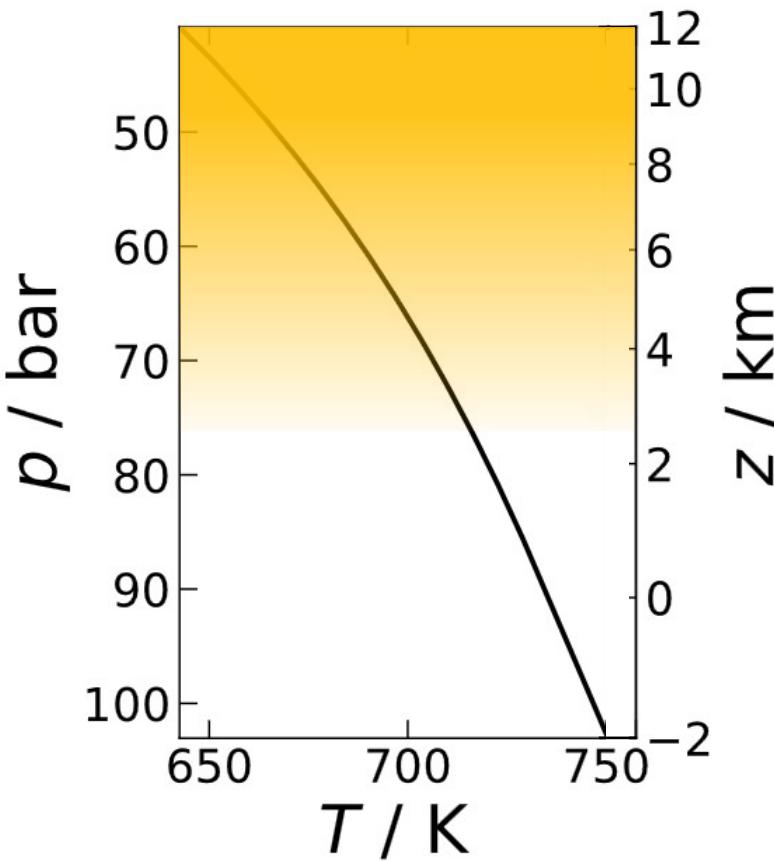
High radar reflectivity



High radar reflectivity

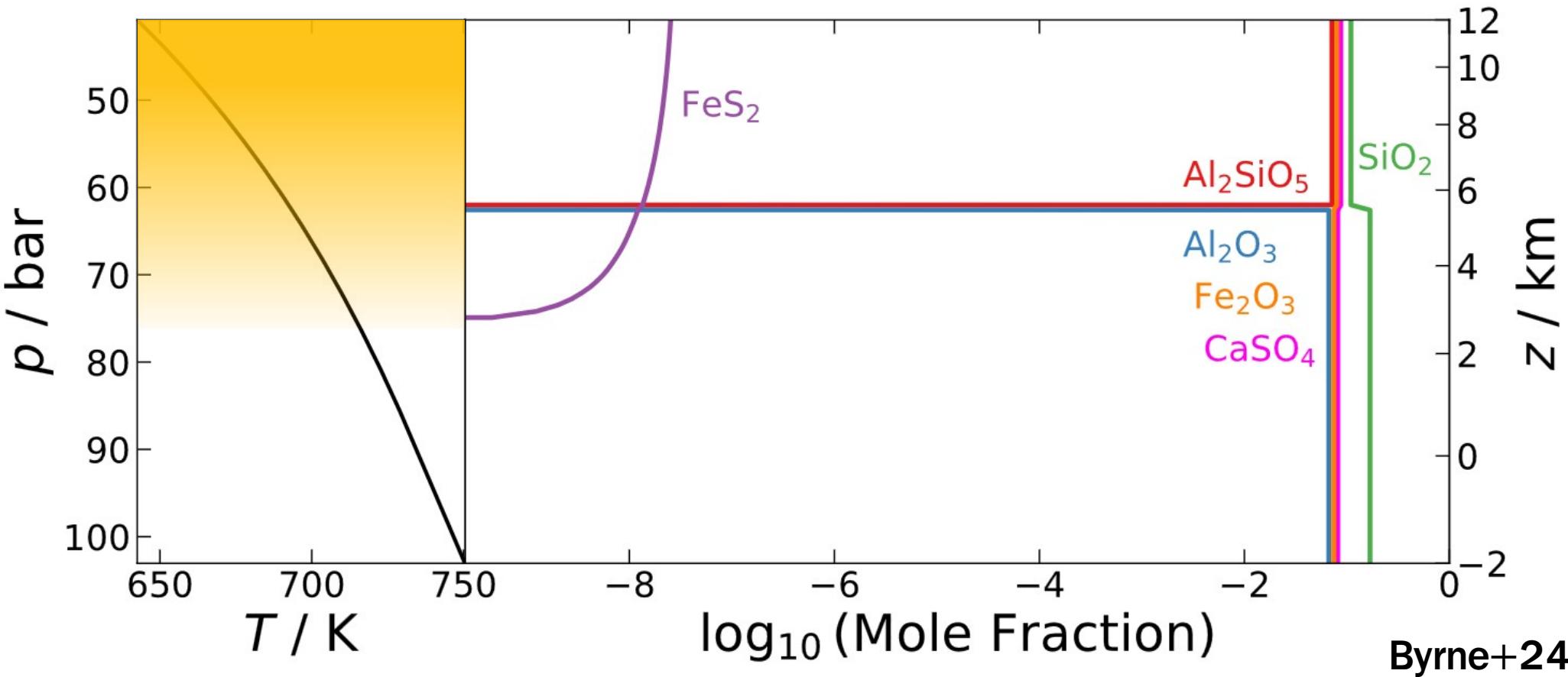
...also high altitude..??

