Understanding the Supercritical State on Venus and DAVINCI+ Opportunity

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Supercritical State on Venus

Measurement of physical conditions from Vega 2 [1] indicate presence of supercritical state in near surface atmosphere. Marked by a strong temperature gradient, increase in concentration of N_2 from surface to higher altitudes has been inferred and discussed extensively in recent studies [2,3]. Current estimates show presence of a state far from two phase region as shown in Fig. 1 and 2, indication dominant gas like behaviour with possibility of liquid state in the past. The deep atmosphere of Venus contains ⅔ mass of Venus atmosphere [4] and the momentum, mass and energy transport interactions governs the climate processes. The understanding of the supercritical environment on Venus will also provide answers with regard to chemical stability of minerals and surface composition.

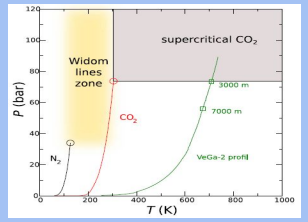


Figure 1. ***Phase diagram of N_2, CO_2*** *and Venus atmosphere from measurements of Vega 2 descent taken from [3]. Physical state of Venus atmosphere is far from the critical point.*

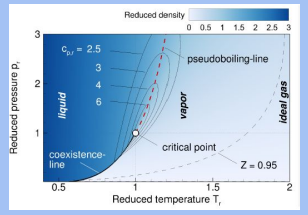


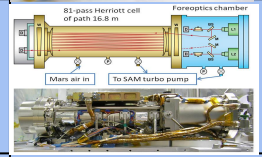
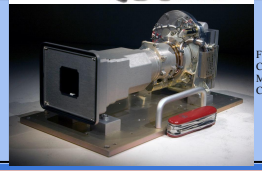
Figure 2. A ***revised phase diagram of subcritical and supercritical states****, given by [5]. It shows transitions between liquid and gas like behaviour w.r.t. Critical point of chemical species and its mixtures*

DAVINCI+ Mission to Venus

DAVINCI+ standing for Deep Atmosphere Venus Investigation of Noble gases, Chemistry and Imaging Plus is a Venus mission now in Phase A led by PI Dr. Jim Garvin (PI), Stephanie Getty (DPI), Giada Arney (DPI), and Natasha Johnson (PS) [6,7]. The mission will explore Venus using a combination of suite of instruments onboard an orbiter and a deep atmosphere chemistry probe. A 1 hr. descent through the atmosphere of Venus to the Alpha Regio will provide new in-situ measurements of trace gas composition [6,7] and temperature below 12 km to the surface including the supercritical CO_2 region for the first time in many decades!

DAVINCI+ Probe Instruments

Table 1. Description of DAVINCI+ probe instrumentation, objectives and flight heritage

Instrument Name	Objectives/ Measurements	Understanding the Supercritical State	Flight Heritage	Images
Venus Mass Spectrometer (VMS)	Isotopic composition, abundance of major constituents, noble gases and aerosols [6].	(i) Mixing ratio of N2 in the supercritical region will prove or negate vertical gradient in N2 mixing ratios from Vega 2 descent. (ii) Variation in mixing ratio of noble gases in supercritical state?	Curiosity SAM/MSL	 Figure 3. Curiosity SAM/ QMS [6]
Venus Tunable Laser Spectrometer (VTLS)	Mixing ratio of trace species from Infrared Spectroscopy using Multipass Herriott Cell [6,8].	(i) Effects of supercritical state on molecular diffusion of trace species. Deducing the transport rates from surface to higher altitudes.	Curiosity SAM/MSL	 Figure 4. Curiosity SAM/TLS. Image credit: NASA
Venus Atmospheric Structure Investigation (VASI)	Physical properties like acceleration, T, P, density etc., thermal structure and stability [6,2].	(i) Physical properties of the supercritical state and deduction of dominant molecular interactions. (ii) Static stability and temperature gradient in the planetary boundary layer and near surface environment. (iii) Wind speeds and transport processes by atmospheric circulation.	Pioneer Venus probes, Galileo probe	 Figure 5. DAVINCI+ VASI instrument illustration [6]
Venus Descent Imager (VenDI)	Images of lower atmosphere, near surface region, characterisation of surface features [6]	(i) Existence of meta -stable states in supercritical region? (ii) Exploring the correlation between mixing ratios of chemicals and potential volcanic or outgassing process.	Curiosity	 Figure 6. Curiosity MSL/Mast Cam [6]

Why is it important?

The measurements of temperatures and chemical composition of the deep atmosphere of Venus have high error bars and are not reproducible [9]. Vega 2 provides the only reliable source of temperature observations below 12.5 km. Thus, it constraints the understanding of atmospheric processes in near surface environment due to lack of accurate measurements.

Another important problem in line with DAVINCI+ science objective [6] is the divergent evolution of terrestrial planets of Earth, Mars and Venus [10]. Any new measurements of physical properties and isotopic compositions will assist in formulation of reference atmosphere models and climate models to study possible pathways of planetary evolution of Venus. Recent work has put forward cases of past climate [11] and existence of liquid H_2O [11] and CO_2[12]

Transition characteristics from a subcritical state to supercritical state and its driving mechanism are currently not understood. Accurate estimation of trace compounds will test the existence of meta-stable states near surface [13] aiding to understand the non-equilibrium phenomena on Venus. The relation between the theories of Venus evolution i.e. runaway greenhouse effect and volcanic resurfacing, and the transition process will play an important role in identification of factors for divergent evolution of Earth, Mars and Venus [10]. Thermal structure of the deep atmosphere would indicate the diffusion processes of different species, in particular N_2 concentration and noble gases. Variation in mixing ratios of isotopes in the supercritical state is not known and needs to be explored. Any possibility of present volcanic activity can be deduced from measurement of trace gas compounds using VMS and VTLS instrument.

Table 2. Some important isotopes and the phenomena associated with their abundances

Isotopes/Chemical species	Associated Phenomena
D, H	Atmospheric escape process of water [11,14], isotopic effects due to physical state of near surface environment?
^{15}N, ^{14}N	Mean molecular mass gradient in lower atmosphere, isotope fractionation due to atmospheric processes
^{40}Ar, ^{4}He	Volcanic processes and outgassing of radiogenic isotopes [10]

References

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