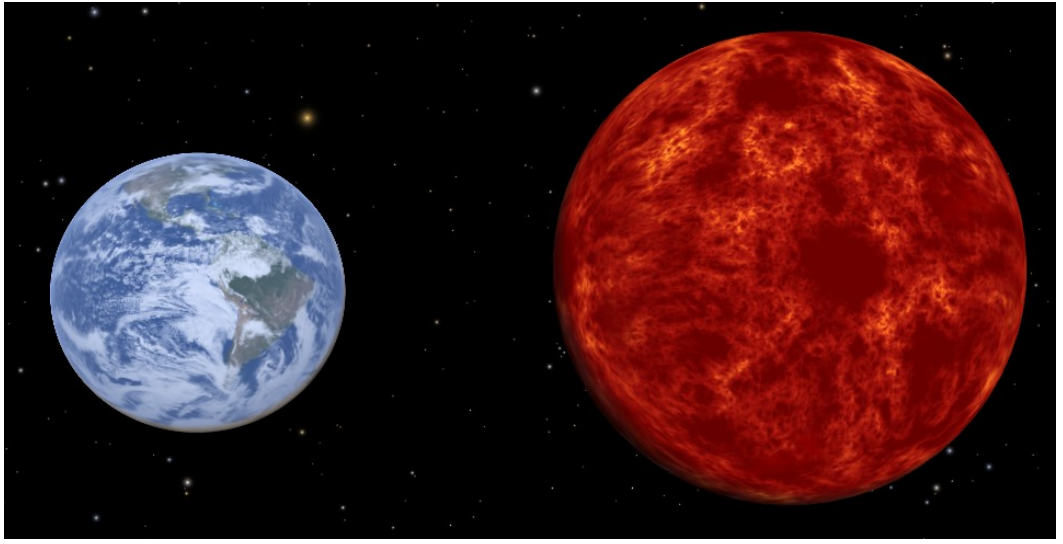
3D simulations of 55 Cnc e's climate and clouds

Maxime Maurice, Benjamin Charnay, Aurélien Falco, Jérémy Leconte, Alice Maurel, Martin Turbet, Yangcheng Luo**,** Spandan Dash, Sébastien Charnoz

- Who is 55 Cancri e?
- So variable… why?
- Modelling its climate
- Model phase curve
- Challenges ahead

Who is 55 Cancri e?

- A super-Earth:
  - $R = 1.875\ R_{earth}$
  - $M = 7.99\ M_{earth}$
- Orbiting a K-type star, 41 light-years away:
  - $a = 0.01544$ AU
  - $P = 17$ h
  - $T_{eq} = 1993$ K

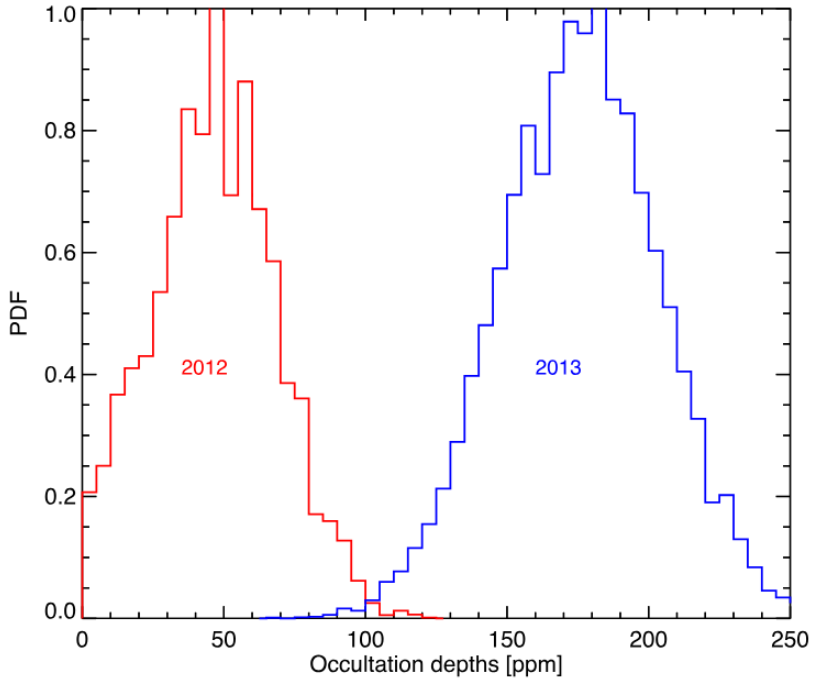


https://science.nasa.gov/exoplanet-catalog/55-cancri-e/

Who is 55 Cancri e?

