

High-Pressure and High-Temperature Behavior of Venus's Atmosphere Near the Surface: A Thermo-Gravitational Study

2473

AGU Fall Meeting

New Orleans, December 16, 2021

Paper: P45E-2473

Sugata P. Tan* ; Jeffrey S. Kargel

Planetary Science Institute, Tucson, AZ 85719

*stan@psi.edu

Acknowledgment:

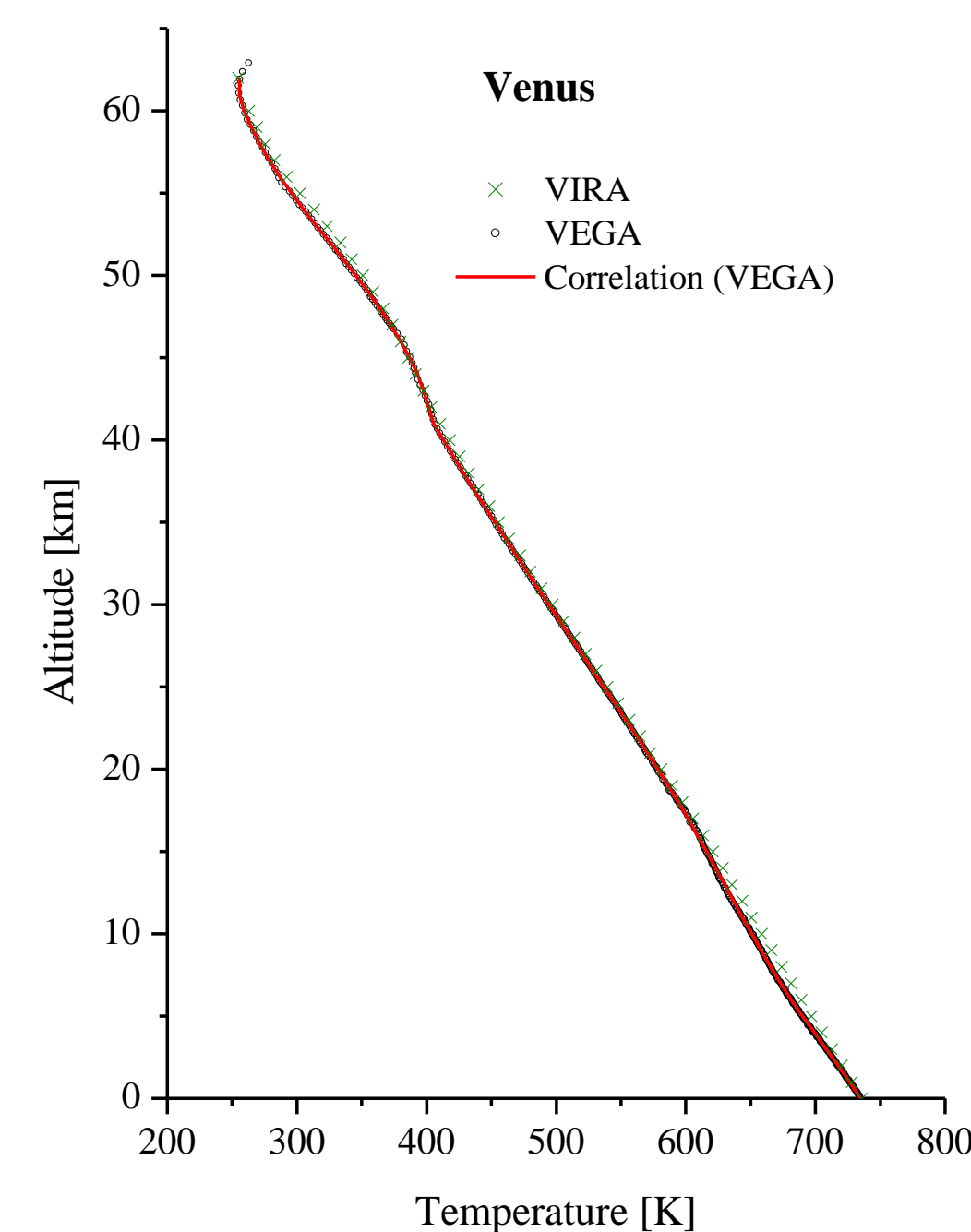
NASA – SSW Project (80NSSC19K0792)

