Venus Airglow Measurements and Orbiter for Seismicity (VAMOS)

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Outline

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- Mission concept overview
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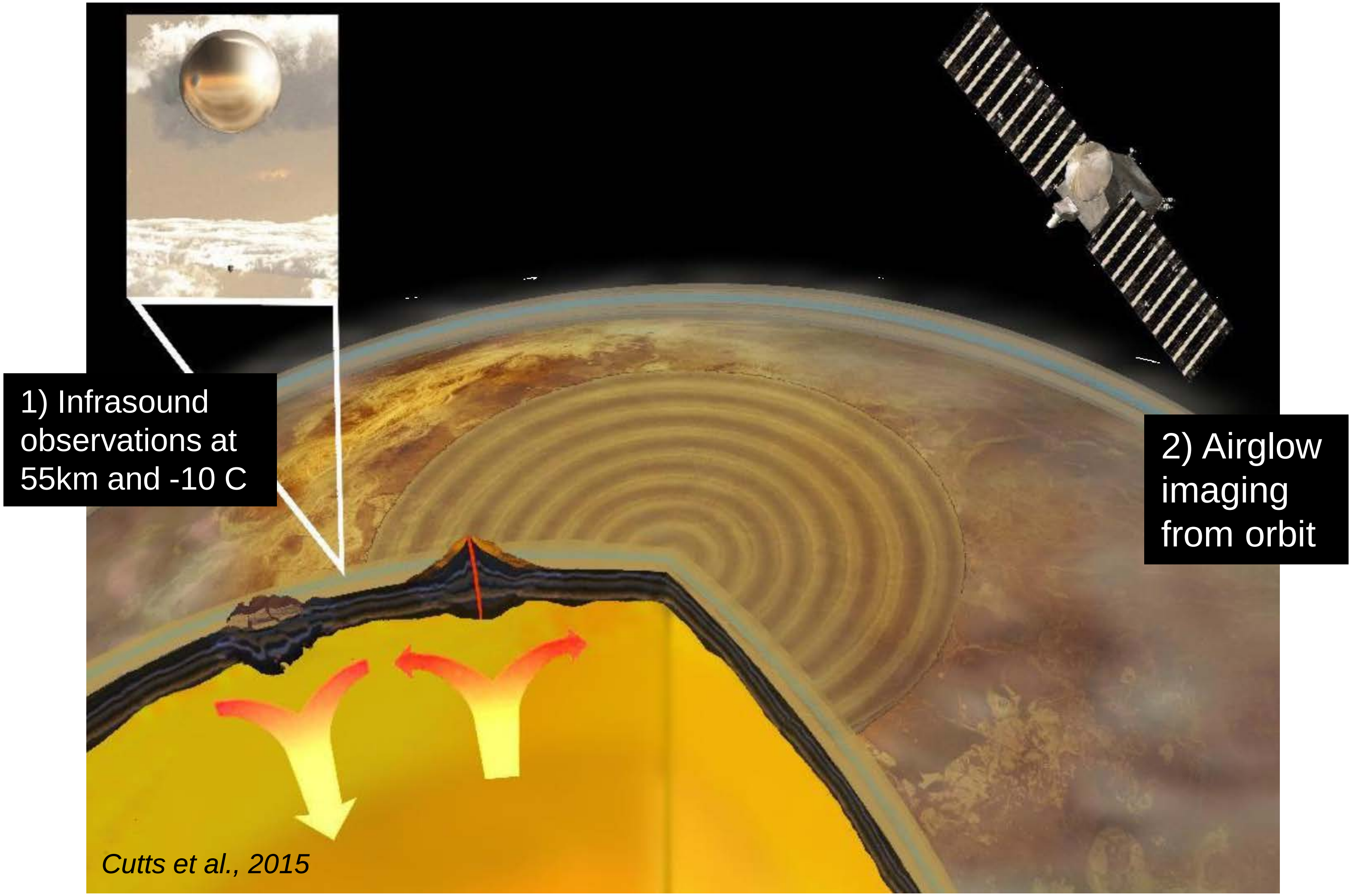
Motivation

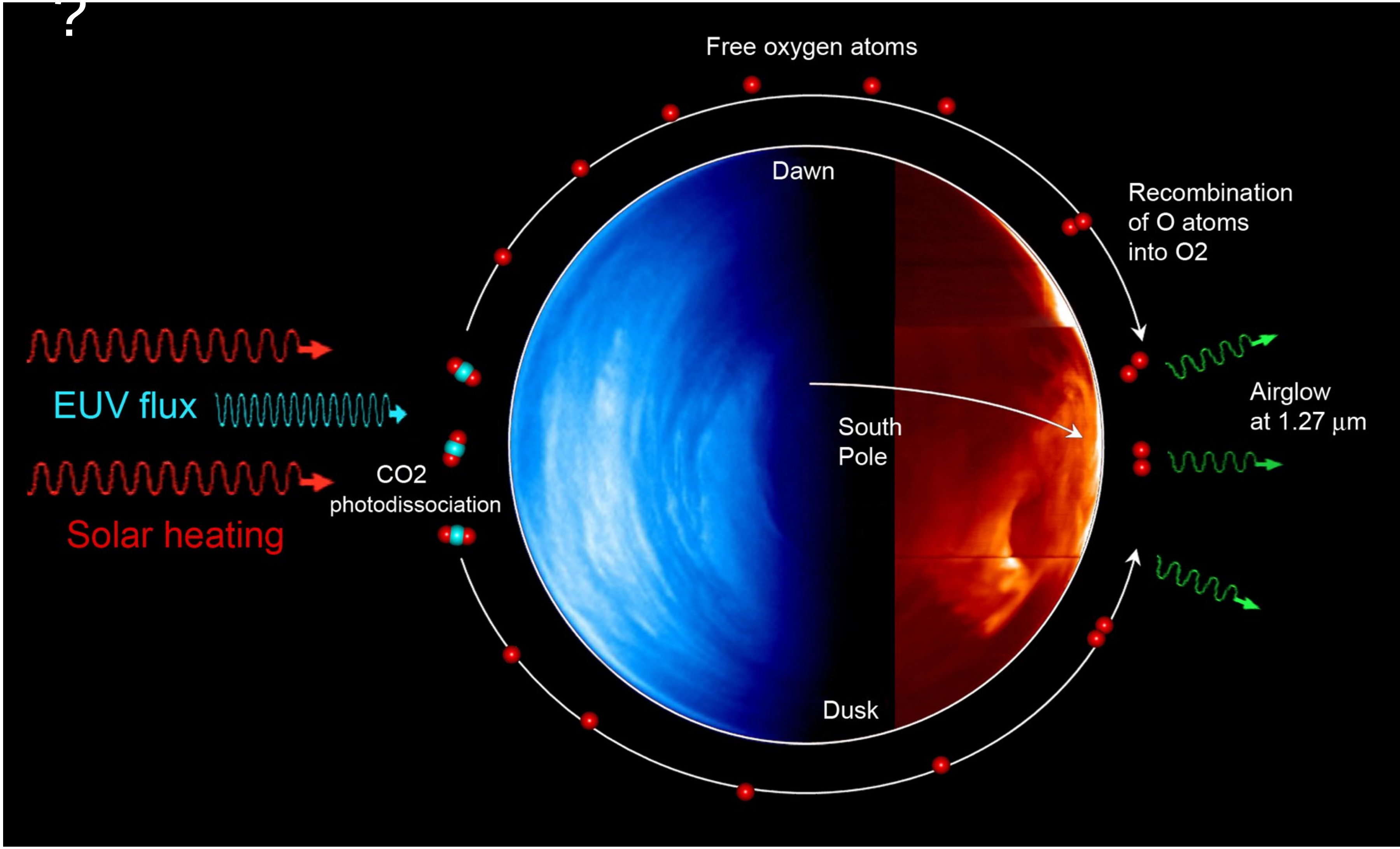
- The planetary evolution and structure of Venus *remain uncertain* more than half a century after the first visit by a robotic spacecraft. Why has Venus become so inhabitable planet? We still do not know.
- To understand how Venus evolved it is necessary to *detect signs of seismic activity*.
  - Due to the adverse surface conditions on Venus, it is infeasible to place seismometers on the surface for an extended period of time.
- Due to *dynamic coupling between the solid planet and the atmosphere*, the waves generated by quakes propagate and may be detected in the atmosphere itself.
- Our <u>main threshold objectives</u> are:
  - Determine the *global seismic activity* of Venus; determine *crustal thickness* and *lithospheric structure*
  - Determine the dominant source regions for *gravity waves* and assess any possible connection to topography
  - Determine *ionospheric instabilities* for Venus

