VENUS EXPLORATION WITH INFRASOUND TECHNIQUES

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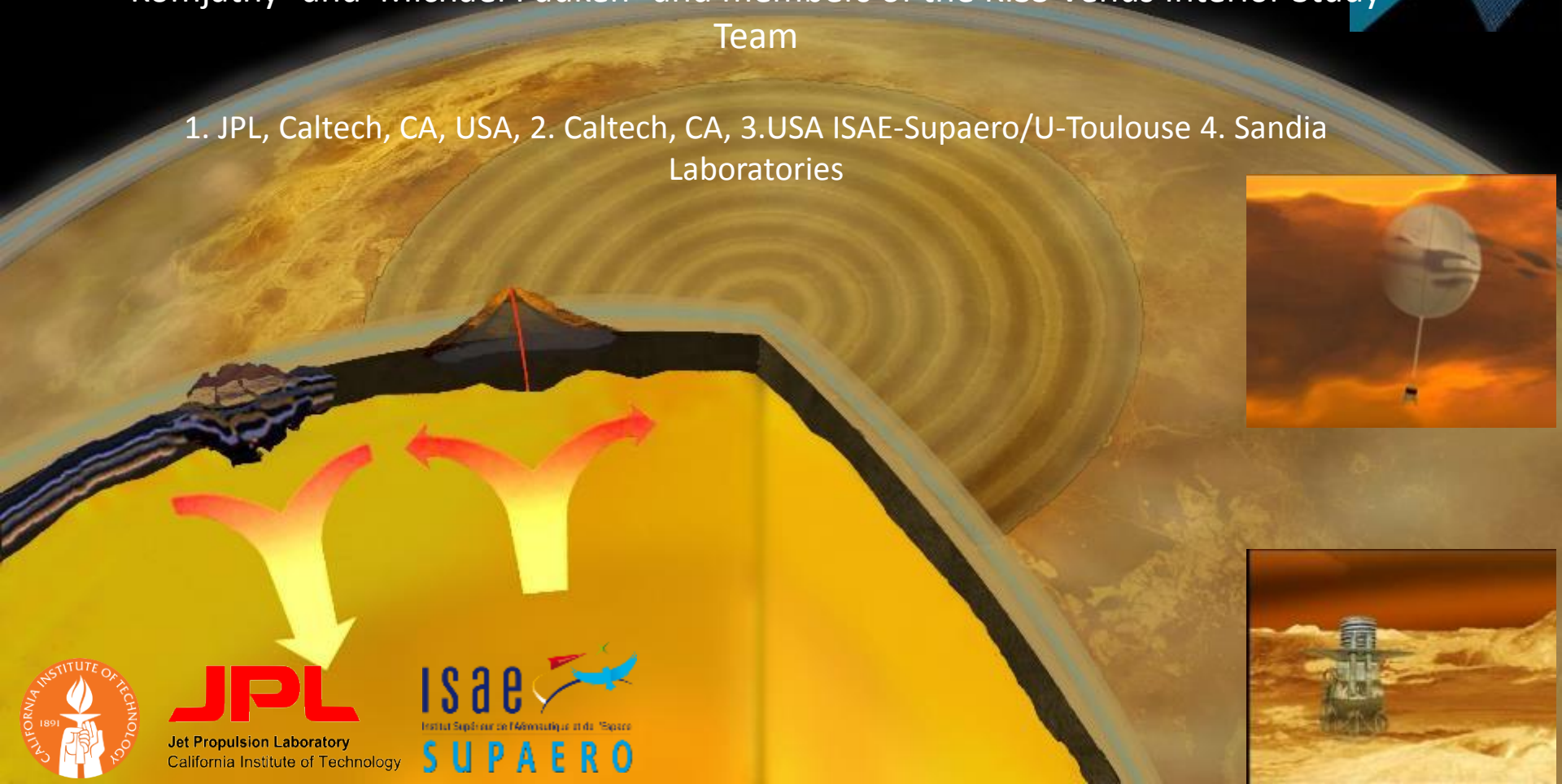

Overview

- The formation, evolution and structure of Venus remain a puzzle more than fifty years after the first visit by a robotic spacecraft.

- Radar images have revealed a surface that is much younger than those of the Moon, Mercury and Mars as well as enigmatic volcanic and tectonic features unlike those formed by plate tectonics on Earth.

- To understand how Venus works as a planet it is necessary to understand if it is still active and, if so, to use Venus quakes to probe its interior.

- Infrasonic techniques can be implemented from balloon platforms and from orbit using existing technologies and take advantage of Venus' dense atmosphere to achieve high sensitivity