Venus's atmosphere: CO₂ / N₂ / SO₂

- The temperature profile of the atmosphere at low latitudes was measured by VEGA (*Linkin et al., Kosmich. Issled. 1987, 25, 659*) and modeled by VIRa (*Seiff et al., Adv. Space. Res. 1985, 5, 3*).
- The temperature profile $T(h)$ by VEGA is correlated using polynomials:

$$T(h) = \sum_{i=0}^8 c_i (h - h_0)^i \quad [\text{K}]$$

in two parts corresponding to the altitude ranges of $h = 0$ -41 km ($h_0 = 0$) and 41-62 km ($h_0 = 41$) as seen in the figure. The correlation has an accuracy of 0.08%. The constants c_i is tabulated below the figure.



i	Altitudes	
	0 – 41 km	41 – 62 km
0	734.863249	406.773623
1	-7.642702	-6.755073
2	-0.71474	2.42324
3	0.12952	-0.931572
4	-0.009494	0.15933
5	3.553979E-4	-0.015415
6	-7.160138E-6	8.545841E-4
7	7.310104E-8	-2.511086E-5
8	-2.897589E-10	3.027652E-7

Thermo-gravitational effects

- In a stable phase α that is subject to gravity and thermo-diffusion:

$$d\mu_i^\alpha = M_i g dh - \frac{Q_i}{T} dT \quad i = 1, \dots, N$$
 where:
 - μ_i – chemical potential of component i
 - N – the number of components
 - T – absolute temperature
 - M_i – molar mass of component i
 - g – gravity
 - h – altitude
 - Q_i – heat due to diffusion of component i (*Firoozabadi et al. AIChE J. 2000, 46, 892*):

$$\frac{Q_i}{RT} = -\frac{\bar{U}_i^R}{4RT} + \frac{1}{4RT} \sum_j \bar{v}_i \sum_j z_j \bar{U}_j^R$$
 - R – gas constant
 - $\mathbf{z} = \{z_i\}$ – composition ($\sum z_i = 1$)
 - \bar{U}_i^R – partial molar residual internal energy of component i
 - \bar{v}_i – partial molar volume of comp i
- For calculations on the vertical profiles of fluid properties, the applied algorithm is the same as that in the AGU Fall Meeting 2020 with the application for Titan's subsurface liquid (*Tan & Kargel, paper # P067-0002*).

Without thermal diffusion

- To see whether the thermal diffusion is significant, Q_i is set to zero ($Q_i = 0$). This is called the zeroth-order approximation or the passive thermal diffusion.