Why are Venus' highlands radar-reflective?

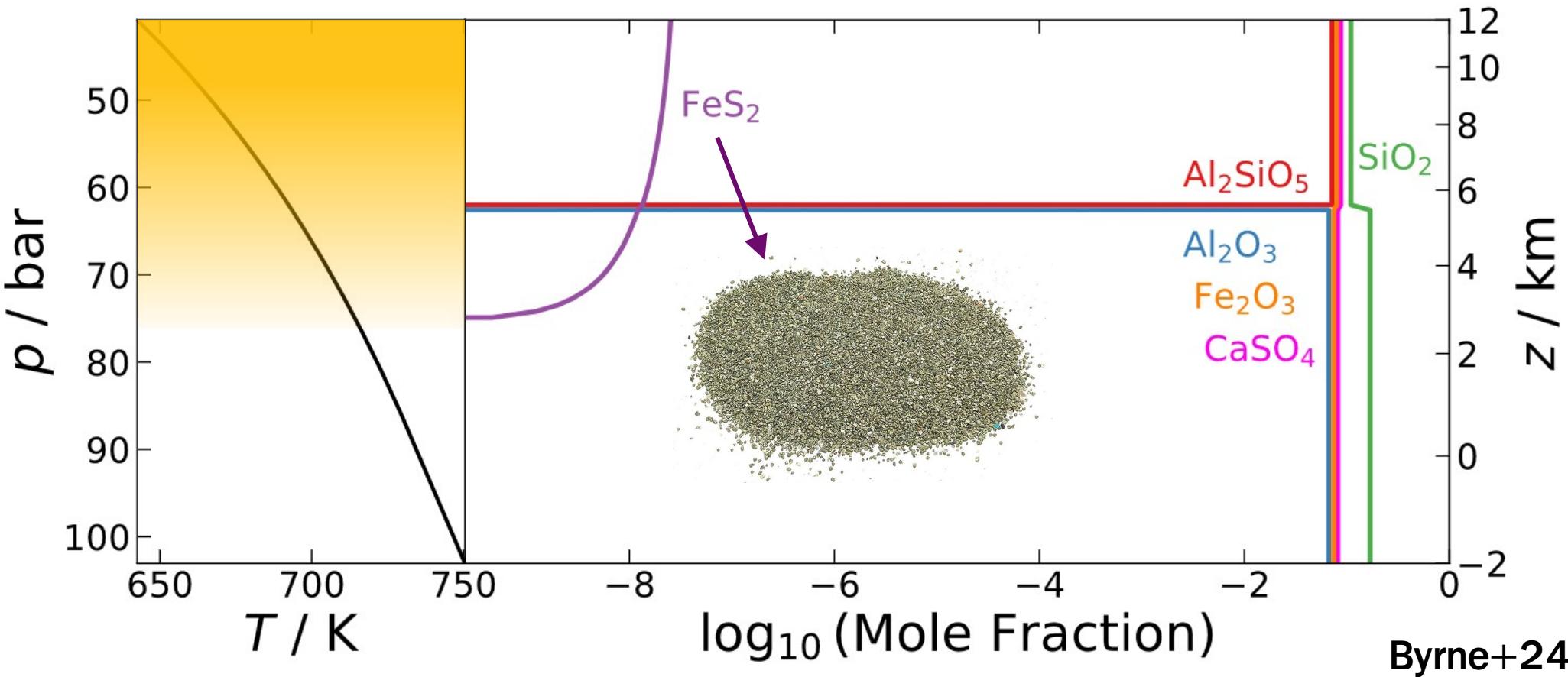


Byrne+24

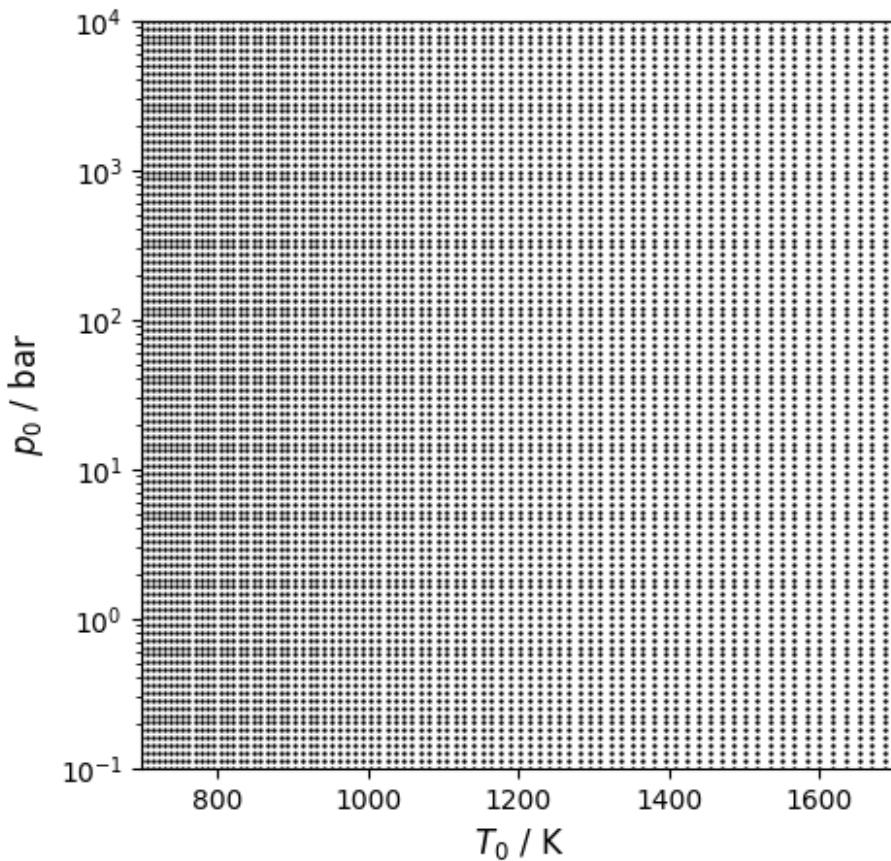