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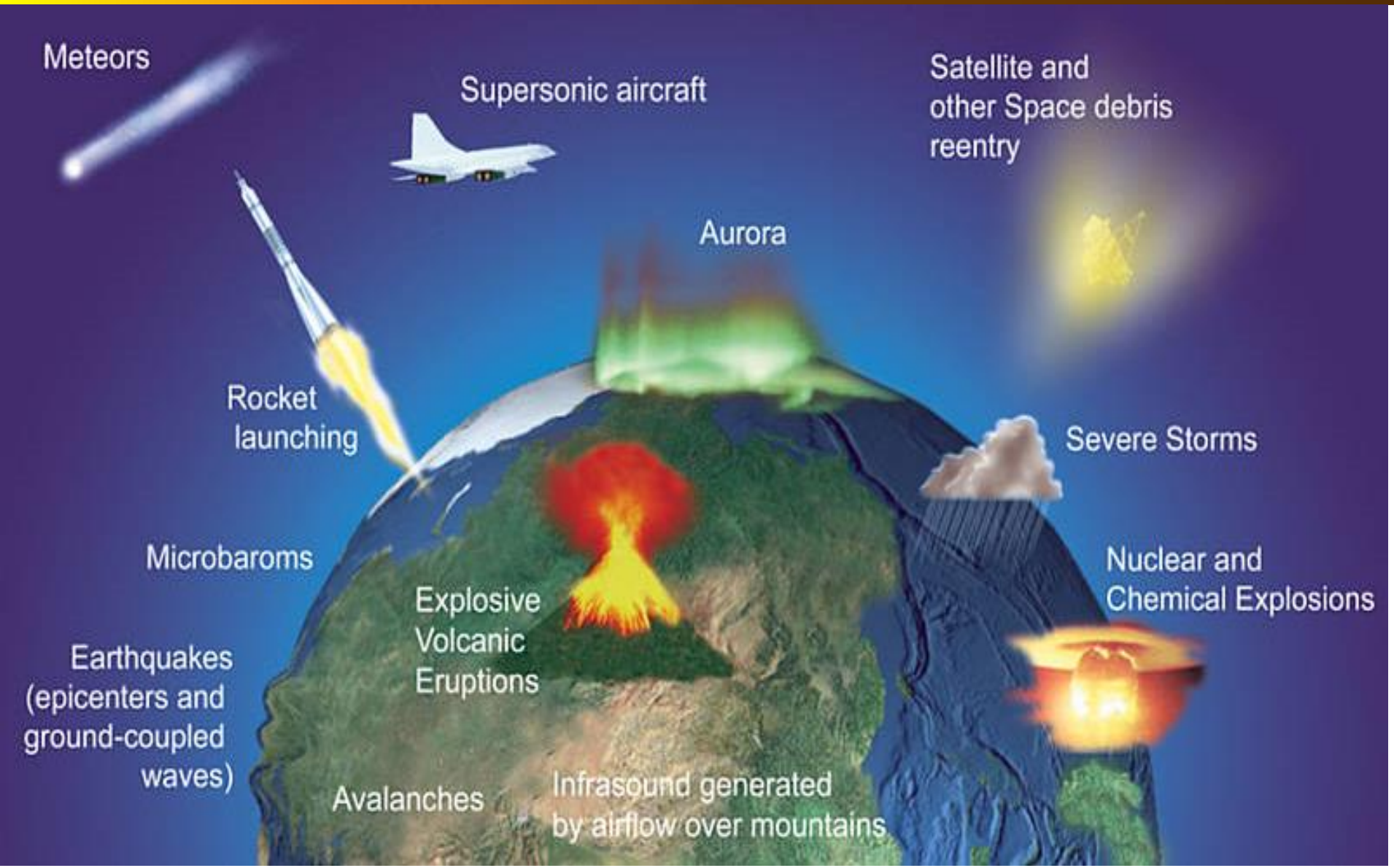
Earth: Sources of Infrasound (<20Hz)



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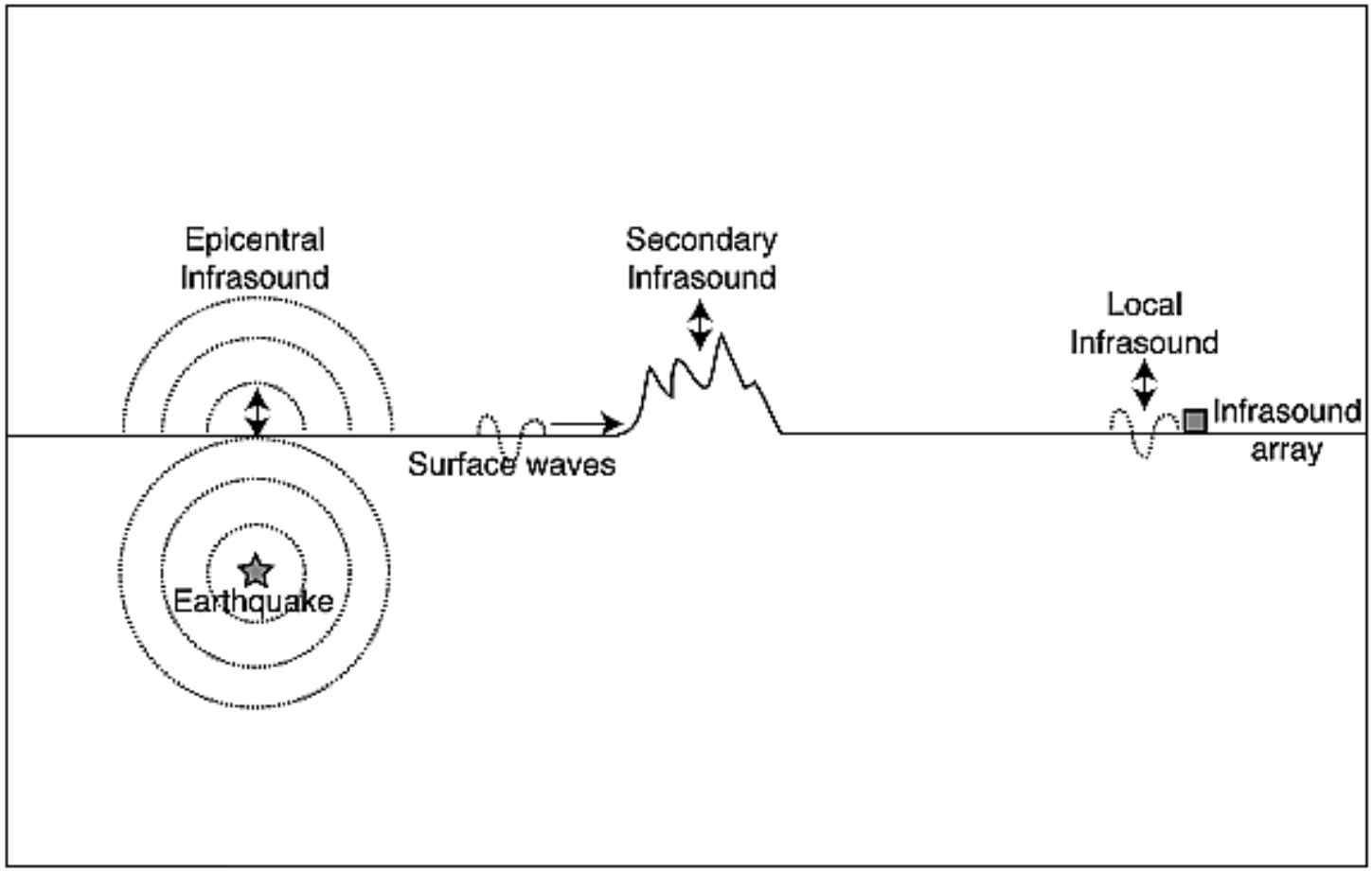
Earth: Generation of Infrasound by Quakes



