Remote Localisation and Characterisation of Venus' Seismic and Volcanic Events through a Network of Balloon-Based Instruments

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Overview

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Seismic and Volcanic Activity

- **Quakes**
  - Observational data: little to no evidence of clear subduction zones.
    But: **extensive rift system** and **several fault lines**.
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- **Localisation** of events (plains, ridges, mountains, coronae, *etc.*)
  can help constrain **whether or not Venus is still active**, and **how**.

Monitoring the Ground from the Atmosphere?

- **Key point:** any surface event (quake, volcanic tremor, *etc.*)
  will generate acoustic atmospheric waves, **infrasound**,
  due to the **mechanical coupling** between the ground and the air.

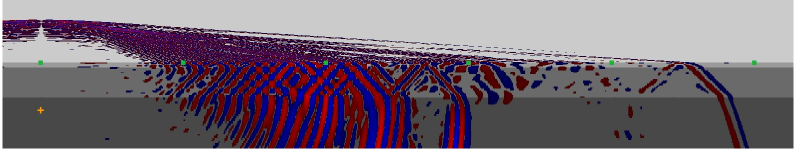

Figure: Numerical simulation of a quake under flat topography, **generating infrasound**. Red/blue is amplitude saturated at ± 1 %: in air (top light grey shade), pressure perturbation is represented; in the layered ground (bottom 3 darker grey shades), vertical velocity is represented. Yellow cross: hypocentre (source). Green dots: recording stations.

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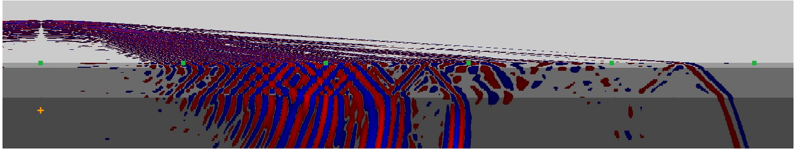

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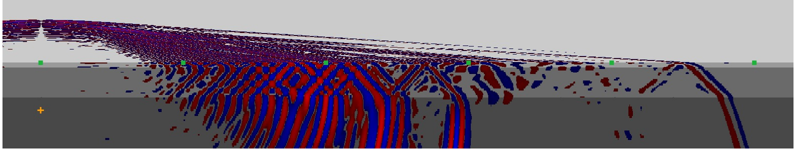
- **Ground-to-atmosphere** wave transmission is well-known [1, 3, 7, 4].
- Propagation of such **infrasound** to **high altitudes** is efficient [2, 6].
  kinetic energy conservation $\Rightarrow \delta v \propto \rho^{-1/2} \Rightarrow \delta v$ increases with altitude



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Atmospheric Conditions

- [9] reviews ways to study Venus' interior, including **balloon-based** concepts
- **Why from the atmosphere?**
  1. Conditions at the surface are **harsh**. ($\simeq 735\,\mathrm{K}$, $\simeq 92\,\mathrm{bar}$)
  2. Between altitudes 55 to 65 km,
     - temperature range **from +27 to −30 °C**,
     - pressure range **from 0.50 to 0.10 bar**.
     - ✓ Technology usable there: **already exists**, and **will survive long enough**.

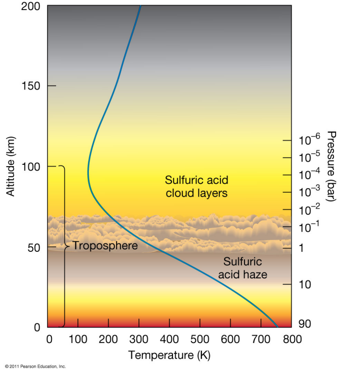

Figure: Venus' atmosphere schematic. Credit: Pearson Education.

⇒ **What type of instruments?**

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     - used hanged below balloon
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Figure: Infrasound sensor (top box) with noise reduction port (below). $\simeq$ 7 kg, $\simeq$ 40 cm high.

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  2. **Inertial Measurement Units** (IMUs)
     - used attached to balloon envelope
     - records balloon envelope deformations

Figure: Commercial IMU (Yost 3-Space). 28 g, 6 cm high.

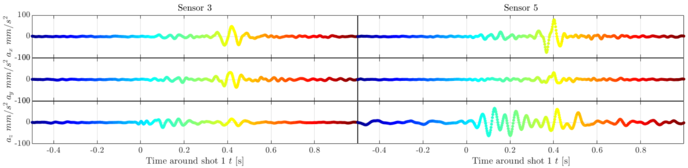

Figure: Balloon IMU data (3D acceleration). 2 sensors. From an underground quarry blast test.

Balloon-Based Instrumentation II

- For any signal - acoustic wave - (seismic/volcanic/atmospheric source), a single balloon can acquire both
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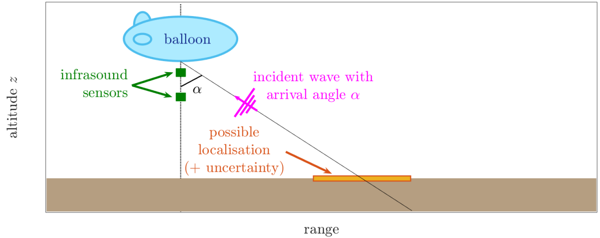

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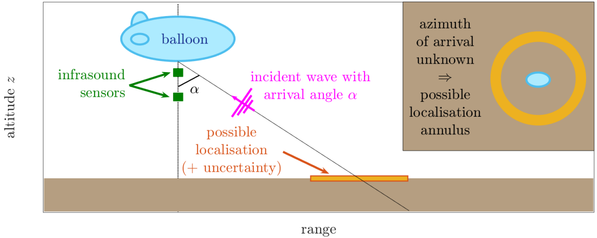

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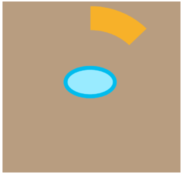

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- What to gain by using **more than one balloon**? Horizon 2061.

