Upscaling Venus:

The Climate, Atmosphere and Observing Implications of a **Super-Venus Exoplanet**

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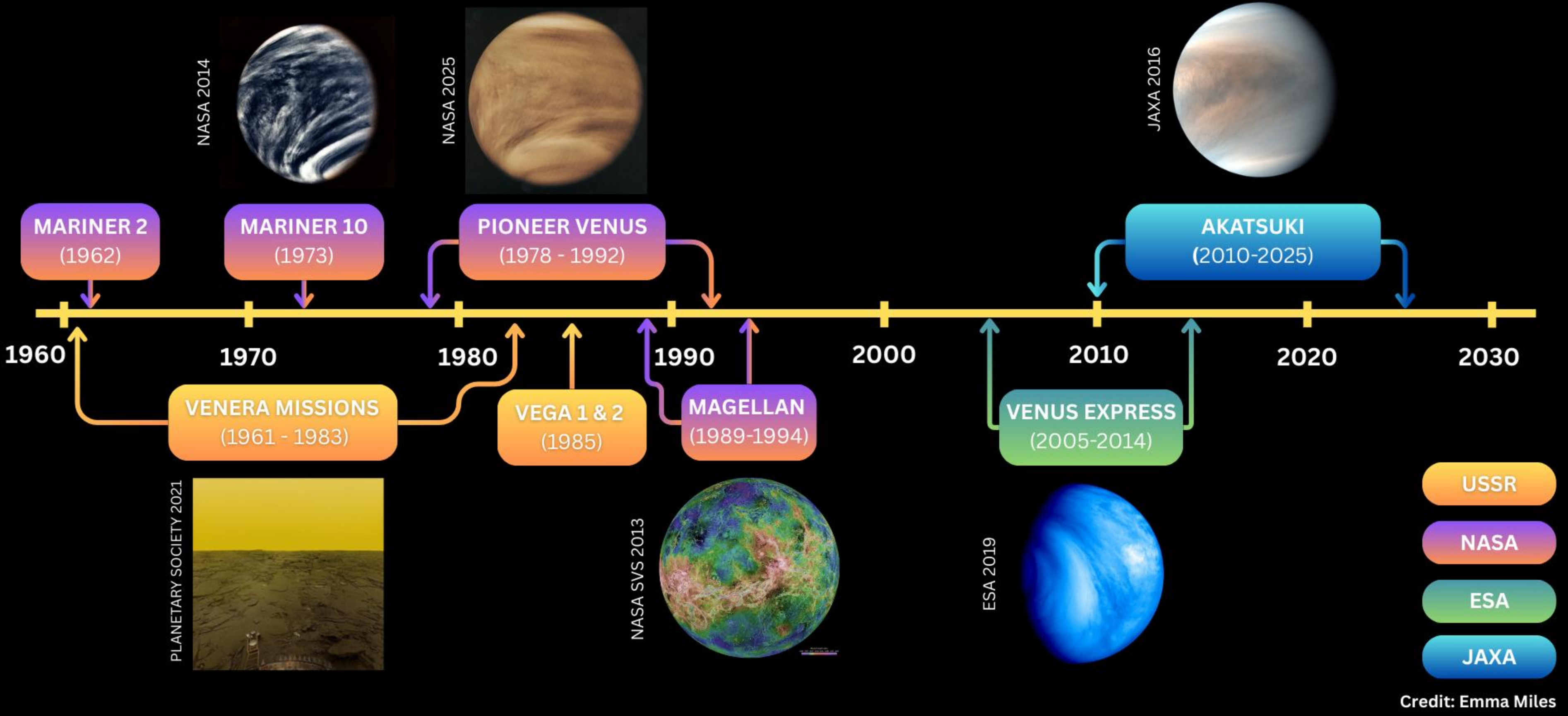
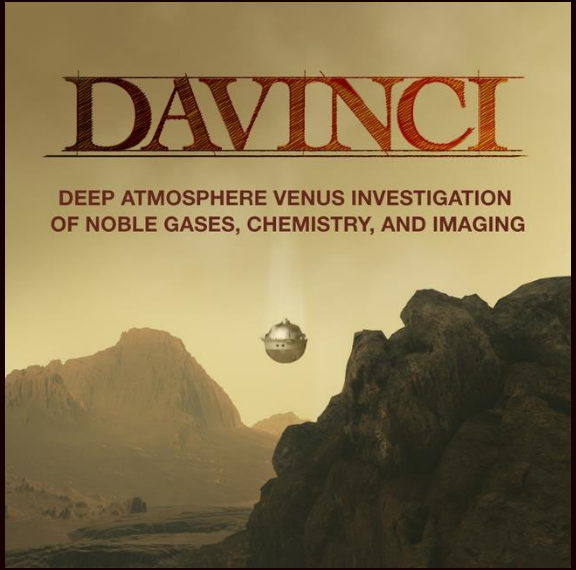
Timeline of Venus Missions