Epicentral infrasound originates from directly above the epicenter and propagates to the infrasound array through the atmosphere

Secondary and local infrasound is generated by surface waves coupling with the atmosphere at a distance from the epicenter

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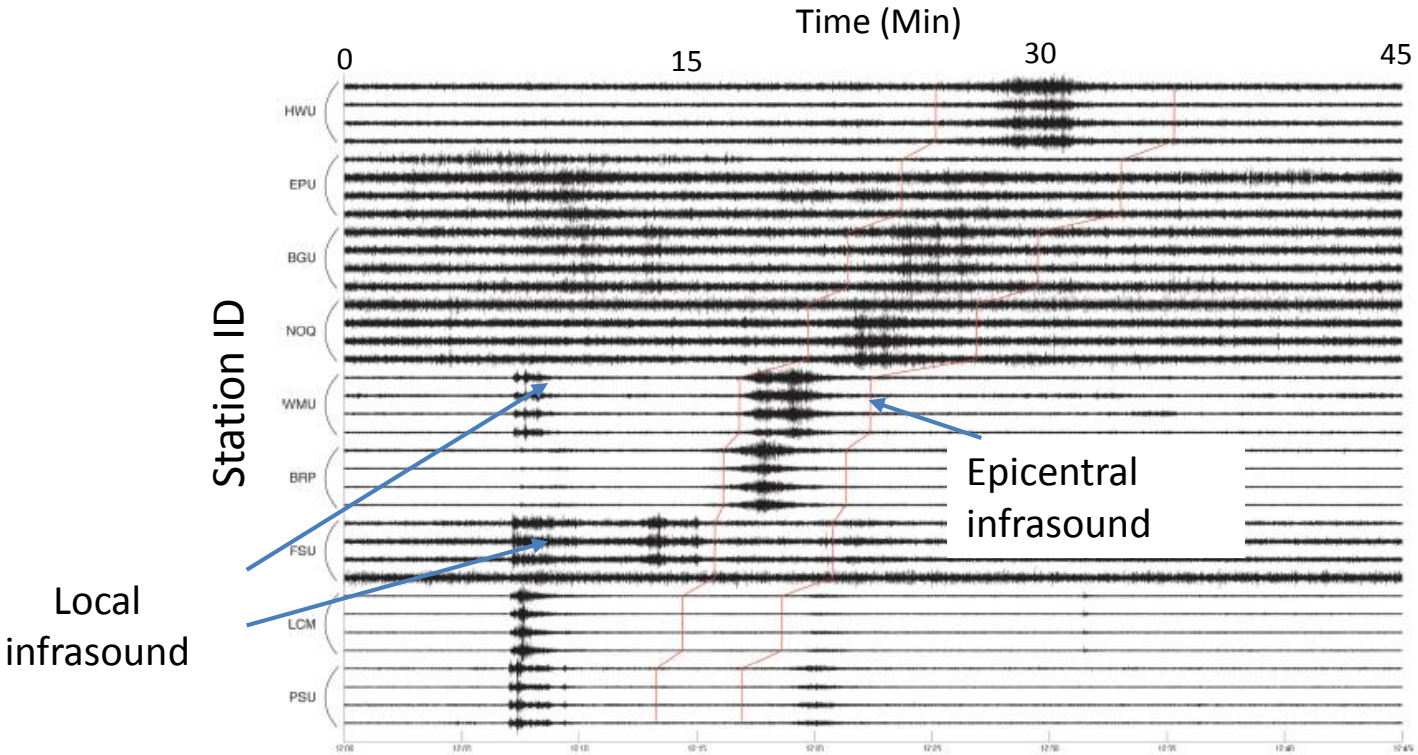
Earth: Detection of Seismo-Acoustic waves



Centerville Earthquake 2011 **M 4.7** . Signals from the nine stations in the University of Utah infrasonic array (1 to 5 Hz)

Epicentral infrasound from a M 4.7 earthquake was detected at six infrasound stations extending up to 500 km from the source

Reproduced from the paper by Arrowsmith et al 2012)