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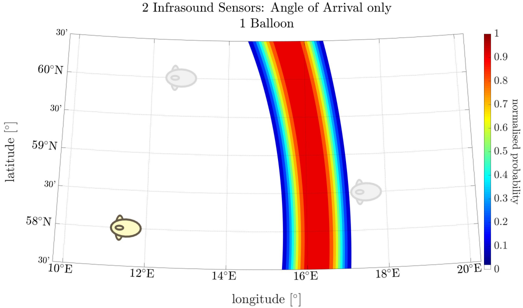

Figure: Localisation estimation using angle of arrival, **for 1 balloon**.

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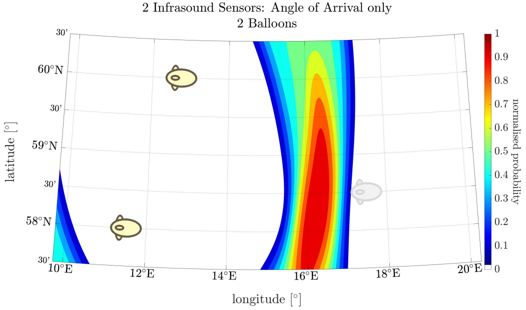

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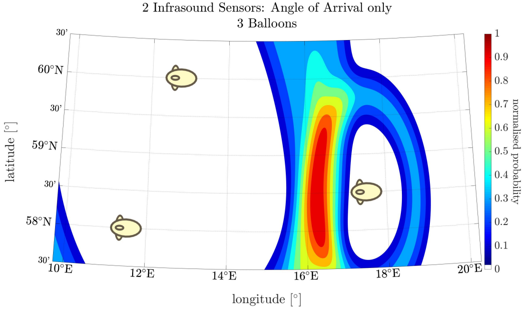

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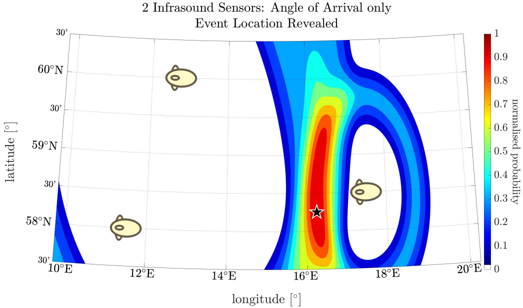

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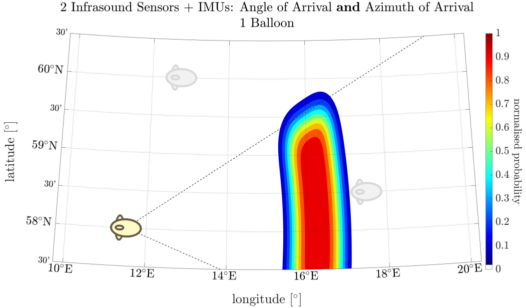

Figure: Localisation estimation using angle of arrival and azimuth, **for 1 balloon**.

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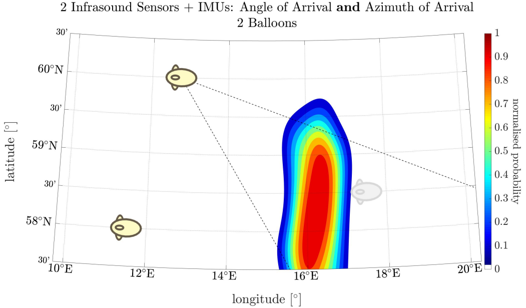

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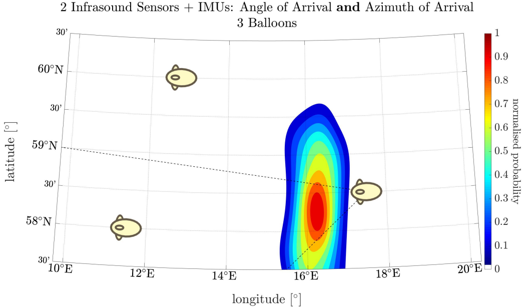

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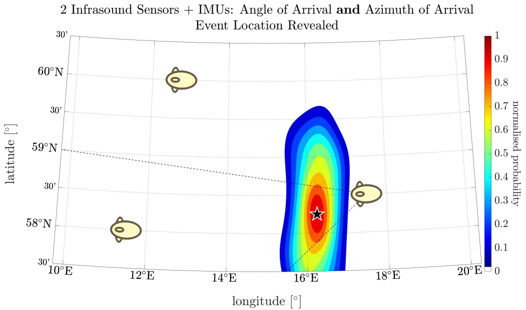

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  - **A better understanding of Venus' geophysics and interior**.
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- Operating a **network** of science balloons $\Rightarrow$ **new possibilities**:
  - **enhanced source localisation** (this presentation),
  - continuous and **global** ($\neq$ local with 1 balloon) monitoring.

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- **Scientific Challenges**
  - Atmospheric *noise* sources:
    - Atmospheric dynamics' effects? Gravity waves, bow waves [5], *etc.*.
    - Noise-reducing inlets for pressure sensors? *E.g.* against wind gusts.
  - Spacecraft effects:
    - Electromagnetic/mechanical noise? Others?
    - Altitude changes (*i.e.* ambient pressure changes)?

Thank you for your attention.

Questions?

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