Observations:

- **Radial velocity** (2004-2010)
- **Thermal emission** (*Spitzer* 4.5 μm Demory *et al*., 2012, 2016a)
- **Thermal phase curve** (Demory *et al*., 2016b)
- Ground-based **transit obserations** rule out an H-rich atmosphere (Esteves et al., 2017, Deibert et al., 2021)
- Secondary **emission spectroscopy** (*JWST* Hu *et al*., 2024, Patel *et al*., 2024) : a C-rich atmosphere?



Demory *et al*., *MNRAS* 2016

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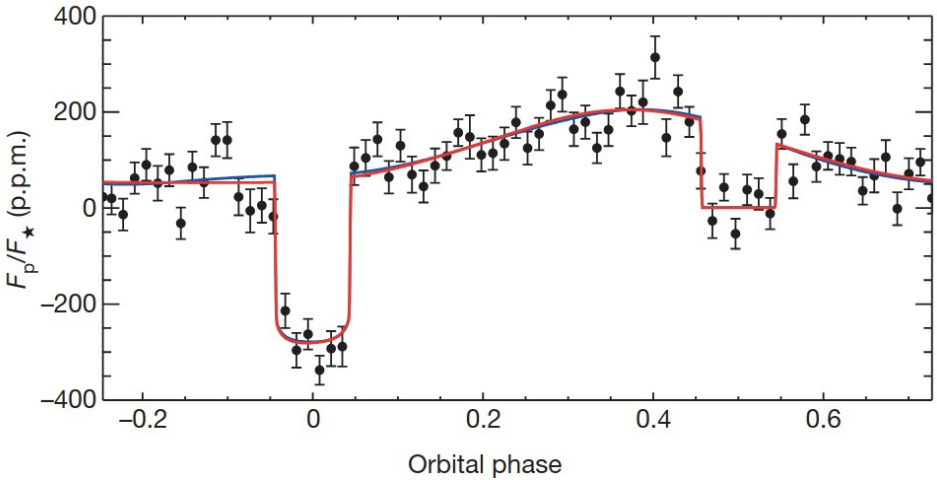