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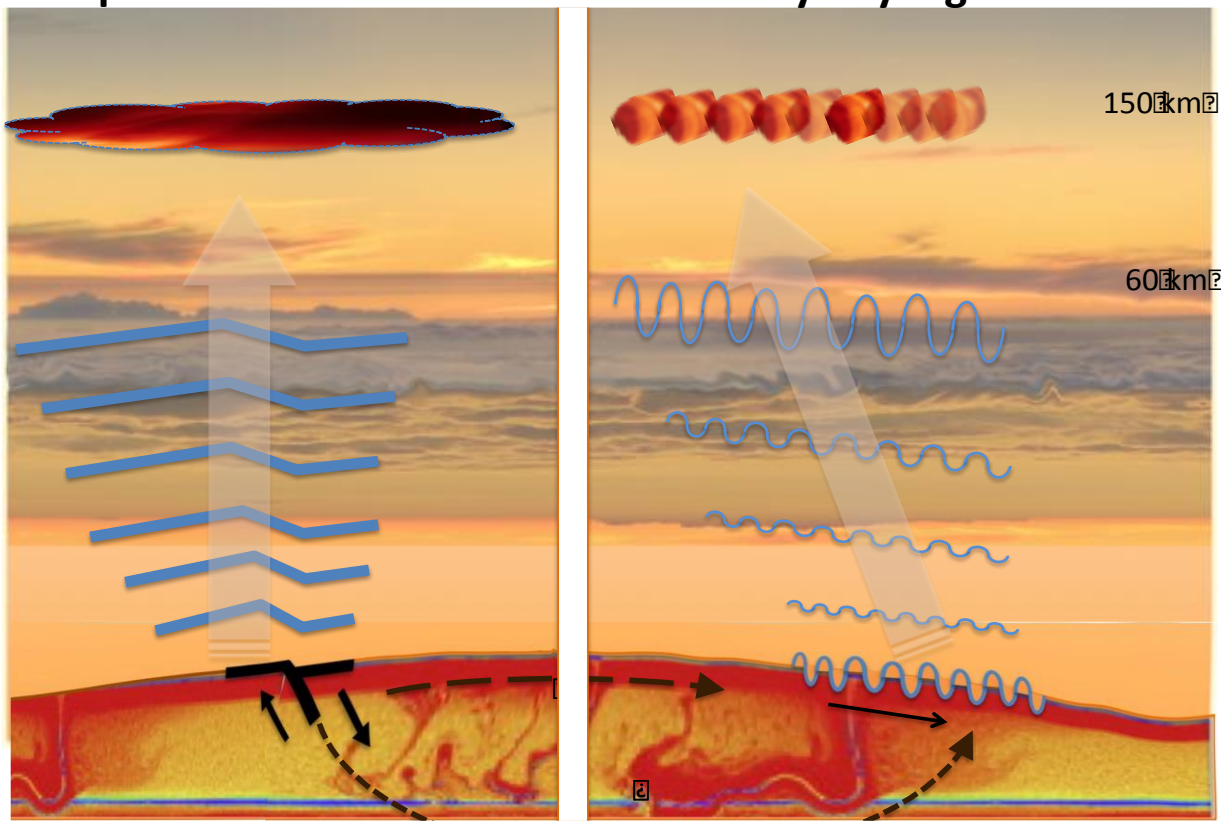
Venus: Seismo acoustic waves at balloon altitudes

Epicentral infrasound **Secondary Rayleigh infrasound**



Seismic signals couple 60X more efficiently into the atmosphere than on earth/
The amplitude of the pressure wave relative to ambient increases with height

Epicentral wave from M 3 quake yields a 50 Pa pressure delta at 60 km
Rayleigh waves from larger earthquakes will be detectable to large distances

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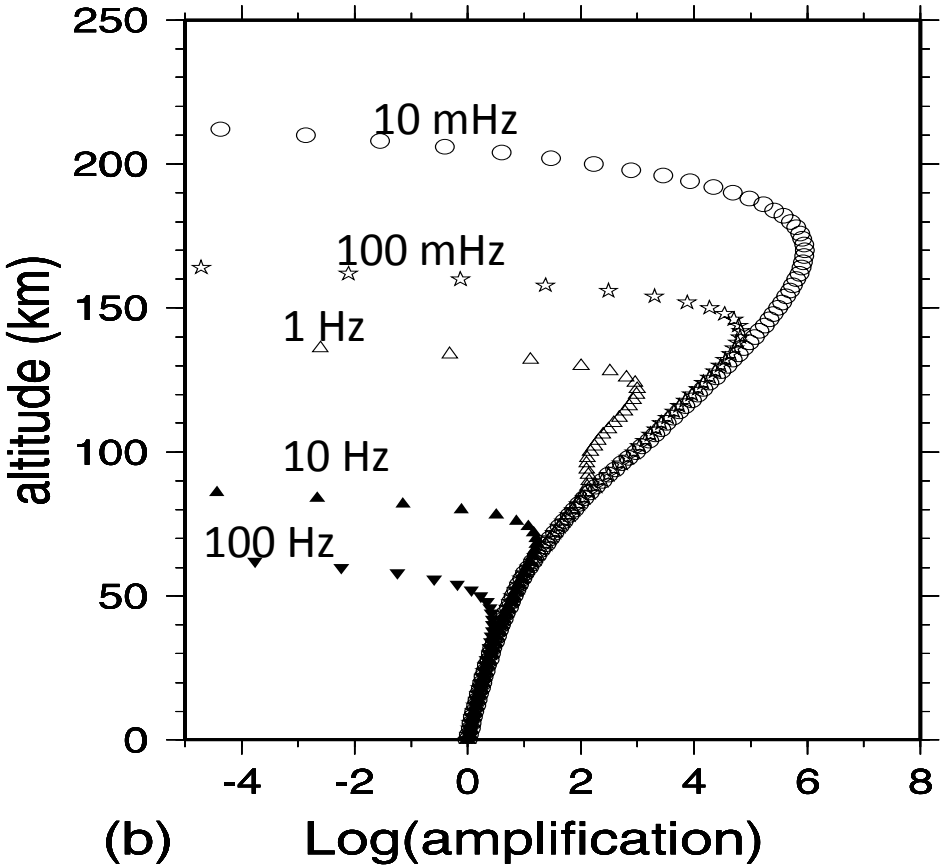
Venus: Infrasonic signal dependence on altitude



Absorption is not a significant factor below 50 km

Absorption has large frequency dependent effects above 50 km

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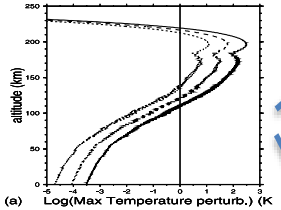
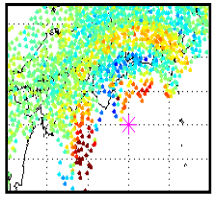
Venus: Detection of seismic infrasonic signature from space

