Venus Geophysical Explorer : A Venus Interior Structure Mission Using Balloons

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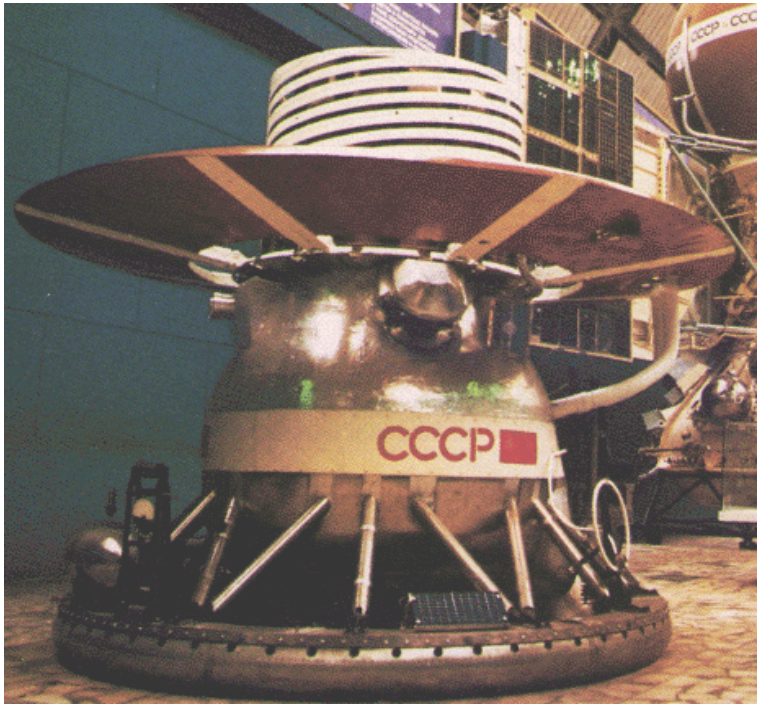
Rationale for a Venus Seismic Mission

- Knowledge of the formation, evolution and structure of the terrestrial planets (including Earth) is currently impeded by the very limited understanding of the interior structure of Venus.
  - Seismology is a powerful technique that is responsible for much of what we know about the interior of the Earth and Moon;
  - Seismology can also play a key role in answering fundamental questions about our twin planet.
- Venus lacks plate tectonics, which is the main source of seismic energy on Earth.
  - However, significant seismic activity can arise when there is distributed lithospheric deformation, just as it does with intraplate tectonics on Earth.
  - The challenge is to devise an methods to determine the level of current seismic activity and constrain the global structure that would work in the severe environment of Venus

Previous Seismic Experiment on venus



Radio / Microphone / Seismometer - Groza-2

Ksanfomaliti et al, 1982

registered a single event (top curve). Since the amplitude U_0 of the signal triggering the counter is known, the presence of a signal at a level of 0.16 V ($\approx 6 \cdot 10^{-6}$ cm) indicates that the vent occurred no later than at elapsed time

$$t \leqslant \tau_n - \tau \ln (U/U_0) = 950 \text{ sec} \quad (1)$$

after landing. Here U denotes the recorded deflection, τ_n marks the start of the n-th cut (1217 sec for the third