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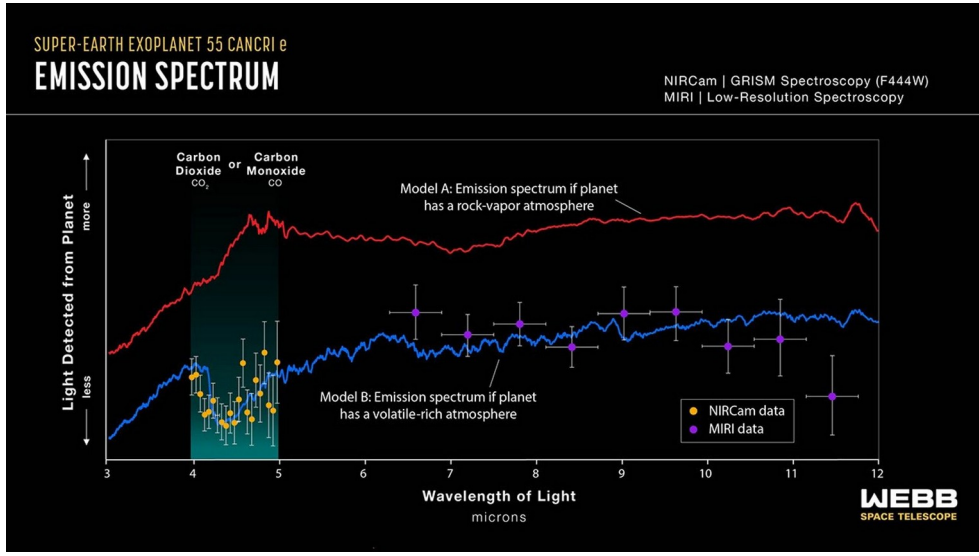
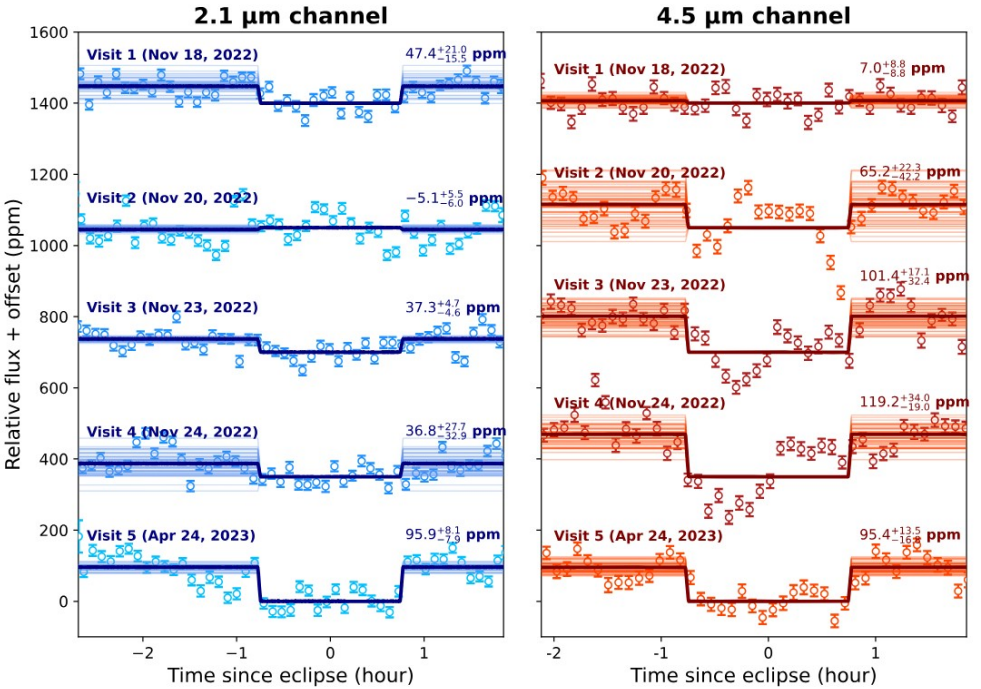


Hu *et al*., *Nature* 2024

Why so variable?

- Variability is observed in **both** IR and optical
- **Uncorrelated** variability between different bands
- Variability observed in secondary eclipse but **not** in transit
- Occultation depth goes down to **zero**
- What can cause this variability?
  - Star variability
  - Asynchronous rotation (Tamburo *et al*., 2018)
  - Volcanic plumes (Demory et al., 2016)
  - Transient degassed atmopshere (Heng 2023)
  - Dust taurus (Meier-Valdés et al., 2023)
  - Refractory clouds limit cycle (Loftus, Luo, et al., 2025)
  - …



