Bridging the gap between Aerobots and Landers for Venus

G. Bailet[1], S. Krishnamoorthy[2], J. Beeley[1], T. Timmons[1], and C.R. McInnes[1]
[1]James Watt School of Engineering, University of Glasgow, Scotland, UK. G12 8QQ
[2]Jet Propulsion Laboratory/California Institute of Technology.

Abstract

The environment on Venus presents a challenge for any exploration missions, but recent scientific interests have emerged, from biomarker detection [1] to simulation-based evidence of at least 37 active volcanoes [2]. This poster will present how a small 1kg pack of femtoprobes could extend the capabilities of a Venusian balloon to detect and investigate several active volcanoes, and in particular detect the eruption columns of active volcanoes.

Context

Aerobot platform

Aerobots have the advantage to explore Venus from within the cloud layer providing them extended lifetime, high mobility but restrict the lower altitude attainable to 47 km and only remote sensing allows balloons to gather data linked with phenomena occurring below the cloud layer. Among the instrumentation of such balloon, an infrasound sensor [3&4] could detect Venus quakes which could be precursors to volcanic eruptions, but in-situ measurements are necessary to gather additional data and solve many scientific questions.

Lander

In order to investigate in-situ phenomena, landers could be dropped from orbit or from an aerobot. Those probes analogous to submarines will reach the surface of Venus to conduct their mission at a surface temperature of 748 K and pressure of 92 bars.

Izraelevitz et al. [5] propose a minimal mass concept for a lander probe dropped from an aerobot aiming to deliver 5 kg at the surface including 1.3 kg of payload. This lander represents 20% of the payload mass of the mentioned aerobot, so any release of the lander probe will be a high-risk decision. Thus, low mass and readily available femtoprobes could be the solution to reducing risk in making the decision to release a more capable probe.

Femtoprobes

Based on our developments [6], the femtoprobe platforms (Fig. 1), weighing only few dozen grams can include a SO_2 gas sensor, basic electronics, power system and low power UHF transceiver to beam back collected data to the balloon. The femtoprobes will not be able to reach the surface of Venus due to the extreme environment, but with their protective Kapton aeroshell and ruggidized electronics they will be able to survive down to 40km. The SO_2 sensor will enable the detection of eruption columns which are characterized by a local SO_2 concentration well above 200 ppm below 48 km.

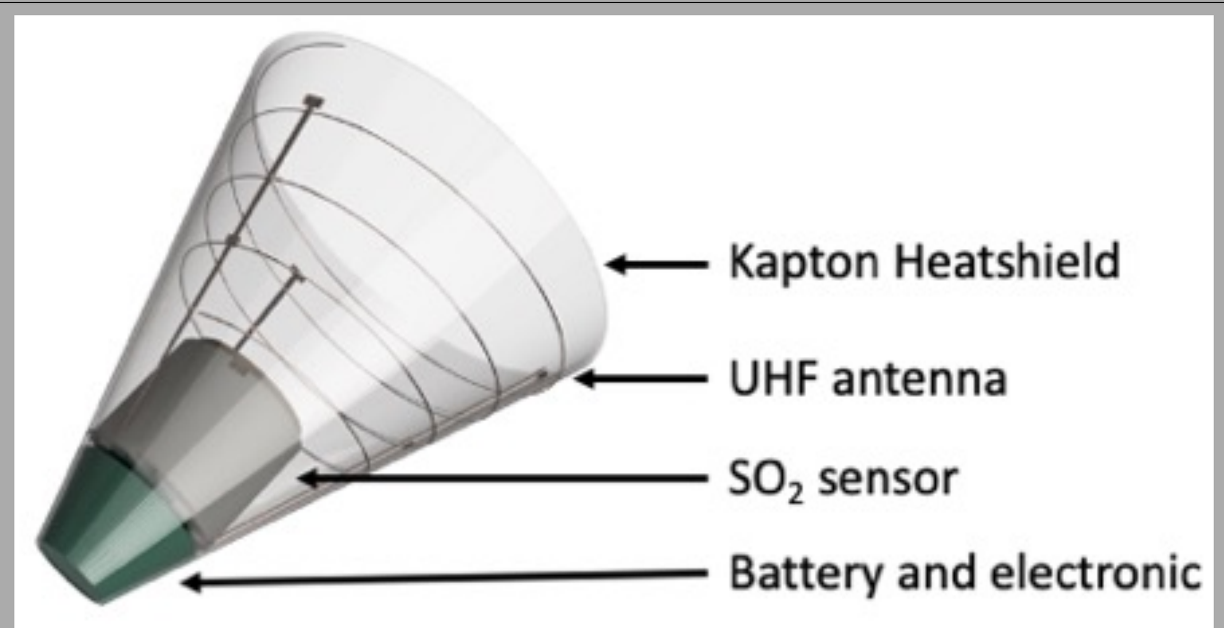

Figure 1: Rendering of a femtoprobe .