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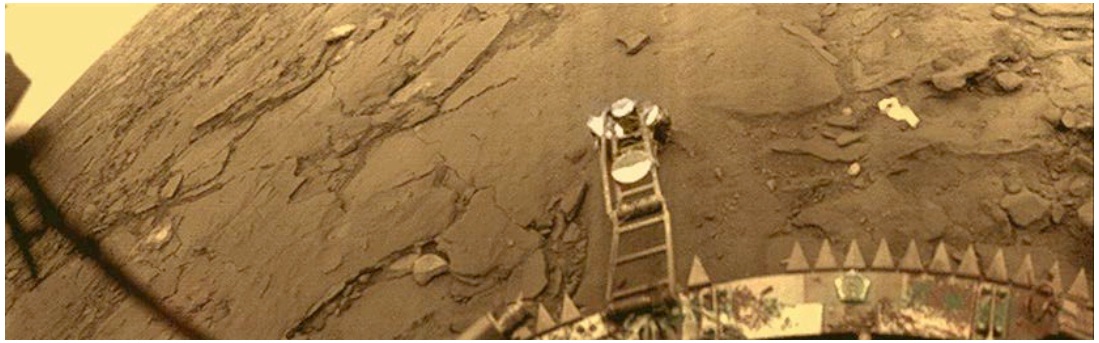
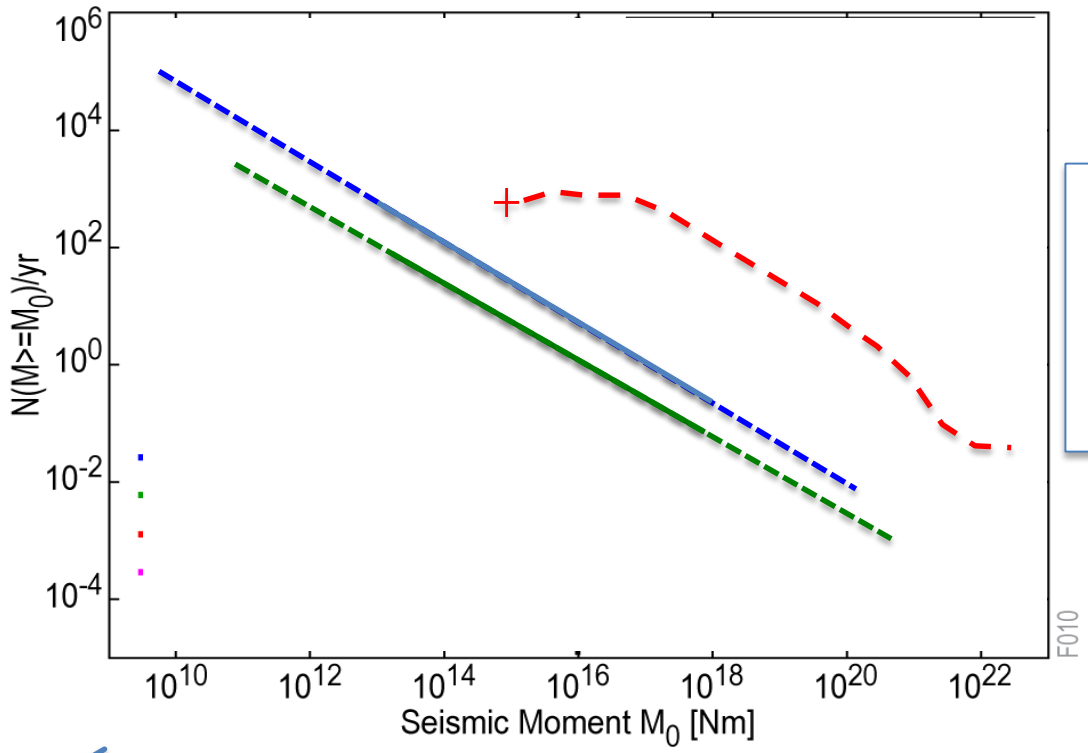


Underlying assumptions of any seismic investigation

- The more sensitive the seismometer is, the more quakes it detects.
- Seismometer sensitivity and mission duration are key to investigation success

Seismicity Models

Number of Quakes per unit of time (N/yr)



(Derived from fault counting)

- Mars High Activity Model
- Mars Low Activity Model
- VISM proposal estimate
- Earth 1984-2004

(After Knapmeyer +Stofan, 1993)

Seismic Detection threshold

A mission duration of a few months and a sufficient sensitivity are required

Technological Challenges for a Venus Seismometer

- Reach the required **sensitivity** and **bandwidth,** with a sufficient coupling with the ground
  - Viking seismometer has mainly seen wind
  - Venera 13/14 has likely seen thermal relaxation
  - Mechanical design can be very simple and robust
  - Electronics is a more difficult issue
    - Acquisition, feedback if broadband seismometer, possibly tether or transmission device
  - Preliminary guess 10^{-8} m/s^2/√Hz [0.05 – 1 Hz] including environment ?