Techniques Defined to Detect Seismicity on Venus



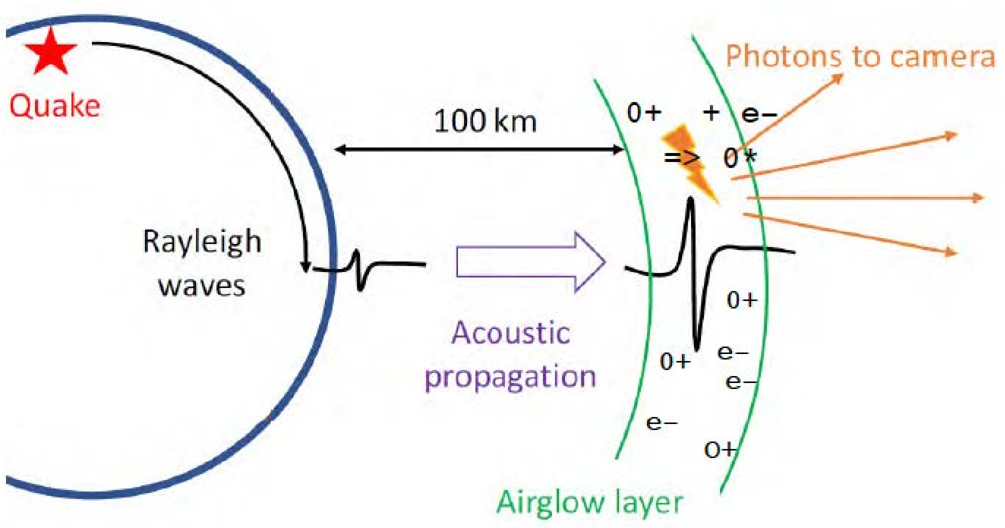
1) Infrasound measurements **2)** Airglow imaging

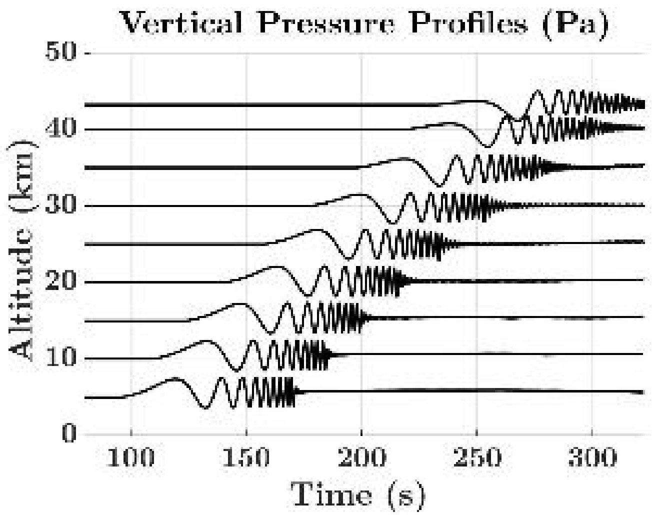
Physical Mechanism for Airglow on Venus



http://www.esa.int/spaceinimages/Images/2007/04/Airglow_production_schematic

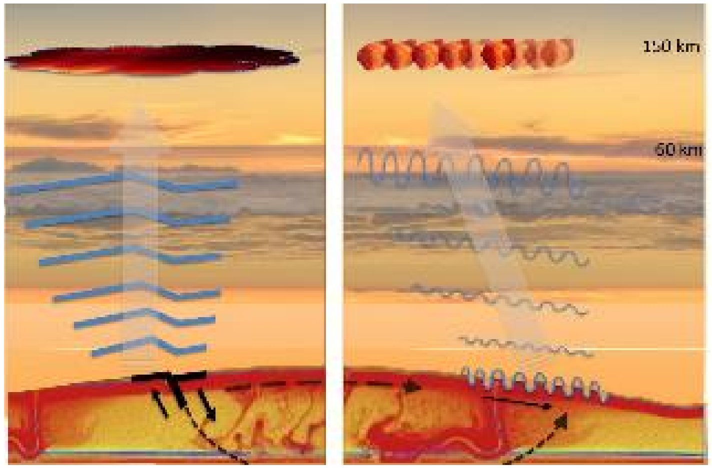
Planetary Quakes Observable in the Atmosphere?





Garcia at al., 2017

Kenda et al., 2018



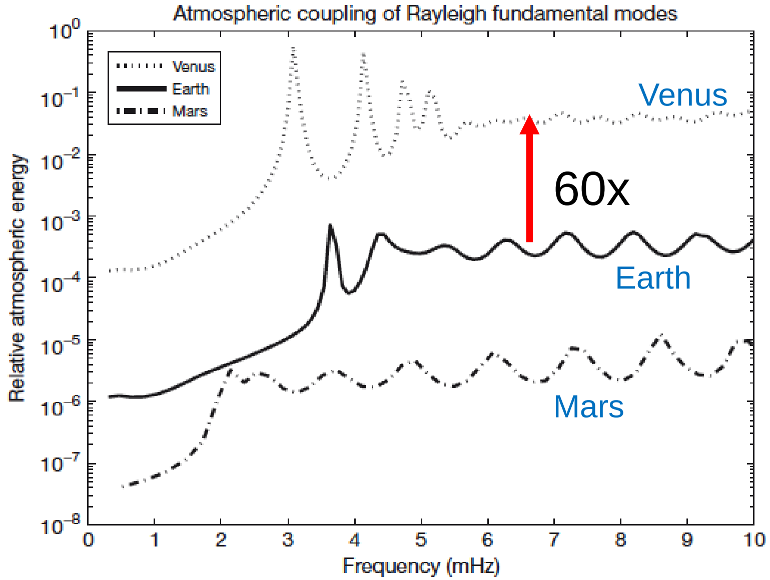
Cutts et al., 2015

- Synthetic seismograms at different altitudes in the atmosphere are shown
- Ground motion from quakes produces infrasonic pressure signals (frequency< 20 Hz) at the epicenter and far away (due to Rayleigh waves)
- Venus' thick atmosphere couples with ground motion 60x better than Earth

