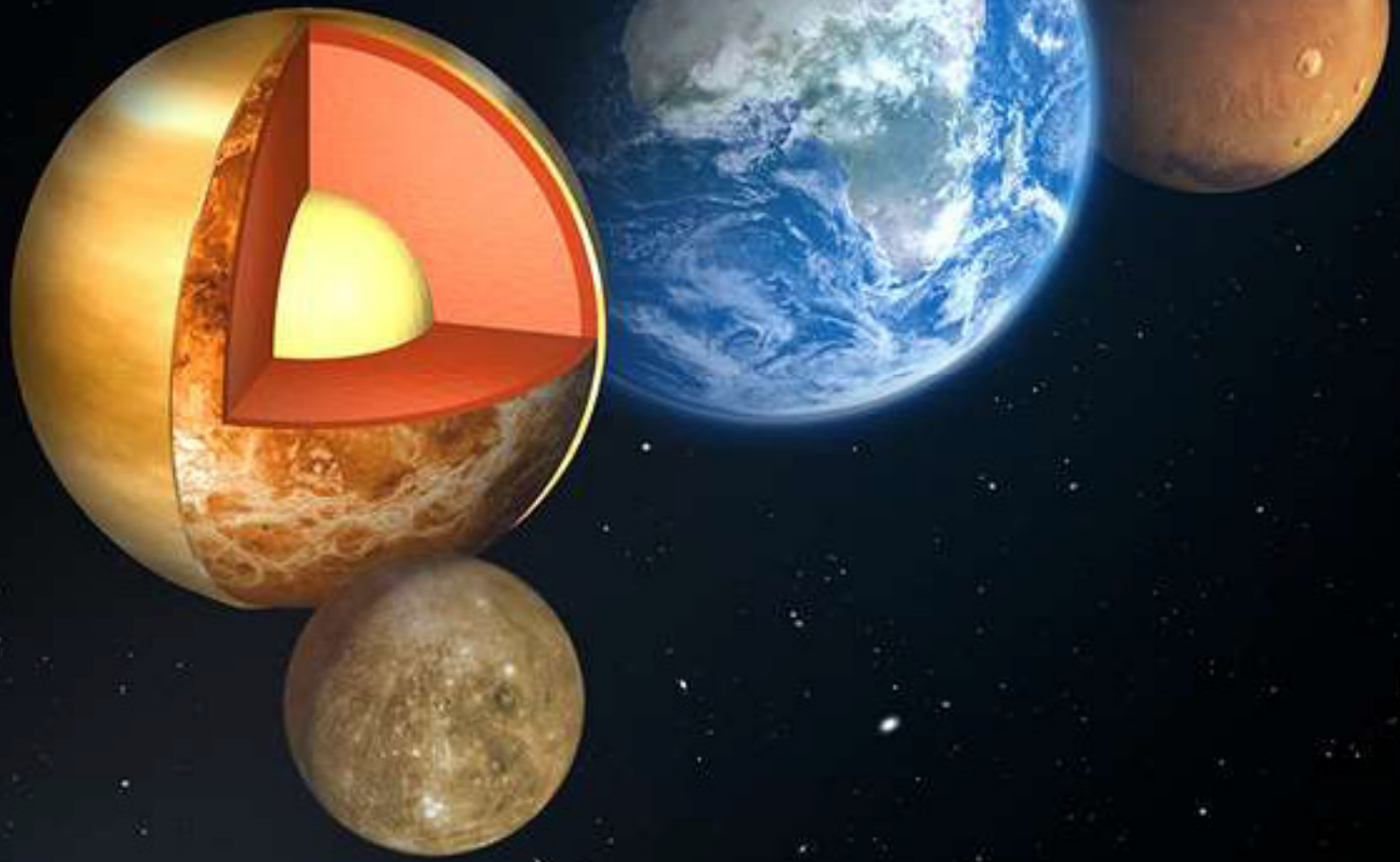
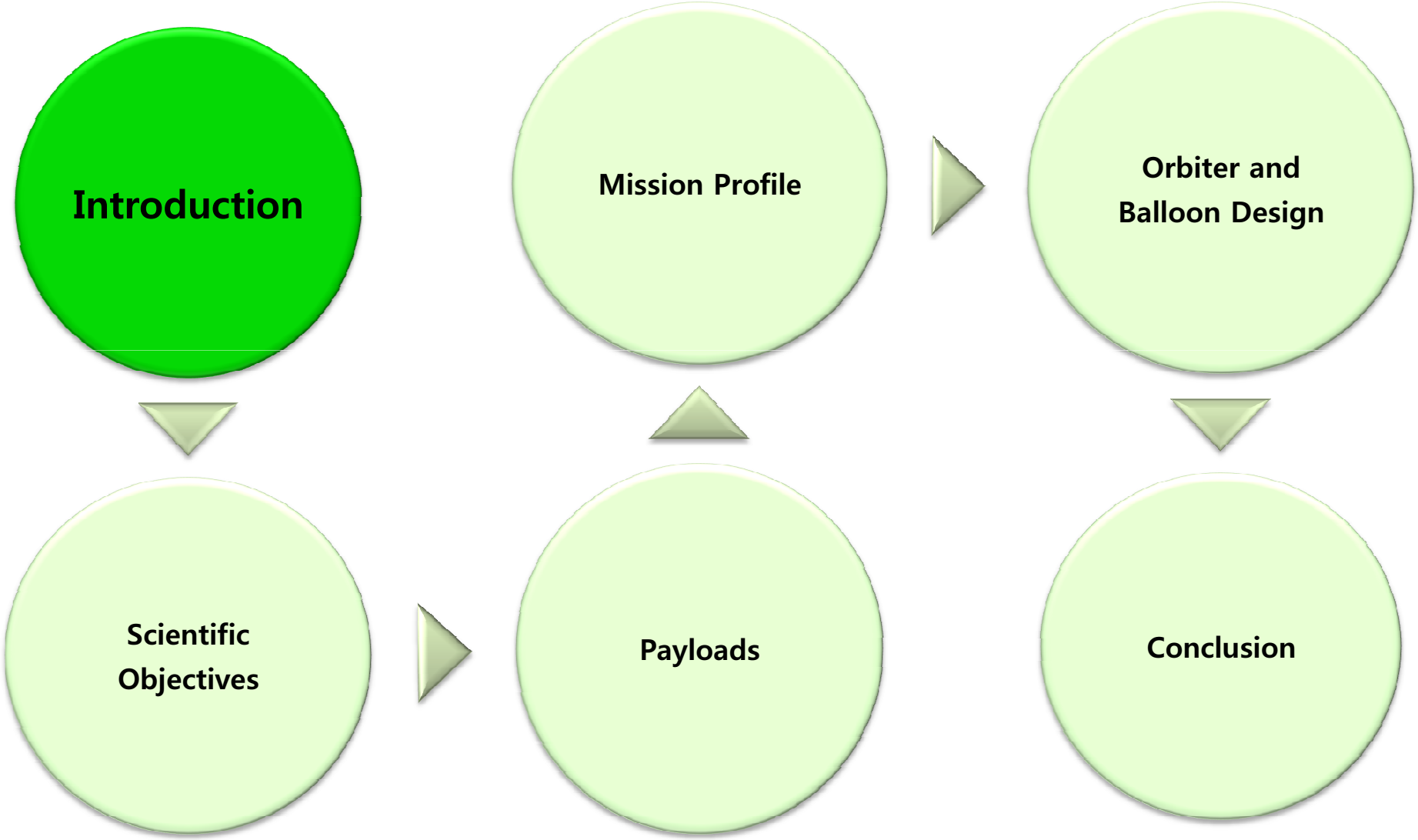
# Aphrodite MISSION



Alpbach Summerschool 2014

Team GREEN

# Aphrodite Mission



# Introduction

*“Venus only looks like the Earth, in the same sense that the evil Mr. Hyde resembles the good Dr. Jekyll”*

*- S. R. Taylor (2012)*

*“As we search for terrestrial-like planets elsewhere, we need to find out the reasons for these differences and the conditions that allow these diverse bodies (…) to form at all.”*

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# Introduction

*"Venus only looks like the Earth, in the same sense that the evil Mr. Hyde resembles the good Dr. Jekyll"*
*- S. R. Taylor (2012)*

*"As we search for terrestrial-like planets elsewhere, we need to find out the reasons for these differences and the conditions that allow these diverse bodies (…) to form at all."*
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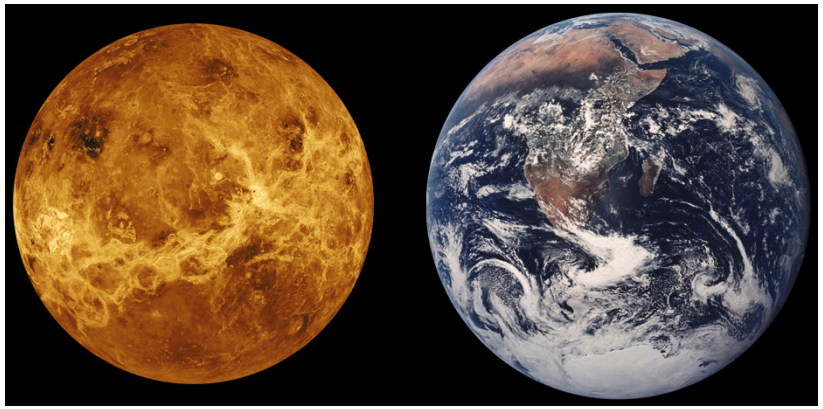
## Why is Venus so different from Earth?



# How is Venus different?

- Magnetic field
- Tectonics and volcanism
- Spin rate
- Atmosphere

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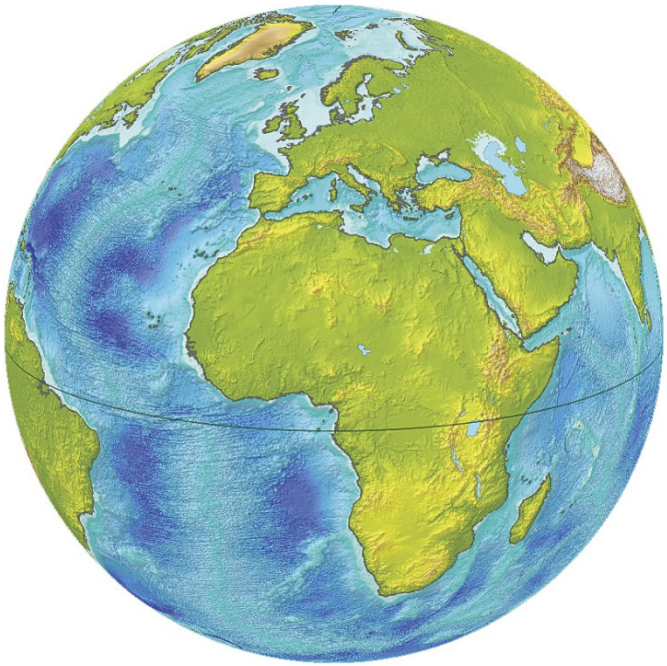

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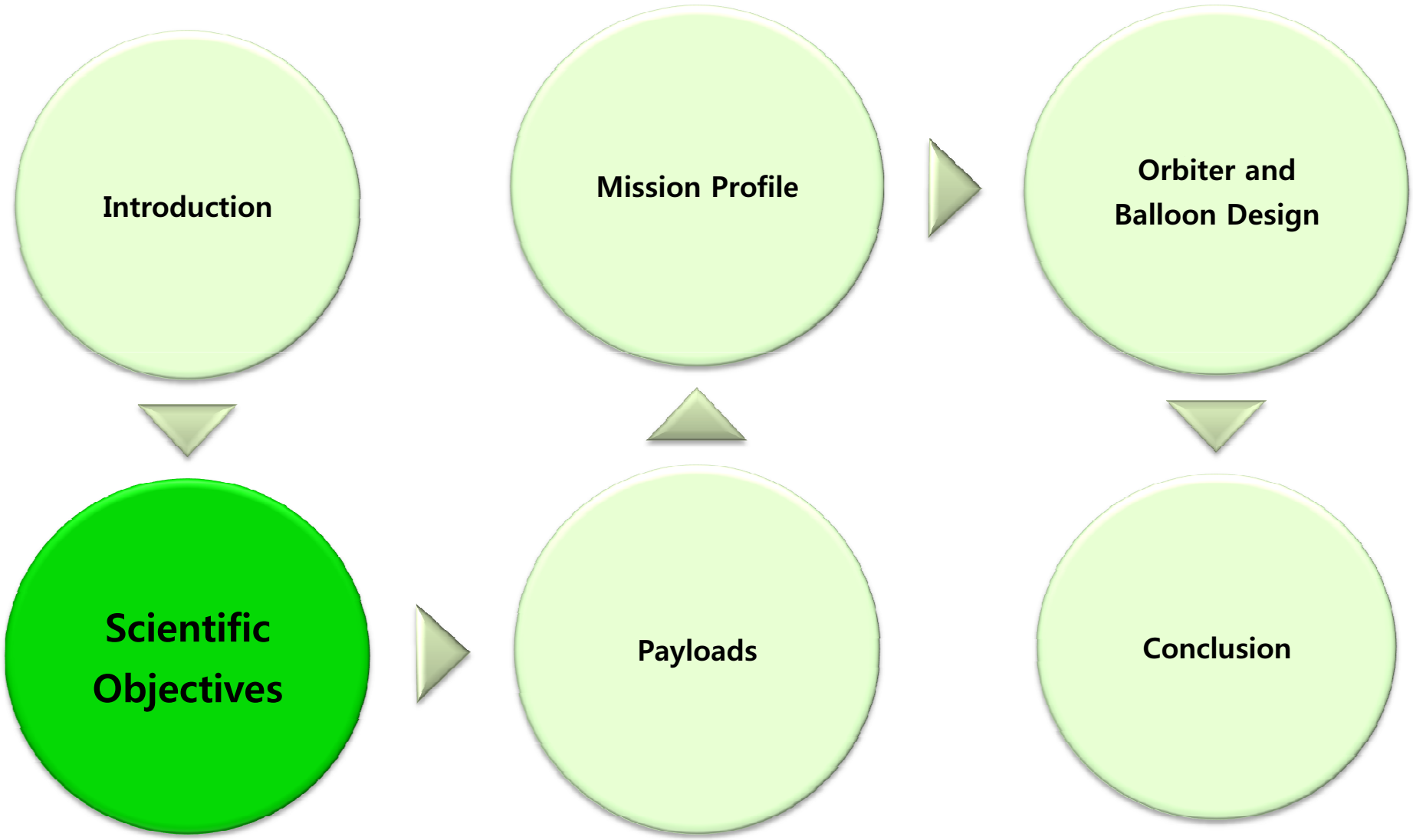
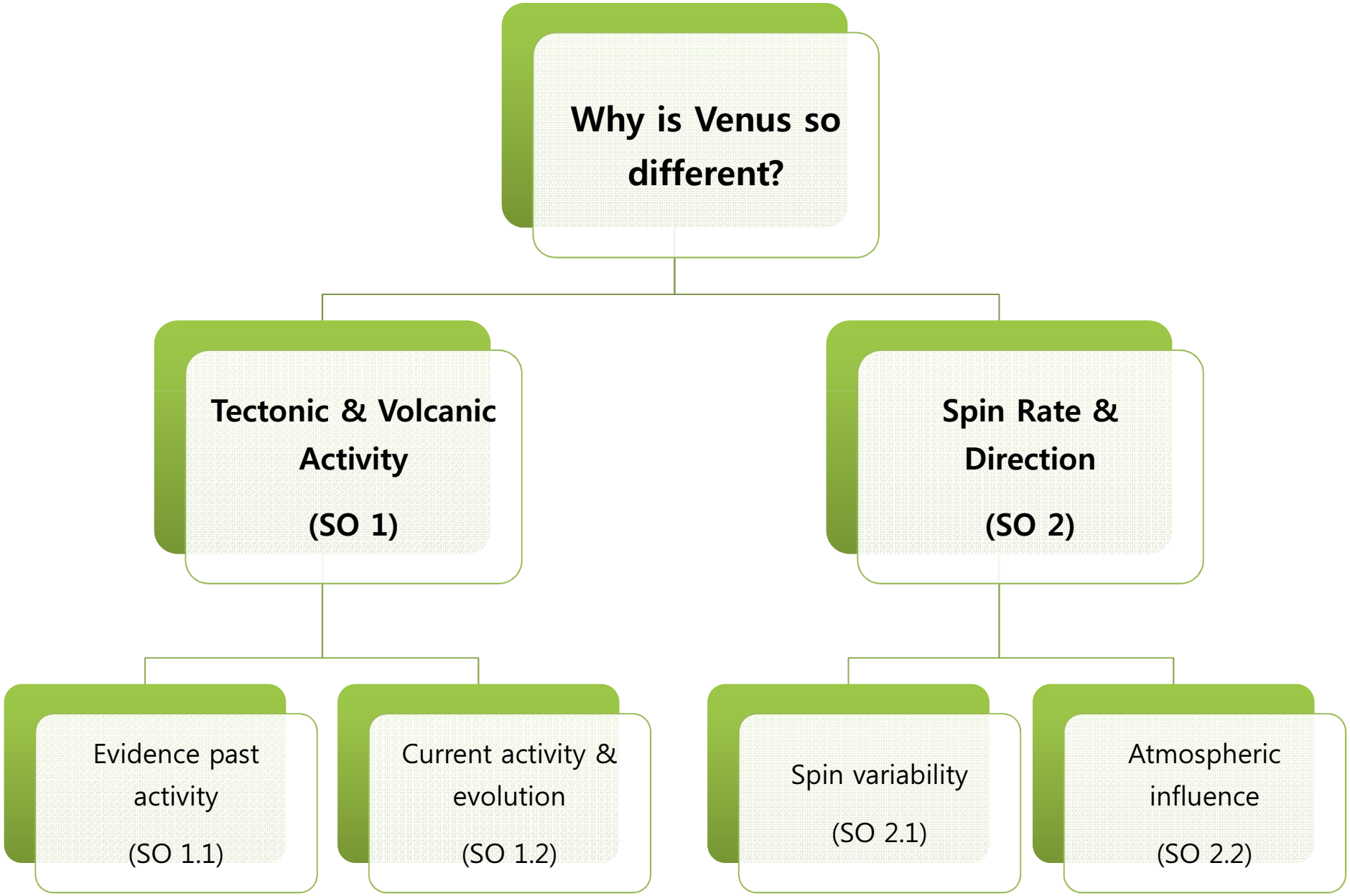
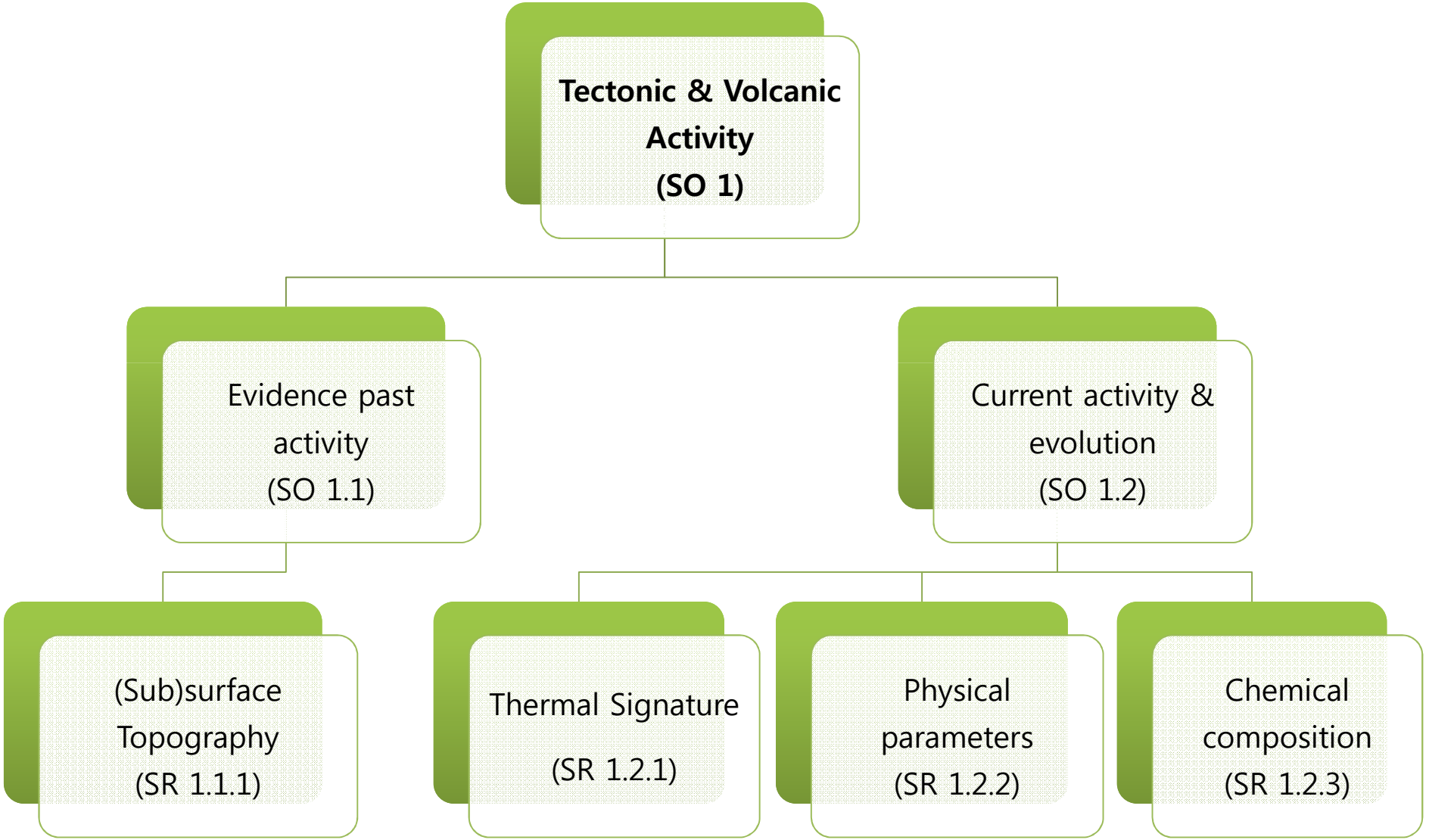