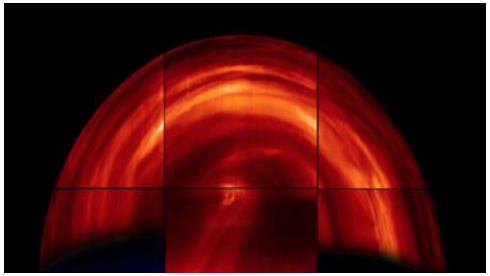
Atmospheric Density Variations



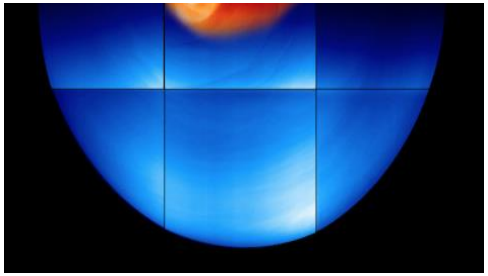
Adiabatic Temperature variations



Total Electron Content (TEC) Variations



Venus IR airglow (here at 1740nm)



UV airglow (here at 480nm)

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Earth: Balloon Detection of Infrasound

- Despite rapid expansion in infrasound research in the last 20 years in connection with treaty verification very little work has been done with balloon based sensors

- Balloon sensors have two key advantages for observing both epicentral and Rayleigh wave
  - Direct observation of upwardly propagating waves
  - Low background wind noise because the station drifts with the wind

- Two short duration stratospheric balloon flights were conducted by Daniel Bowman of the University of North Carolina-Chapel Hill in 2014 and 2015

- Further long duration flights are planned by JPL working with ISAE-Toulouse and by Sandia laboratories in the coming year

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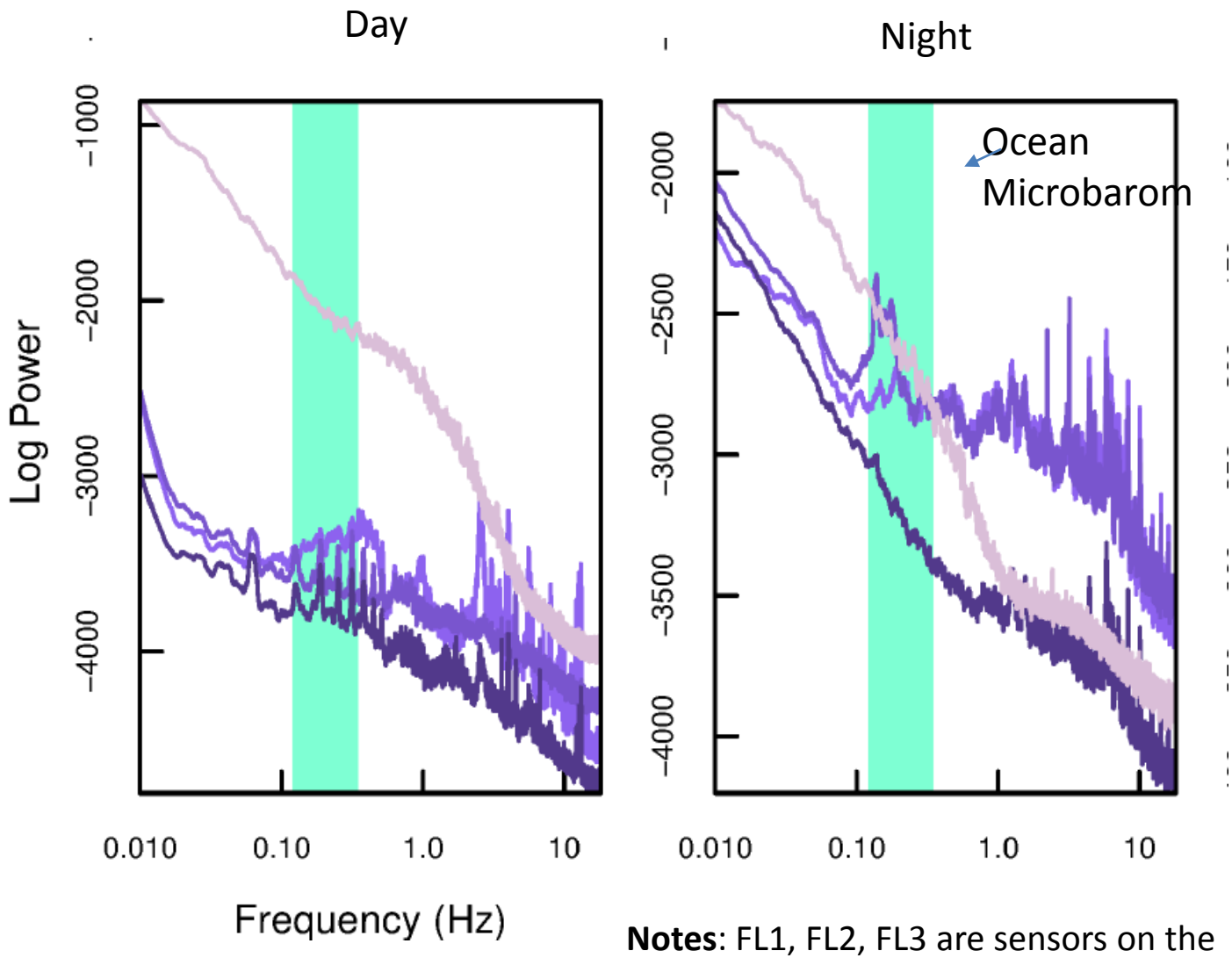
Earth: Balloon Detection of Infrasound –NASA-HASP

High Altitude Student Platform (HASP)