Seismic Wave Generated Ionospheric Disturbances on Earth

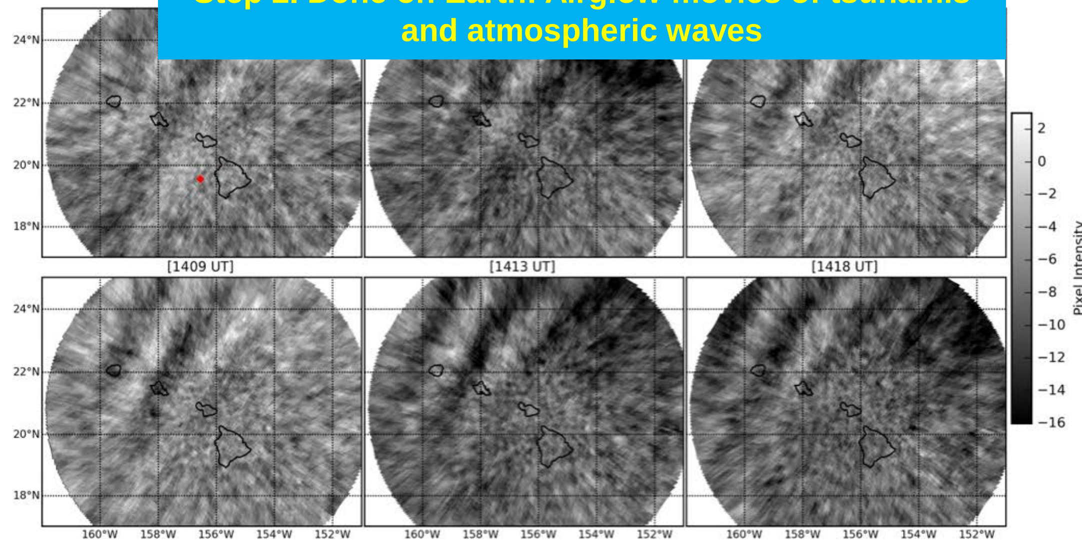
Step 1. Done on Earth: TEC movies of tsunami and seismic waves

Science Background



Lognonne et al., 2016

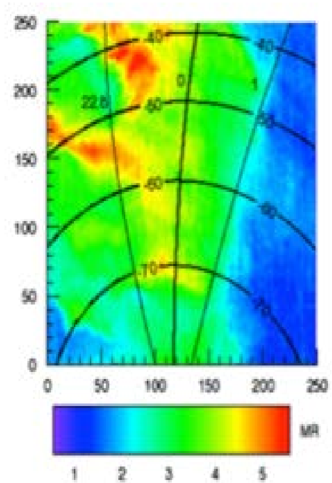
Step 2. Done on Earth: Airglow movies of tsunamis and atmospheric waves



after Grawe and Makela, 2017.

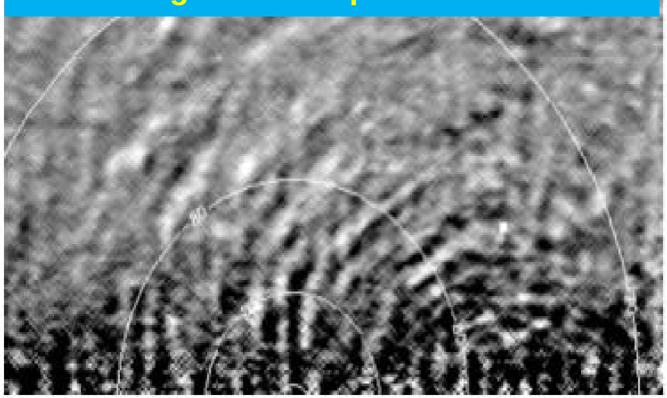
Venus:

- Seismicity on Venus is assumed to be 25x less than that on Earth
- 50 quakes per year with Mw > 5 and 1 to 2 with Mw > 6.5



after Garcia et al., 2009

Step 3. Done on Venus by VEX : Airglow image of atmospheric waves



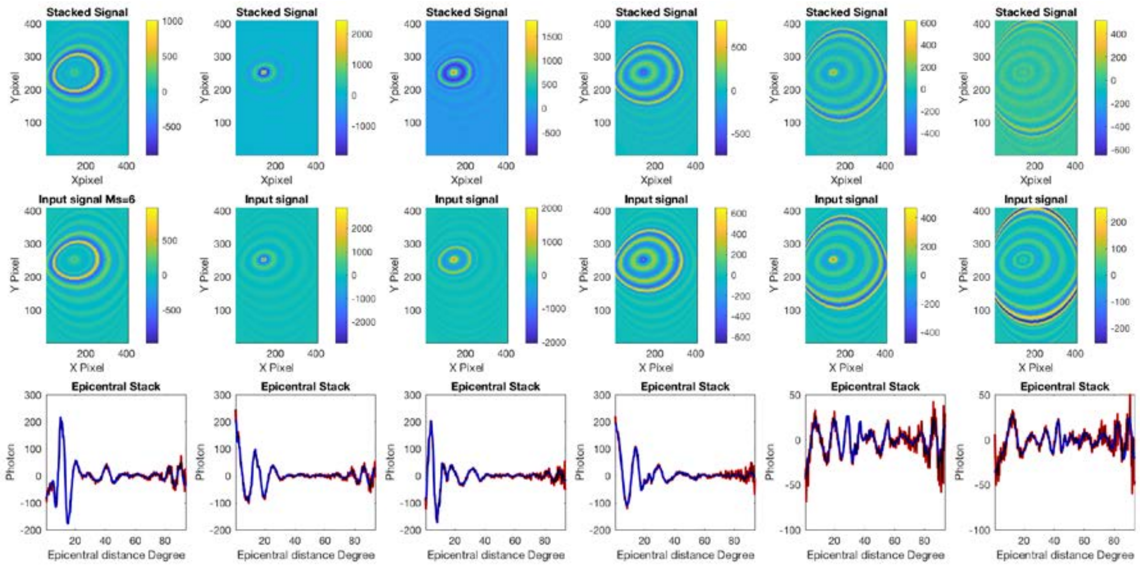
Migliorini et al., 2011; Garcia et al., 2009.

Modeled Airglow Fluctuations Due to Seismic Waves on Venus

Step 4 to come: We will make airglow movies of seismic and atmospheric waves on Venus!