# Scientific Objectives



# Tectonic & Volcanic Activity

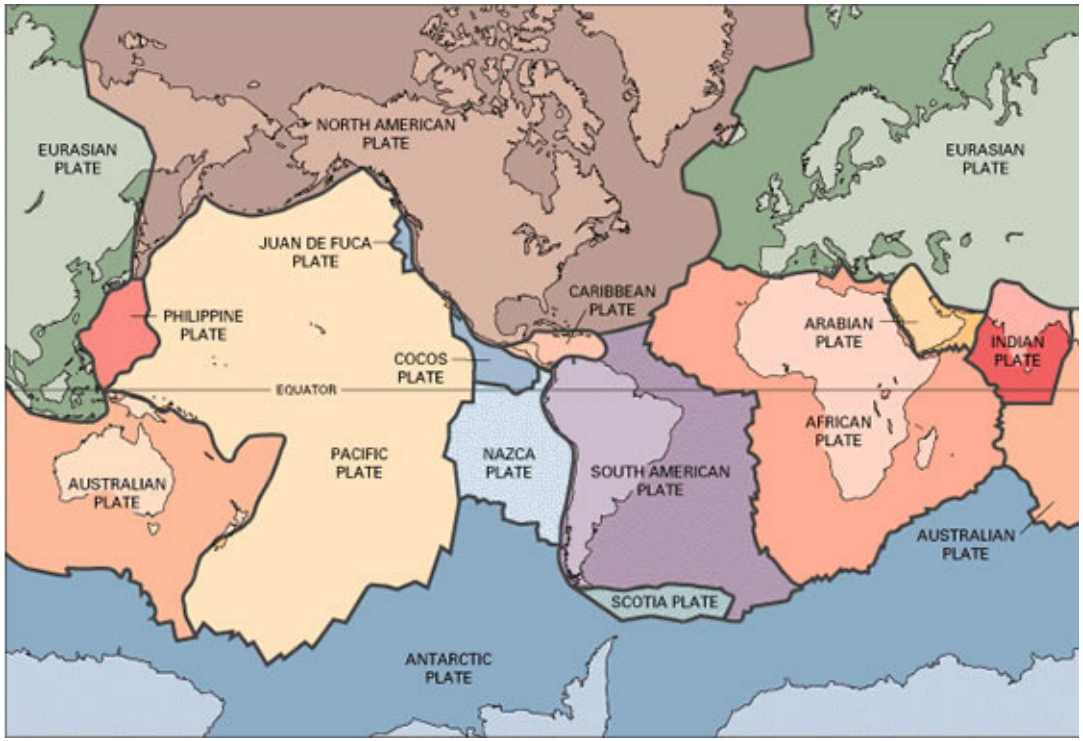


# Tectonics & Volcanic Activity

**SO 1**

## Questions:

- Why doesn't Venus have plate tectonics like Earth?
- Can we link atmospheric features to tectonics and volcanic activity?
- Is there active volcanism on Venus?
- Can we detect volcanic atmospheric shock waves or gases?




www.geology.com

# Evidence of past activity

**SO 1.1 & SR 1.1.1**

- Study the (sub)surface to understand the volcanic and tectonic processes.
  - Structure subsurface magmatic bodies
  - Structure and stratigraphy lava flows
  - Detection lava tubes
- Composition of the surface material.

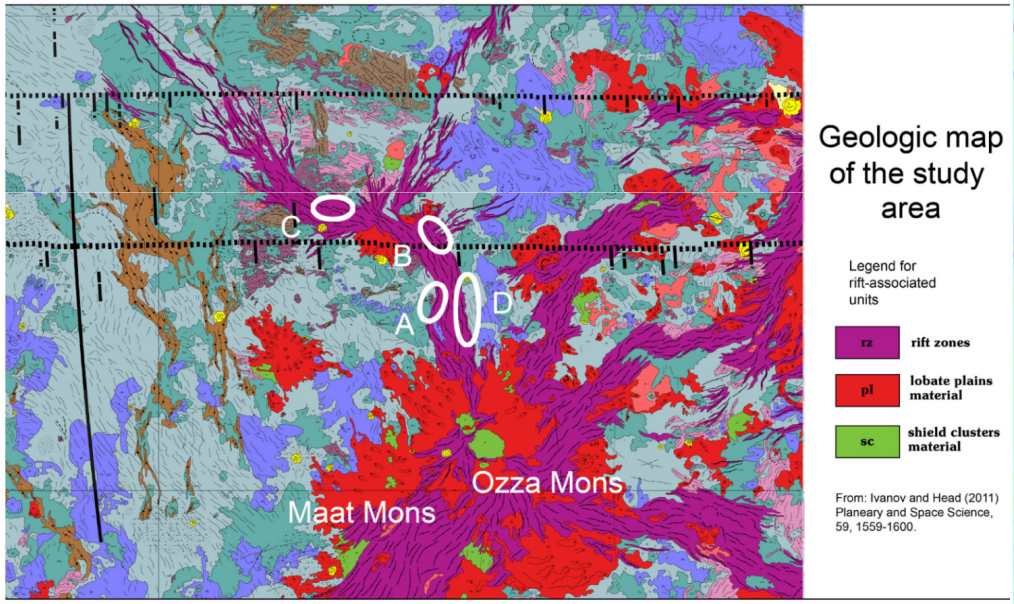
| Vertical resolution | Penetration depth |
|---|---|
| 10 m | 0 - 100 m |

© Peter Bird

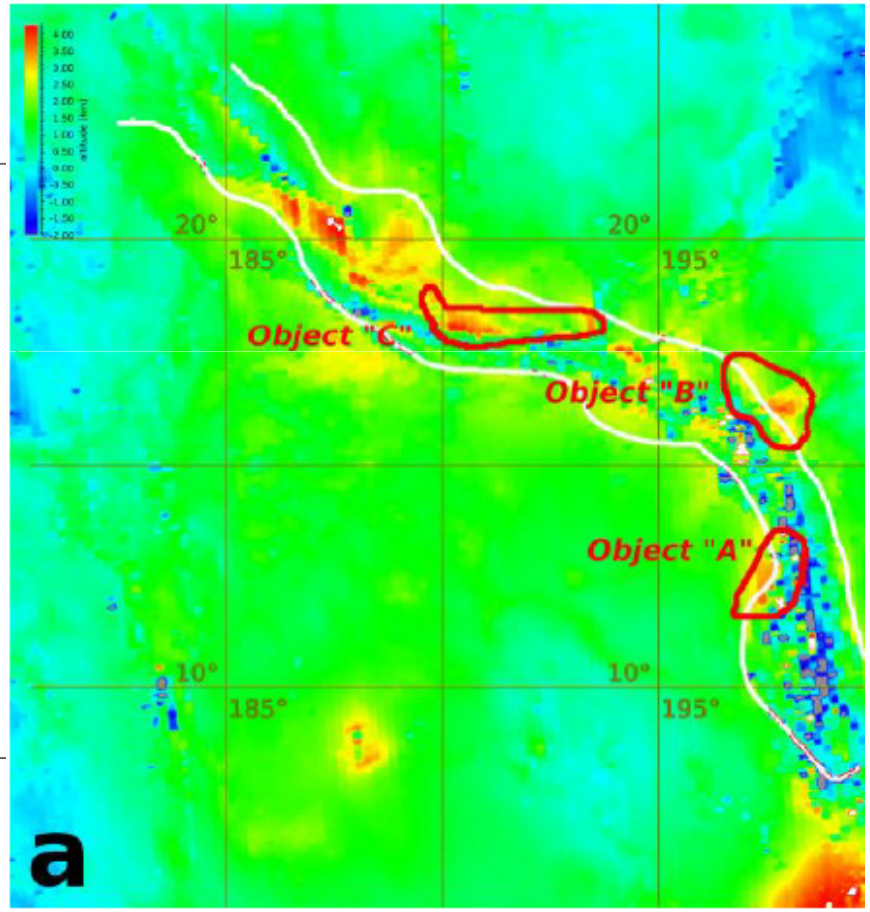
# Current activity & evolution

*Ganiki Chasma, Atla Regio*

**SO 1.2**




Geological map of the Atla Regio, Venus. (Ivanov & Head (2011))




Topographic map (Shalygin et al. 2014)

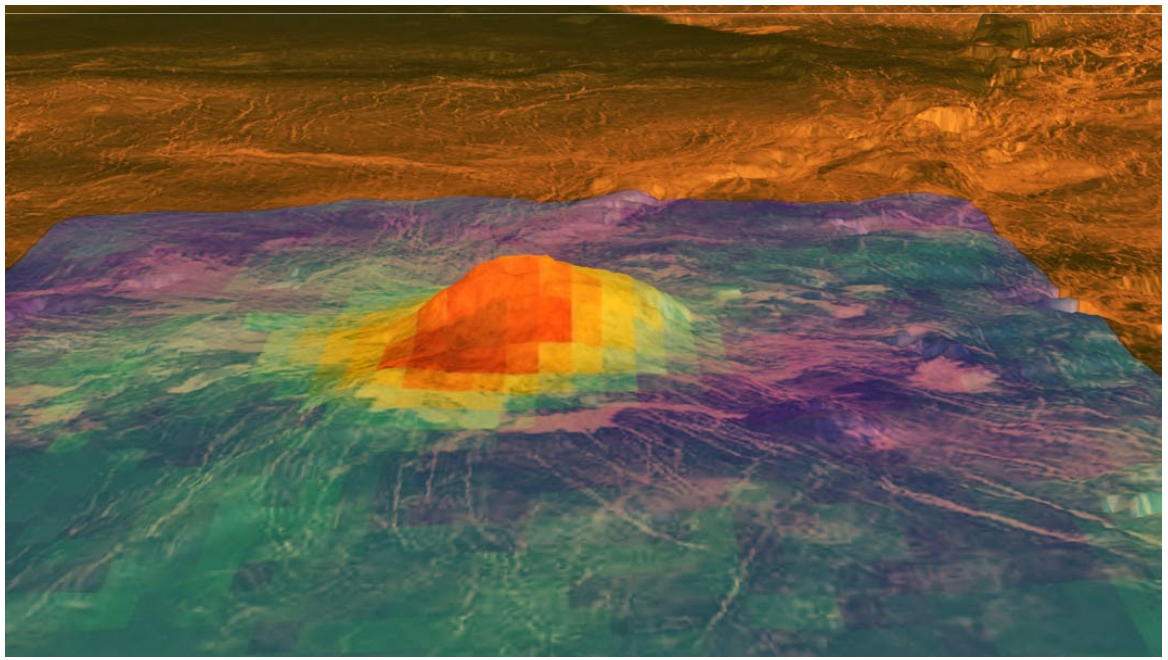
# Current activity & evolution

**SR 1.2.1**

## *Thermal Signatures*

- Hot spots as indicators for current activity
  - Magma chambers
  - Eruptions
  - Lava flows

| Smallest volcano | Sensitivity |
|---|---|
| 2 km diameter | 0.1 K |



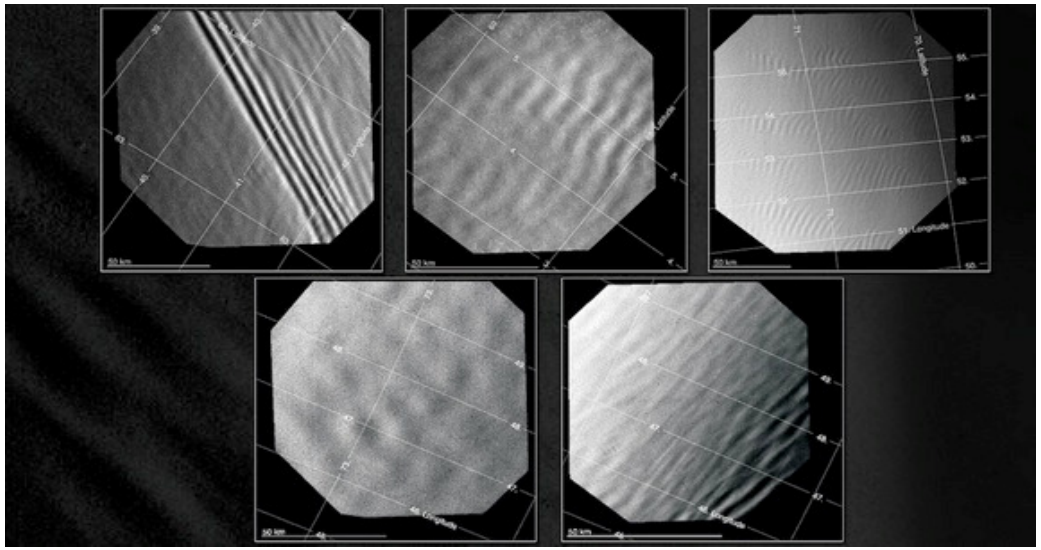
Idunn Mons, ESA/NASA/JPL (Smredar et al. 2010)