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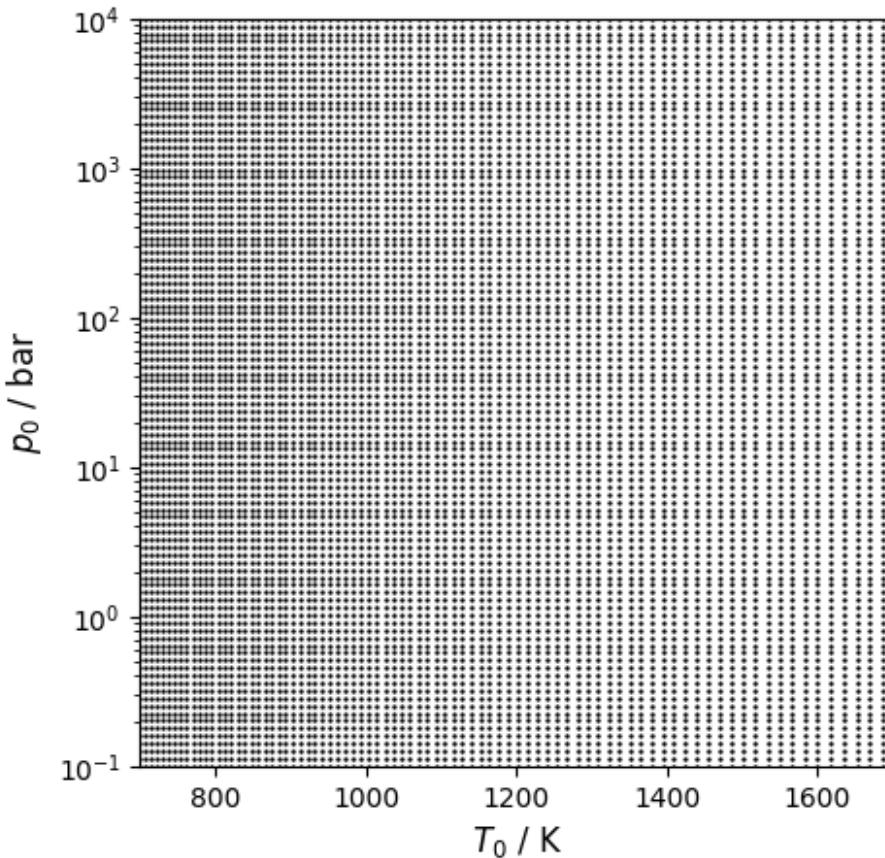
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Exploring pressure-temperature space