Noise-free simulation

Modeling Airglow Signatures on Venus



Ms 6.0 quake observed by 4.28 μm

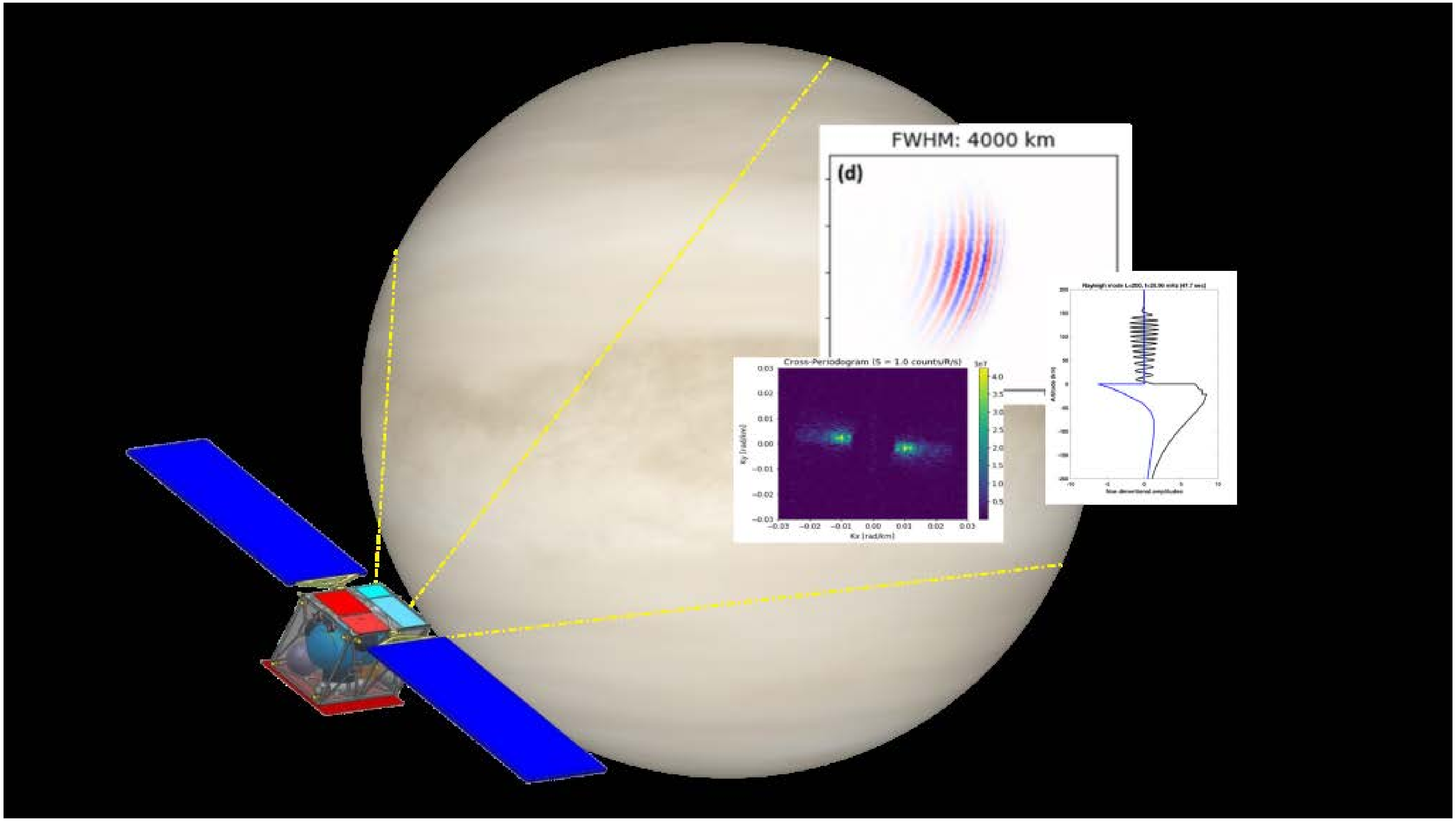
The simulations indicate that the *shot noise* associated with the background is the *most significant source of noise for* 1.27 μm (night-glow) compared to the signal strength. However, 4.28 μm airglow is not affected.

Estimated thresholds for reaching the different seismic science goals

Requirements	1.27 µm	4.28 µm
Determine the global seismic activity of Venus (± 1 Moment magnitude unit)	Ms 6.25	Ms 5.5
Determine the mean thickness of the crust	Ms 6.25	Ms 5.5
Determine the regions of seismic/volcanic activity	Ms 6.0	Ms 5.0
Determine the thickness variations of the crust	Ms 6.5	Ms 6.0

Mission Concept Overview

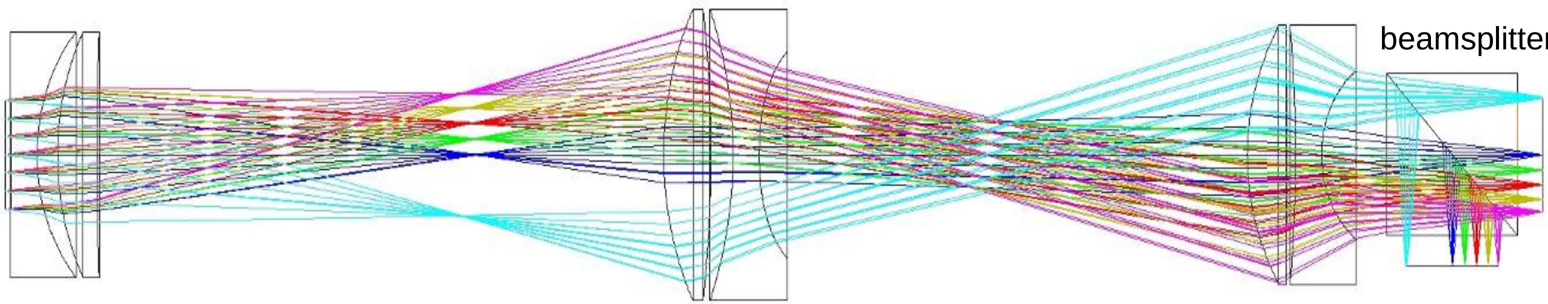
A Continuously Observing Small Spacecraft in High Circular Venusian Orbit

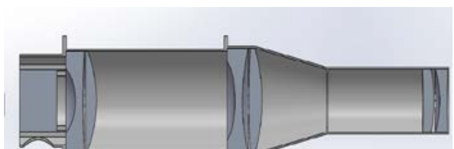


Instrument and Spacecraft Description

A simple infrared telescope with dual detectors on a SEP SmallSat

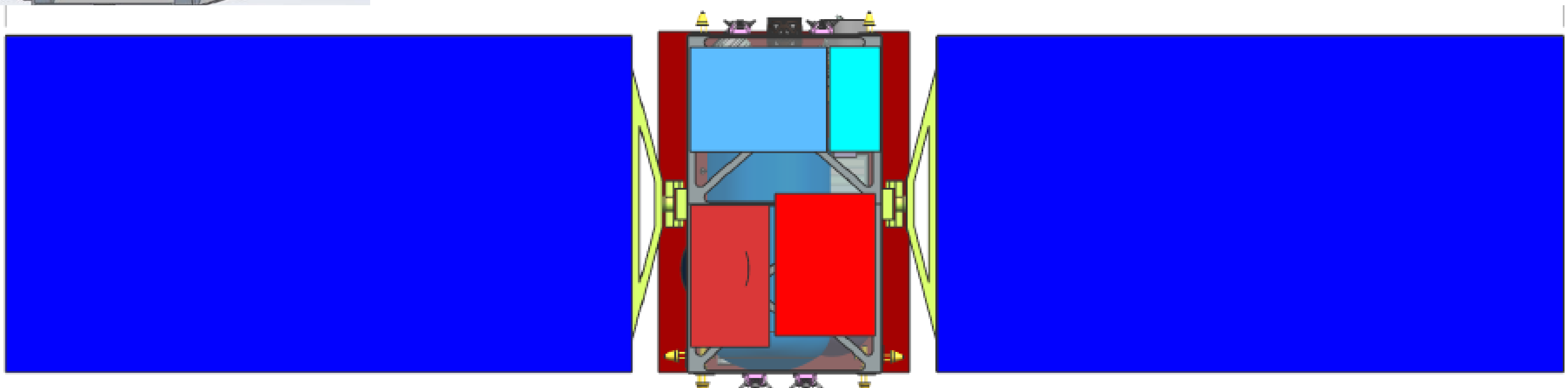
- Three doublet lenses
- Field-stop
- Pupil
- Beamsplitter
- 70 cm in length