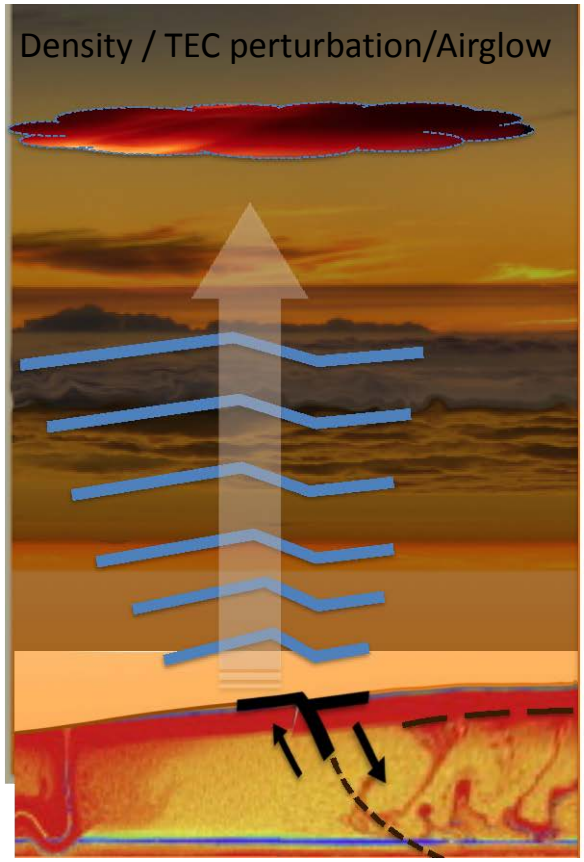
- Reach the **required duration** for the measurement… under Venus conditions
  - Provide power, data processing and telecommunication functions for at least 1 year (TBC)

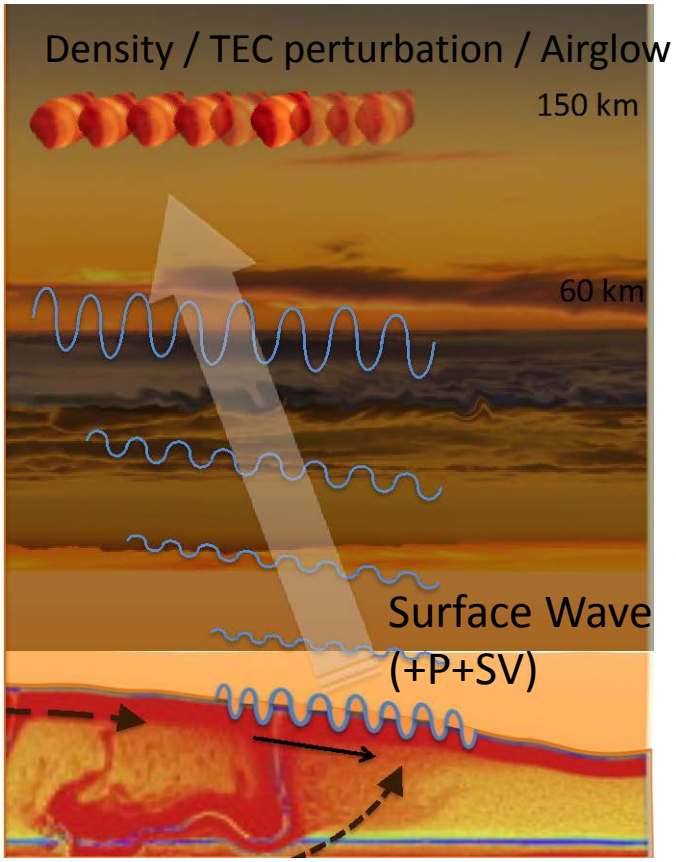
(Hunter and al)

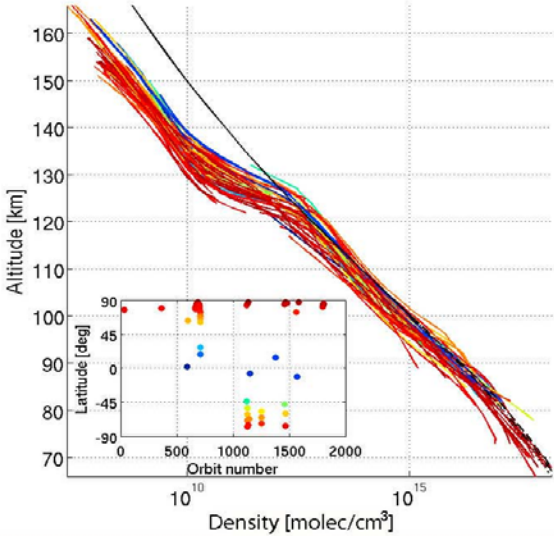
Sustaining a Venus probe and the seismometer about one year at 500° C 90 atm is a significant challenge