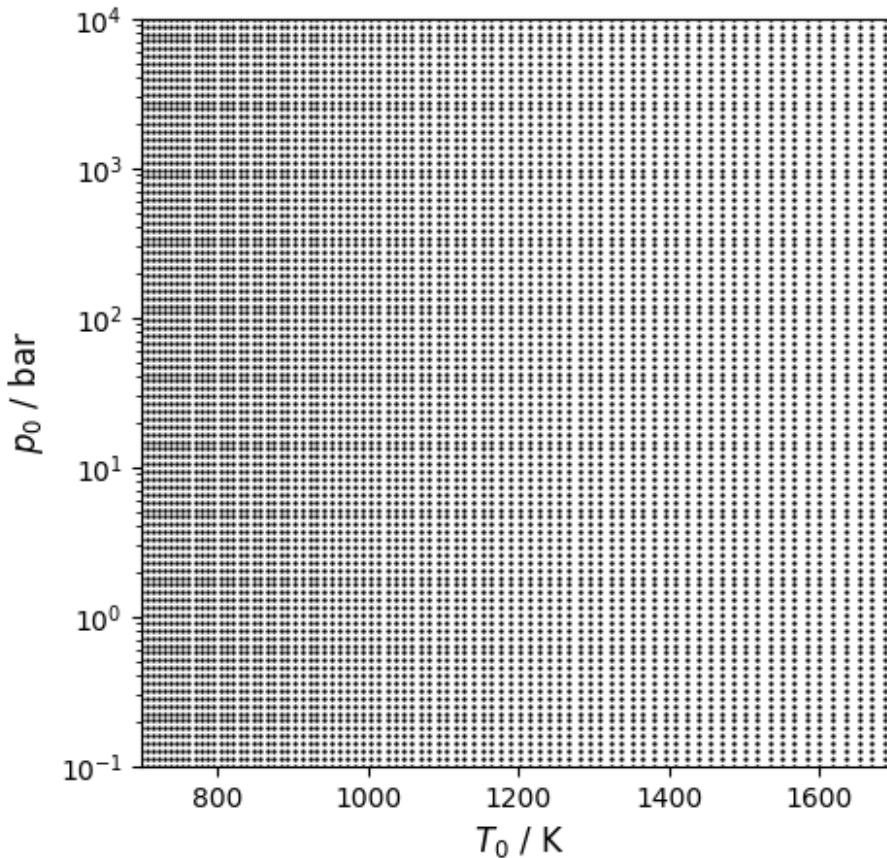


Exploring pressure-temperature space



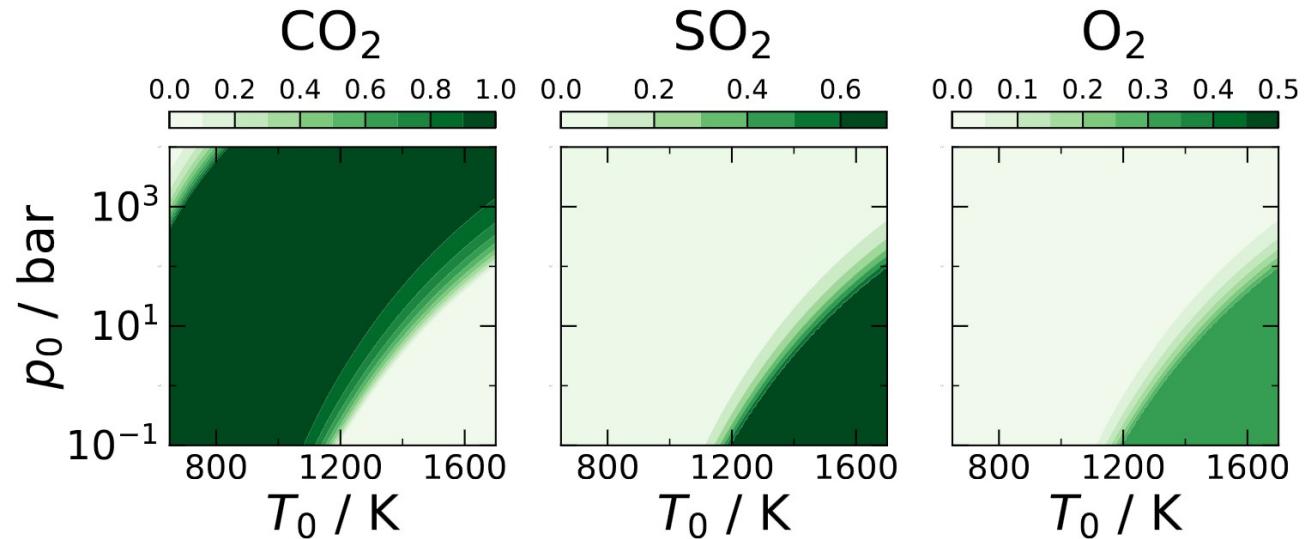
- If eq. atmosphere changes across a boundary, can constrain surface (p, T) with atm. observations

Exploring pressure-temperature space

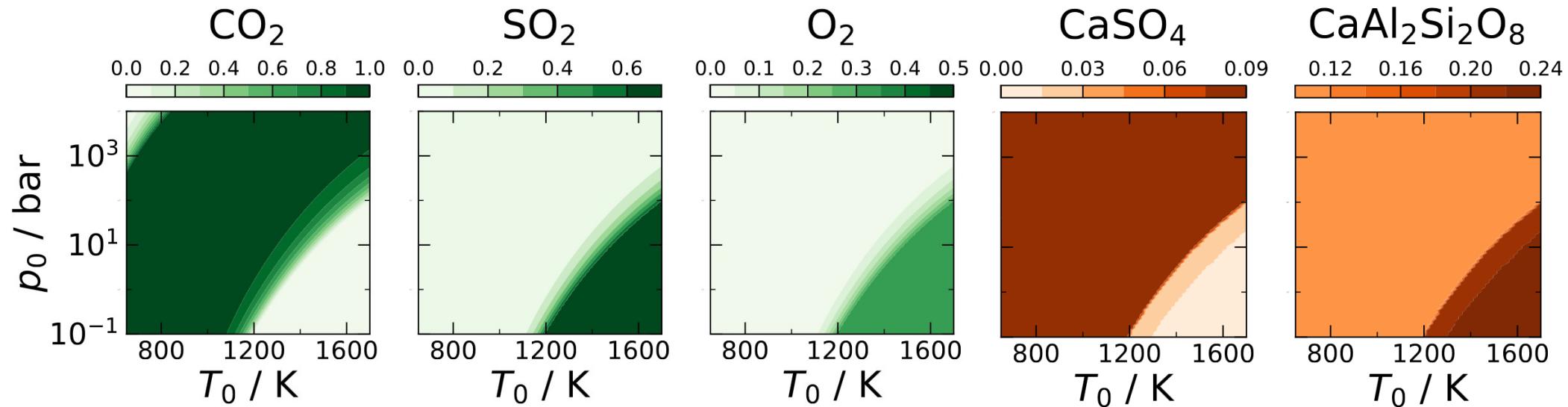


- If eq. atmosphere changes across a boundary, can constrain surface (p , T) with atm. observations
- If eq. mineralogy changes at the same time, can also infer surface mineralogy