Preparing for Upcoming Missions to Venus

VERITAS



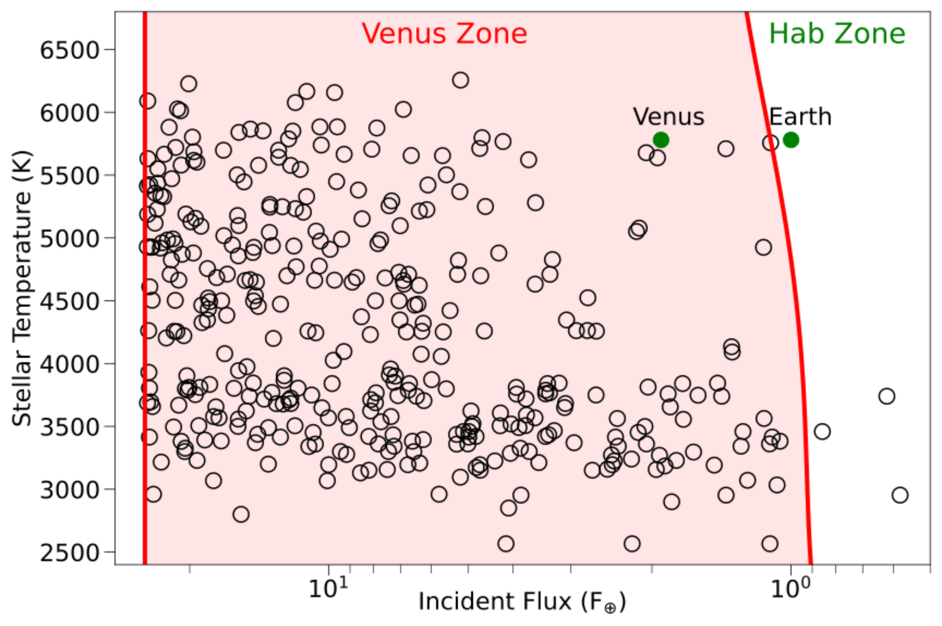
Check out Stephen Kane's
poster on DAVINCI