Solid Venus / Atmosphere coupling

- Long period waves couple at the planet surface with atmospheric gravito-acoustic waves propagating upward in the atmosphere [Lognonné et al., 1998; Occhipinti et al., 2006; Hickey et al., 2009]. Due to kinetic energy conservation and to the exponential density decrease in the atmosphere, these waves are amplified and generate significant perturbations in the thermosphere/ionosphere system







(Mahieux et al, 2012)

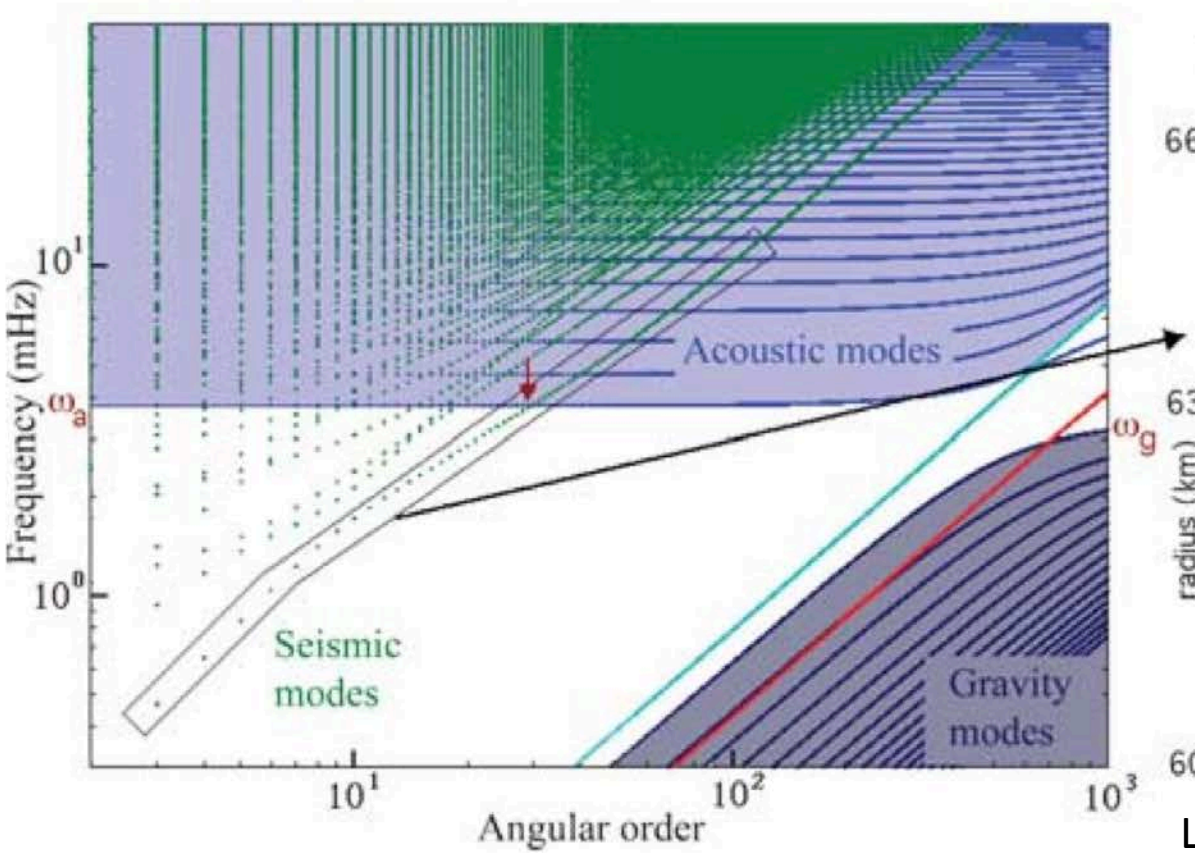
Amplification from 6E6 to 6E7
between 150 & 250 km altitude