Patel et al., *A&A* 2024

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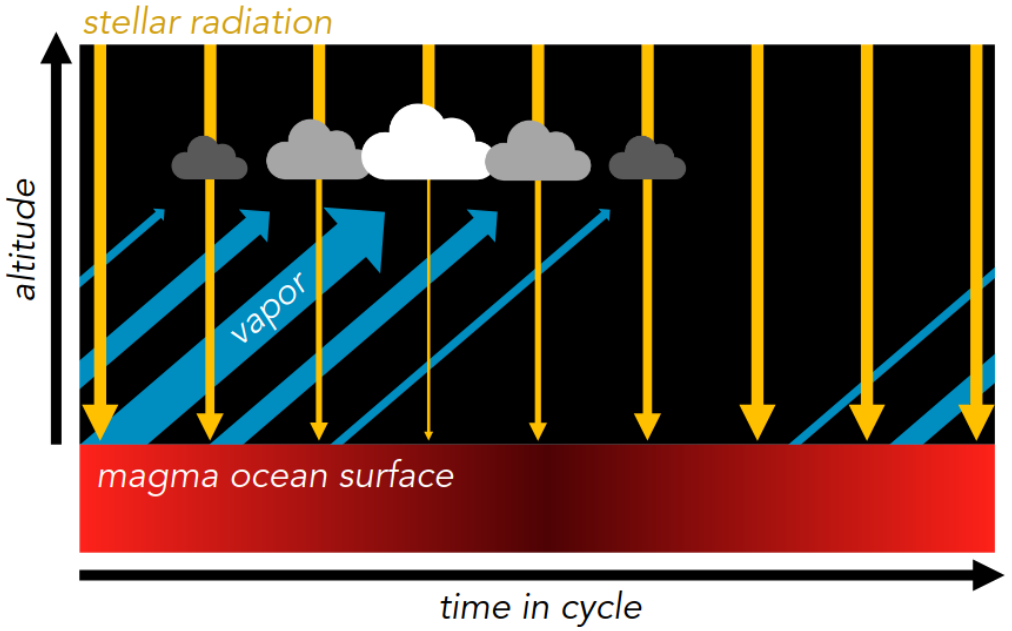
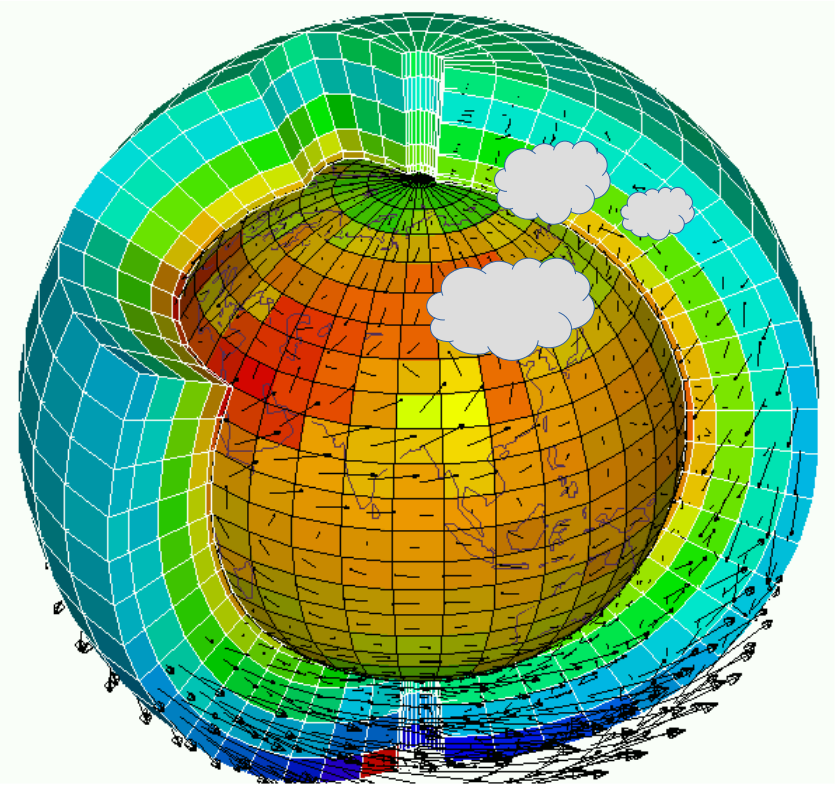


Loftus, Luo, *et al*., *PNAS* 2024

Modelling its climat

- Need for a **versatile GCM**: the Generic PCM (Forget *et al*., 2028)
- Resolution: 64 (lon) x 48 (lat) x 15 (vert)
- Background **1 bar CO or a CO_2** atmosphere (in agreement with Hu *et al*., 2024)
- High-T corr-*k* table from **Exomol** database
- Generic aerosol condensation/vaporization scheme (Teinturier *et al*., 2024) for **$MgSiO_3$**
- Imposed mixing ratio for refractory vapor at the surface of the dayside