ESA | NASA
envision

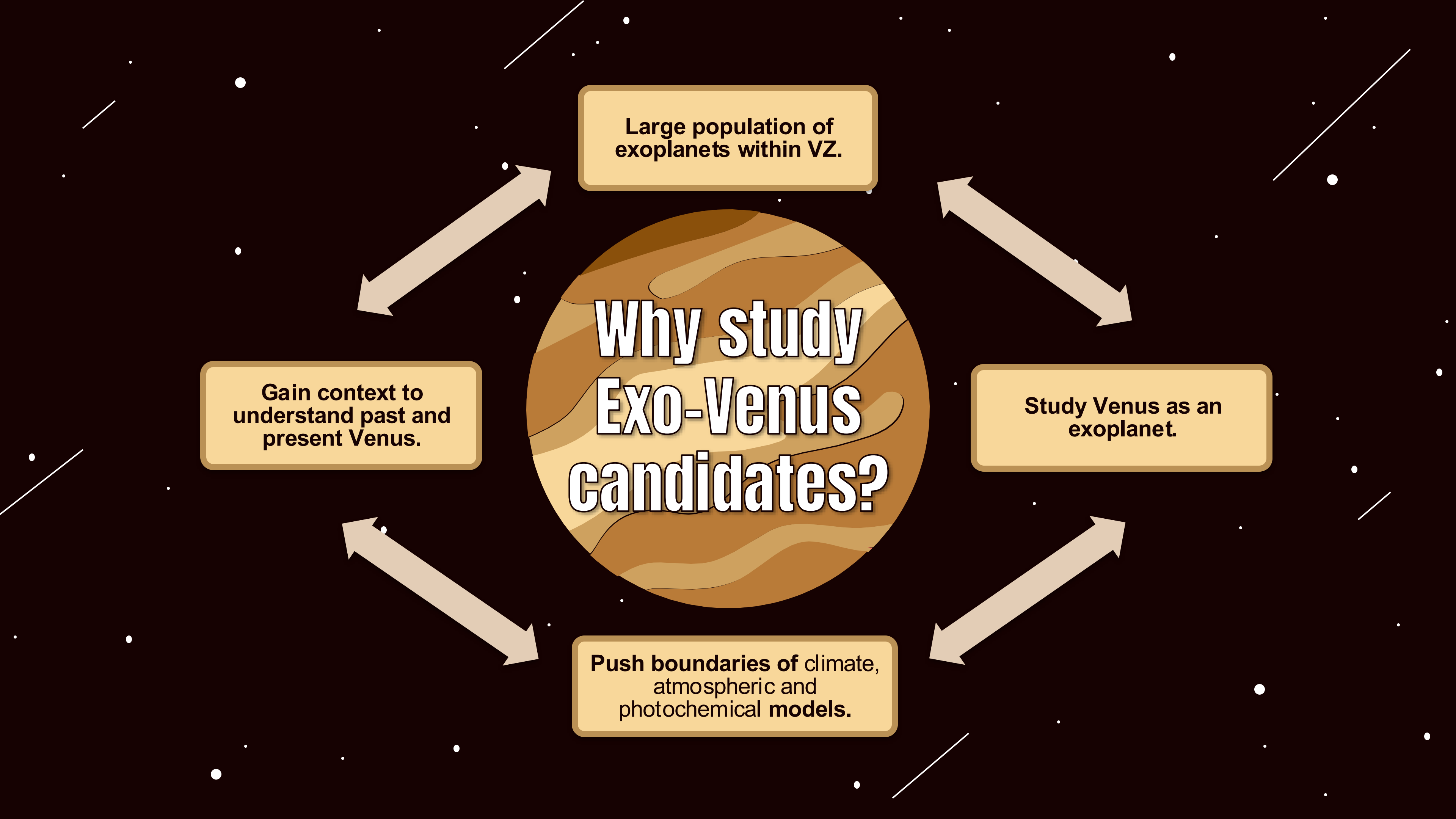
Venus as an Exoplanet

- 6000+ exoplanets have been discovered.
- 370 are within the Venus Zone (VZ) of their host star [4].

Potential exo-Venus canditates can be identified within the VZ.