Femtoprobes dimensioning

The piggy-back concept presented in the poster (Fig. 2) will use a balloon aerobot as the mother craft to release the femtoprobes equipped with SO_2 sensors as described in the previous section. According to [7], a suitable candidate would be a 7.4-meter diameter superpressure balloon supporting a 110-kg gondola module including a maximum of 30 kg for the science payload.

Deployment location

To provide the critical measurements, the femtoprobes will have to be deployed as close as possible to the eruption epicenter candidate detected by the infrasound sensor for the femtoprobe to transit through the bounds of the eruption column. Fortunately, at the range of altitude for the measurements (40-48km), the eruption column widens to form the "umbrella region" giving more margins for detection.

Communication range

The low mass of the femtoprobes (30 g), being an advantage for its expendability in low-risk in-situ sensing, it also comes with the drawback of a low-power UHF transceiver and a small battery. With the balloon traveling at 300 km/h [7], it is essential that the femtoprobes reach the measurement altitude in a short amount of time thus allowing for an acceptable link margin for the transmission of the measured data back to the balloon.

A sensitivity analysis (Fig. 3) is performed using a 3 DoF trajectory code to characterize the distance between a femtoprobe and the balloon as well as the time of descent in function of the drag coefficient and cross section of the aeroshell. This enables us to design the femtoprobe for a conservative maximal distance of 150 km. **The selected femtoprobe design is: 30 g weight, 45mm diameter, and 1.3 for the drag coefficient.** Higher masses for the femtoprobe will result in shorter distance. Tables 1 to 4 provide additional data on the system.