Without SO₂: binary CO₂/N₂

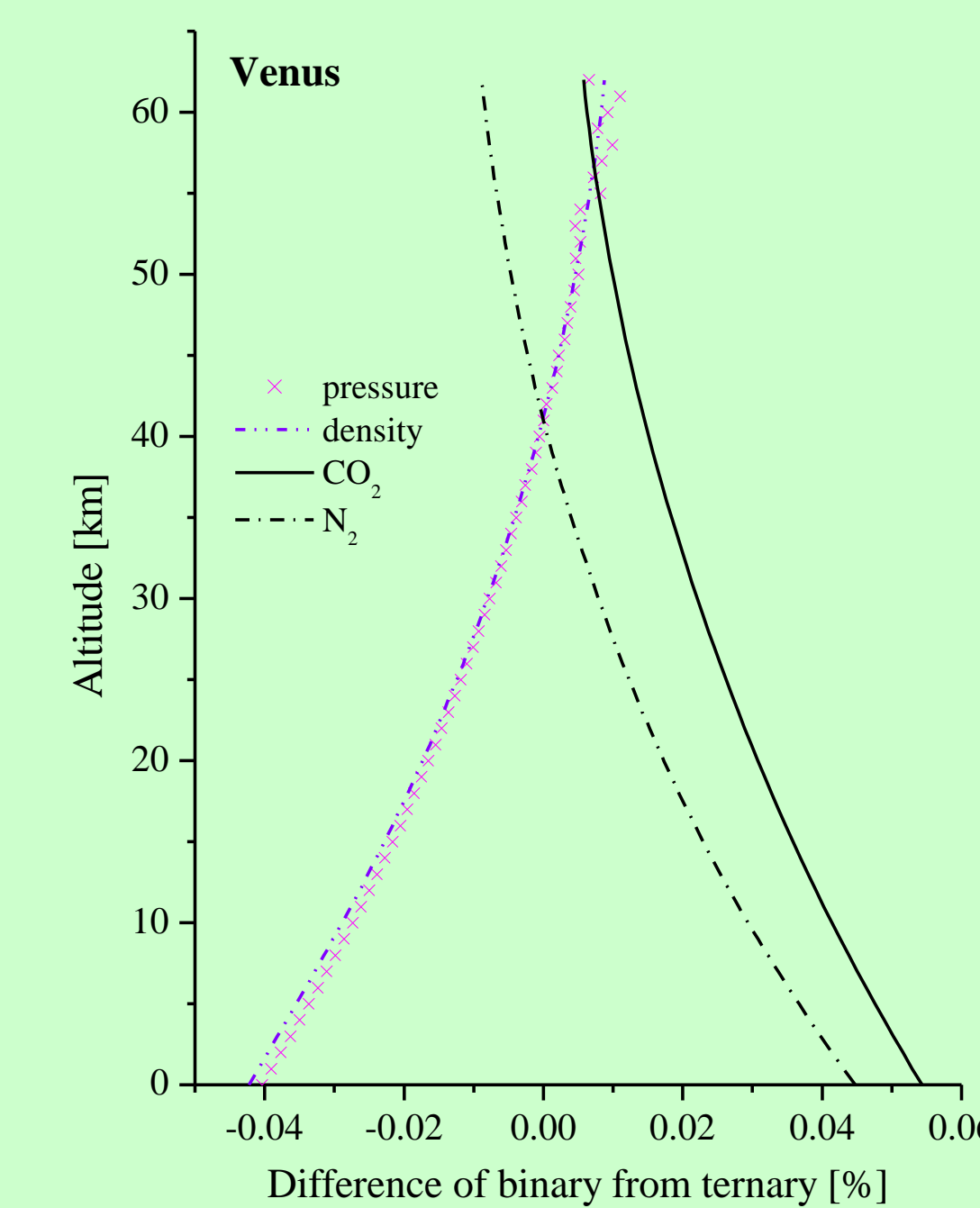