# Current activity & evolution

**SR 1.2.2**

## *Physical parameters*

- Gravity waves
  - convection below
  - horizontal flow passing an obstacle
  - volcanic eruption



| Wavelength |
| --- |
| 2 - 20 km |

Gravity waves observed by the Venus Monitoring Camera aboard Venus Express (Piccialli et al. 2014)

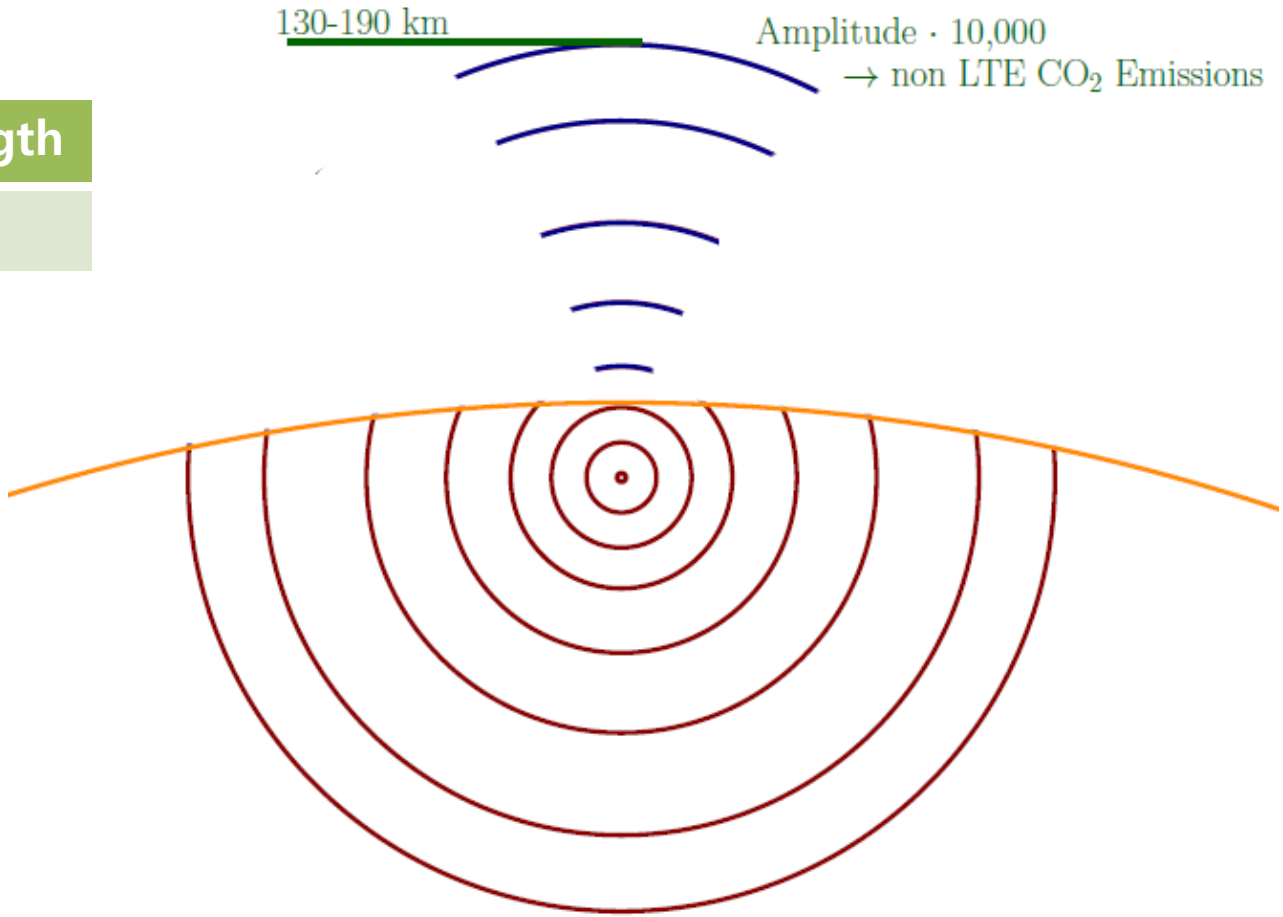
# Current activity & evolution

**SR 1.2.2**

## *Physical parameters*

- Acoustic waves – tectonic activity on Venus

| Wavelength |
| --- |
| 4.3 µm |



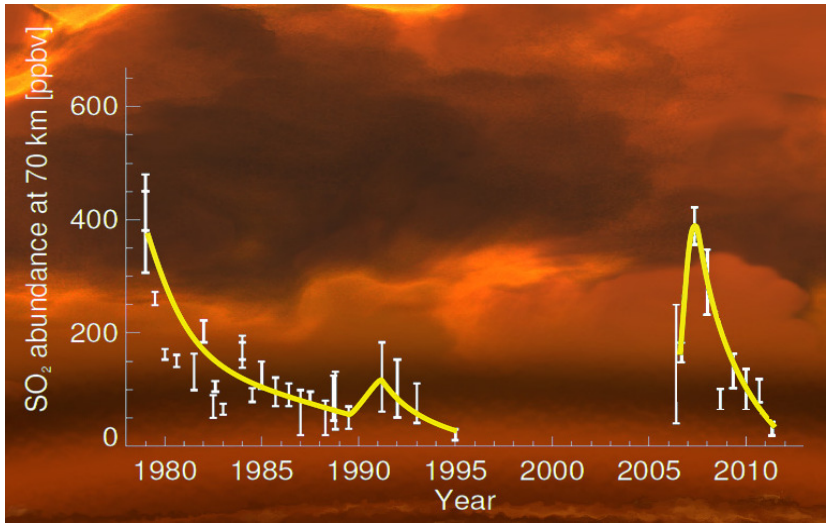
# Current activity & evolution

**SR 1.2.3**

## *Chemical composition*

- Chemical and isotopic measurements of the atmosphere above, through and below the cloud layer
  - evolution of the atmosphere and its link to volcanic processes
  - variability of $SO_2$ gives indication to the rate of current volcanism large volcanic eruption
  - plume and composition of source magma

| Species / Ratio | Atmosphere |
|---|---|
| $H_2O$ | 30 ± 15 ppm (1-4 ppm in clouds) |
| $SO_2$ | 150 ± 30 ppm |
| D/H | 0.016 ± 0.002 |
| $^{16}O/^{18}O$ | 500 ± 80 |
| $^{32}S/^{34}S$ | n.n. |



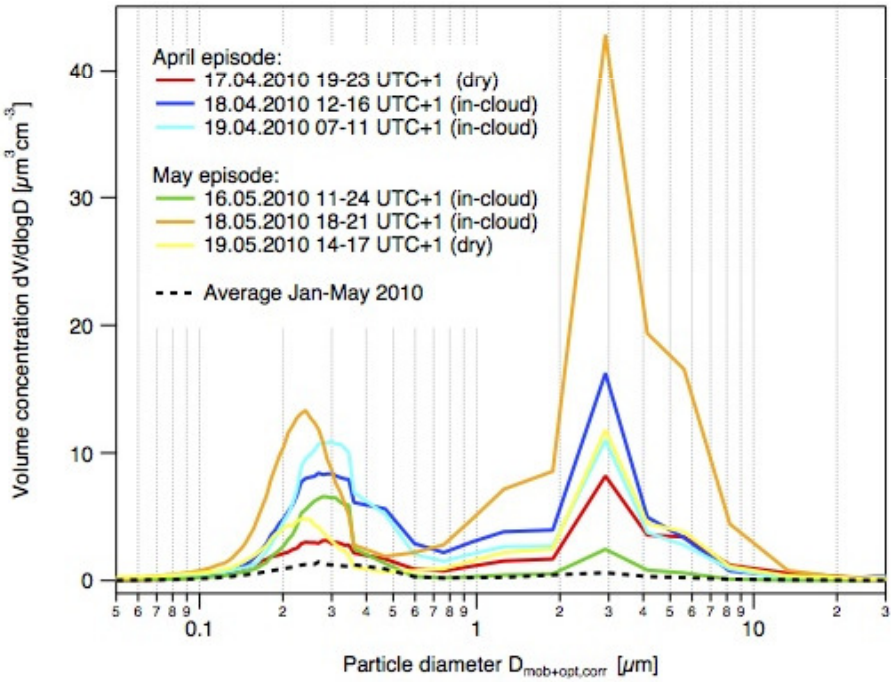
# Current activity & evolution

**SR 1.2.3**

## *Chemical composition*

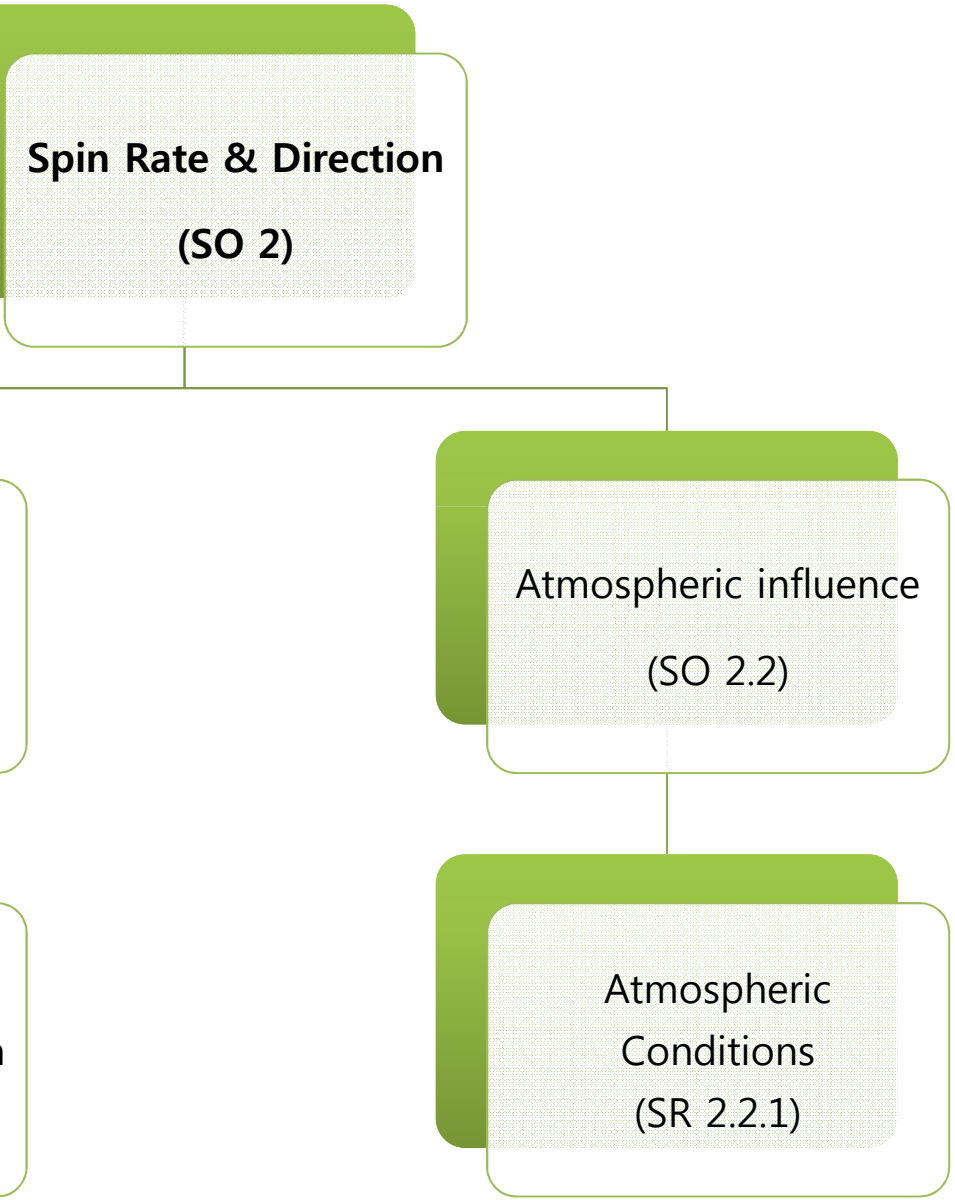
- Identification of a volcanic ash layer at the lower cloud base
  - study the nature of the layer at the base of the cloud
  - particle size volcanic ash and dust particles
  - $H_2SO_4$ aerosols

| Range | Sensitivity |
|---|---|
| 0.1 µm to 10 µm | 0.1 µm |

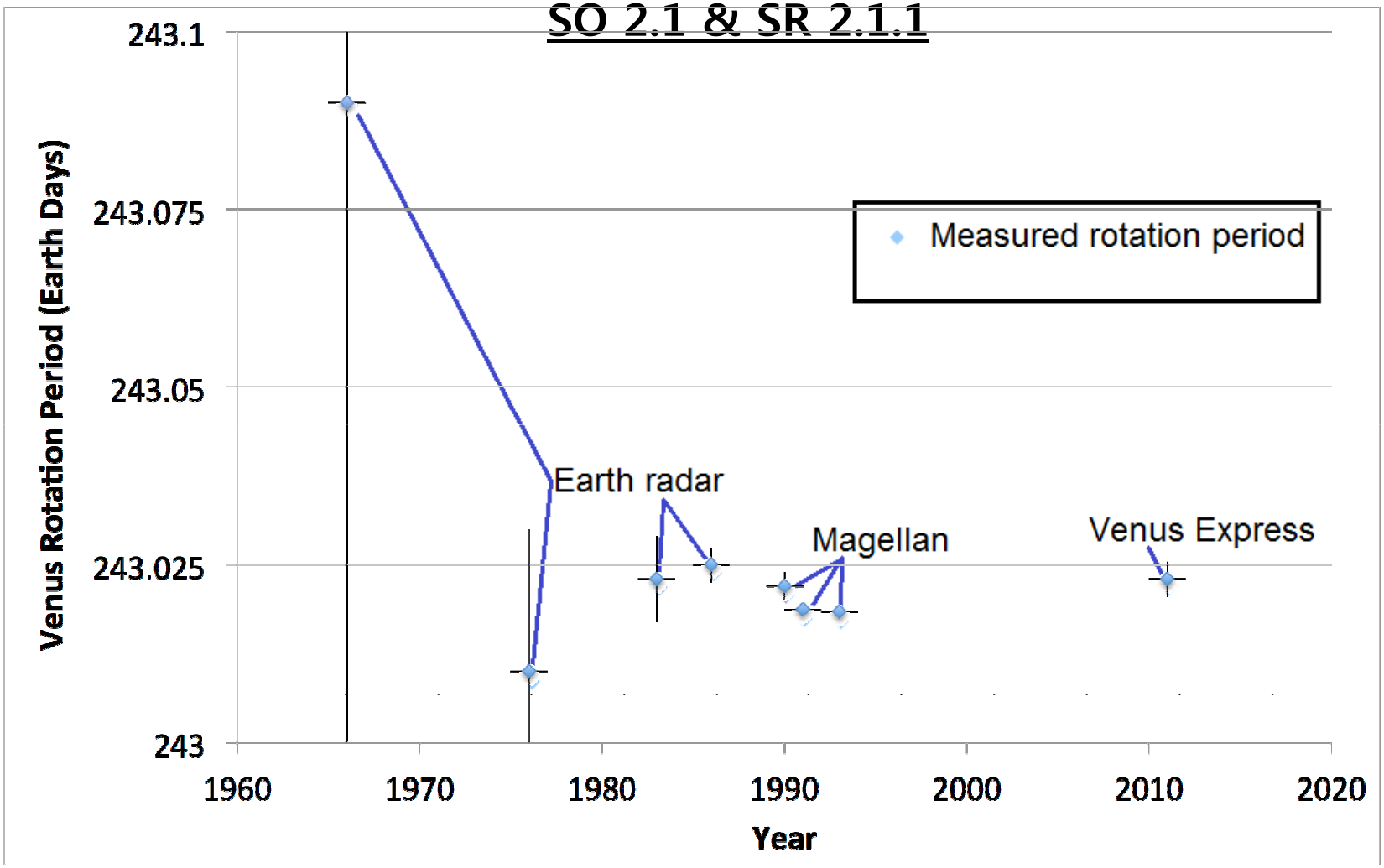



Reference:
Bansize distribution of an explosvive volcanic eruption on Earth was used as estimate,
see Bukowiecki et al.: In-situ measurements of the Eyjafjallajökull aerosol plume, 2011