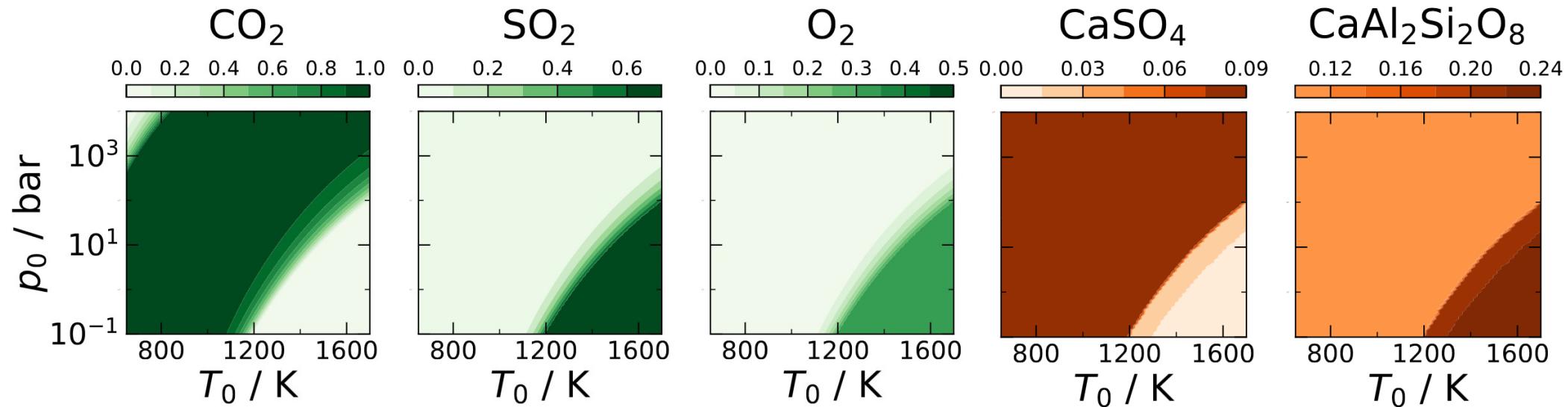
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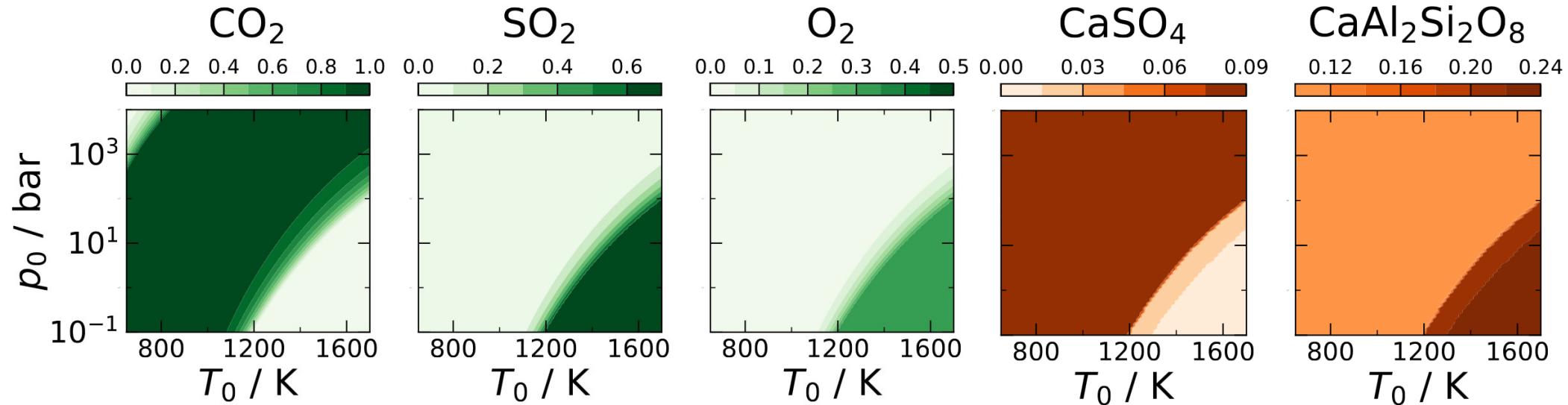


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=> Can infer mineralogy from atmospheric observations!

