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## The quest for quakes on Venus

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Last year, the first active lava flow on Venus was discovered by Herrick & Hensley (2023), adding to the growing body of evidence that Venus is currently volcanically active with frequently erupting volcanoes (Byrne & Krishnamoorthy, 2022; Van Zelst, 2022). This discovery immediately begged the question as to whether Venus is seismically active at present as well. Indeed, more and more theoretical studies show that Venus could be seismically active today (Van Zelst et al., 2024). In the next decade, we will unravel some of Venus' secrets through a multitude of Venus-bound missions, but determining the seismic activity of the planet is not one of their main goals. Missions to Mars and the Moon have shown the wealth of information that can be gleaned from seismic studies of a planet. We argue here that the seismological exploration of Venus — 'the quest for quakes on Venus' — should be the next priority of space agencies.

We first estimate upper and lower bounds on the expected annual seismicity of Venus by scaling the seismicity of the Earth. We consider different scaling factors for different tectonic settings and account for the lower seismogenic zone thickness of Venus. We find that 95 — 296 venusquakes equal to or larger than moment magnitude ( $M_w$ ) 4 per year are expected for an inactive Venus, where the global seismicity rate is assumed to be similar to that of continental intraplate seismicity on Earth. For the active Venus scenarios, we assume that the coronae, fold belts, and rifts of Venus are currently seismically active. This results in 1,161 — 3,609 venusquakes equal to or larger than  $M_w$  4 annually as a realistic lower bound and 5,715 — 17,773 venusquakes equal to or larger than  $M_w$  4 per year as a maximum upper bound for an active Venus.

To assess whether any quakes could occur at all at Venus' high temperatures, we estimate the seismogenic thickness of the planet in three independent ways: through estimates from flexure,

through geodynamic models, and through estimates from mantle density anomalies. For all these estimates, we look at the depths of the 600°C and 800°C isotherms as the maximum limit of brittle failure and hence the maximum depth of the seismogenic zone. The seismogenic thickness estimates we find show a large range depending on the assumptions we make for each different method, but in general show that the seismogenic thickness on Venus is on average approximately 10 to 35 km globally.

To learn more about venusquakes and deduce the interior structure of Venus from them, the detection of seismic waves is crucial. Various concepts to measure seismic waves on Venus have already been explored in the past decades. These detection methods include typical geophysical ground sensors already deployed on Earth, the Moon, and Mars; pressure sensors on balloons; and airglow imagers on orbiters to detect ground motion, the infrasound signals generated by seismic waves, and the corresponding airglow variations in the upper atmosphere. Here, we provide a first comparison between the detection capabilities of these different measurement techniques and our estimates of Venus' seismic activity. In addition, we discuss the performance requirements and measurement durations required to detect seismic waves with the various detection methods.

We also briefly suggest target regions with a high likelihood of significant surface deformation and/or seismicity for current and future missions. These targets are particularly useful for the upcoming VERITAS (Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy) and EnVision missions. They would specifically benefit from the repeat pass interferometry of VERITAS, which detects surface deformation and can therefore in principle constrain the maximum displacement of surface faulting at locations that are visited twice during the mission.

Our extensive study into the potential seismicity of Venus could be used to drive the design of future mission concepts aiming to study the seismicity of Venus.

## References

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