# Spin rate & direction



# Determination & variability



# Atmospheric influence

**SO 2.2 & SR 2.2.1**

- Atmospheric coupling to the surface
  → interaction spin ↔ global circulation

| Parameter | Sensitivity | Range |
|---|---|---|
| Spin rate | Venus day +-10sec | |
| Acceleration | < 10 E-5 $m/s^2$ | 0-0.1 m/s^2 |
| Pressure | 0.1 bar | 0.1-100 bar |
| Temperature | 1 K | 150-750 K |
| Wind Speed | 1 km/h | 0 – 800 km/h |

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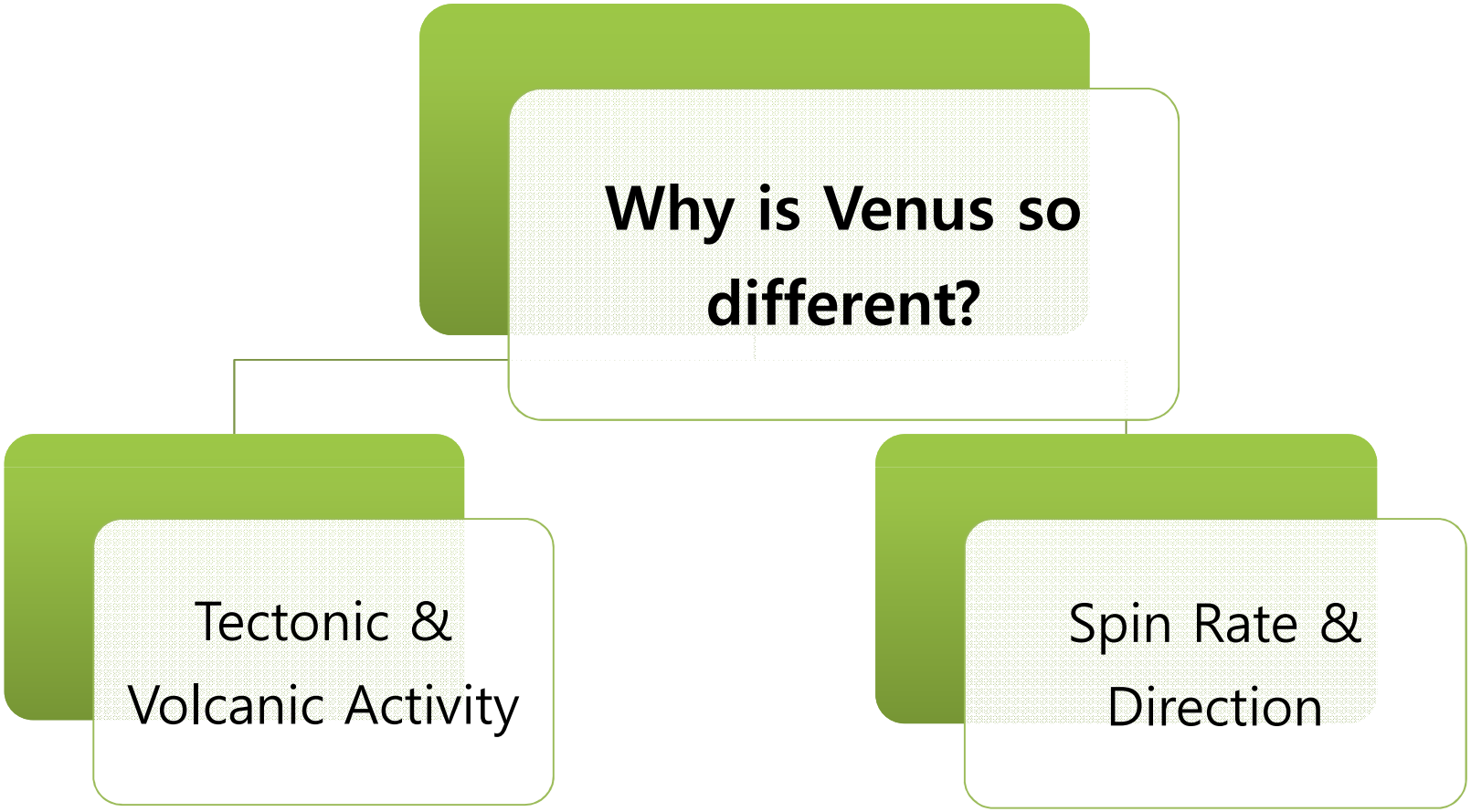
- Moment of Inertia
- Information about internal structure

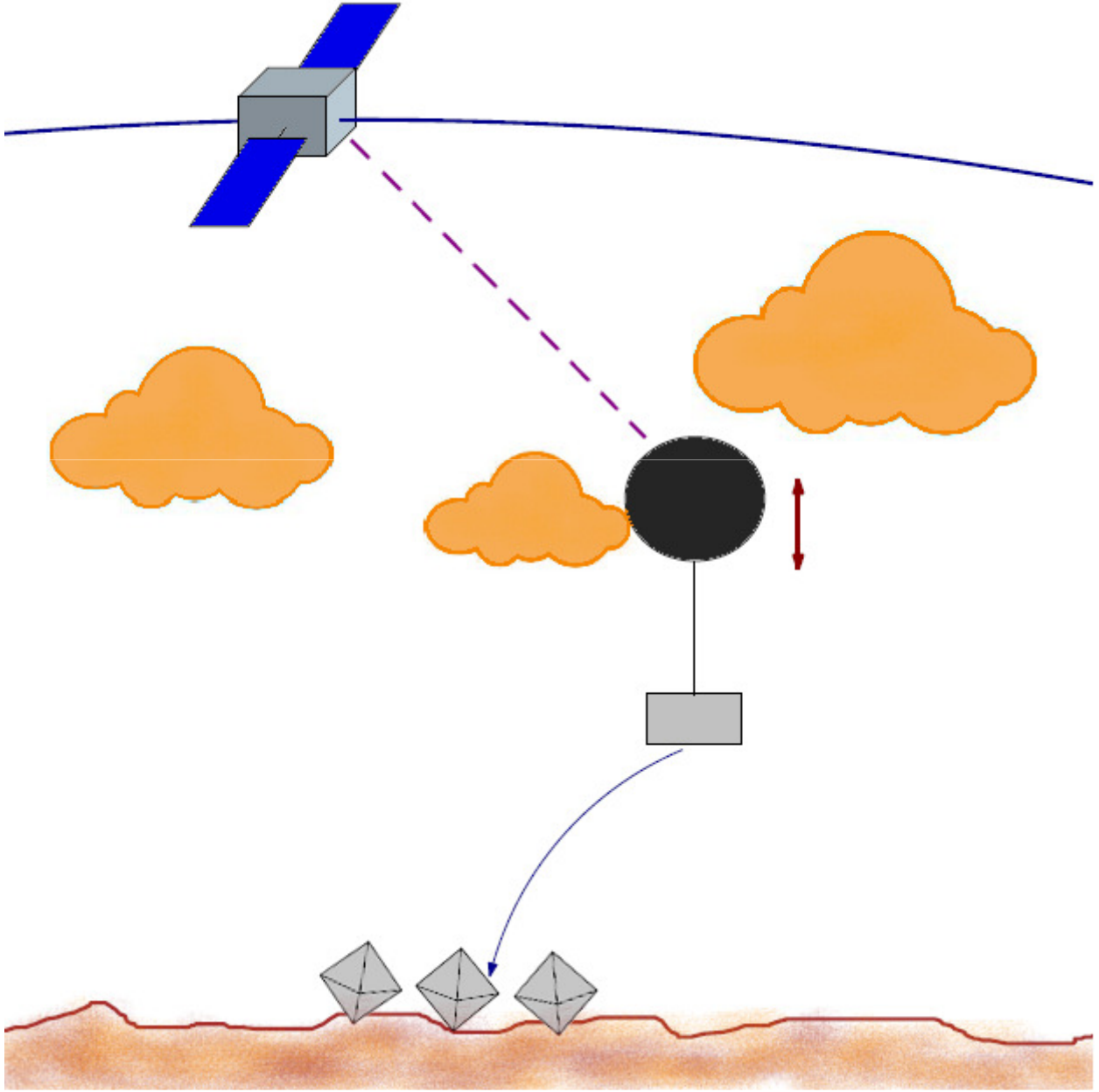
# SO summary


Why is Venus so different?
Tectonic & Volcanic Activity
Spin Rate & Direction

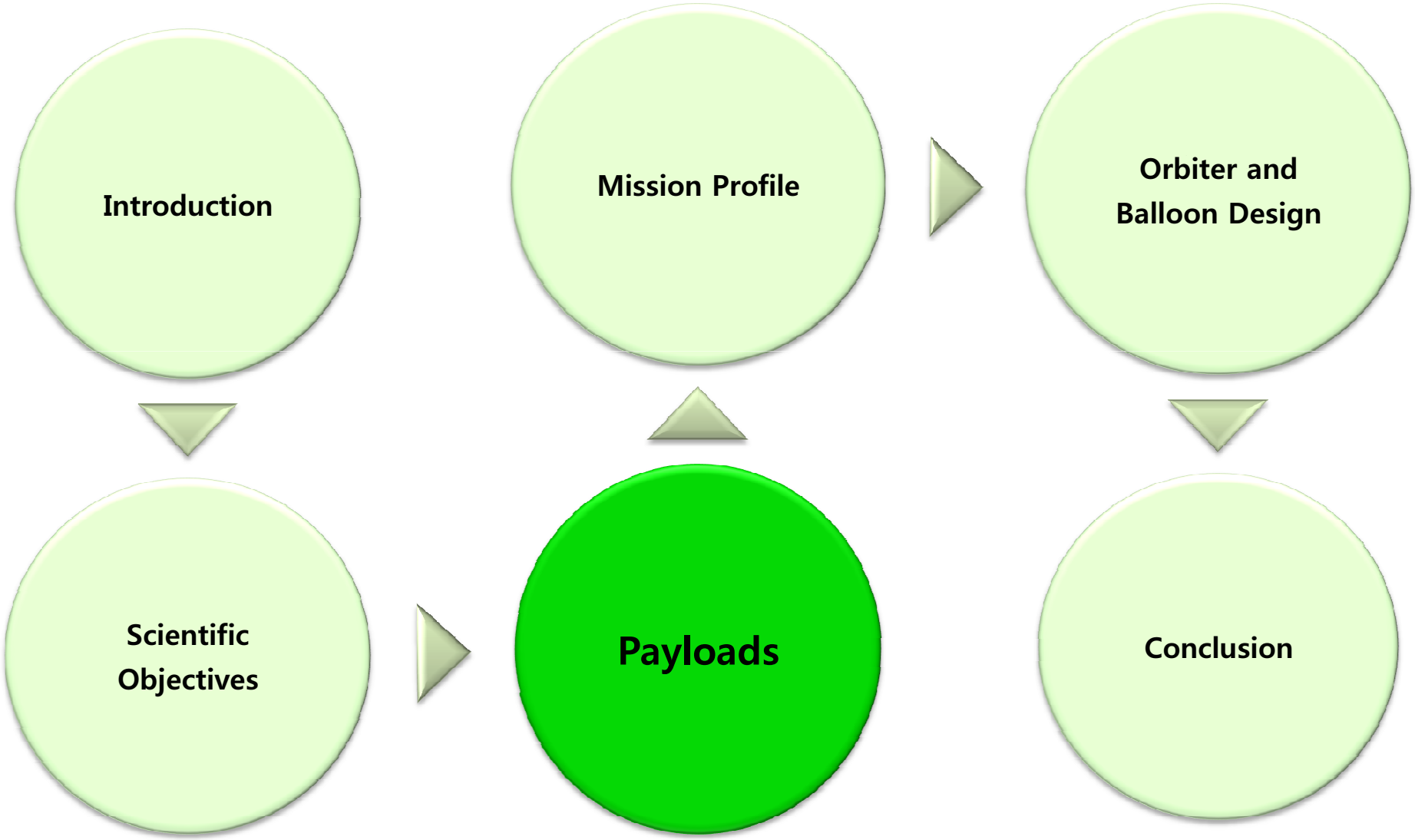
# Exoplanets geophysics

- Venus: testing planet in the Solar Sytem
  - Correlation geophysical processes and atmosphere

# Aphrodite Mission



# Aphrodite Mission



# Payload Overview

| Payload | SR 1.1.1 | SR 1.2.1 | SR 1.2.2 | SR 1.2.3 | SR 2.1.1 | SR 2.2.1 |
|---|---|---|---|---|---|---|
| **Hephaestos** | | | | | | |
| Spectral Imager | | ■ | ■ | | | |
| Sub-mm Sounder | | | | ■ | | ■ |
| GPR | ■ | | | | | |
| SRMP + **Aglaea** 1,2,3 | | | | | ■ | |
| **Adonis Balloon** | | | | | | |
| NMS | | | | ■ | | |
| ASS | | | | | | ■ |
| Nephelometer | | | | ■ | | |
| Microflown | | | ■ | | | |
| Context Camera | | | | | | |

# Hephaestos Orbiter Payload

| Payload | SR 1.1.1 | SR 1.2.1 | SR 1.2.2 | SR 1.2.3 | SR 2.1.1 | SR 2.2.1 |
|---|---|---|---|---|---|---|
| **Hephaestos** | | | | | | |
| Spectral Imager | | ■ | ■ | | | |
| Sub-mm Sounder | | | | ■ | | ■ |
| GPR | ■ | | | | | |
| SRMP<br>+ **Aglaea** 1,2,3 | | | | | ■ | |

# Spectral Imager

***Scientific Requirements:***

Thermal signature (SR 1.2.1)

Physical parameters (SR 1.2.2)

- Heritage : Venus Express, Rosetta
- Improvement of the field of view would better accommodate the requirements (planned future instruments : NOMAD – ExoMars Trace Gas Orbiter, 2016)

| | Requirement | Sensitivity | Range |
|---|---|---|---|
| Spectral | 4.3 µm<br>0.1 K | 3 nm (VIS)<br>15 nm (IR)<br>< 0.5 K | 0.25-1 µm (VIS)<br>1-5 µm (IR) |
| Spatial | | 1 mrad | |

# Submillimeter Sounder

***Scientific Requirements:***

Chemical composition (SR 1.2.3)

Atmospheric conditions (SR 2.2.1)

Measurement of:

- various chemical species (e.g. $H_2O$, $SO_2$, $H_2SO_4$ )
- wind speed, temperature

Flexibility: the instrument can be adapted at the required measurement range

| | Requirement | Sensitivity |
|---|---|---|
| $H_2O$, $SO_2$ | 1-4 ppm | < 1 ppb |
| Wind speed | 1 km/h | 18 km/h |
| Temperature | 1 K | 1-2 K |