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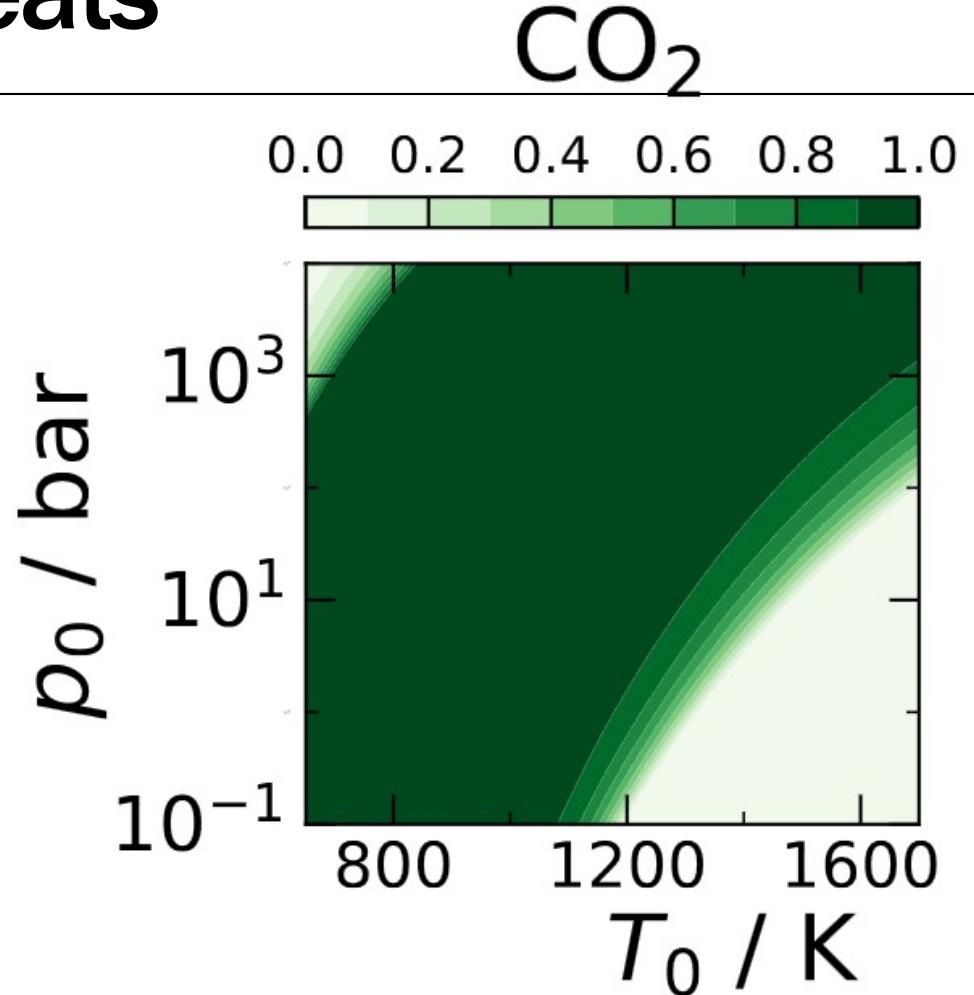


=> Can infer mineralogy from atmospheric observations!
...assuming Venus' composition

Caveats

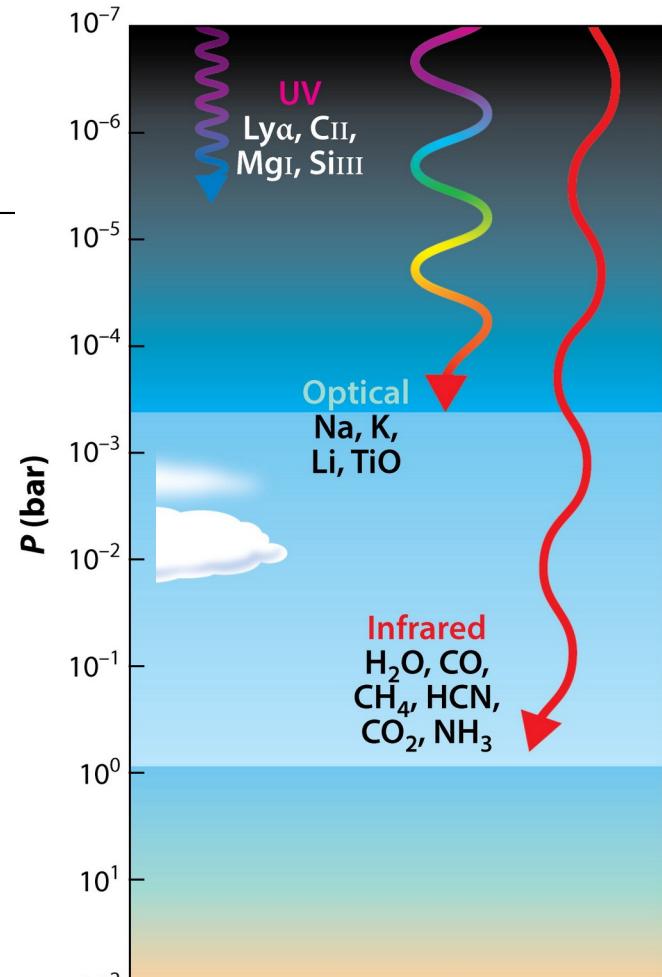
Caveats

- Regime not completely sharp



Caveats

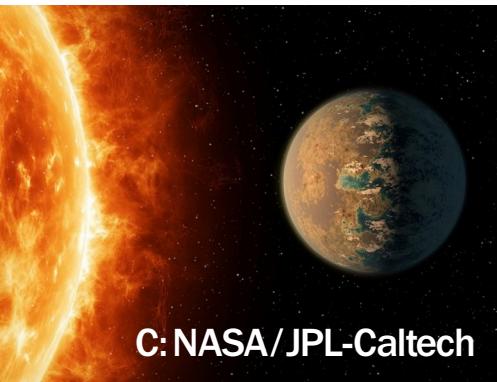
- Regime not completely sharp
- Surface may not be in eq. with TOP of atm.