Updated plot from Ostberg et al. 2023

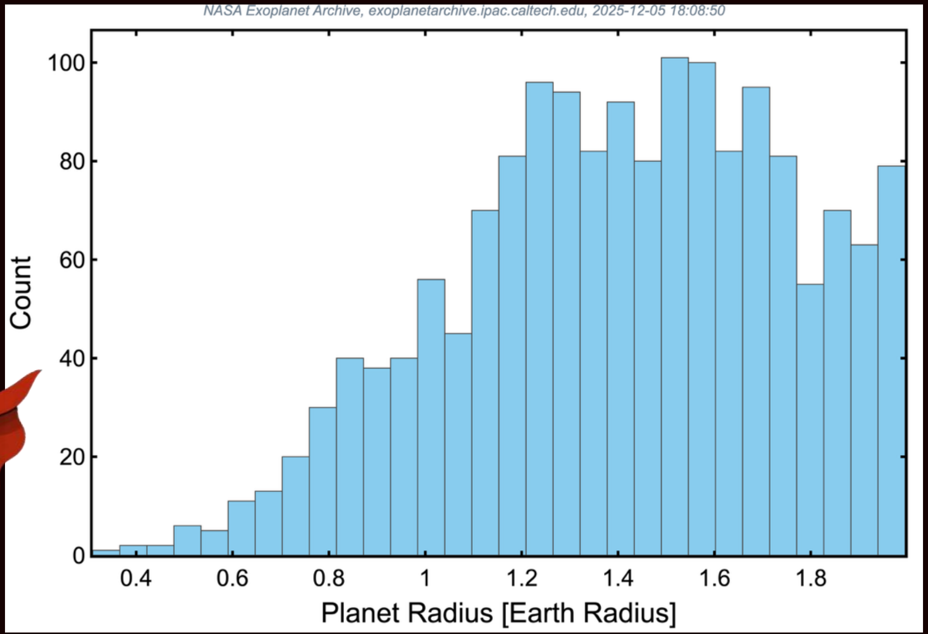


Why study Exo-Venus candidates?
Large population of exoplanets within VZ.
Study Venus as an exoplanet.
Push boundaries of climate, atmospheric and photochemical models.
Gain context to understand past and present Venus.

Super Venus population

- ~40% of the VZ population have a radius between 1 and 1.5R⊕.
- A large percentage of VZ planets would be considered super-Venus [2].

Why study Super-Venus?



Research Questions

How do **Venus-like atmospheres** and **surface conditions** **change** in the **high mass-radius regime?**

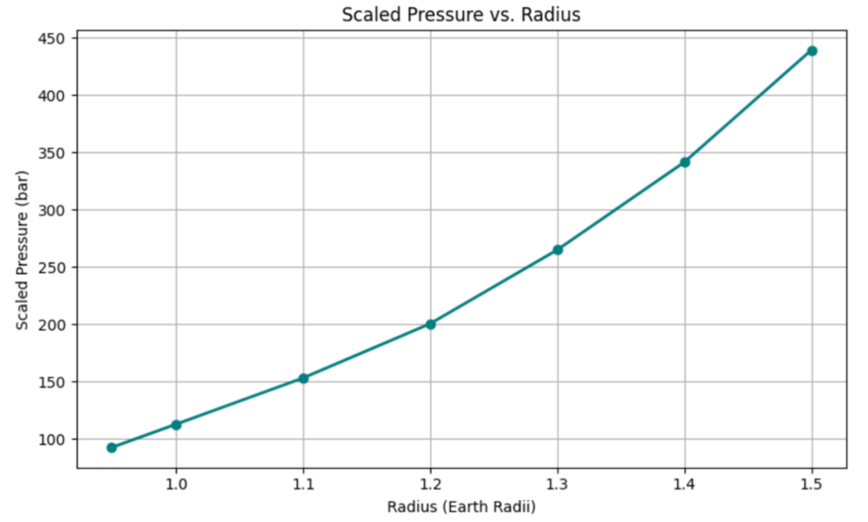
What are the **observable signatures** of a **super-Venus atmosphere?**

How do you upscale Venus into a super-Venus?

1. Begin with radius criteria (R = 1 – 1.5$R_\oplus$)
2. Increase mass with radius.
3. Scale Venus' atmospheric mass and surface pressure to high mass-radius values.

$$P_{scaled} = \frac{g_P \left(\frac{M_P}{M_V}\right) m_{V,atm}}{A_{surf}}$$

Radius (R⊕)	**Mass** (M⊕)	**Scaled Surface Pressure** (bar)
0.95	0.80	92.39
1.00	1.00	112.82
1.10	1.41	153.19
1.20	1.92	200.57
1.30	2.59	264.98
1.40	3.41	341.49
1.50	4.44	439.32