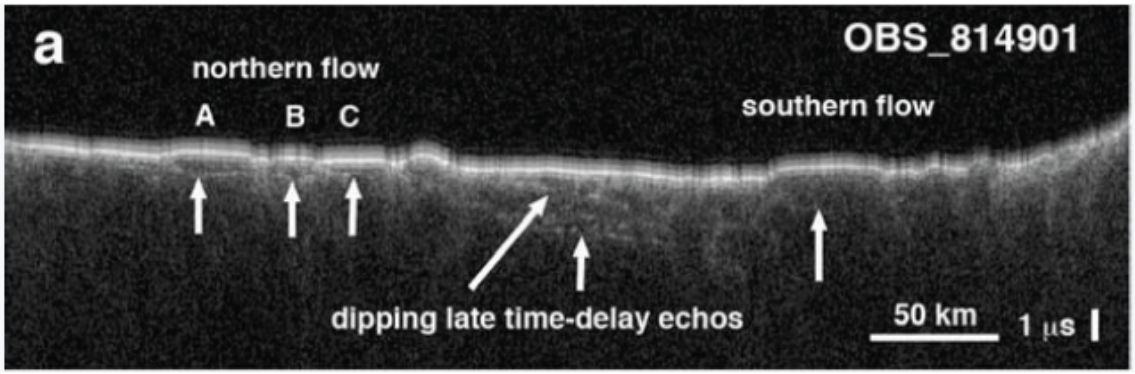
# Ground Penetrating Radar

***Scientific Requirement:***
(Sub)surface Topography (SR 1.1.1)

- Heritage : Mars Reconnaissance Orbiter
- Frequency band: 20 MHz

| | Requirement | Sensitivity | Range |
|---|---|---|---|
| Horizontal | 1 km | 0.3-3 km x 3-7 km | |
| Vertical | 10 m | 7.5-15m | up to 1km |

Carter, L. 2014. SHARAD/MARSIS User Data Workshop presentation




Tharsis volcanic region, Mars (SHARAD)

# SRMP

***Scientific Requirements:***

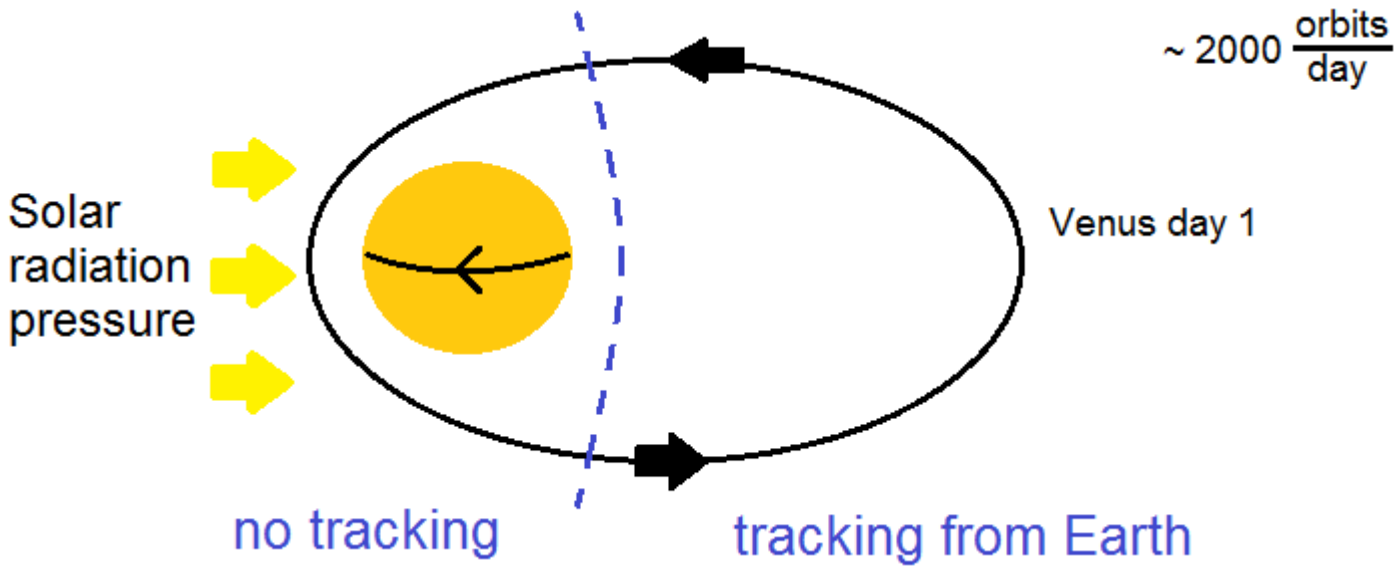
Spin Determination & Variability over Mission (SR 2.1.1)

- 2 methods: orbit determination and surface feature tracking
- Accurate accelerometer to determine shape of orbit
- Radar tracking from Earth to determine position
- Surface passive reflectors to ping with X-band antenna for precise surface reference

| Instrument | Requirement | Resolution |
|---|---|---|
| Accelerometer | < 10 E-5 $m/s^2$ | < 3 E-9 $m/s^2$ |

# SRMP

- Track and match orbit shifts for each Venus day
- Find systematic shifts ("errors") in orbits
- Sum shifts of all orbits for each Venus day
- 1000s of orbits: noise will cancel out



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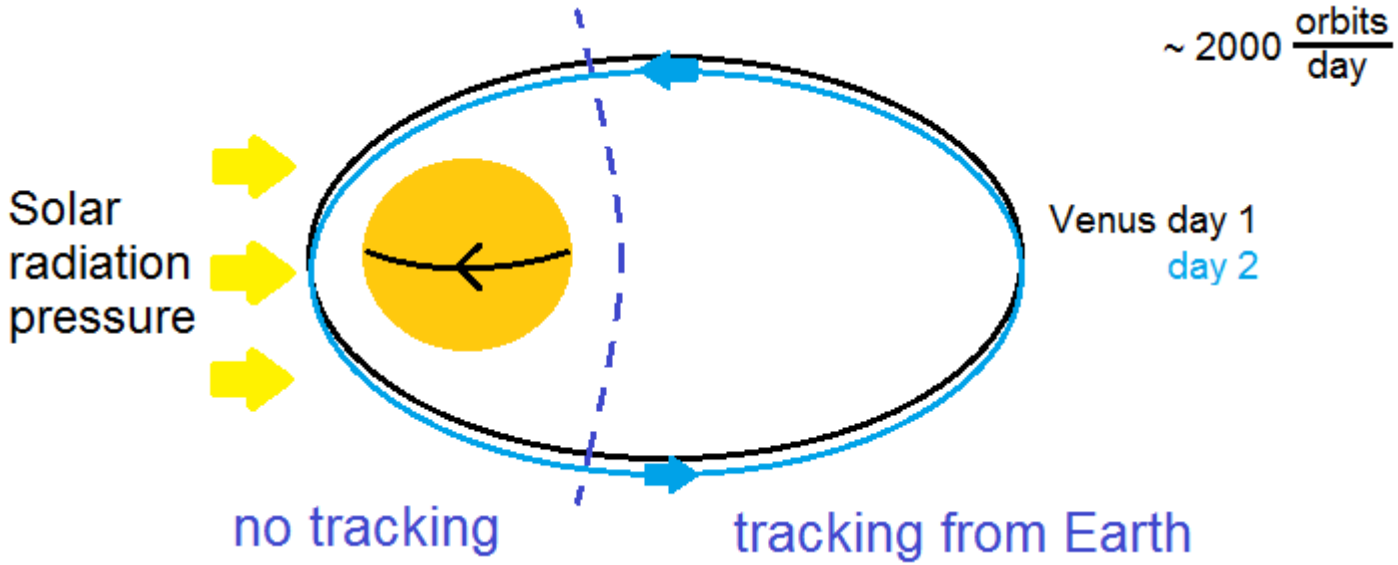

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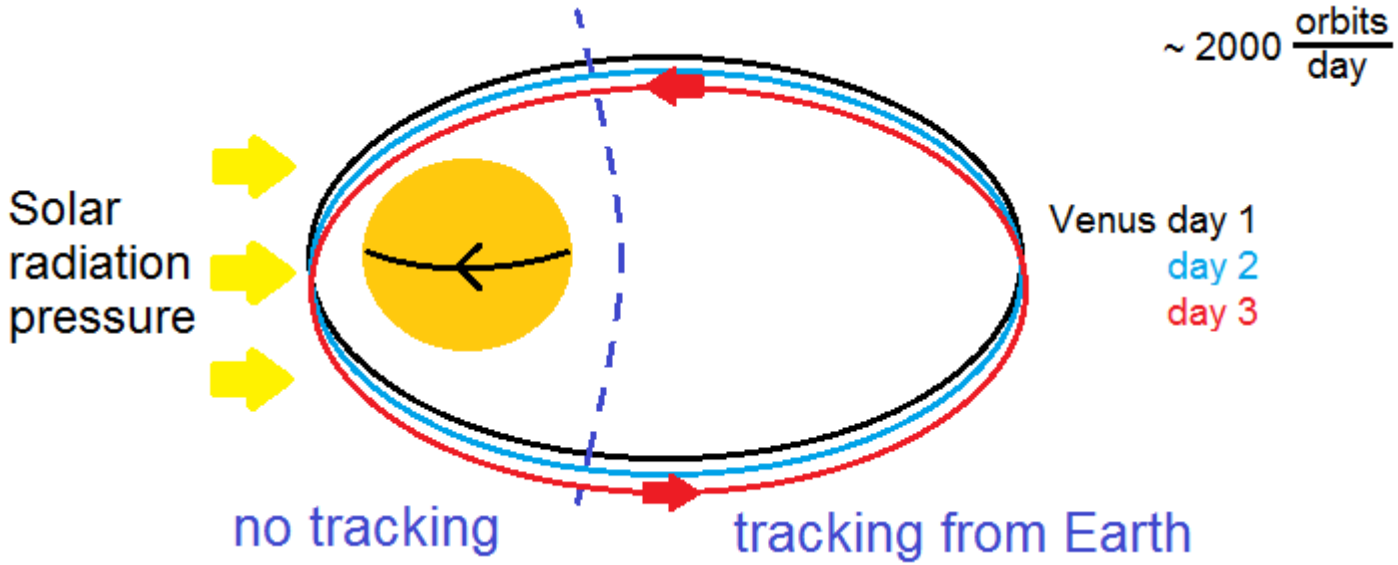


# Adonis Balloon Payload

| Payload | SR 1.1.1 | SR 1.2.1 | SR 1.2.2 | SR 1.2.3 | SR 2.1.1 | SR 2.2.1 |
|---|---|---|---|---|---|---|
| **Adonis Balloon** | | | | | | |
| SRMP<br>+ **Aglaea** 1,2,3 | | | | | ■ | |
| NMS | | | | ■ | | |
| ASS | | | | | | ■ |
| Nephelometer | | | | ■ | | |
| Microflown | | | ■ | | | |
| Context Camera | | | | | | |

# SRMP

***Scientific Requirements:***

Spin Determination & Variability over Mission (SR 2.1.1)
Atmospheric Conditions (SR 2.2.1)

- 3 passive reflectors on surface
- Dropped by balloon at equator equipartially
- 3 times per Venus day:
  High precision positioning of surface probe by X-Band antenna

| Instrument | Requirement | Resolution |
|---|---|---|
| Clock + Electronics | 0.1 ps | 0.1 ps |

# SRMP

***Scientific Requirements:***

Spin Determination & Variability over Mission (SR 2.1.1)
Atmospheric Conditions (SR 2.2.1)

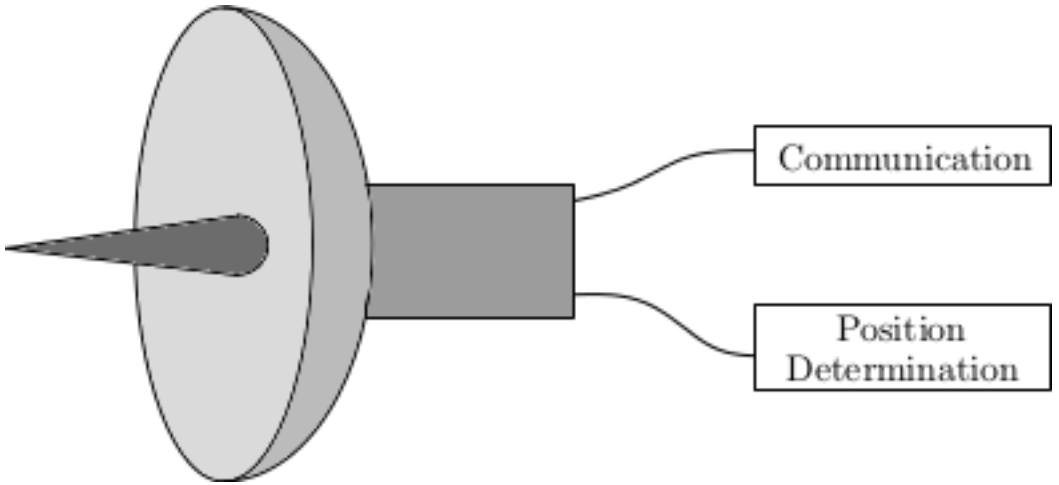
- 3 passive reflectors on surface
- Dropped by balloon at equator equipartially
- 3 times per Venus day:
  High precision positioning of surface probe by X-Band antenna
- Could also be detected by radar from Earth


| Instrument | Requirement | Resolution |
|---|---|---|
| Clock + Electronics | 0.1 ps | 0.1 ps |

# SRMP: Aglaea

**X-band antenna:**

- Needed for distance determination to probe
- Available from communication system
- Use clock and electronis of a radar altimeter, connect it to x-band antenna
- X-band antenna must be able to switch from sender to receiver within 2 ms ( ~distance / time of flight)

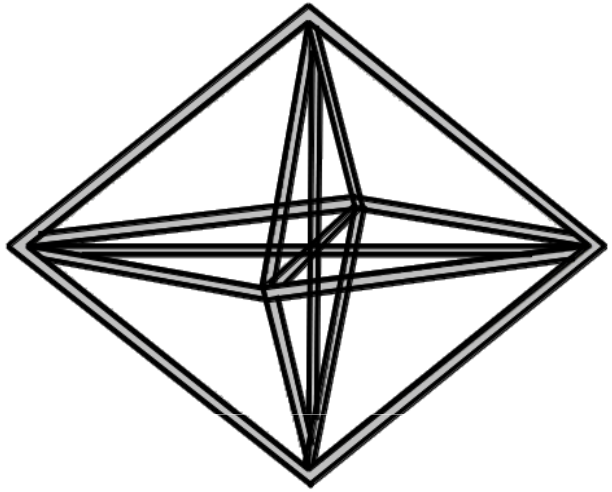


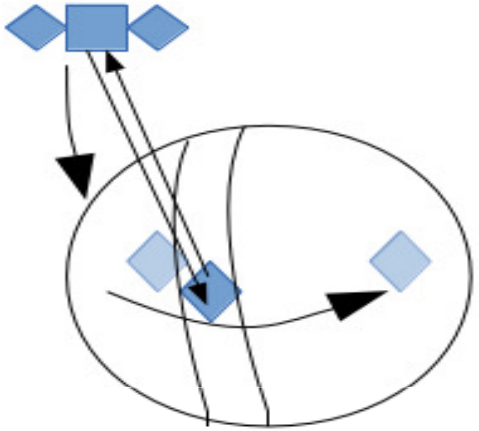
# SRMP: Aglaea

**Probe Design**:

- Material: TiO2

- Reflecting:
- Octahedral corner reflector





| Mass | Size | Melting Point | Hardness | Dielectric constant |
|---|---|---|---|---|
| 5 kg | (25 cm)^3 | 1855 °C | 40 GPa | 80 - 170 |

# Atmospheric Science Suite

***Science Requirement:***

Atmospheric Conditions (SR 2.2.1)

| Instrument | Requirement | Sensitivity | Range |
|---|---|---|---|
| Pressure Sensor | 0.1 bar | 0.1 mb up to 0.1 bar<br>25 mb up to 92 b ar | 0.01-1 bar<br>0.1-10 bar<br>1-100 bar |
| Temperature Sensor | 1 K | 1 K | 150-750 K |
| Wind Speed Sensor | 1 km/h | 0.18 km/h | |

# Mass Spectrometer

**Neutral Mass Spectrometer (NMS) + Tunable Laser Spectrometer (TLS)**

***Scientific Requirement:*** Chemical composition (SR 1.2.3)***:***
chemical and isotopic composition of the atmosphere

→ link to volcanic processes, evolution of the atmosphere

*Heritage:* Huygens, adapted for Venus chemical composition

Improved accurancy compared to: *Pioneer Venus and Venera 13-14*

| Species / Ratio | Requirement | Sensitivity |
|---|---|---|
| $H_2O$ | 30 ± 15 ppm (1-4 ppm in clouds) | < 5% |
| $SO_2$ | 150 ± 30 ppm | <10% |
| D/H | 0.016 ± 0.002 | <1% |
| $^{16}O/^{18}O$ | 500 ± 80 | <0.1% |
| $^{32}S/^{34}S$ | n.n. | <0.2% |

# Polarization Nephelometer

***Scientific Requirement:*** Chemical composition (SR 1.2.3)

Sample gas from the atmosphere,
Illuminate with laser and measure light scattering

*Heritage:* already flown on planetary missions.
Identified study to augment capabilities to desired resolution[1)].