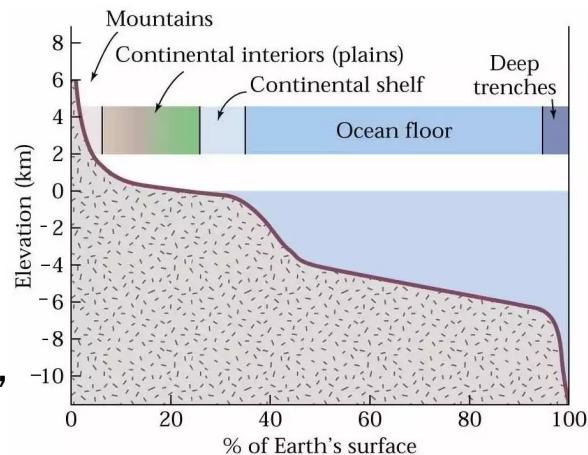
Madhusudhan N. 2019.
Annu. Rev. Astron. Astrophys. 57:617–63

Caveats

- Regime not completely sharp
- Surface may not be in eq. with TOP of atmosphere (observable)
- This work is 0D – 3D effects could complicate



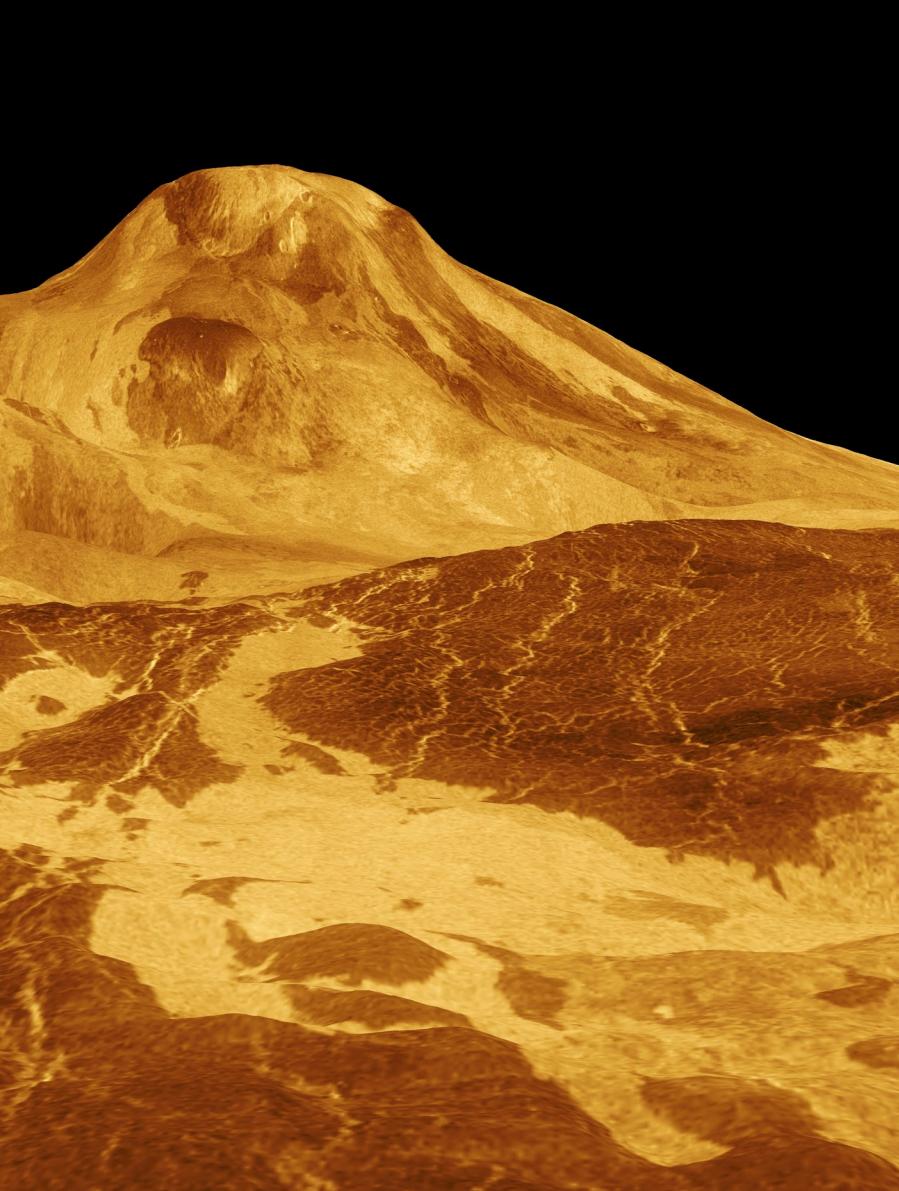
C: Marshak, 2005:
“Earth – Portrait of the Planet”



Caveats

- Regime not completely sharp
- Surface may not be in eq. with TOP of atmosphere (observable)
- This work is 0D – 3D effects could complicate
- Difficulty in inferring elemental composition (polluted WDs?)