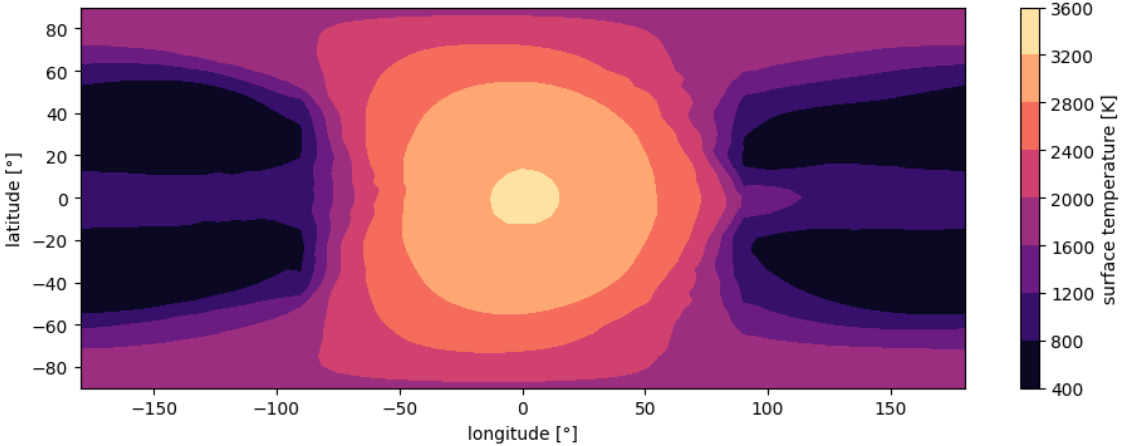


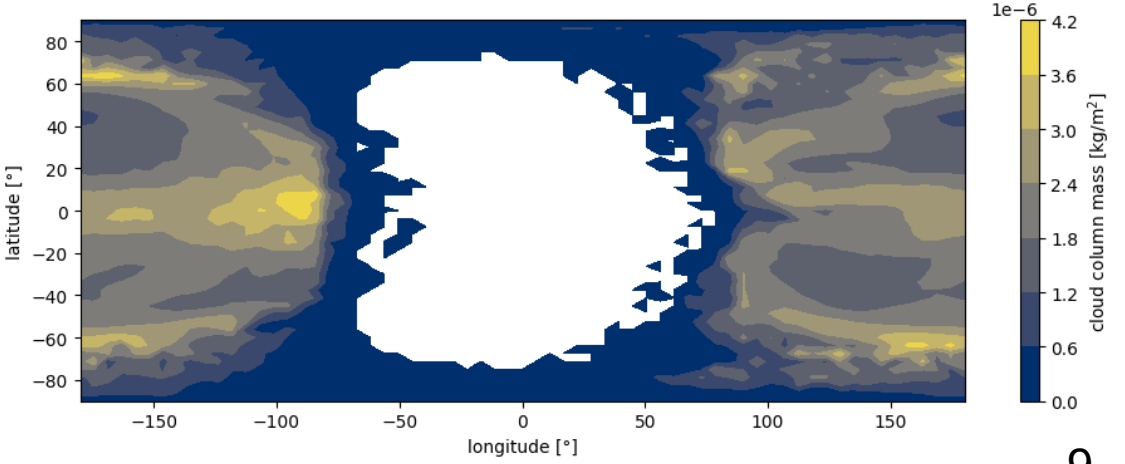
Laurent Fairhead / LMD

Modelling its climat

1 bar CO_2 atmosphere

- Large **thermal amplitude** (expected for high molar mass atmospheres)
  - Substellar point > 3600 K
  - Nightside < 400 K
- Clouds form on the **nightside** (although vapor is formed on the dayside)
- Because of a hot dayside up to the top of the amtosphere (at least of the modelled one)