| Requirement | Sensitivity | Range |
|---|---|---|
| 0.1 µm | 0.1 µm | 0.1 µm to 10 µm |

Integration time between two samples: 100s

Reference:
1 Banfield , Planetary Polarization Nephelometer, 2005

# Microflown Infrasound Detector

***Science Requirement:***

Physical parameters (SR 1.2.2)

- Listen to acoustic waves

| Sensitivity | Range |
|---|---|
| 0.01 Hz | 0.1-10 Hz |

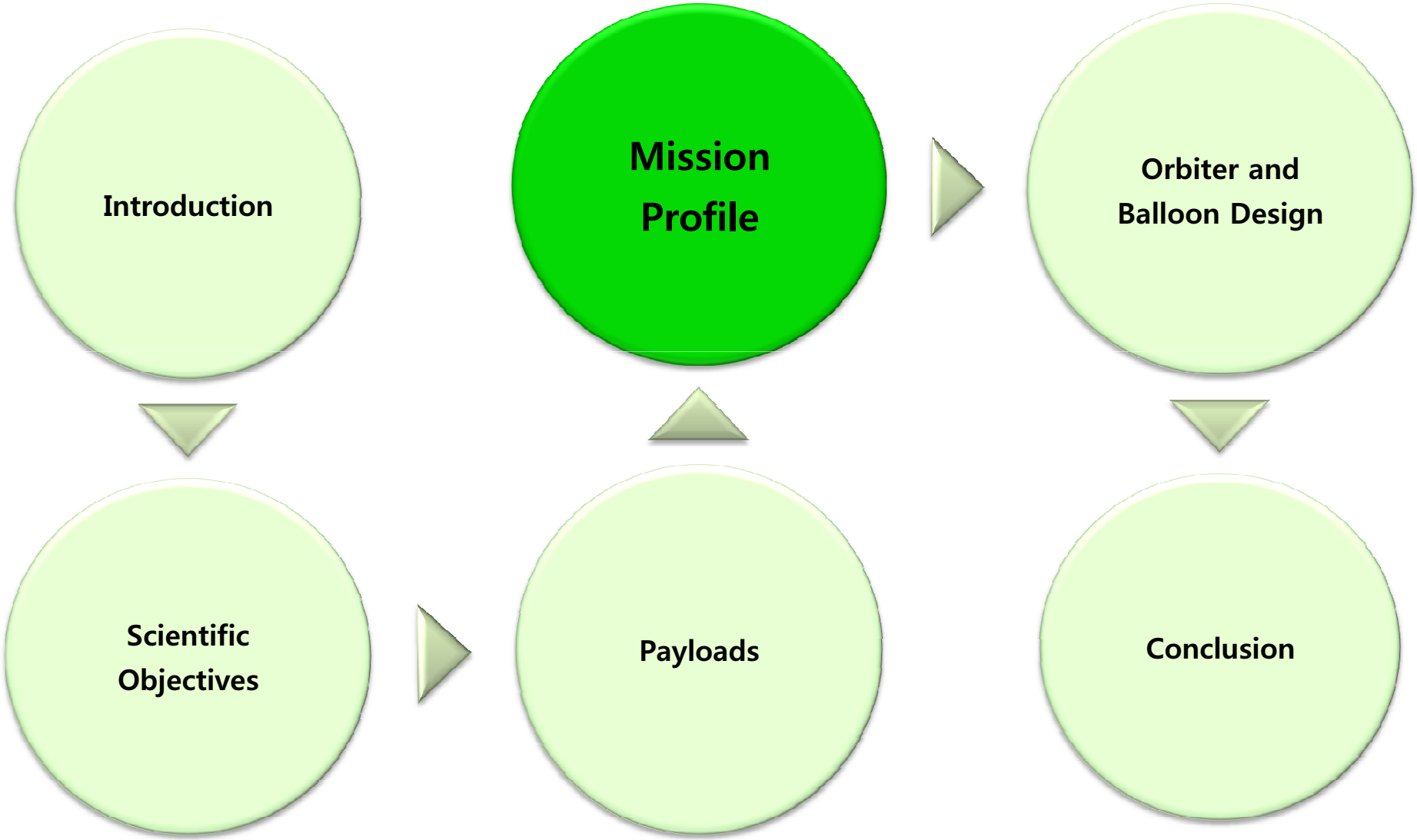
# Context Camera

***Purpose:***

- Provide context for other measurements
- Pictures of/inside clouds

| Resolution | Wavelength |
|---|---|
| 1 megapixel | visible / UV |

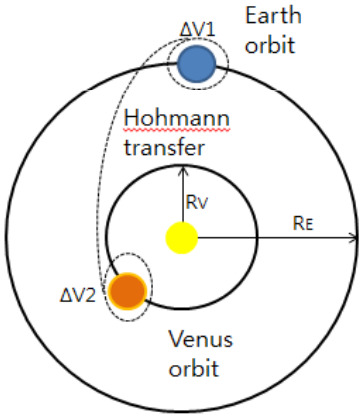
# Aphrodite Mission

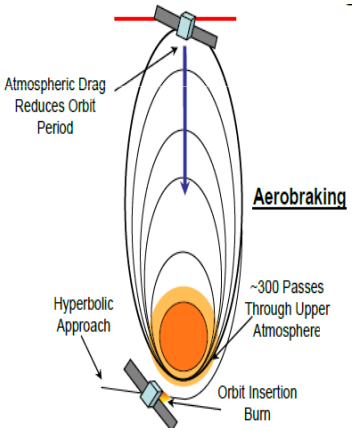


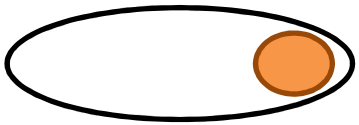
# Timeline

Hohmann transfer

Venus final orbit and commissioning phase



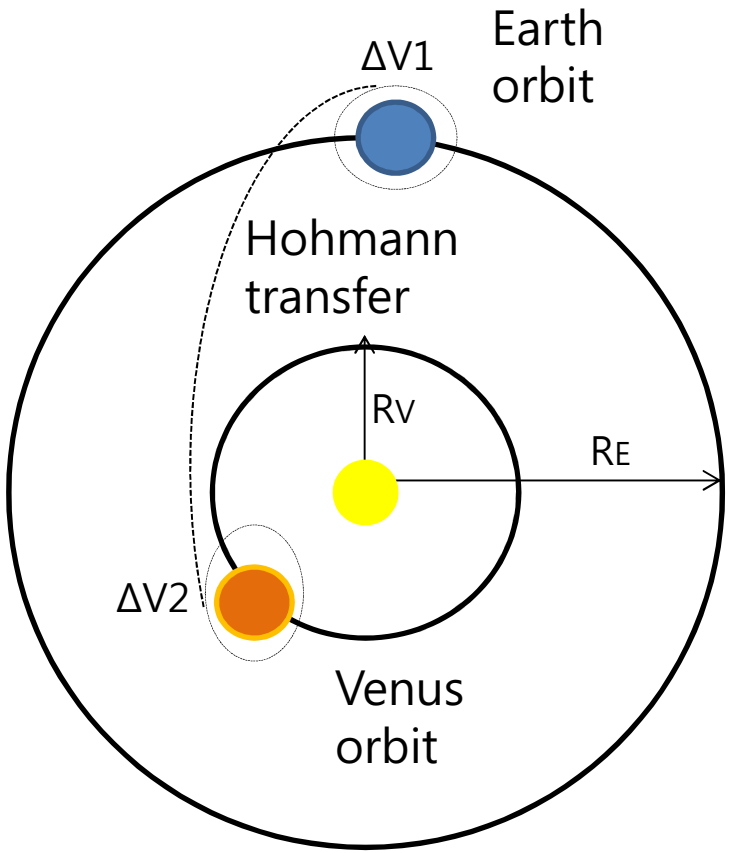

3 years operation

Balloon release
25 days joint science operations

Launch

Aerobreaking

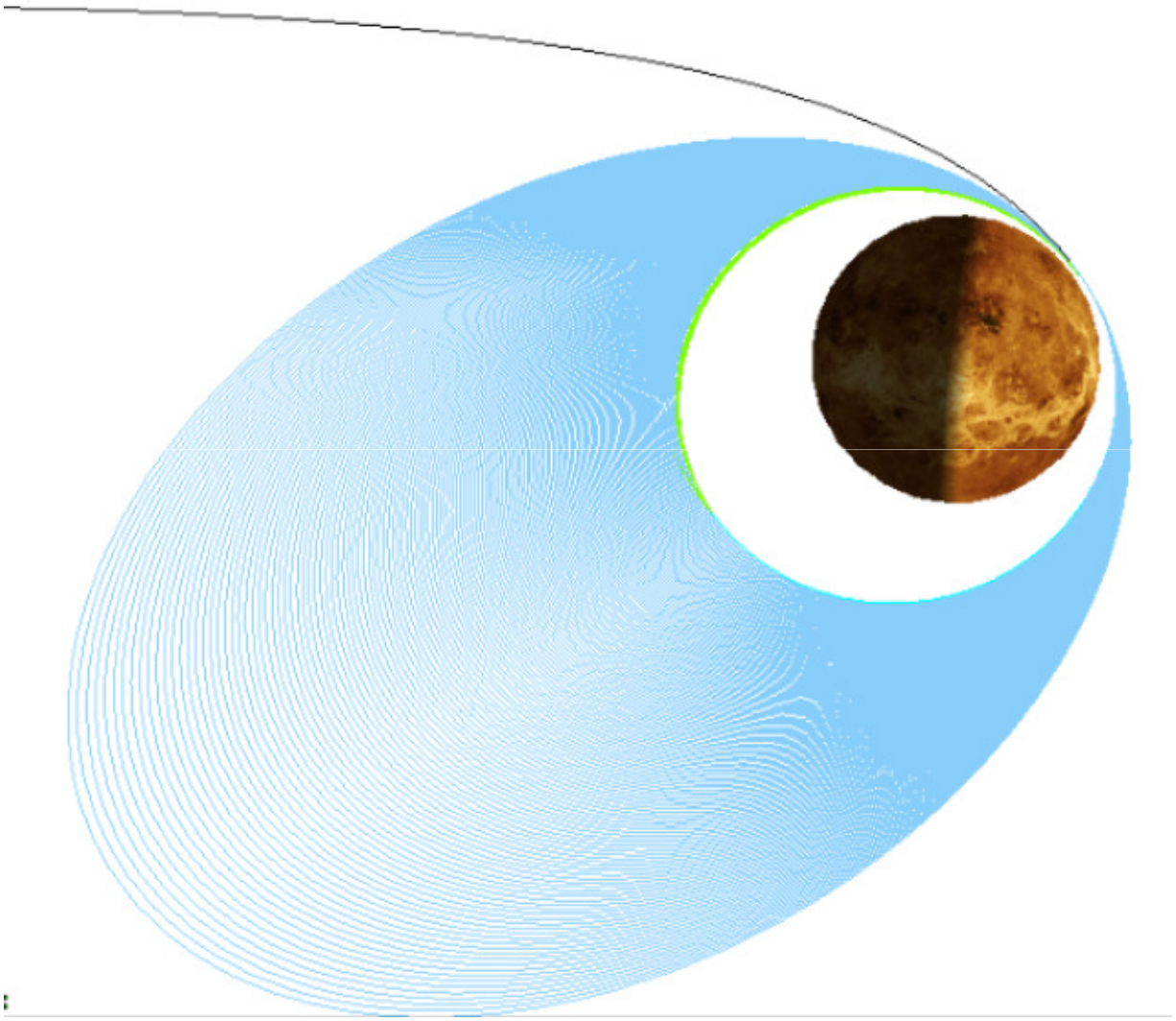
# Hohmann transfer




- **Hohmann transfer** to Venus sphere of influence in a hyperbolic trajectory
- Low propellant usage to transfer between planetary orbits
- **Ending 3 Apr 2033**

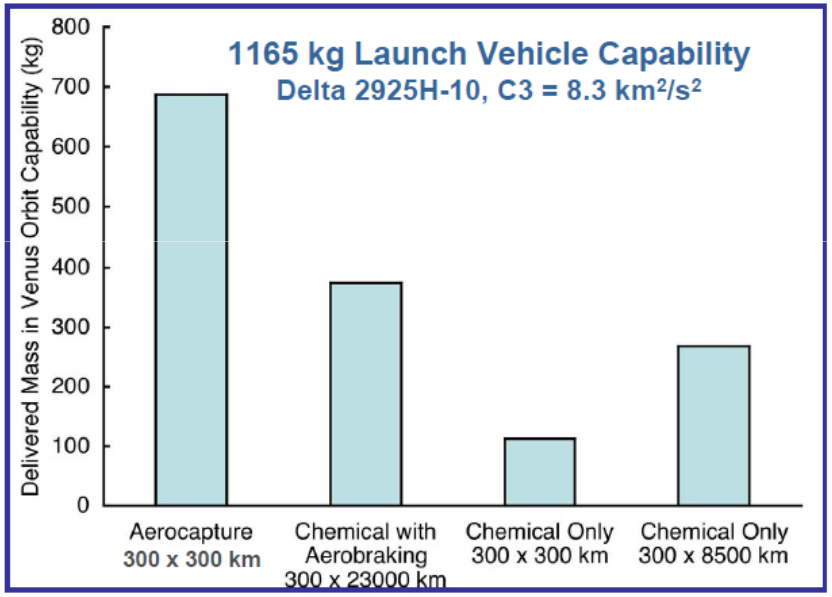
  **Δv = 2.7 km/s**

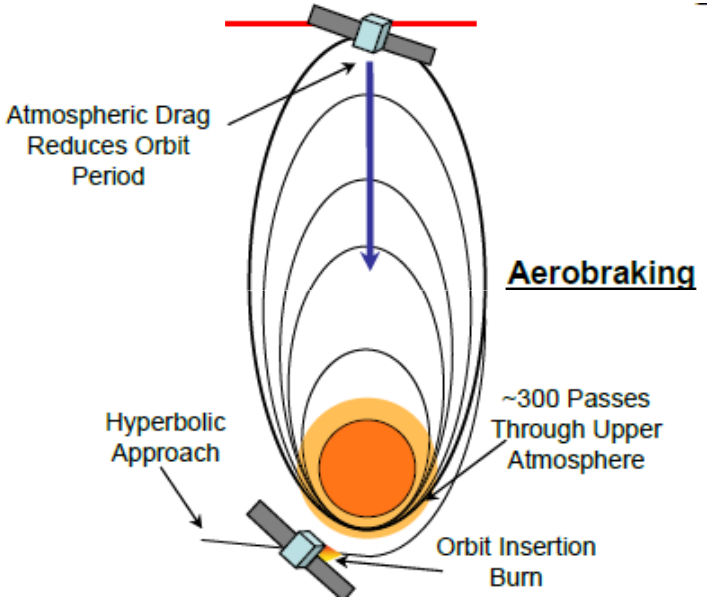
# Aerobreaking



# Aerobreaking

- This is a low fuel-use method to decrease the apoapse of the Venus orbit.




**Ending 11 August 2033**

**Δv = -1 km/s**

# Venus Orbit

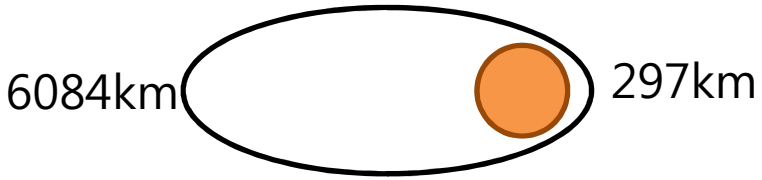
- When apoapse is 6000km,
  burn to raise the periapse above the atmosphere
  and achieve the final orbit
- Periapsis 297km Apoapsis 6084km

- **Ending 18 September 2033**

  **Δv = 0.05 km/s**

# Venus Orbit Parameters

- Periapsis – 297 km
- Apoapsis – 6084 km
- Semi-major axis – 9242 km
- Eccentricity - 0.31
- Period – 2.72 hours
- Max velocity – 8.2 km/s
- Min velocity 4.3 km/s
- Ground speed at periapsis – 776 km/s
- Inclination - 78°




Mission lifespan 3 years once parking orbit has been ac hieved.