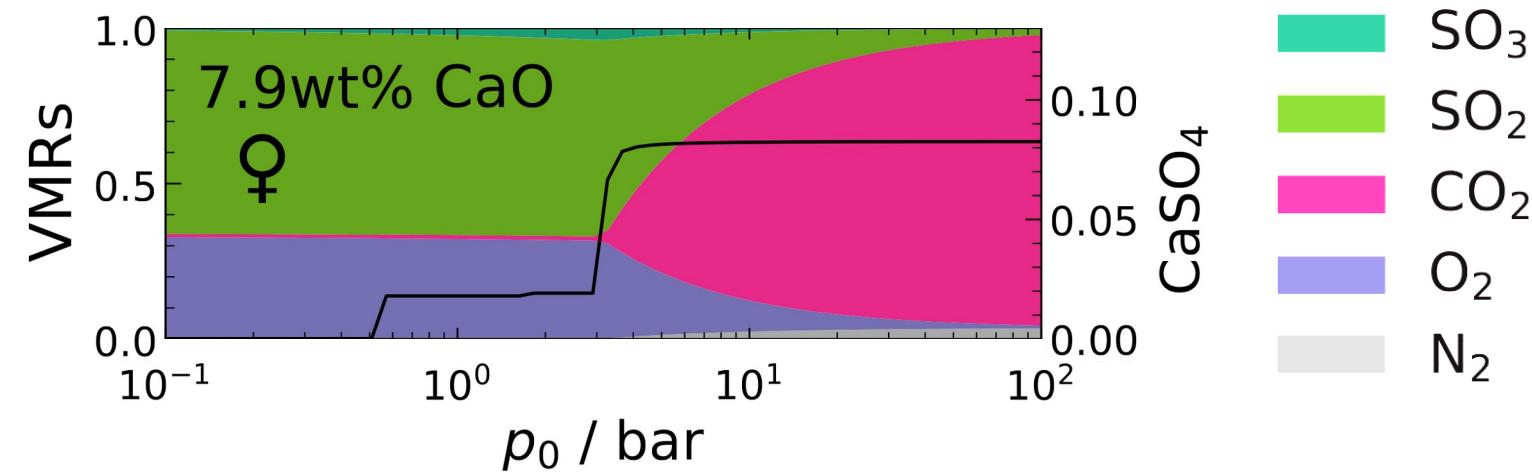




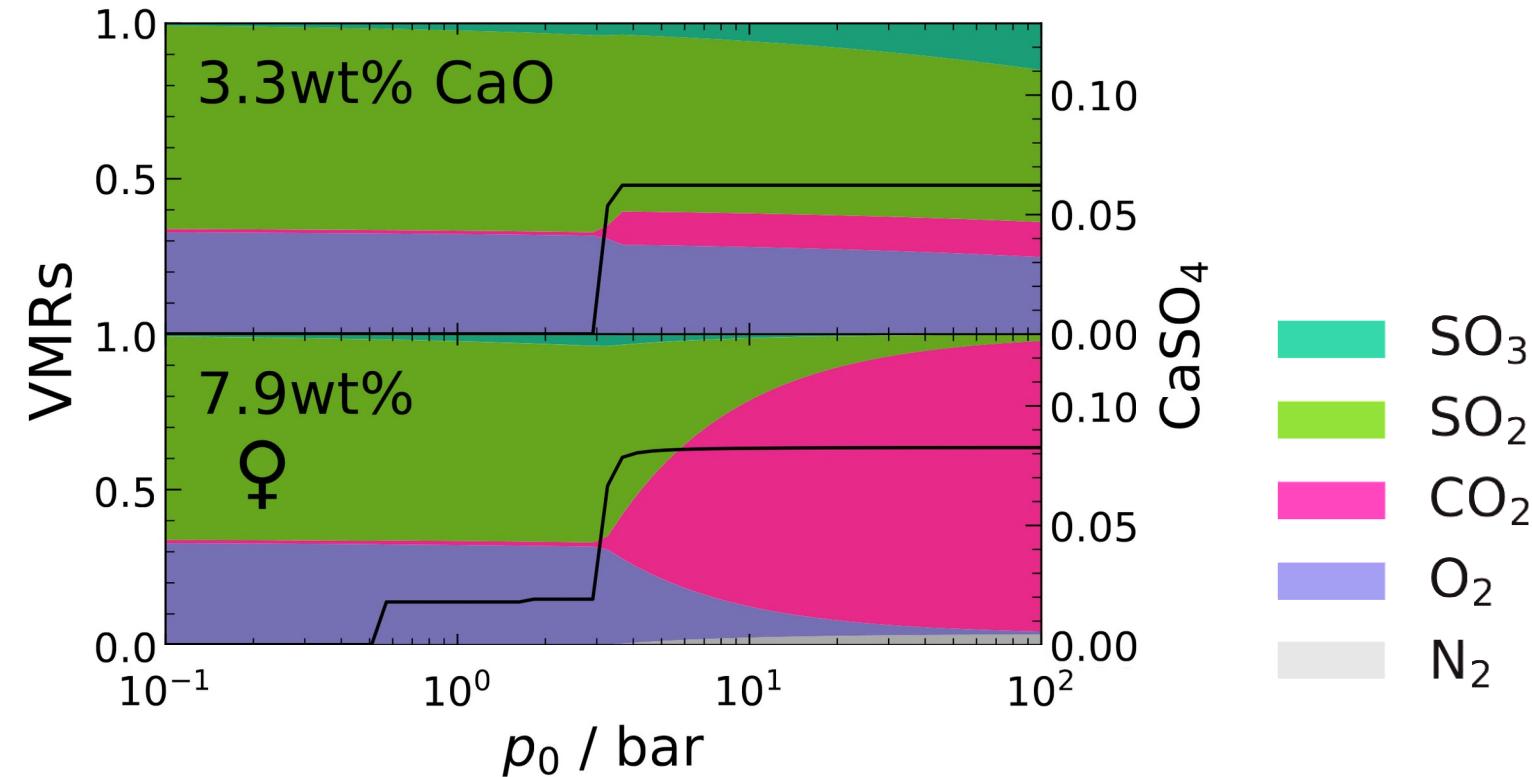
Conclusions

- At equilibrium, surface and atmosphere can have correlated compositions
- Explains Venus' highland radar reflectivity
- Could enable inferences on mineralogy from atm. observations

How does this depend on composition?



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