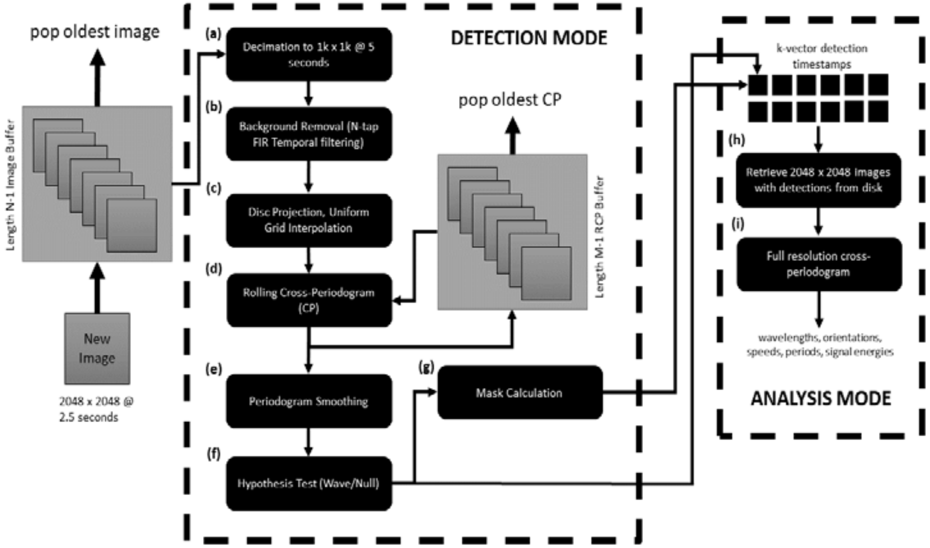
Baseline concept for refractive design:

- two detectors, one at 1.27 micron (non-sunlit regions) and one at 4.28 micron (for sunlit) regions).



VAMOS flight system with solar arrays fully deployed has a 4.2-meter wingspan and collects 1.5 kW of solar power at Venus. Dimensions (64 cm x 72 cm 91 cm). Would likely fit ESPA.

Event Detection Algorithm

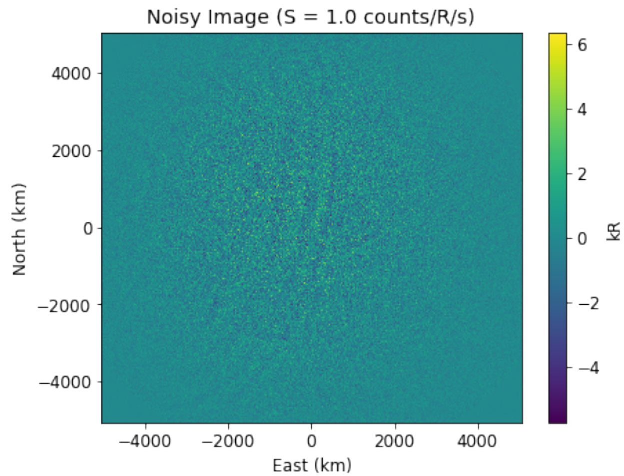


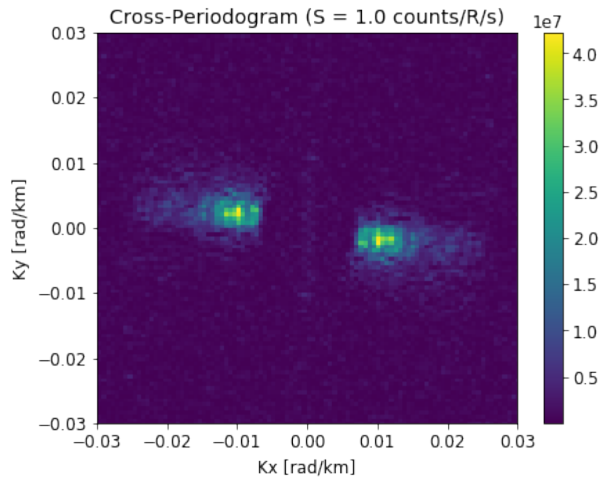
Overview of the wave detection and analysis algorithm.

- Detection mode is designed to run in real time on a decimated version of the image sequence.
- Analysis mode works with the full resolution data and runs on image blocks triggered by detection mode when switched on

Real-time Wavefront Detection

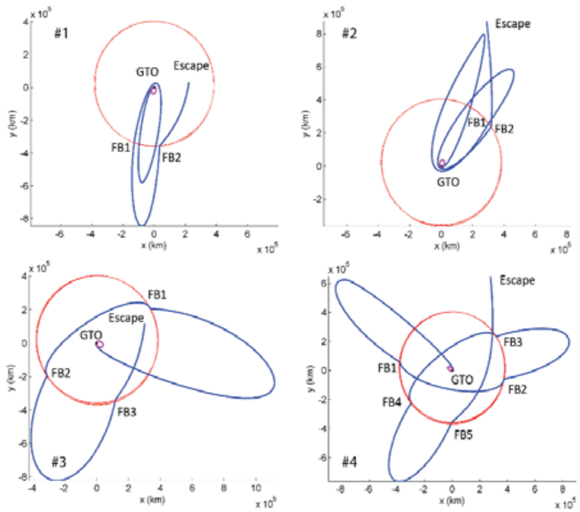
(left) Simulated image of raw data; (right) two-frame cross-periodogram demonstrating detection feasibility.