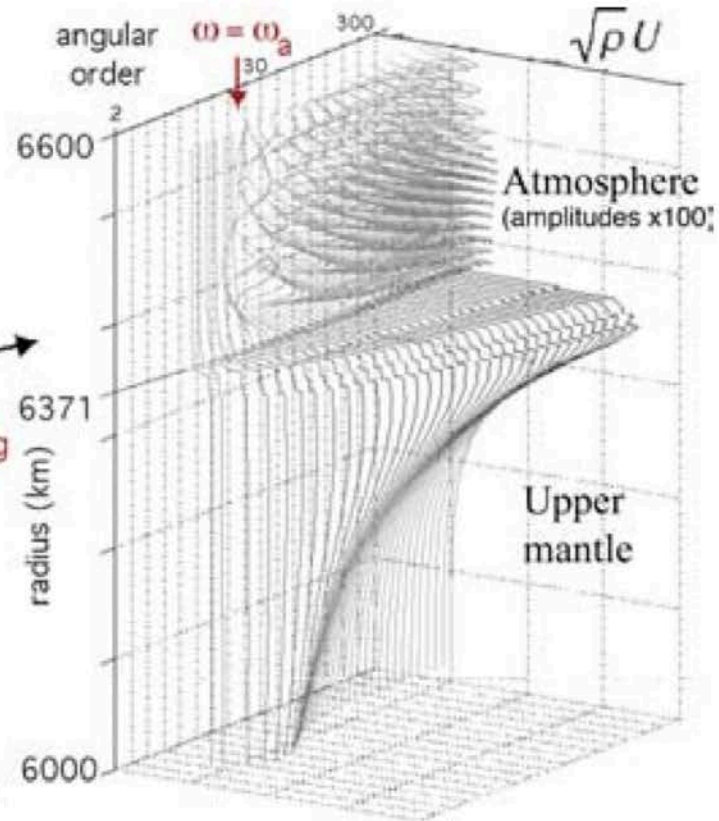
$$\sqrt{\frac{\rho(0)}{\rho(z)}} \longleftarrow \rho v^2 = constant$$

The theoretical background

- Acoustic Gravity Wave Theory :
  - ✓ **Hines, 1960**
- Earth atmosphere coupling :
  - ✓ **Wolcott et al., 1984**

- Eigenfrequency extended to Earth with ocean & atmosphere:
  - ✓ **Lognonné et al., 1998 ;**
  - ✓ **Artru et al., 2001 ;**
  - ✓ **Lognonné et Clévédé, 2002 ;**