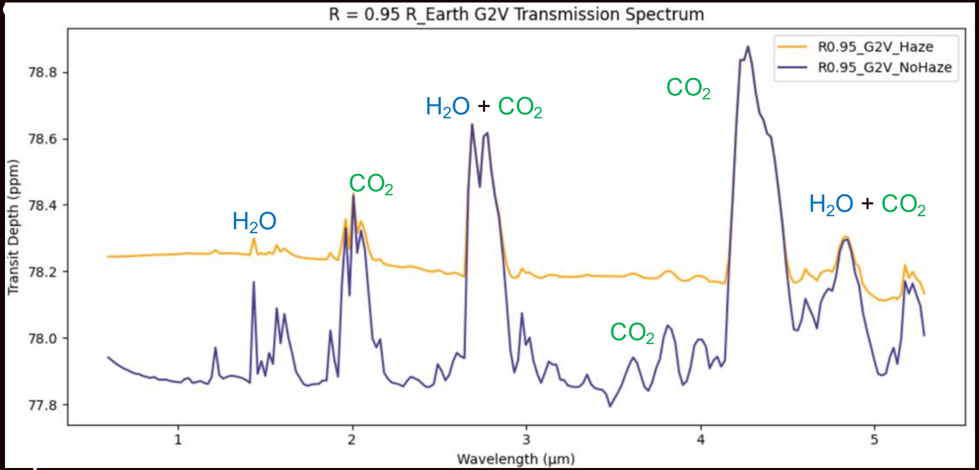


Model super-Venus spectra using PSG

As first order estimate of potential observables of super-Venus:

- Model transmission spectra of super-Venus cases in Planetary Spectrum Generator (PSG) [5].
- Venus-like atmosphere (with & without H_2SO_4 haze) in high mass-radius regime orbiting in the VZ of different star types.

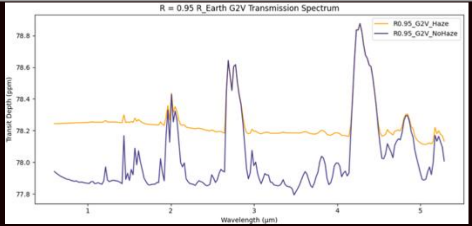
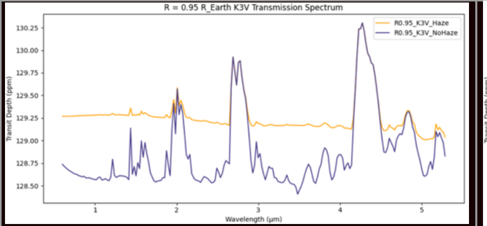
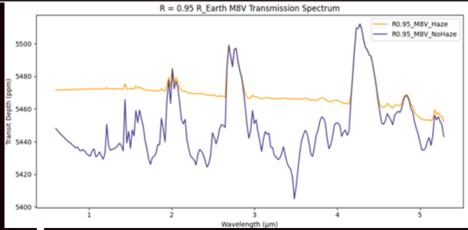
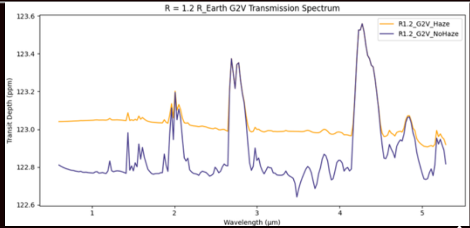
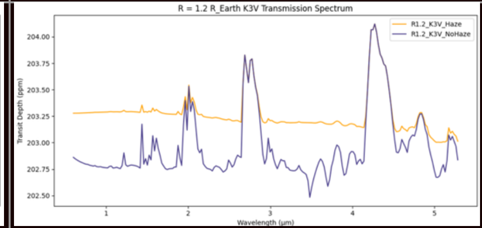
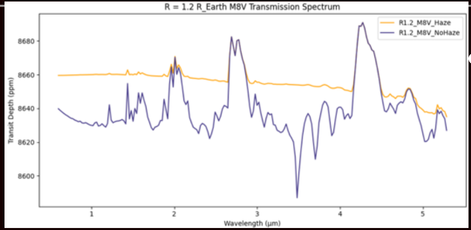
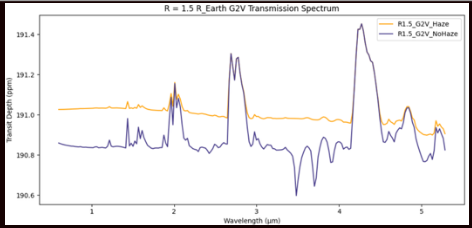
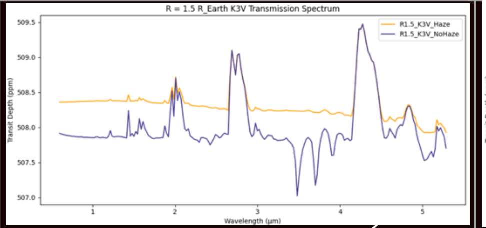
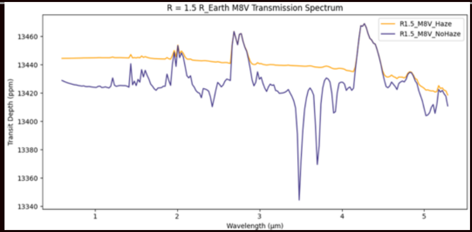
Star Type	Star T_{eff} (K)	Star Radius ($R_\odot$)	Planet Orbital Distance (AU)
G2V	5777	1.000	0.7200
K3V	4699	0.778	0.3600
M8V	2566	0.119	0.0166