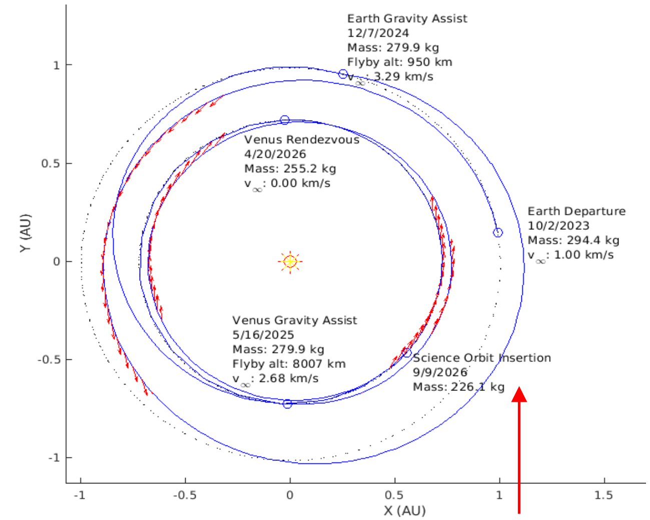


Trajectory Design

Earth-Moon System Escape

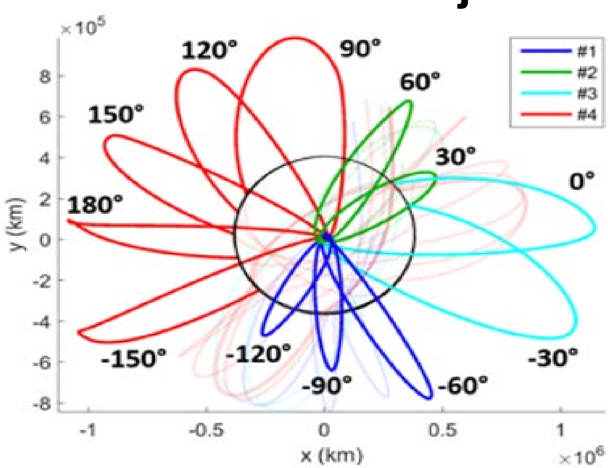


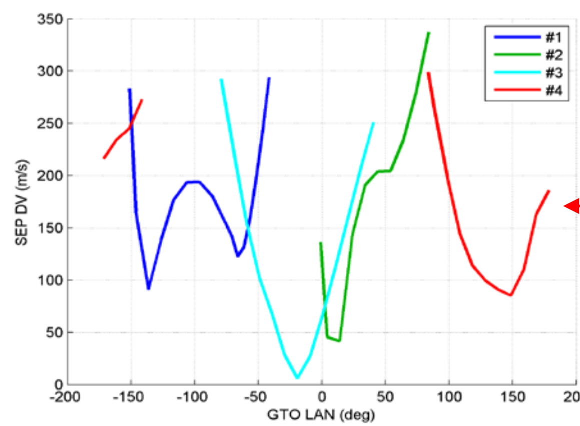
Interplanetary Cruise



A worst-case escape followed by a 31-month cruise and 5-month spiral-down achieves a science orbit with 74 kg of xenon.

Trajectories Investigated





The cost of targeting the moon from the first apogee changes significantly as a function of the initial GTO (LAN).

Flight System Capabilities

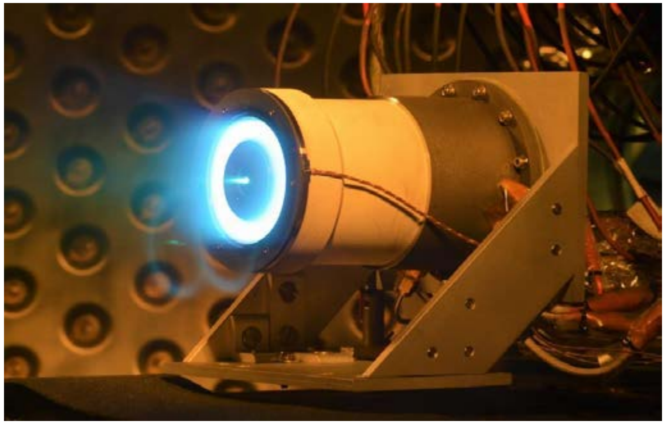
Command and Data Subsystem

Real-time science processing rate	~1 GFLOPS
Data volume per event (pre-processing)	7 GB
Data volume per event (after processing)	10 MB
Raw frame, compressed	1.5 MB
Events per week	~4
Expected radiation dose	30-40 krad

Telecommunications

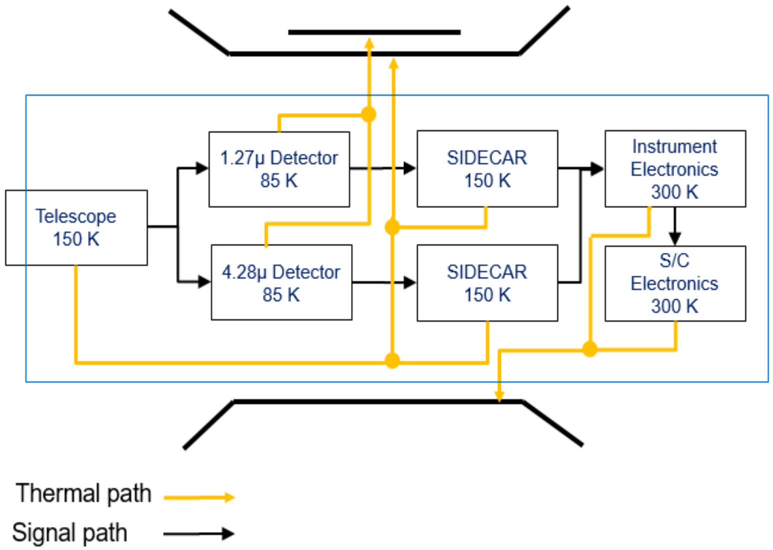
Earth Antenna	DSN 34 m BWG
Bit-Error Rate	1e-5 (CMD), 1e-4 (TLM)
Telecom Band	X
Downlink Rate	0.65-14 kbps
Uplink Rate	125 bps
DTE Link Margin	3 dB
Transmit Power	25 W

Propulsion Subsystem



The MaSMi thruster is a JPL-developed magnetically shielded, center-cathode Hall thruster, shown operating at 500 W discharge power.

Thermal Control Subsystem



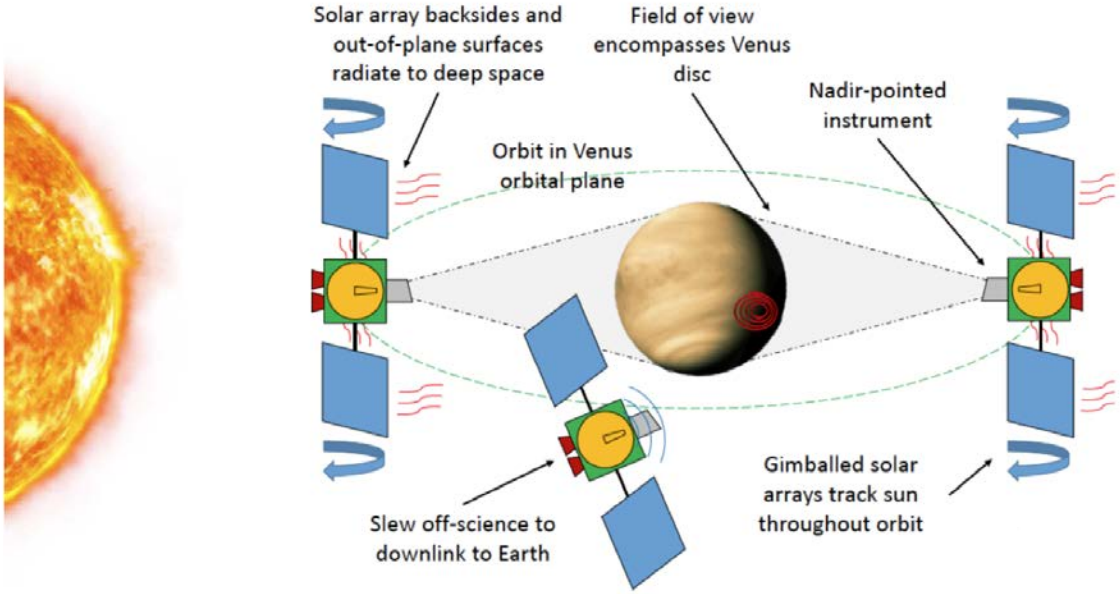
No active cry-cooling is needed

Cost Options

	Mass in kg	Development Cost in $K	Project Cost in $K Including Operations Cost and Launch Vehicle
SEP Design	262	256,200	301,300
Chemical Design	342	232,500	265,700
VAMOS Class D Classification Variant	262	150,400	168,500
VAMOS Chemical with DSI S/C	~300	55,041	92,053