Orbit maintenance requires **Δv = 0.01 km/s** per year

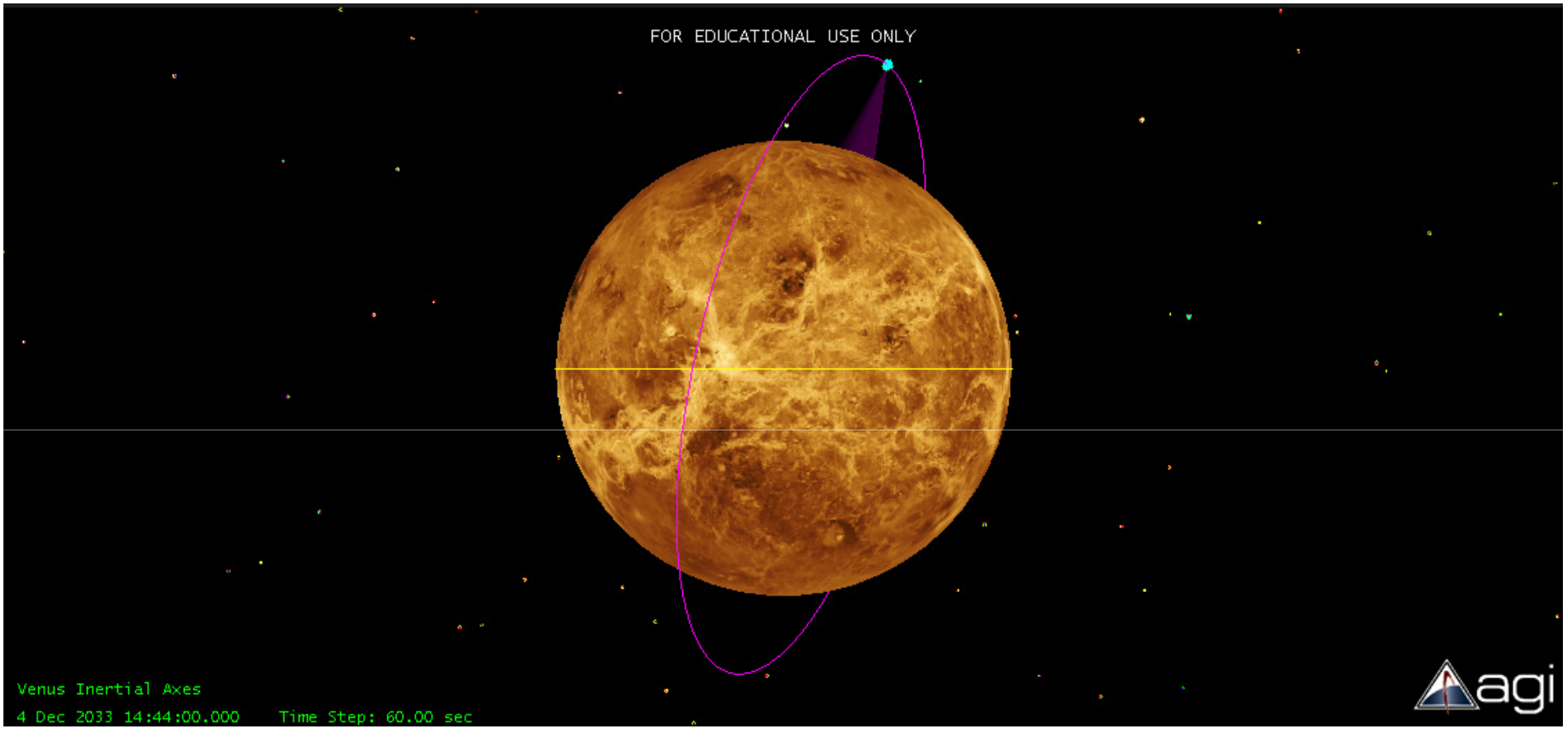
# Propulsion

- This orbit requires a propulsion method with at least 500N thrust. 526kg of fuel necessary.
- European Apogee Motor uses bipropellant MMH and MON (Monomethyl Hydrazine and Mixed Oxides of Nitrogen)

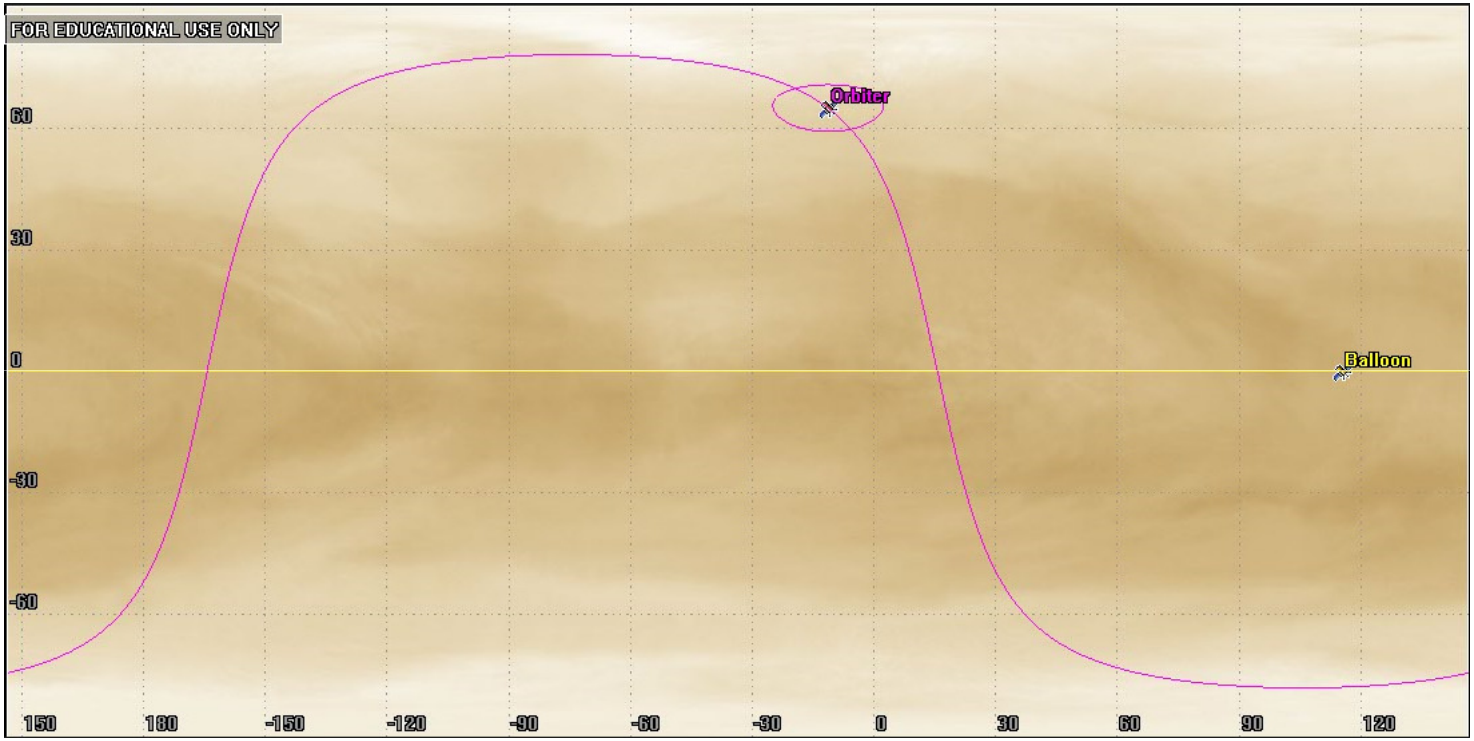
  - isp 325s

| Manoeuvre | Delta-v(km/s) | With margin (km/s) | Prop. Used (kg) |
|---|---|---|---|
| Venus targetting | 0.004 | 0.0042 | 2 |
| Aerobreaking entry | 1 | 1.05 | 425 |
| Aerobreaking exit | 0.05 | 0.053 | 18 |
| Perigee raising | 0.006 | 0.0063 | 2 |
| Maintenance (/year) | 0.01 | 0.02 | 4 |
| Total | 1.066 | 1.129 | 451 |

# 3-D STK


FOR EDUCATIONAL USE ONLY
Venus Inertial Axes
4 Dec 2033 14:44:00.000
Time Step: 60.00 sec
agi

# 2-D STK


FOR EDUCATIONAL USE ONLY
Orbiter
Balloon
60
30
0
-30
-60
150
180
-150
-120
-90
-60
-30
0
30
60
90
120

# Balloon Release

- Balloon is released at apoapse.
- The balloon fires entry thrusters
  ➔suitable atmospheric entry angle
- Protected by Thermal Protection Shell

# Balloon EDI

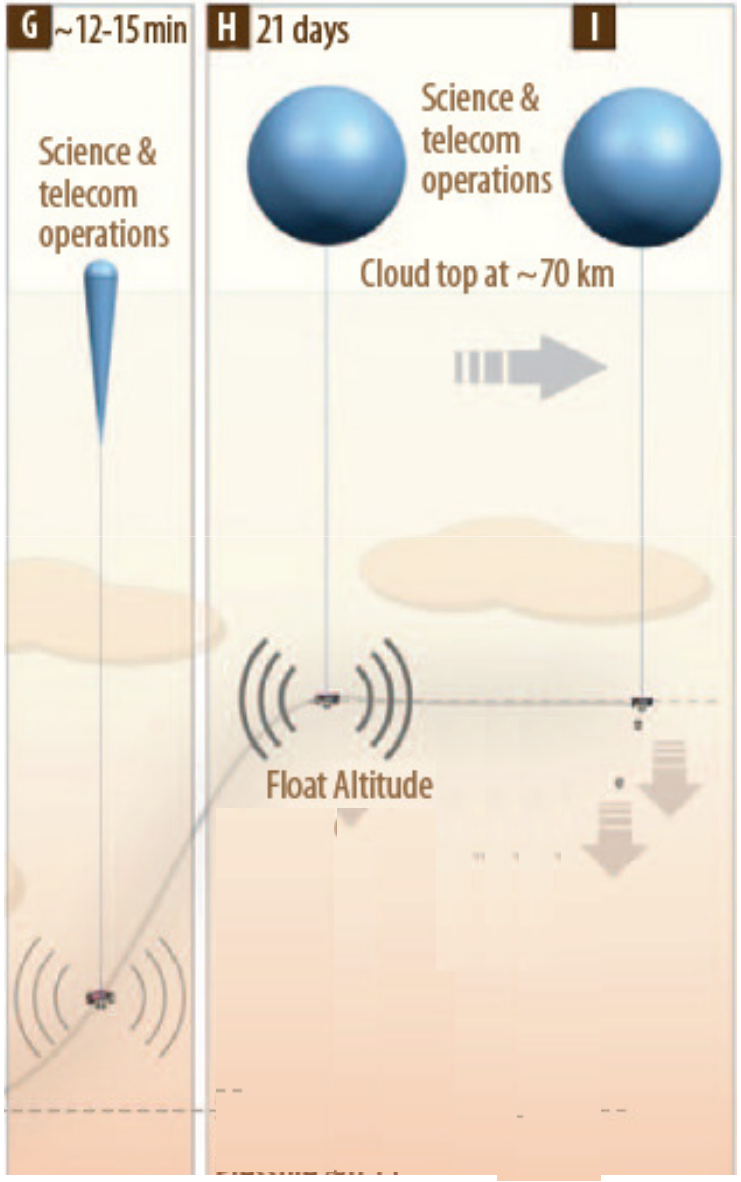
- Atmospheric drag slows the probe
- stabilised during transonic regime by drogue chute
- The Thermal Protective Shell separates

# Balloon EDI

- Main subsonic parachute deploys
- balloon begins inflation
- Parachute is jettisoned before positive buoyancy is achieved

# Balloon EDI

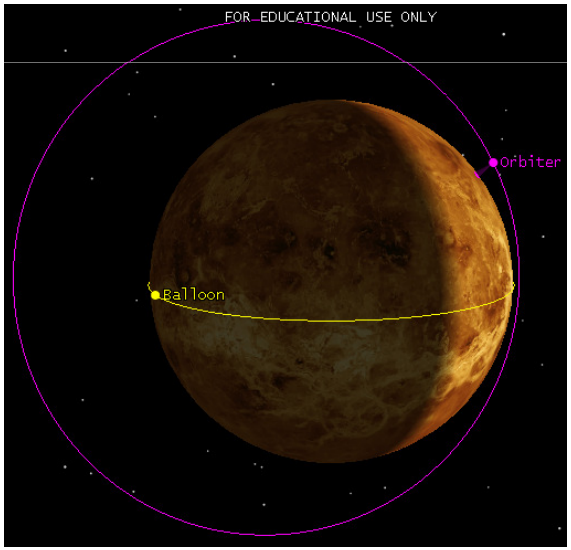
- Balloon fully inflated
- Stable altitude is reached
- Science operations begin

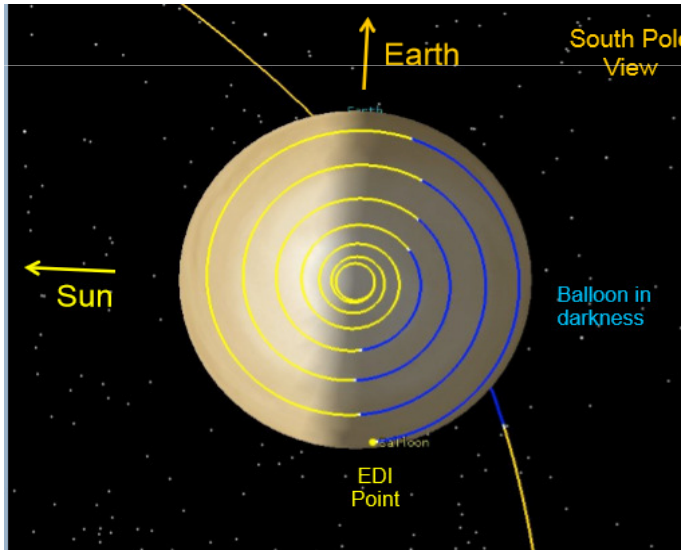


# Balloon mission overview

- Zonal and Meridional winds

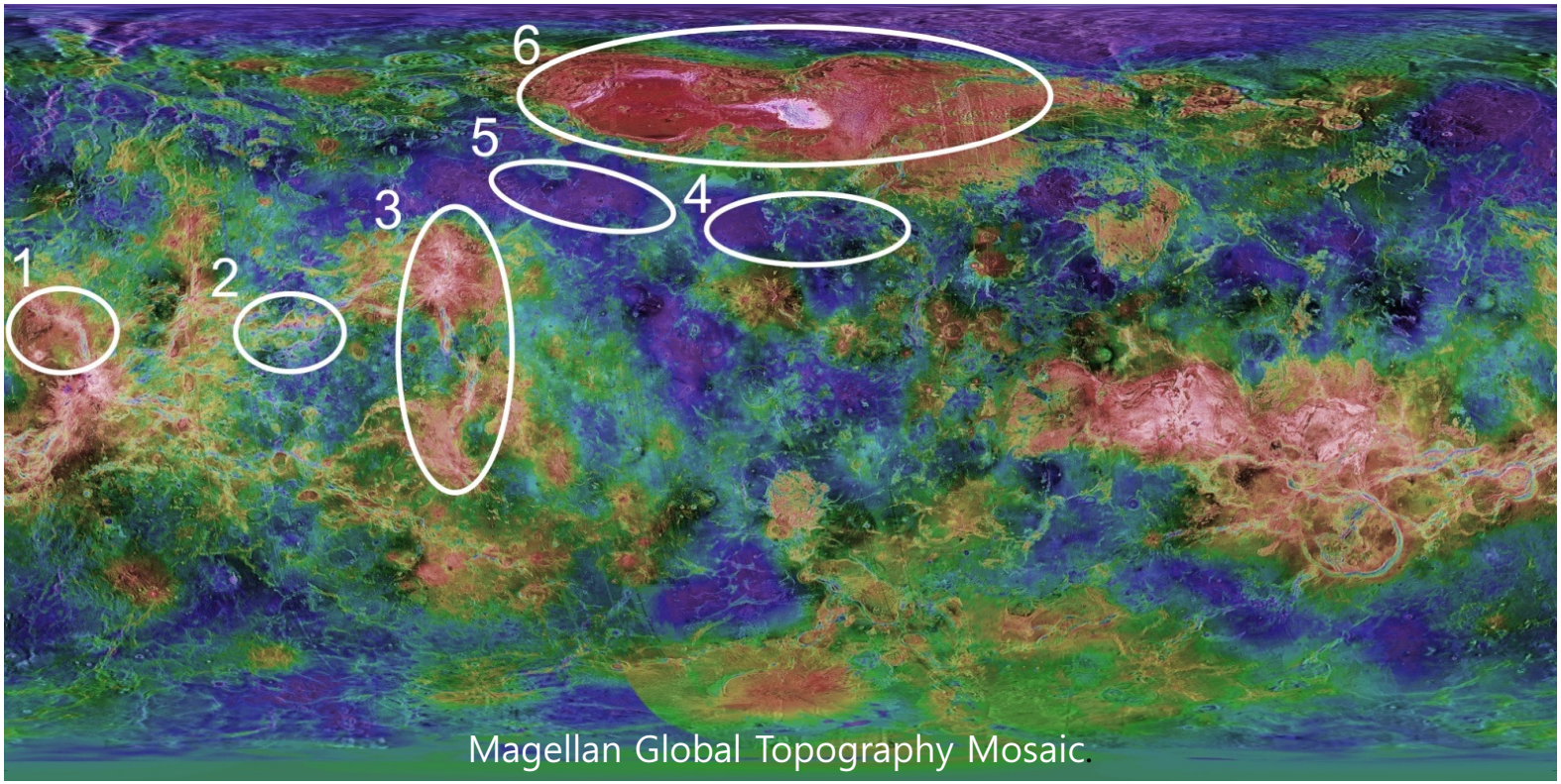
- The balloon gradually spirals towards the North pole during its 25 day duration.