HASP 2015

FL1 FL3 FL5 SNAK

Notes: FL1, FL2, FL3 are sensors on the balloon train. SNAK is a ground station

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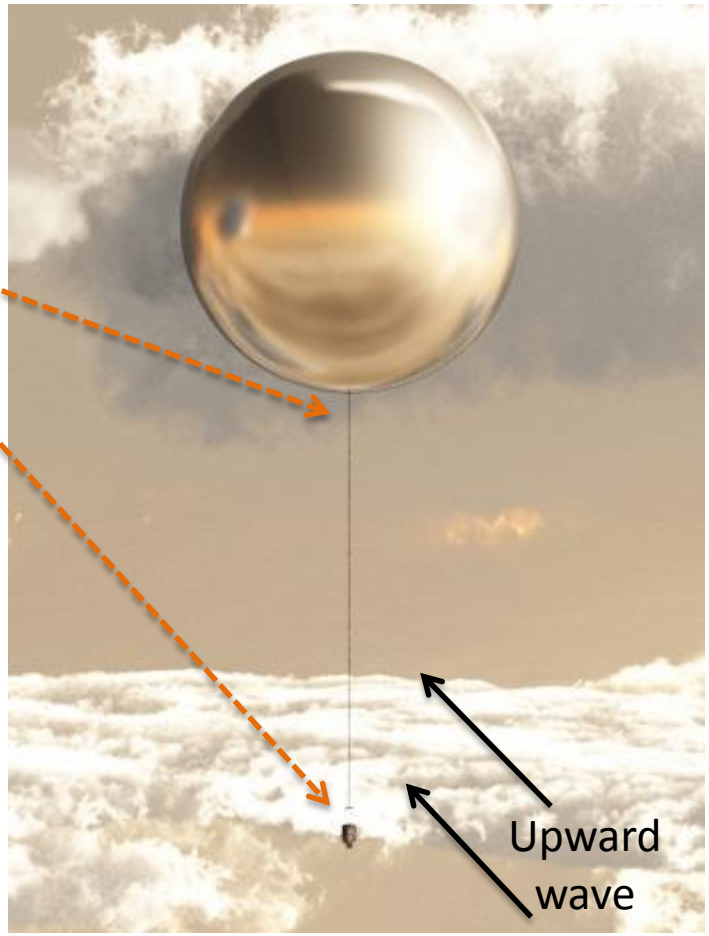
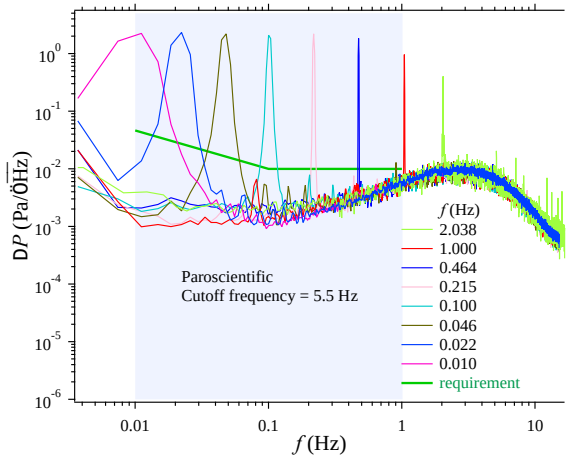
Venus: Concept for infrasonic detection of quakes

Paroscientific 213B microbarometer





More detail in Garcia et al presentation

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Venus: Superpressure Balloon Development at JPL

- Two superpressure balloons were floated in the Venus atmosphere by the USSR in 1985. .
- During the last decade, JPL and its partners have been developing balloons for Venus of progressively larger payload capacity
- These full scale balloons have been thoroughly tested to assess buoyancy, leakage, sulfuric acid resistance and folding/packaging robustness.

	VEGA	JPL	JPL
Diameter (m)	3.5	5	7.0
Carry mass (kg)	7	45	110
Altitude (km)	54	54	54
Lifetime (days)	2	30-100	30-100
Tech Readiness	9	6	5

First 5.5 m Venus prototype balloon in lab testing.

The technology is in place for balloon-borne infrasonic investigation of Venus; The experimental technique needs work

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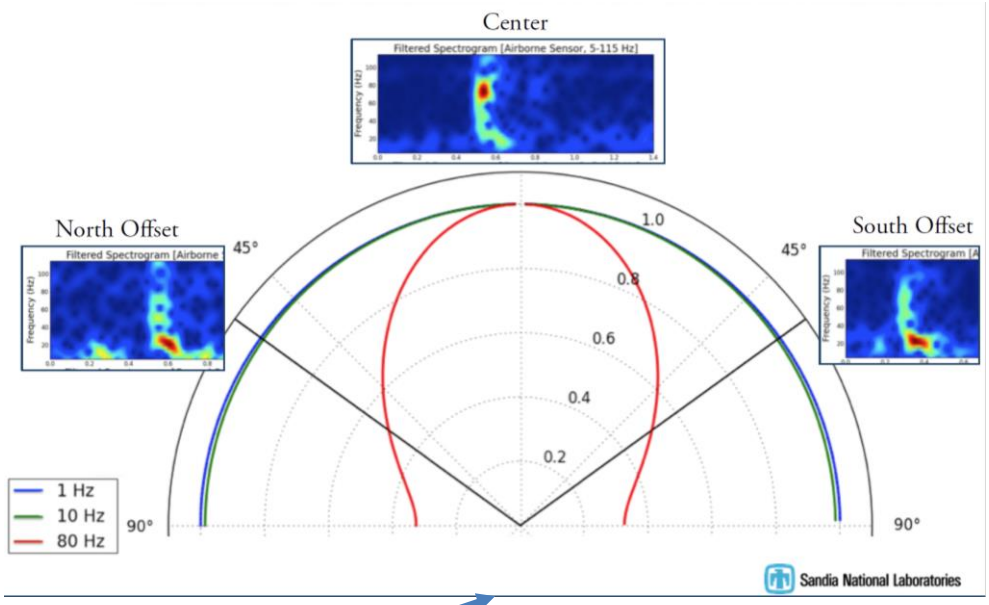
Venus-Analog Infrasound Studies – Phase 1