Lognonne and Clévédé, 2002

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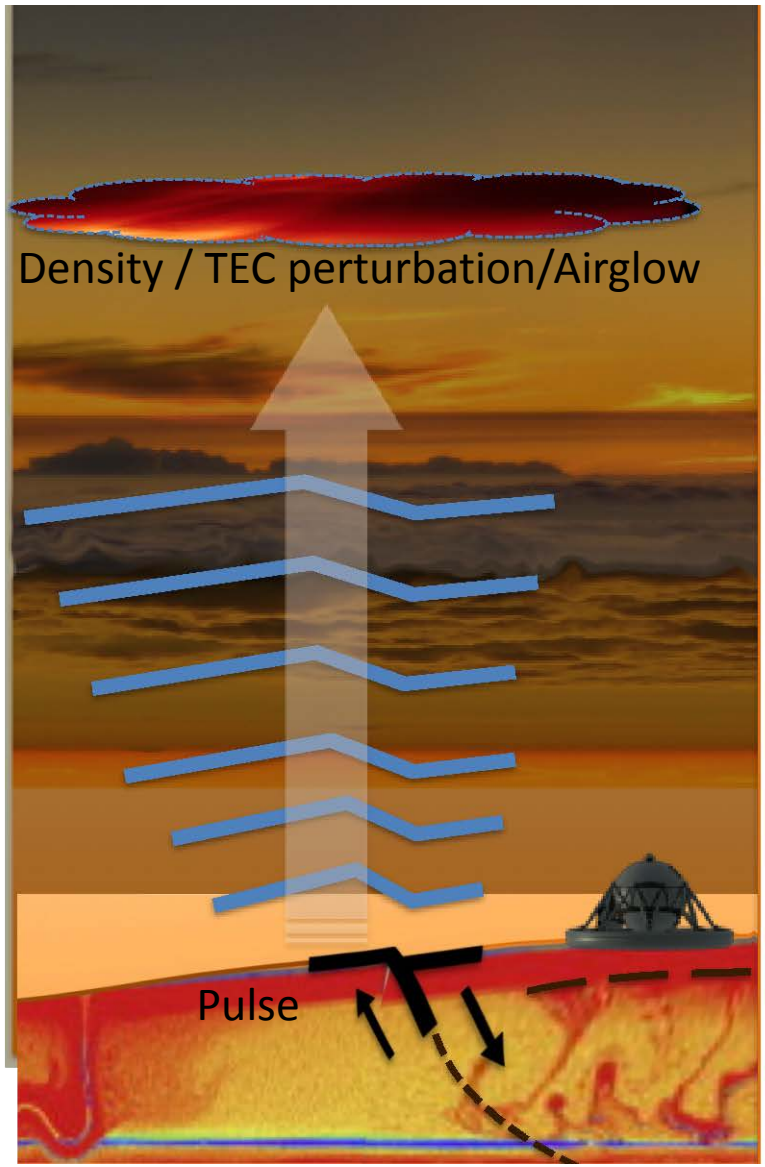
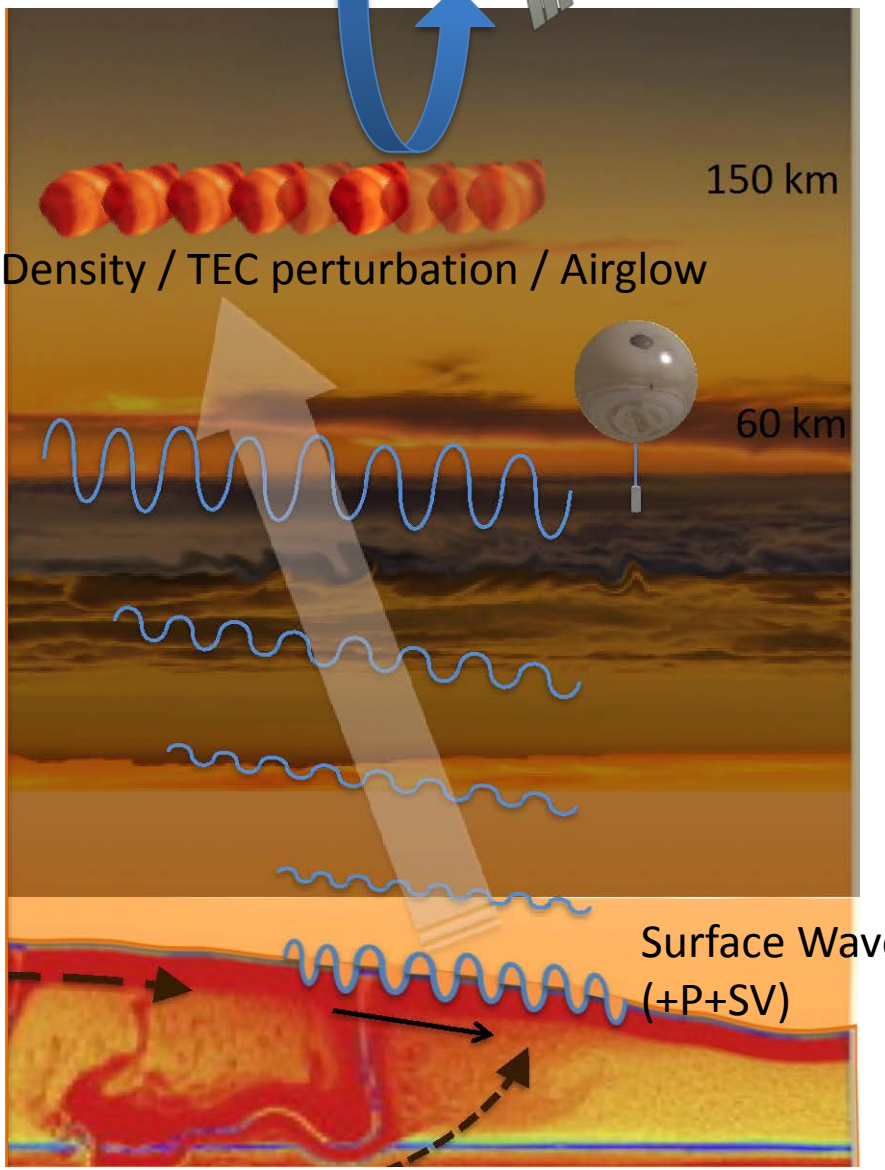
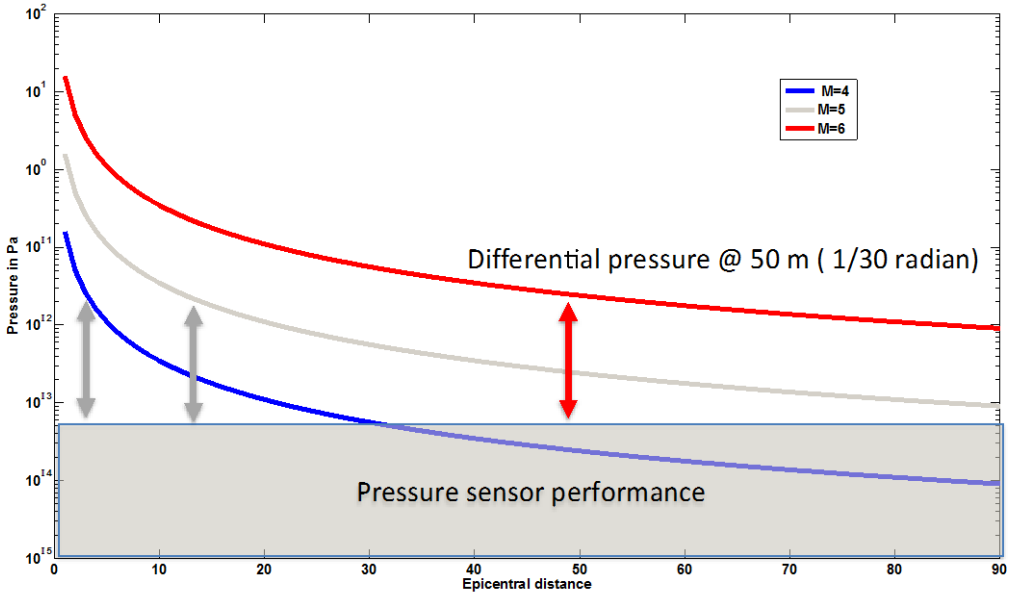
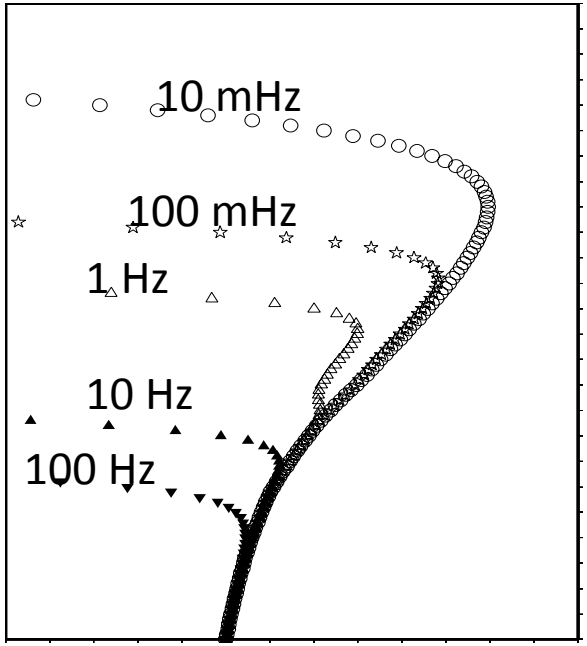