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1 bar CO atmosphere

- Lower thermal amplitude
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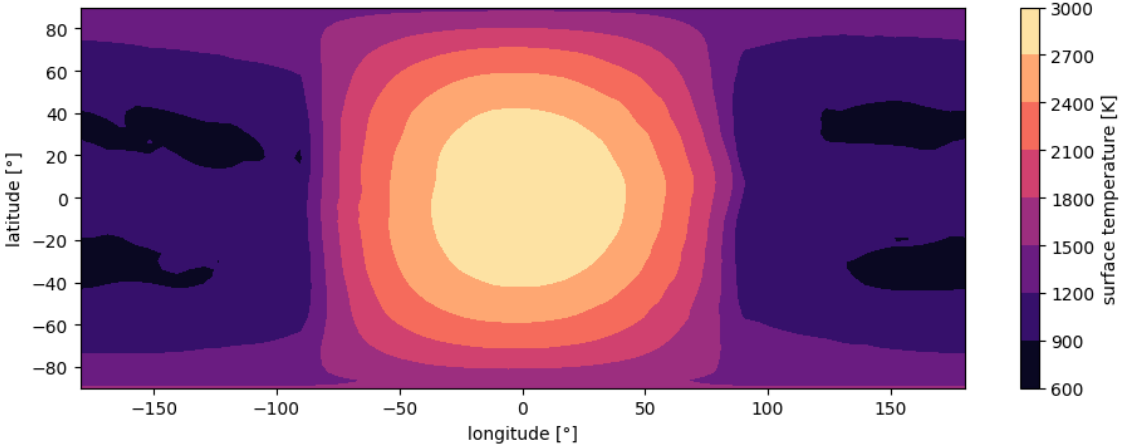
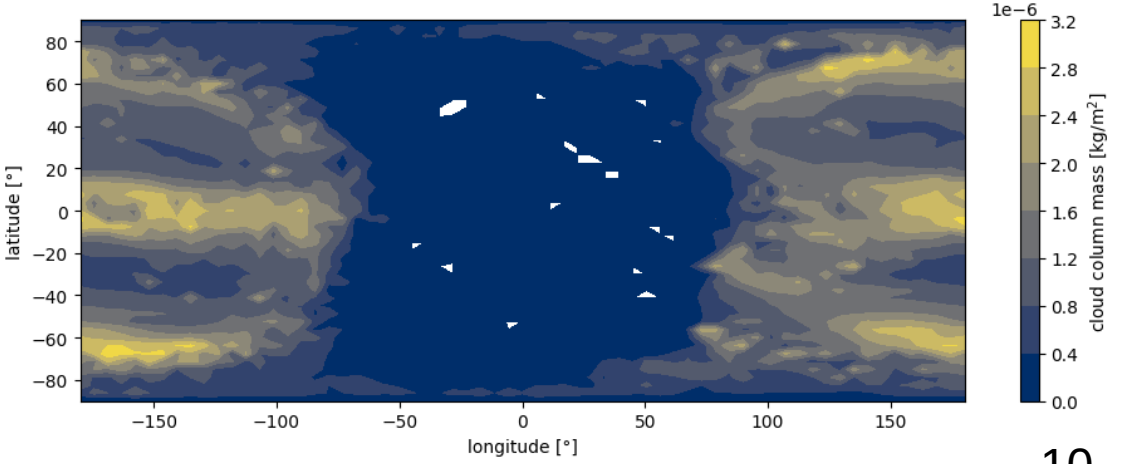
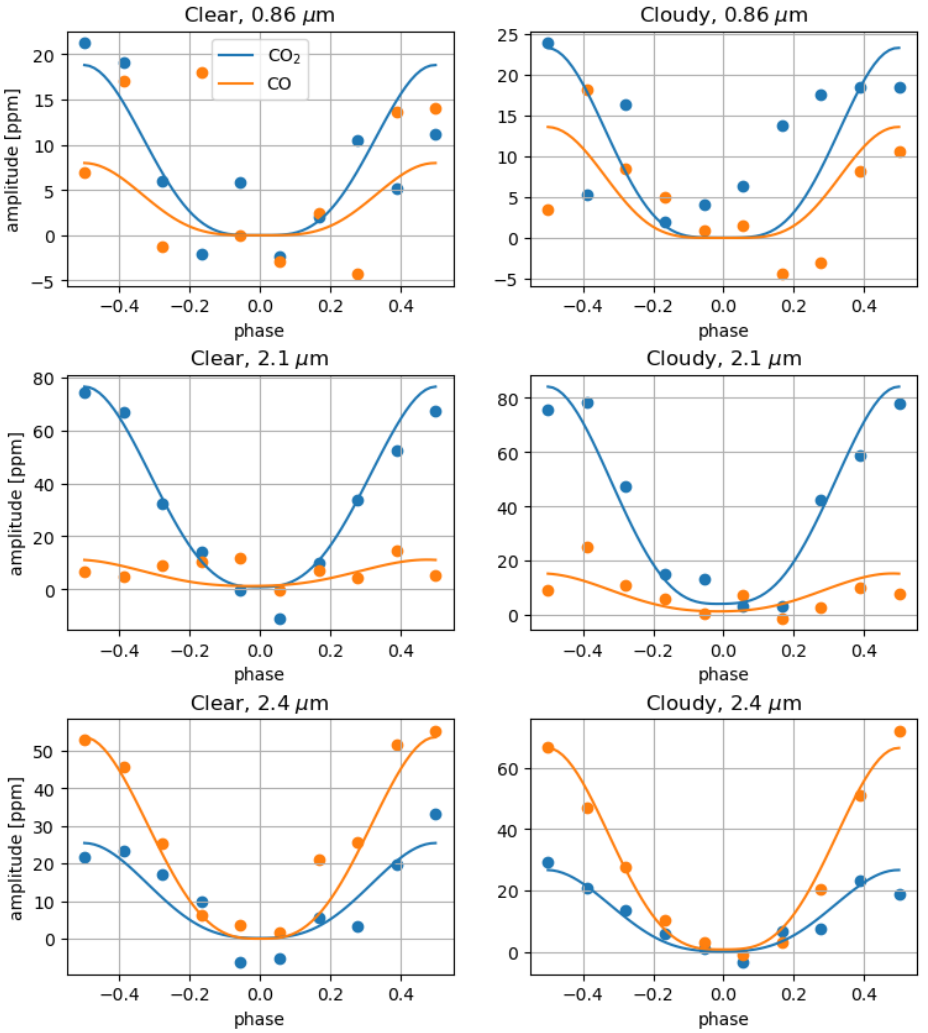
- Top of the modelled atmosphere almost 1000 K colder