Transmission Spectrum – primary transit observed at ~15pc in NIR wavelength (0.6 – 5μm).

Upscale present Venus in Generic-PCM into a super-Venus.

Transmission Spectrum – primary transit observed at ~15pc in NIR wavelength (0.6 – 5μm).

Radius ($R_\oplus$)	G2V	K3V	M8V
0.95			
1.20			
1.50			

Next step

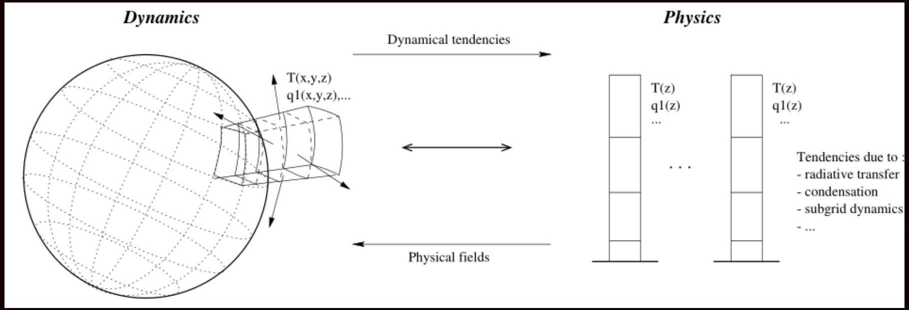
Use **mass and surface pressure estimates** to alter initial conditions to **upscale Venus** into **super-Venus** regime in **Generic-PCM**.

What is the Generic Planetary Climate Model?

Generic-PCM is a 3D General Circulation Model (GCM) used to simulate climate & atmospheric dynamics of terrestrial planets & exoplanets [1].

- Computes:
  - Radiative transfer
  - Atmospheric chemistry
  - Cloud microphysics
  - Surface conditions & interactions

- Can be applied to broad range of:
  - Pressures
  - Temperatures
  - Atmospheric compositions
  - Stellar parameters