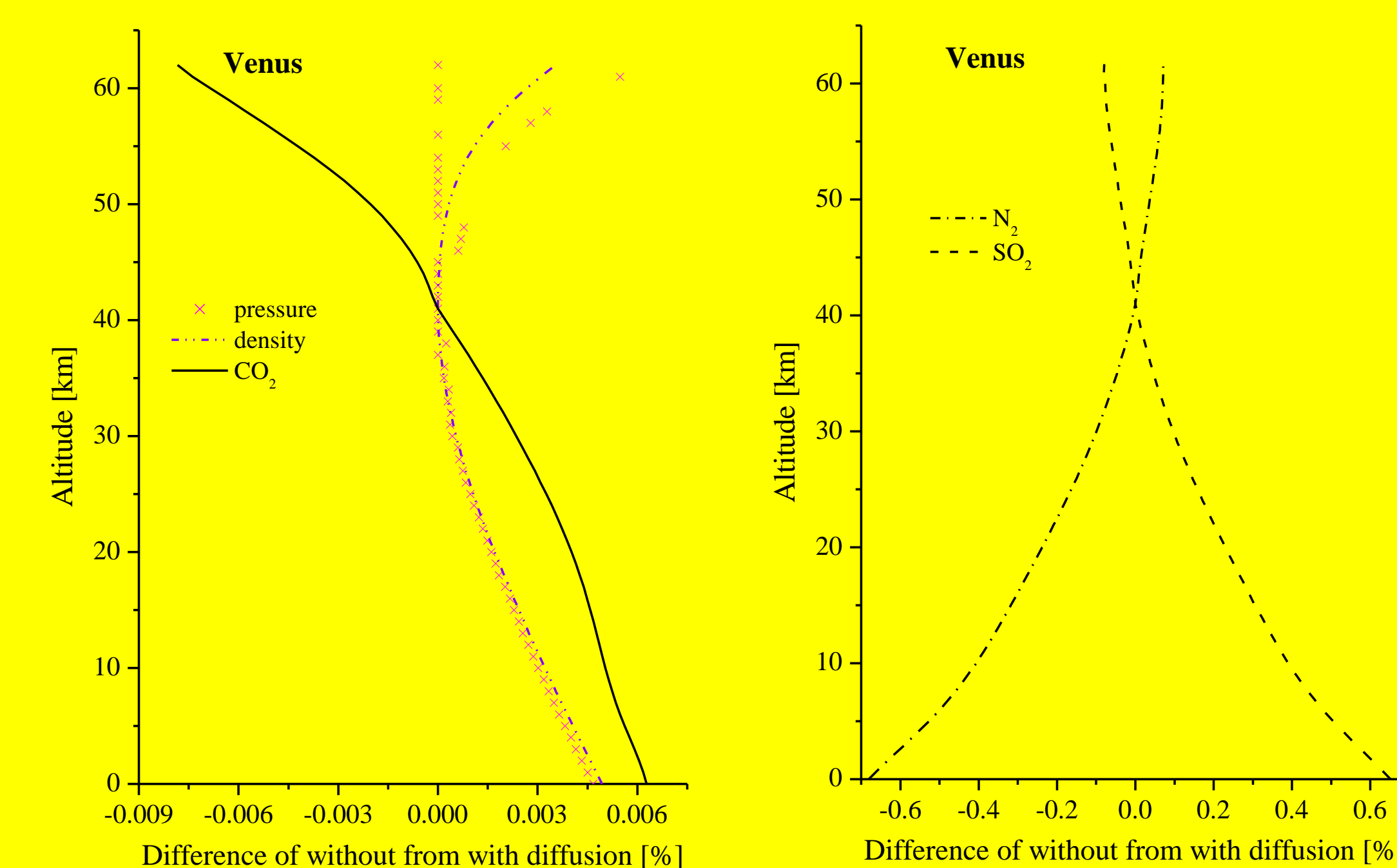
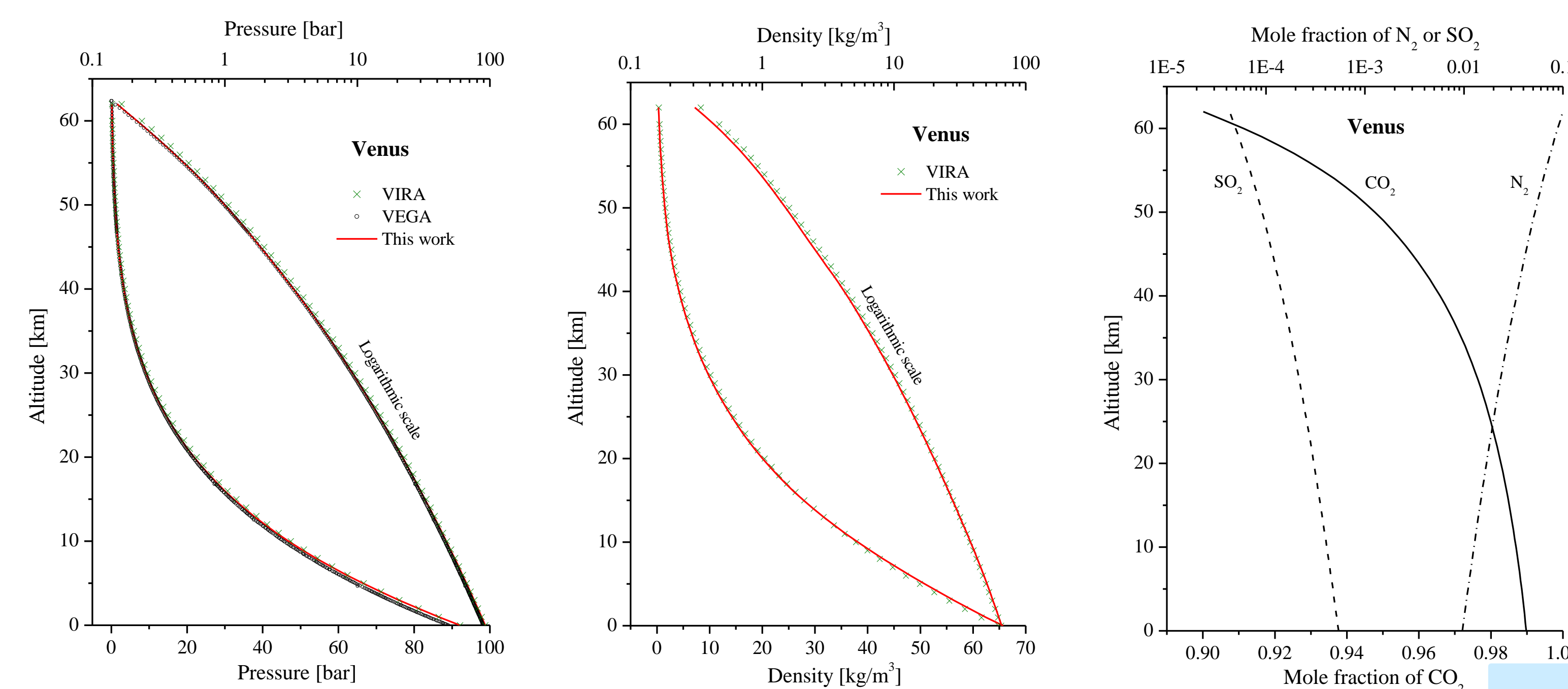
- Due to the tiny mole fraction of SO₂, it is of modeling interest to see the effect of the inclusion of SO₂.