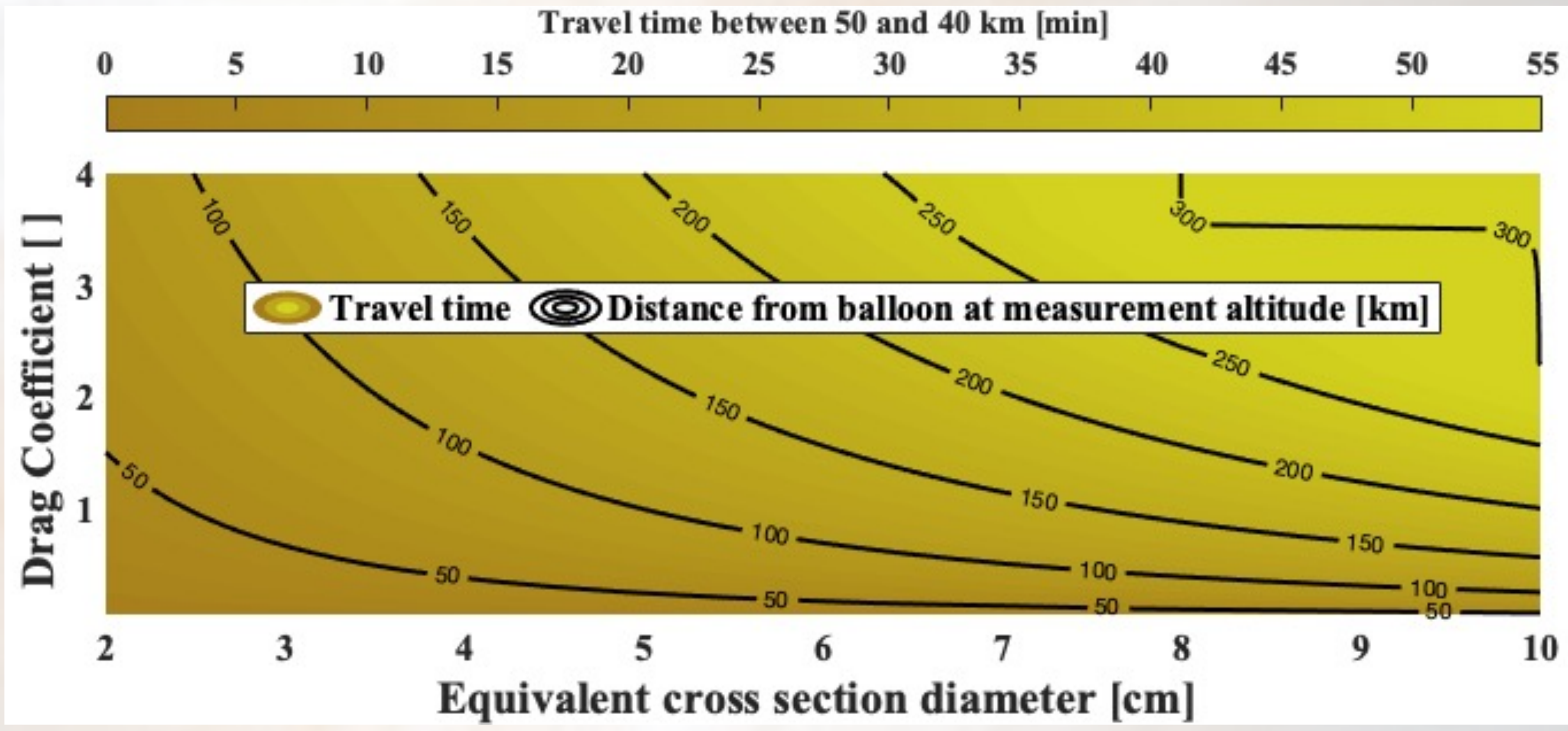

Figure 3: Sensitivity analysis to design the femtoprobe.

Table 1: Data packet format

Component	Bytes
Preamble	1
Synchronization	1
RSSI	1
Temperature + Pressure	3
IMU (3 DoF acceleration)	6
SO_2 sensor	6
Total	**18**

Table 2: Power Budget

1 Femtoprobe	
CPU	47
IMU/temperature (1% duty cycle)	0.08
Transmitter (99% duty cycle)	58
Receiver (1% duty cycle)	18
Pressure sensor (×2; 0.5% dc)	0.1
Total, mW	**123.2**

Table 3: Mass Budget

Component	Mass [g]
1 Femtoprobe	
PCB core	5
Aeroshell with integrated antenna	10
Battery	10
SO_2 sensor	5
Total for 1 Femtoprobe	30
Balloon add-on	
Femtoprobe deployer	140
Relay station	40
Stack of Femtoprobes (27)	810
Total piggyback payload	**990**

Table 4: Worst case link budget

	Femtoprobe to Balloon	Femtoprobe to Femtoprobe
Frequency [MHZ]	436.55	436.55
Transmitter power [dBm]	10	10
Transmit antenna gain [dBi]	6	5
Range [km]	150	10
Free-space path loss [dB]	-128.8	-105.3
Receive antenna gain [dBi]	10	5
System noise temperature [K]	600	600
System losses [dB]	-3	-3
Data rate [bps]	1000	1000
Eb/N0	35.7	53.3
C/N	32.7	50.3
Link margin [dB]	**24.1**	**41.7**