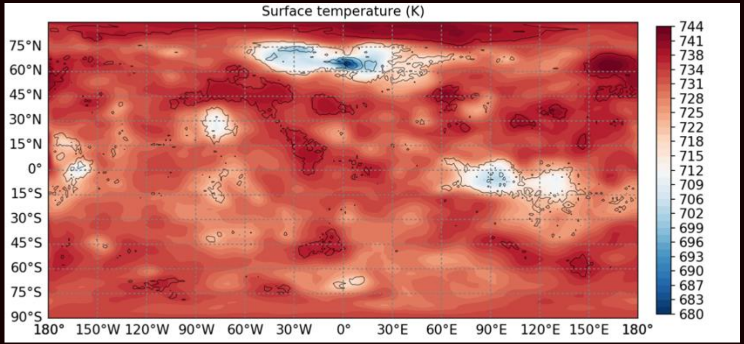


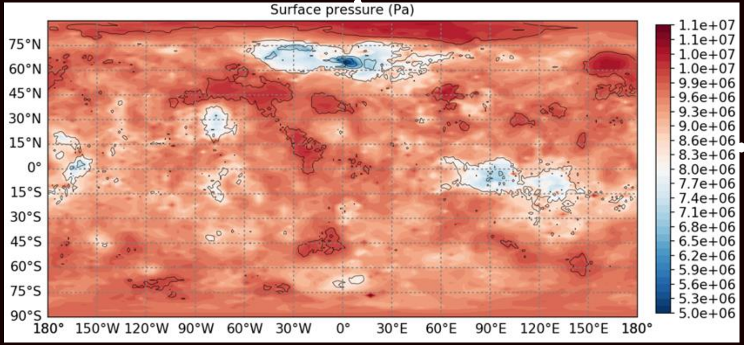
Source: LMDWiki

Generic-PCM allows researchers to explore climate regimes far beyond Earth's.

Base model of present Venus in Generic-PCM

Venus-PCM outputs

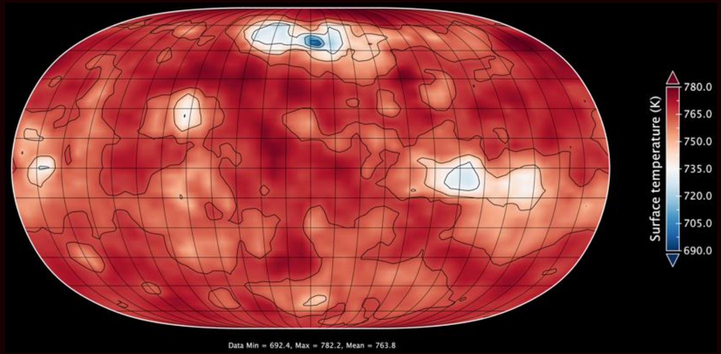




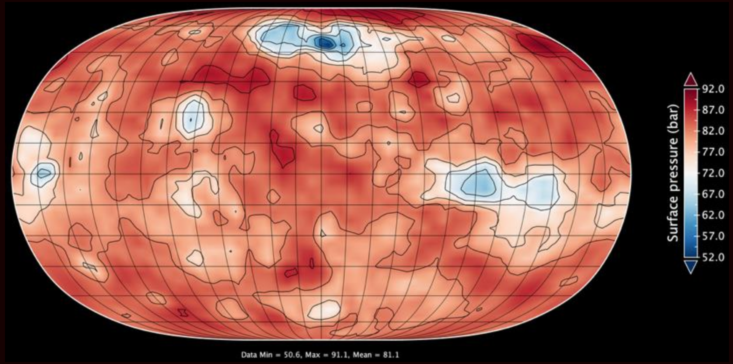
Plots from Venus Climate Database [3]

Generic-PCM outputs

Surface Temperature (K)



Surface Pressure (Pa)



Main takeaways

- Significant questions about Venus still need to be addressed.
- Venus & exo-Venus are closely linked:
  - Understanding Venus helps interpret the atmospheres and climates of exo-Venus candidates.
  - Exo-Venus observations can provide understanding of Venus conditions within a broader population of terrestrial worlds.
- Super-Venus candidates make up substantial portion of VZ planets.
  - Studying this archetype will push the limits & enhance our models.
  - Improve our understanding of extreme atmospheric and surface conditions on terrestrial planets.

This research will prepare future observations with **JWST, HWO,** and the **upcoming Venus missions.**

References

1. Bhatnagar *et al.* 2025 *EGUSphere* 3423 4 (preprint).
2. Kane *et al* 2013 *ApJL* **770** L20.
3. Martinez *et al.* 2023 *Icarus* 389 115271.
4. Ostberg *et al* 2023 *AJ* **165** 168.
5. Villanueva et al. 2018 *JQSRT* 217 86.