Equation of state

- The equation of state (EOS) used in the calculation is the PC-SAFT (*Gross & Sadowski, 2001, Ind. Eng. Chem. Res., 40, 1244*).

Results and Discussion

- The resulting pressure profile agrees well with both VEGA and VIRa, particularly in the higher altitudes with VEGA and lower latitudes with VIRa.
- The resulting density profile agrees well with VIRa.
- The resulting compositional grading due to the thermo-gravitational effects reveals that CO₂ and SO₂ decrease while N₂ increases with altitudes, which implies the dominance of gravitational effects over the thermal diffusion counterpart as N₂ is the lightest component.

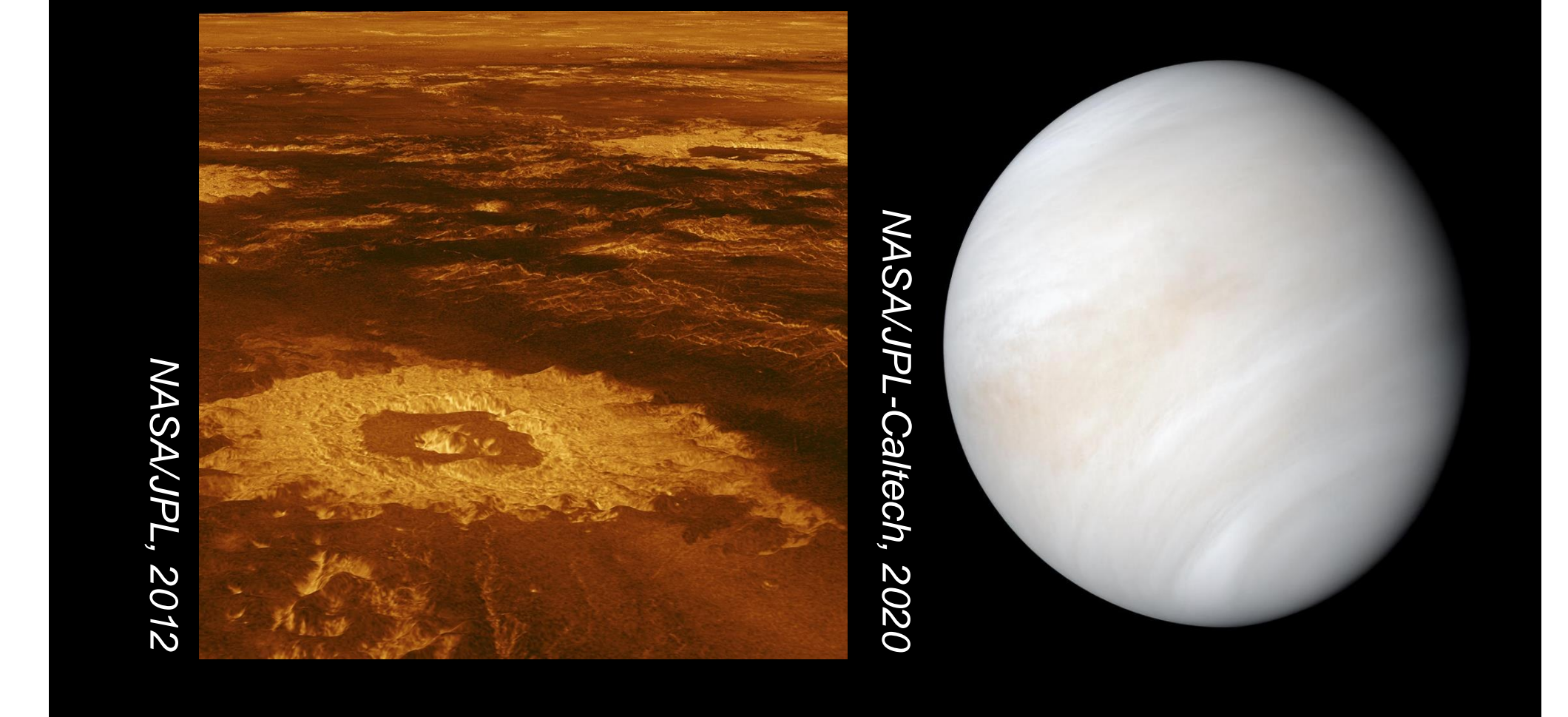


The omission of thermal diffusion makes:

- The pressure and density to overestimate by 0.005% on the surface.
- CO₂ to underestimate by 0.008% at the altitude of 62 km and overestimate by 0.006% on the surface.
- N₂ and SO₂ to underestimate and overestimate by about 0.65% on the surface, respectively.