Platform for Infrasonic sensor validation

Seismic Hammer 0.19Mega-joules, 3 times per minute



Directivity of infrasonic radiation from the seismic hammer

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Venus Analog Infrasound Studies – Phase 2 and 3

Phase 2 Dedicated Small Superpressure balloon flight

Location: Eastern Oregon
Duration: 1 to 2 days

Phase 3 NASA Superpressure Balloon – payload of opportunity

Location: New Zealand
Duration: 30 days

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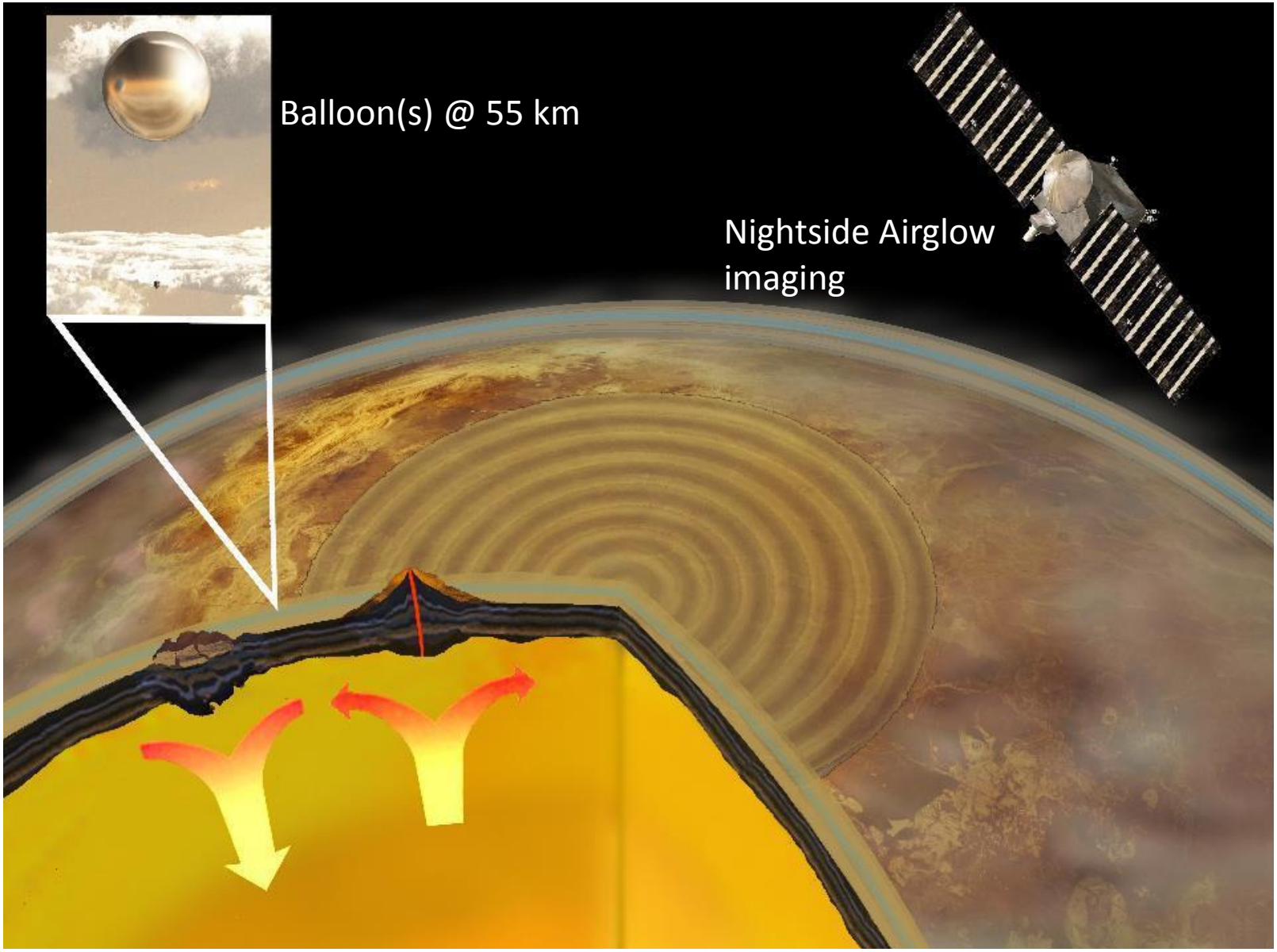
Venus: Mission Concepts for studying the interior