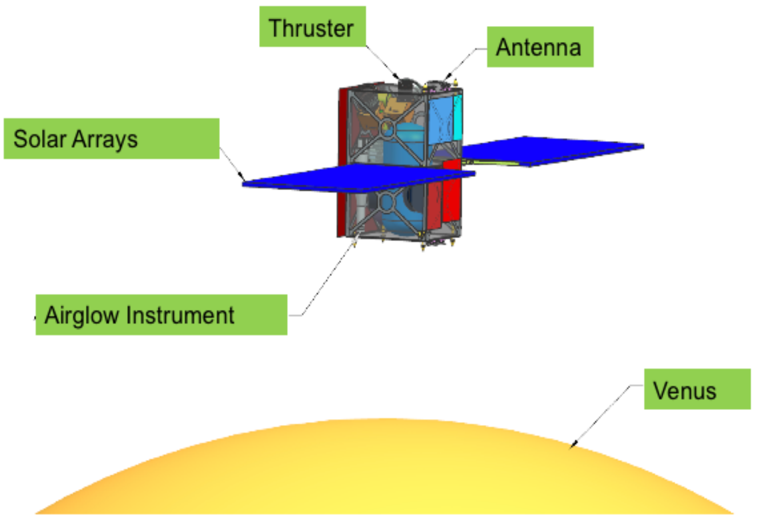
- 3 of 4 options investigated to meet ESPA Grande mass requirement
- 1 of 4 options to meet <$100M cost cap requirement

Summary



Team Members/Institutions:

- Principal Investigator: A. Komjathy of JPL
- Team JPL: engineering, science
- U. of Illinois, U. of Michigan: modeling and signal signal processing
- IPGP, CNES, and Geoazur, France: modeling, science



Mission Overview:

- Inject into trajectory to Venus using SEP (one Earth flyby and one Venus flyby); Insert into Venus circular orbit in the Sun-Venus plane.
- Use 1.27 μm infrared channel for nighttime and 4.3 μm channel for daytime detection.
- Determine regions of seismic/volcanic activity, gravity waves and ionospheric instabilities on Venus

Acknowledgements

- This material is based upon work supported by the National Aeronautics and Space Administration under ROSES 2016 NNH16ZDA001N-PSDS3 issued through the Planetary Science Deep Space SmallSat Studies Program.
- Support to the French team has been provided by CNES.
- This work was conducted at the NASA Jet Propulsion Laboratory, a division of California Institute of Technology.

Backup Slides

VAMOS Science Objectives

Threshold Science Objectives:

- Determine the global seismic activity of Venus (± 1 Moment magnitude)
- Determine the thickness of the crust
- Determine oxygen atom abundance and variability at 90-110 km altitude from O2 emission
- Determine horizontal wind velocity amplitude (±30 m/s) and direction (±30°) from gravity waves detected in O2 emission
- Characterize the nighttime and daytime variability of Venus ionosphere
- Assess very large day-to-day variability of the ionosphere

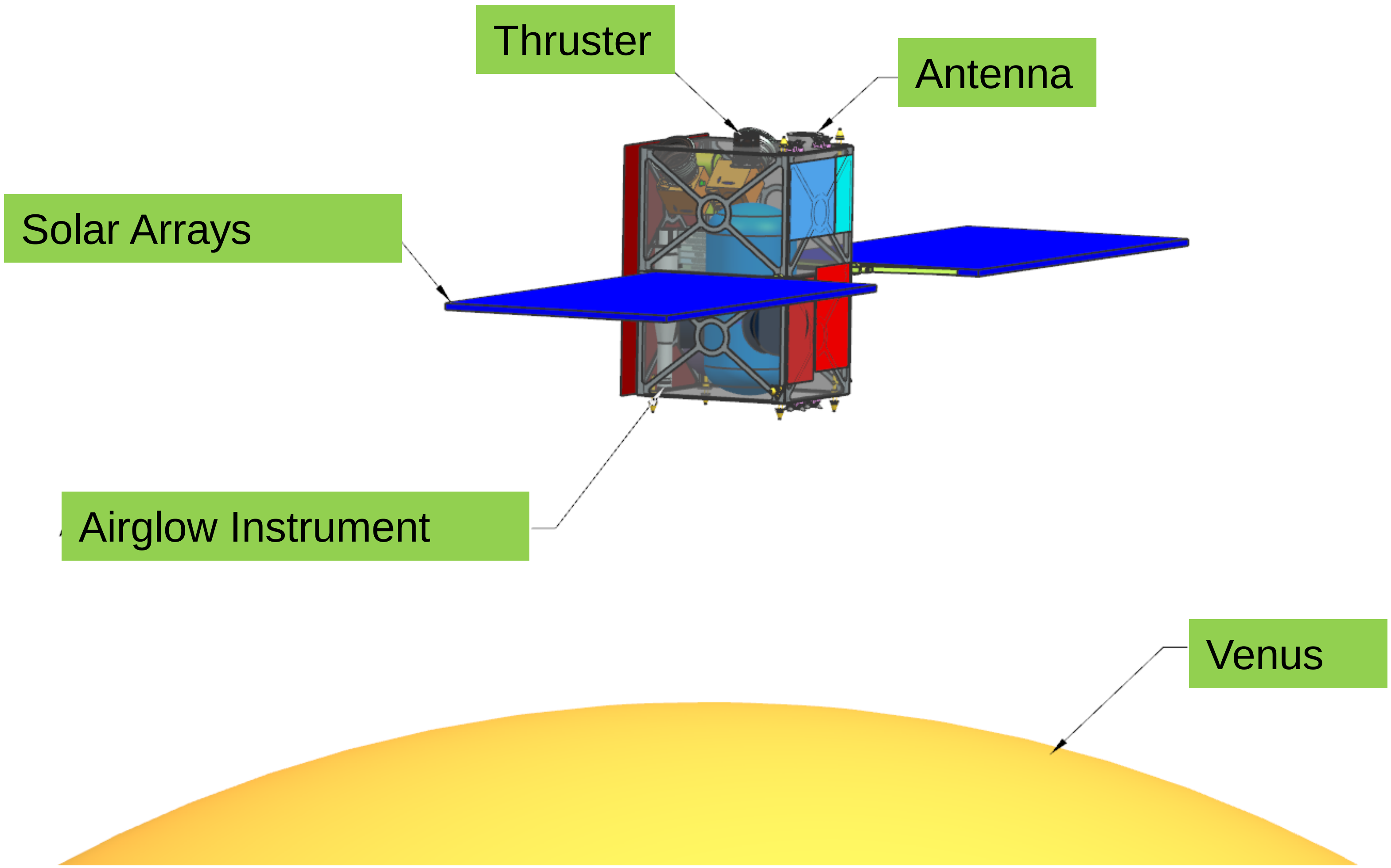
Baseline Science Objectives Beyond Threshold:

- Determine the regions of seismic/volcanic activity (**L1-SCI-007)**
- Determine the dominant source regions for gravity waves and assess any possible connection to topography
- Determine ionospheric instabilities for Venus