Investigation preliminary feasibility

- The pressure wave can be recorded by a micro-barometer





(a) Pressure Signal Amplitude for surface waves, M=4,5,6 magnitude as a function of quake epicentral distance

Acoustic wave amplification as a function of altitude on Venus from Garcia et al (2005)

Already existing sensors have the capability to detect these waves

Potential noise contributors for a infrasonic measurement

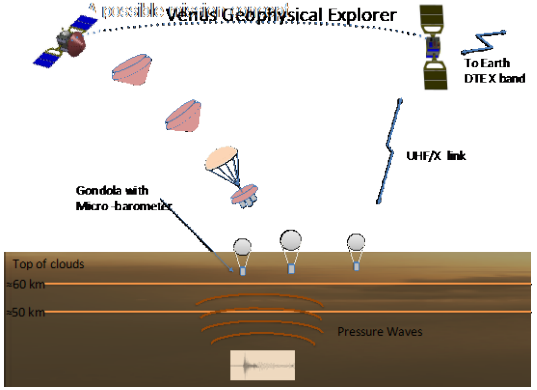
- Venus Atmosphere is very dynamic
- There are several potential perturbations from the upper atmosphere
  - Local effects :
    - turbulence, wind, motion of the gondola
  - Regional effects
    - Acoustic gravity waves ?
    - Volcanoes , storms ?