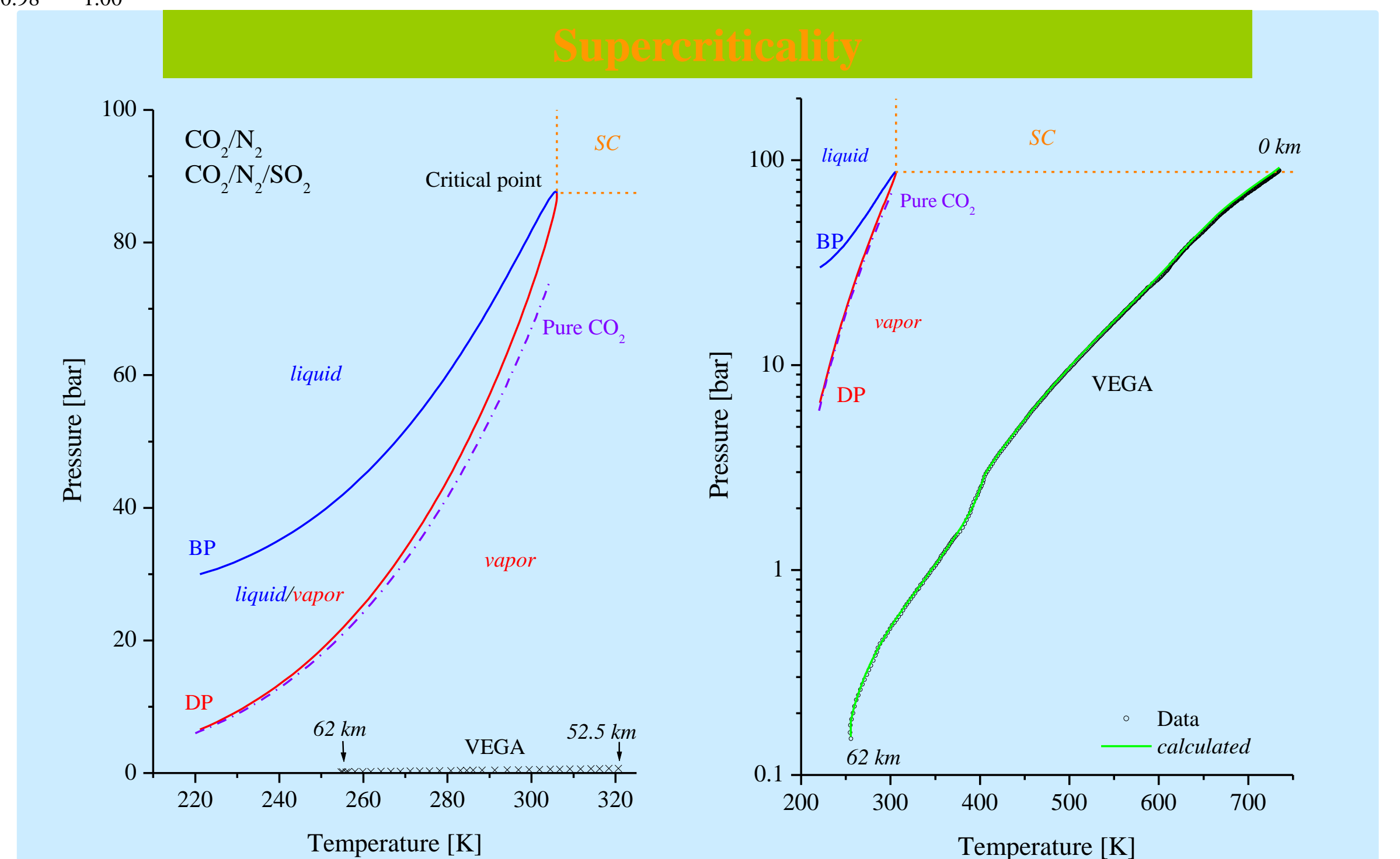
The use of binary CO₂/N₂ instead of ternary CO₂/N₂/SO₂ makes:

- The pressure and density to underestimate by 0.04% on the surface.
- CO₂ and N₂ to overestimate by 0.054% and 0.045% on the surface, respectively.



- The atmospheric properties at the surface and the altitudes of 41 km and 62 km are tabulated below.

	Altitudes		
	0 km	41 km	62 km
Temperature [K]	734.86	405.60	255.44
Pressure [bar]	92.12	2.94	0.1534
CO ₂ [mole fraction]	0.9898	0.9645	0.9001
N ₂ [mole fraction]	0.0096	0.0354	0.0999
SO ₂ [mole fraction]	5.42E-4	1.40E-4	0.43E-4
Density [kg/m³]	65.75	3.81	0.31



- Vapor (low density) and liquid (high density) phases can only coexist between the dew-point curve (DP) and bubble-point curve (BP) on the P - T phase diagram forming the so-called phase envelope.
- The phase envelop of ternary CO₂/N₂/SO₂ with the total composition of {96.45%, 3.54%, 0.014%} is indistinguishable from that of binary CO₂/N₂ with a total composition of {96.46%, 3.54%} on the diagram.
- The supercritical region of the atmosphere (SC) is located above the critical point (where DP meets BP) on the phase diagram.
- The P - T relationship of the atmosphere (green curve) is mostly in the vapor phase, except for that in the lowest of 6-7 km, where the atmosphere becomes supercritical.
- There is no indication of “gas-gas” equilibrium along the P - T function of the atmosphere as it must be above the phase envelope.