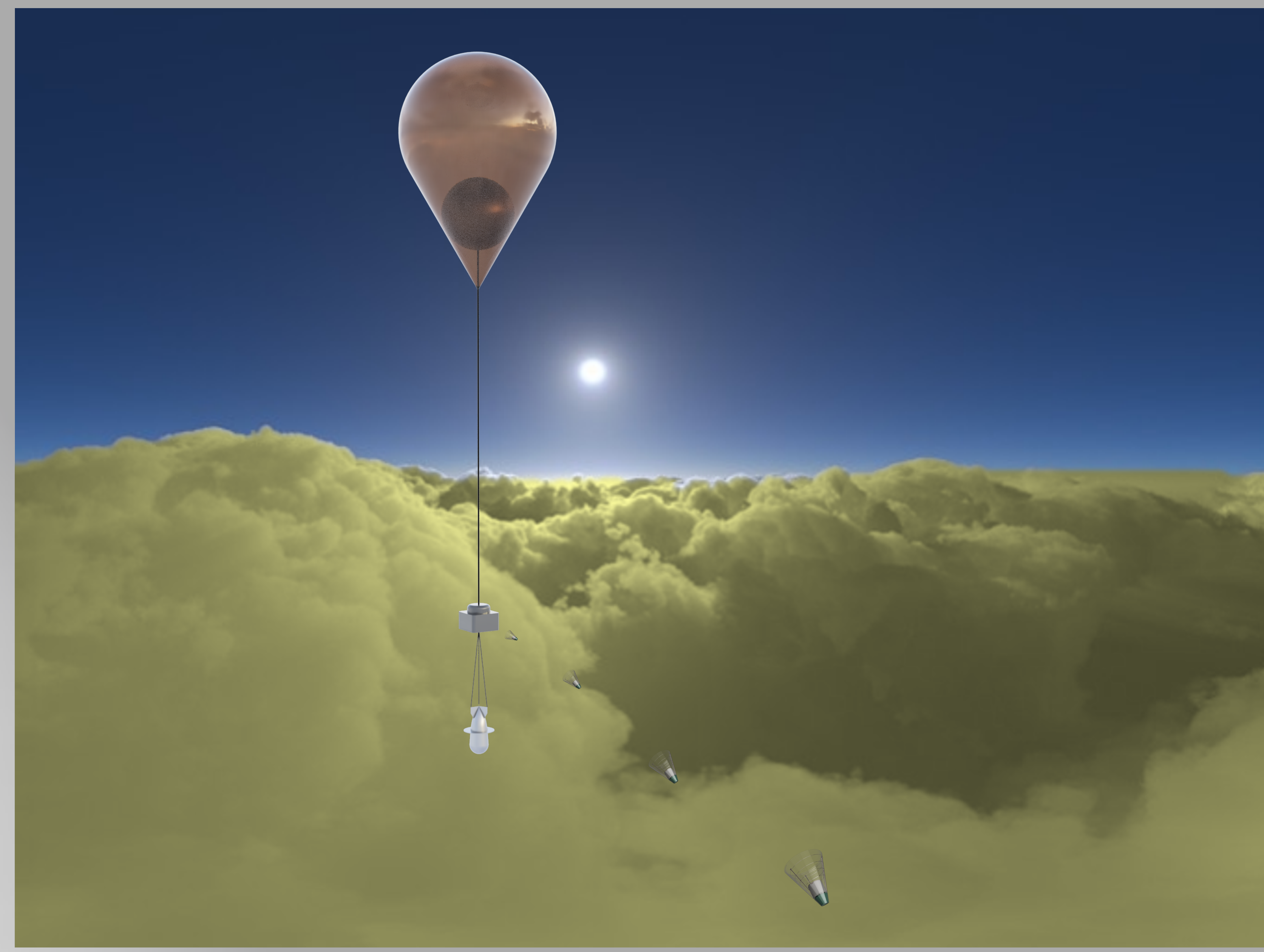

Figure 2: Rendering of the mission concept (aerobot, lander, and femtoprobes).

Conclusion

Our analysis shows that 27 femtoprobes will be able to be accommodated within the allocated 1 kg mass allowing to detect eruption columns. Moreover, releasing sequentially several femtoprobes would characterize spatially the shape of this column.

Compared to the 5kg minimal mass lander, the low-mass and low-risk femtoprobe platform represents a new tool to investigate multi-node/multi-point sensing in extreme environments and bridge the gap between aerobots and landers for optimal mission planning and scientific return where more advance landers are used only when there is a high probability of scientific return.

Acknowledgments

This work is supported by a Royal Academy of Engineering Chair in Emerging Technologies (CMcI, GB, JB) and EPSRC studentship EP/R513222/1 (TT).

References

[1] Greaves, J. S. et al. (2020), *Phosphine gas in the cloud decks of Venus*, Nature Astronomy.

[2] Gülcher, A. et al. (2020), *Corona structures driven by plume–lithosphere interactions and evidence for ongoing plume activity on Venus*, Nature Geoscience.

[3] Krishnamoorthy S., et al. (2019), *Aerial Seismology Using Balloon-Based Barometers* *IEEE Transactions on Geoscience and Remote Sensing*, vol. 57, Issue: 12.

[4] Q. Brissaud et al. (2021), *The first detection of an earthquake from a balloon using its acoustic signature*, Geophysical Research Letters.

[5] Izraelevitz, J. S. and Hall, J. L. (2020), *Minimum-Mass Limits for Streamlined Venus Atmospheric Probes*, Journal of Spacecraft and Rockets, p. 683-691vol. 57, n. 4.

[6] Timmons, T. et al (2021), *Mars atmospheric characterization with a ChipSat swarm*, Journal of Spacecraft and Rockets, on-line.

[7] Venus Aerial Platforms Study Team (2018), *Aerial Platforms for the Scientific Exploration of Venus*, Summary Report JPL D-102569.

For more information and collaborations: gilles.bailet@glasgow.ac.uk