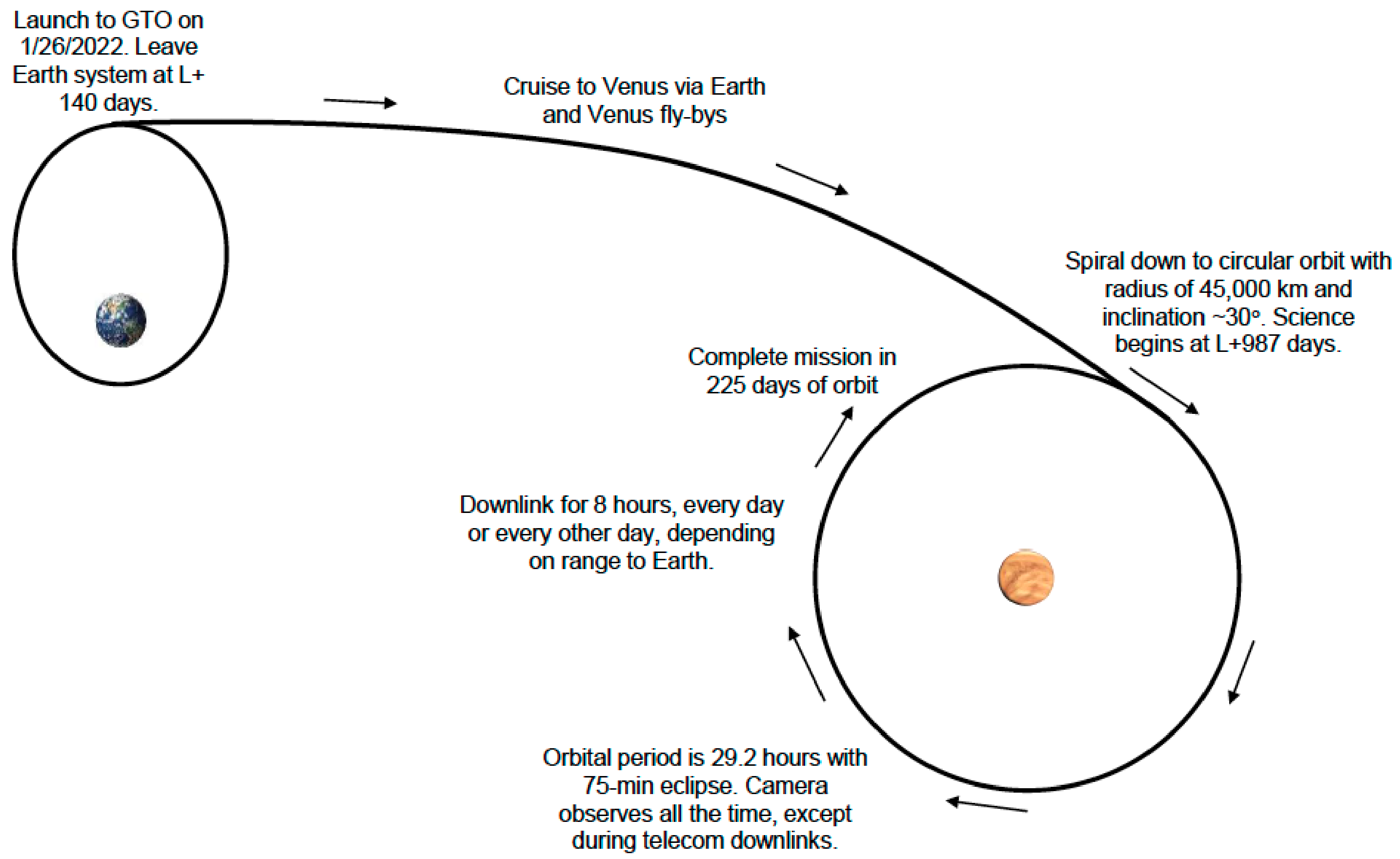
Mission Specifications

Science mission duration:	1 Venus year
Launch conditions:	GTO rideshare, >80% of LAN possibilities
Launch mass:	<300 kg (<180 kg would be ideal, but it is unlikely we could fit in)
Mission cost:	<$100M
Instrument accommodations:	~6 kg, 10 W, 50 mm x 50 mm x 700 mm, 85 Mbps raw
Downlink:	14 kbps (0.3 AU), 650 bps (1.7 AU)
Final Venus orbit:	45K km altitude, circular, inclination <10-15 degrees

Concept of Operations



Operational Scenario



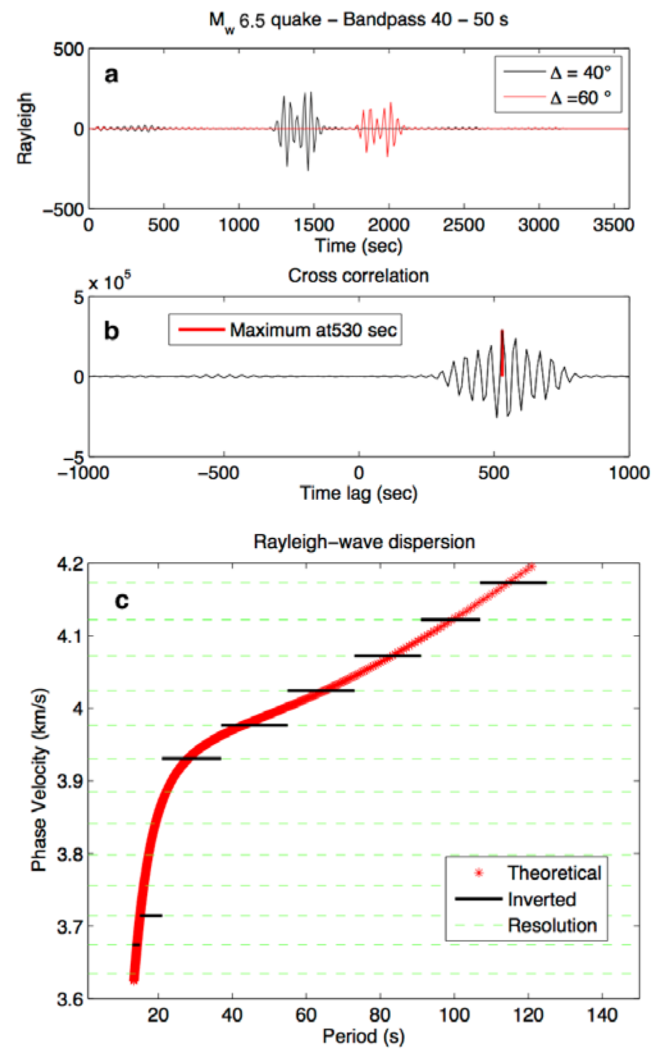
- Science-only orbit: Day-side Orbit (27.95 hours) + Eclipse Orbit (1.25 hours) over one period (28.2 hours)
- Science + telecom orbit: Telecom Downlink (8 hours) + Eclipse Orbit (1.25 hours) + Day-side orbit (18.95 hours)

Option Comparisons and Major Trades

- Chemical propulsion option for lower cost at the expense of suboptimal science orbit
- Advanced CubeSat/SmallSat CDHS vs. RAD750-based systems
- Possible commercial bus partnerships
- Direct-delivery via Venus-bound mission
  - Simplifies propulsion, power design, but drastically limits launch flexibility
  - Unique VAMOS orbit further unlikely to be offered

Determination of Surface-Wave Velocities

- Rayleigh waves are dispersive indicating that velocities depend on wave periods – different periods indicate different depths
- Time lags between airglow-grams at different epicentral distances can be measured, e.g. by using cross-correlation
- Propagation times indicate velocities in the corresponding frequency bands
- Repeating the operation in different bandwidths yields the dispersion curves
- Dispersion curves are sensitive to the structure of the crust and of the upper mantle



Kenda et al., 2018