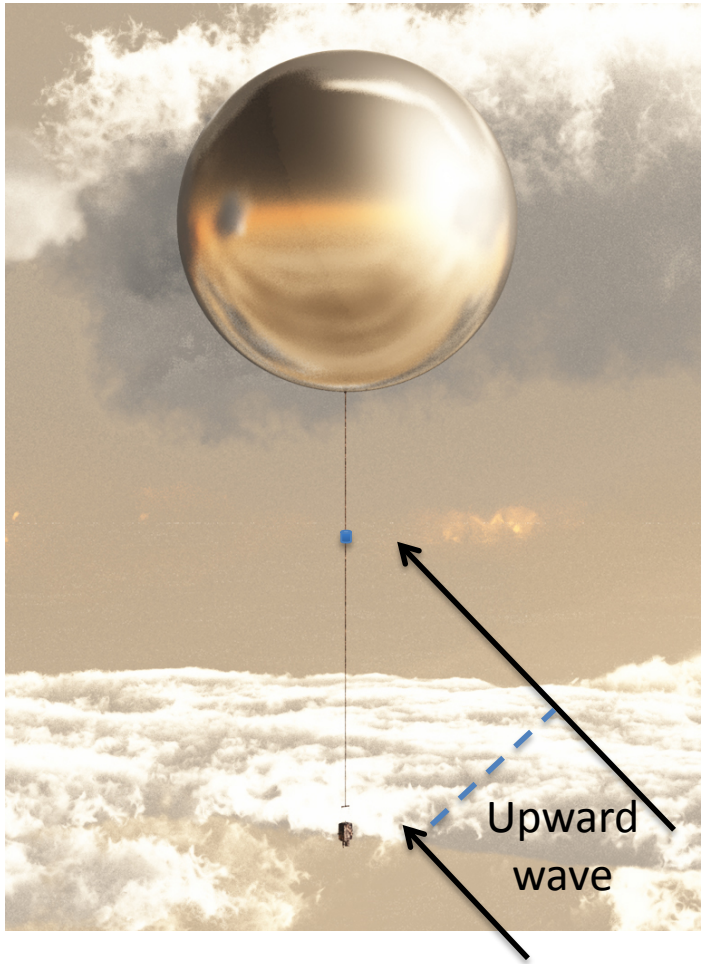
(Taylor, 2006)

Investigation complementary to atmospheric science

Propagation in the upper atmosphere

- Infrasonic sensors may be able to record the seismic signal [0.05 5 Hz] –TBC (with some delay (propagation in minutes)
- Filtering of upward waves to discriminate perturbations from signal
- 2 or 3 long lived balloons – typical life duration : about 6 months to 1 year
  - Autonomously powered : solar vs RTG ?
  - Overall data management : Limited bandwidth
  - Autonomous event detection
  - Time synchronization between gondolas
  - Need of a relay orbiter, likely equatorial





Summary : comparison of techniques

Platform Location/Number	Environment	Primary Observable	Technology Maturity	Lifetime	Ready for flight ?	Technology demonstration mission
Venus Surface Landers (1 to 3)	460°C, 90 bars	Seismic waves (P waves and S waves)	Low. Electronics to survive at these temperature	3 hours (TRL 6) 3 months (TRL 2)	No	Difficult
Venus Balloons at 55 km altitude (3 to 5 ?)	20C, 0.4 bars	Gravito-acoustic waves (P waves + Surface waves only)	Mod to high	3 to 6+ months	Yes	Easy
Venus Orbiter (1 to 3)	Space with direct and scattered solar radiation	Infrasonic induced variations in thermal emission and electron density → Rayleigh wave dispersion	High	10 years	Yes	Feasibility to be assessed