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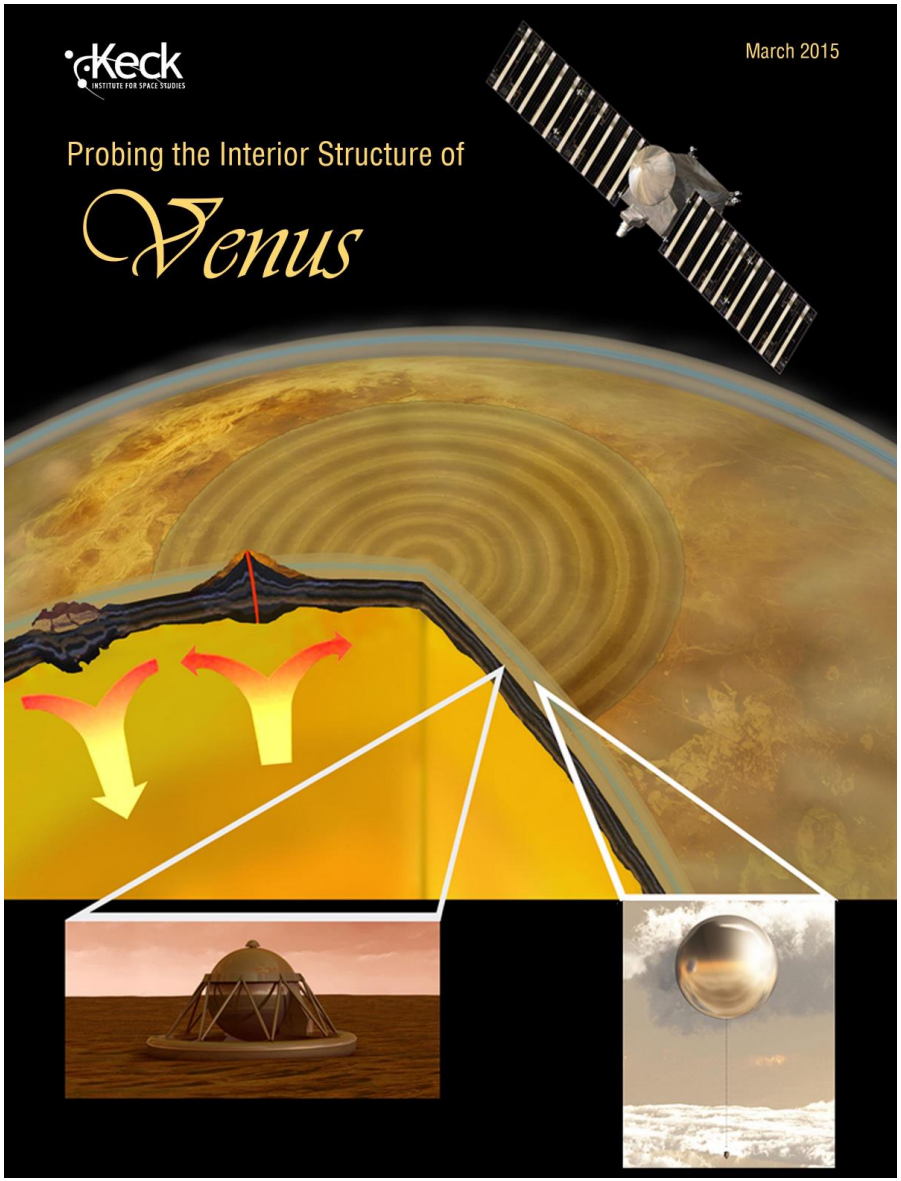
KISS Venus Seismology Workshop report



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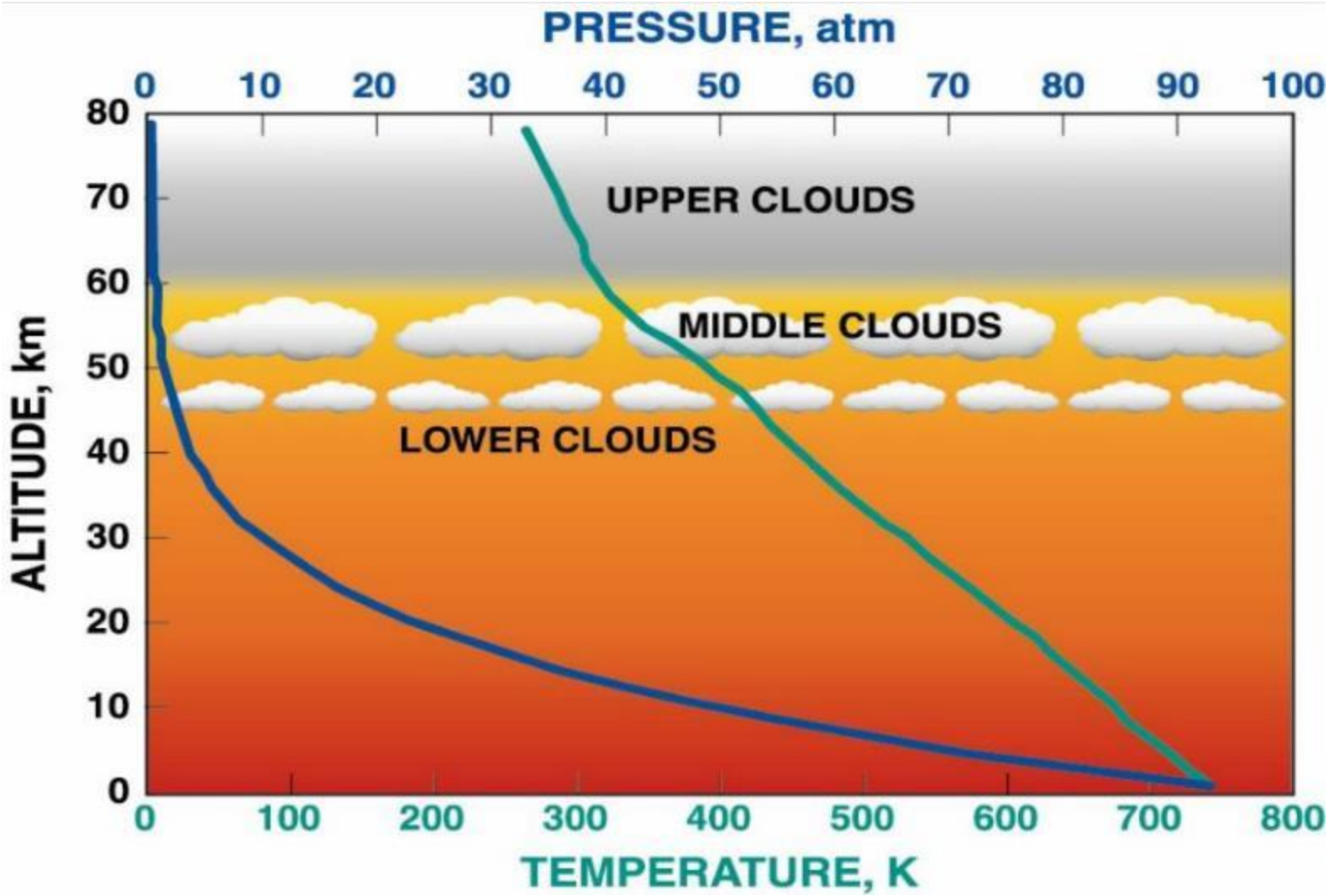
The challenge and the opportunity



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