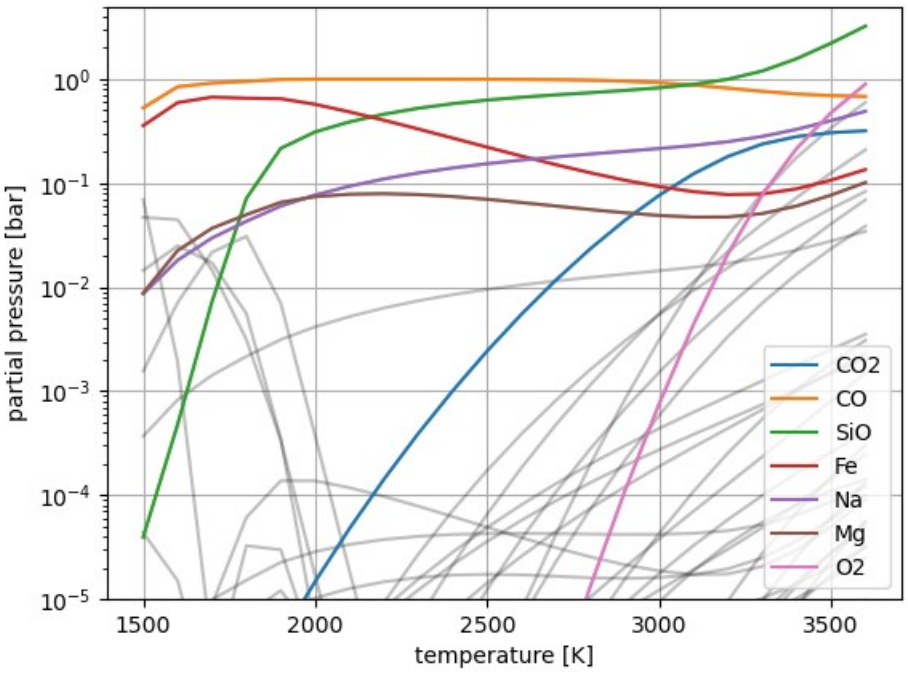
Model phase curve

- Generated with **Pythmosph3r**
- 3 channels plotted to illustrate **multiband** phase curve
- No significant **offset** of the phase curve
- Phase curve could **discriminate** between a CO and CO_2 atmosphere
- Harder to tell for clouds (with this model setup)



Challenges ahead

- Self-consistent prediction of refractory vapor using **MAGMAVOL** (*cf* Spandan Dash's talk)
- Take into account refractory vapor **opacity**
- Identify expected **aerosols**
- What about **equilibrium chemistry**?
- Magma ocean effect (**albedo**? **heat redistribution** is likely small)



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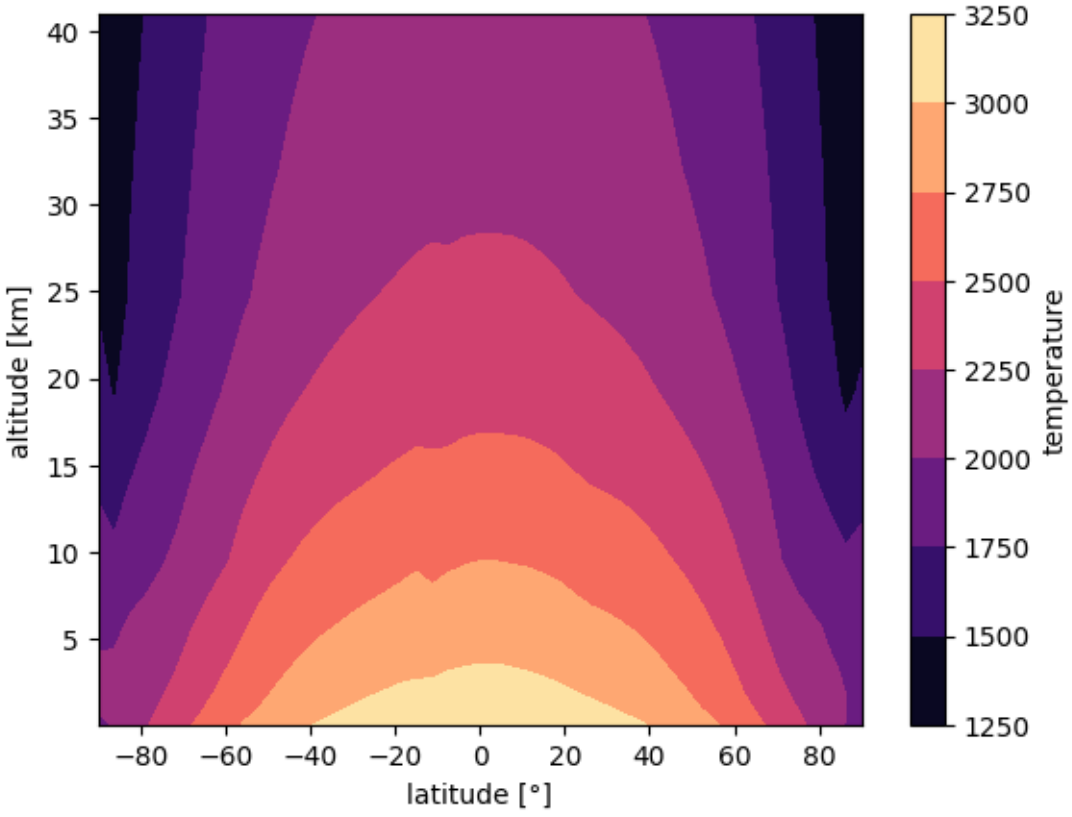

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