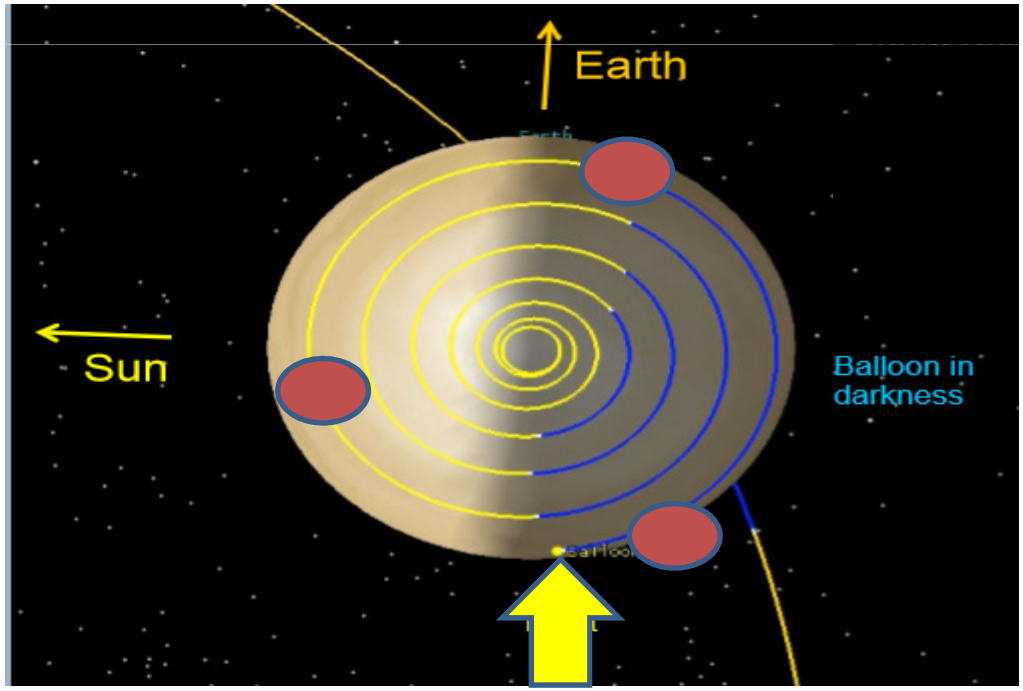
# Exploration of the N-hemisphere

- *Why explore the northern hemisphere?*
  - Active volcanic region candidate: Ganiki Chasma, Atla Regio [1]
  - Similar geological structures resembling Ganika Chasma [2 & 3]
  - High distribution of coronae structures [4 & 5]
  - Tessera regions [6]
  - Wave-like structures (60°-80° N) in the atmosphere above Ishtar Terra. [6]



# Reflector deployment

- During first 2 days
- 3 reflectors separate from gondola and free fall to the surface.
- They are distributed at 120° intervals around Venus equator



# End of Mission for Adonis

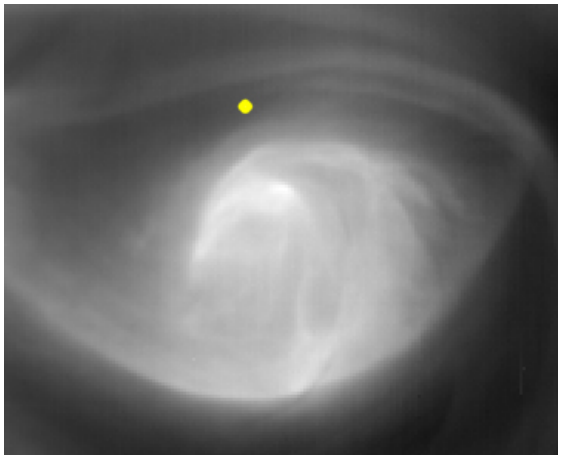
Expected lifespan: 25 days
Expected final location: in North polar vortex and < 50 km

**free fall descent to the surface**

- Gondola disconnected from balloon
- Real time communication to orbiter
  - line of sight time window: 12min
  - expected free fall time: ~5min
- Operational payload during descent:
  - Atmospheric suite
  - Context Camera
  - Infrasound Detector

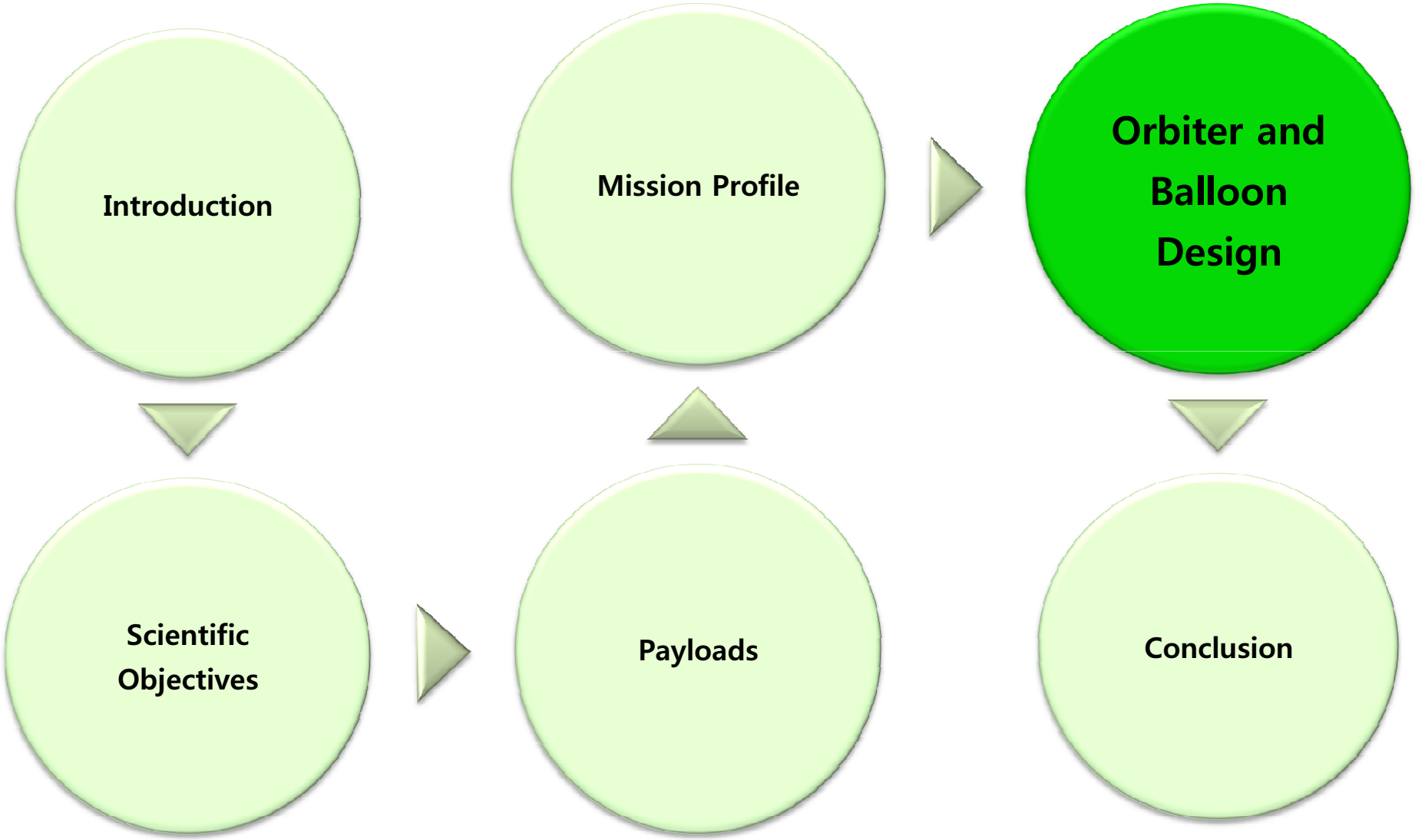
*Scientific objectives:*

- vertical temperature, pressure and density profile
- descent imagery and sound

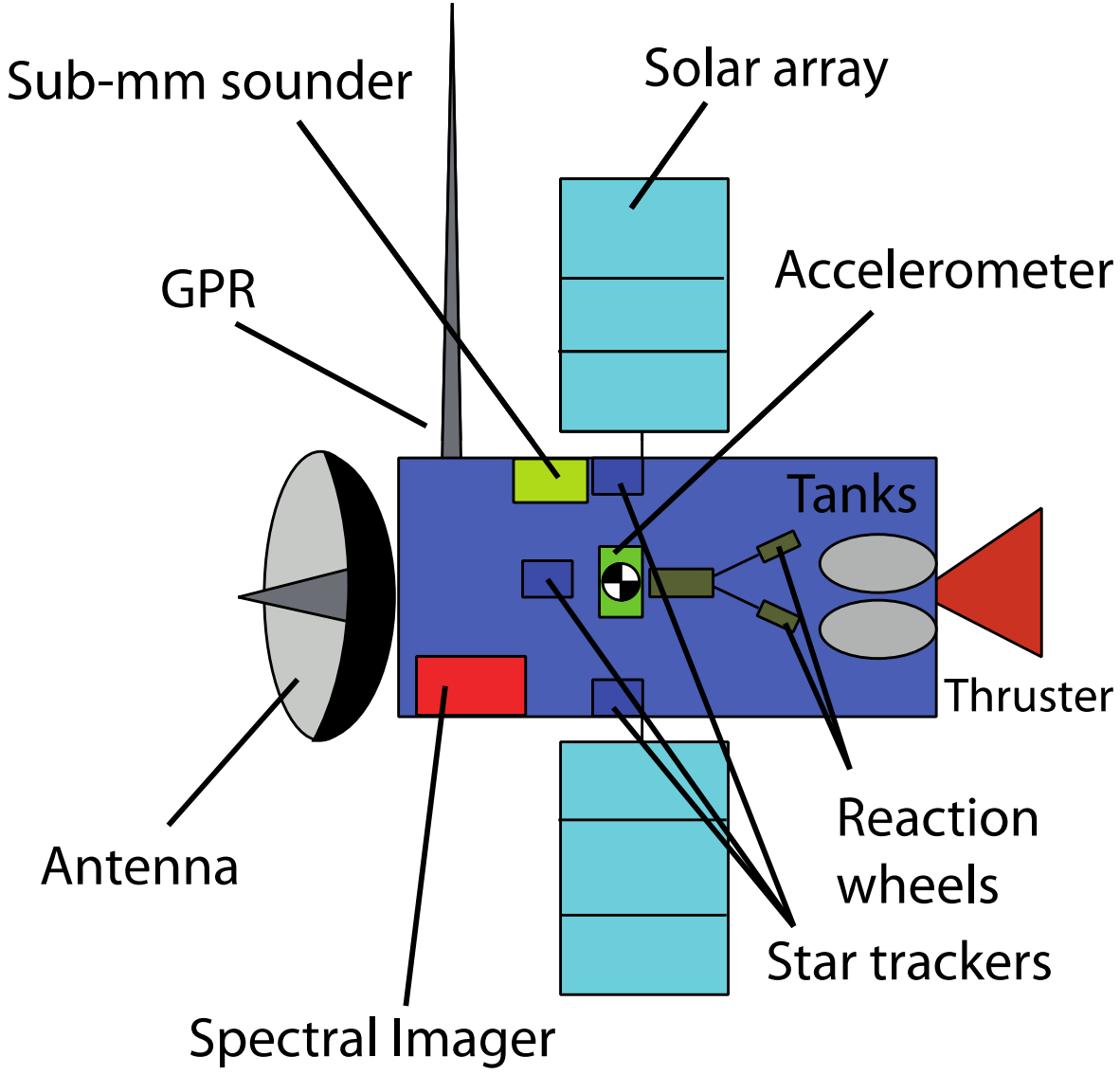


Venus's polar vortex
ESA/VIRTIS/INAF-IASF/Obs.de.Paris-LESIA/Univ.of.Oxford

# Aphrodite Mission



# Hephaestos design



# Hephaestos design

**Attitude and Orbit Control**
(3-axis-stabilisation):
VenusXpress heritage
**Sensors:**
- 3 Star trackers,
- Sun sensors
- Inertial measurement units

**Actuators:**
- 4 reaction wheels (periapse rate of change = 1,8°/s)
- 4 redundant thrusters (hydrazine, 10N)
- Bi-propellant European Apogee Motor (500N, 325 Isp, 5kg)

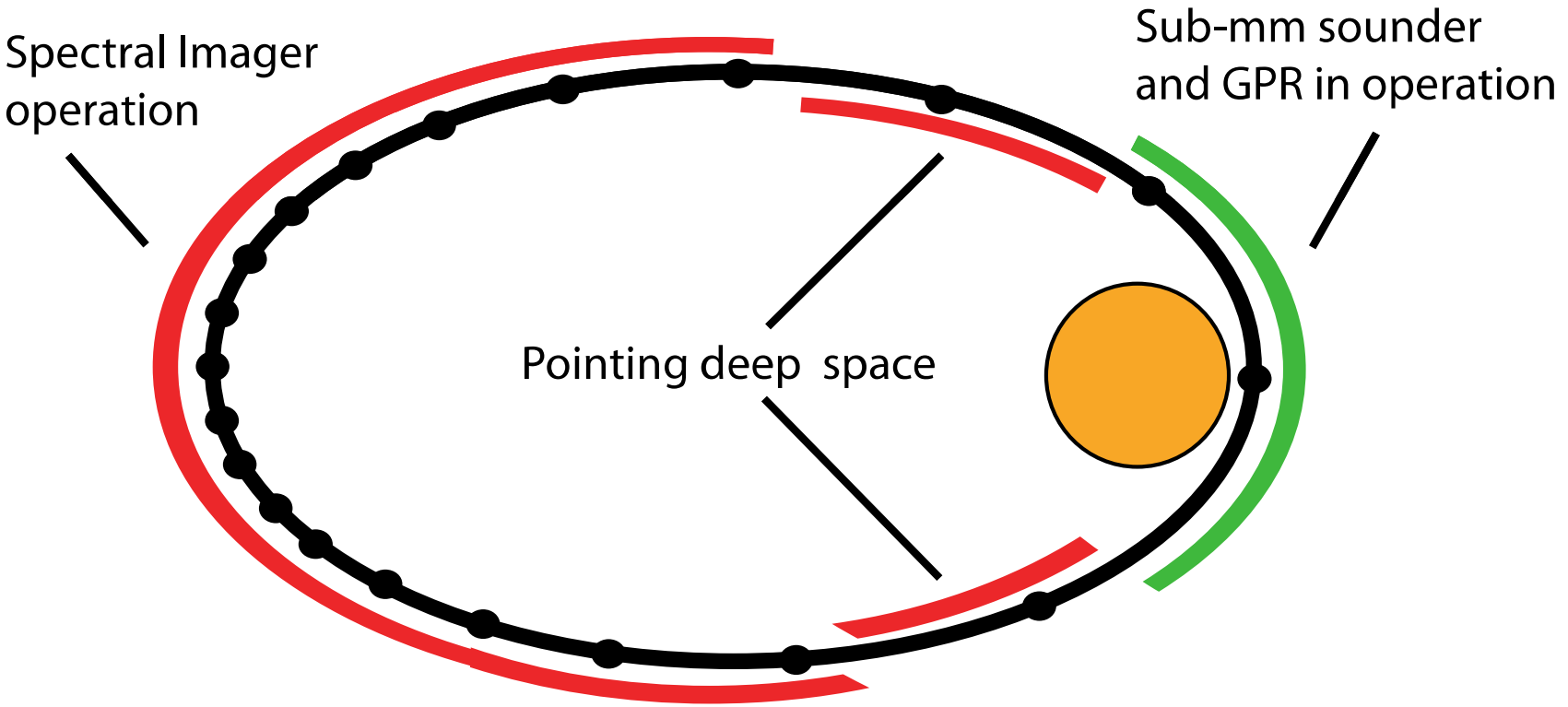
# Operational Strategy

- Orbit period – 2.7 hours
- Balloon period – 4 days

1. Science instrument requirements
2. Data uplink and downlink

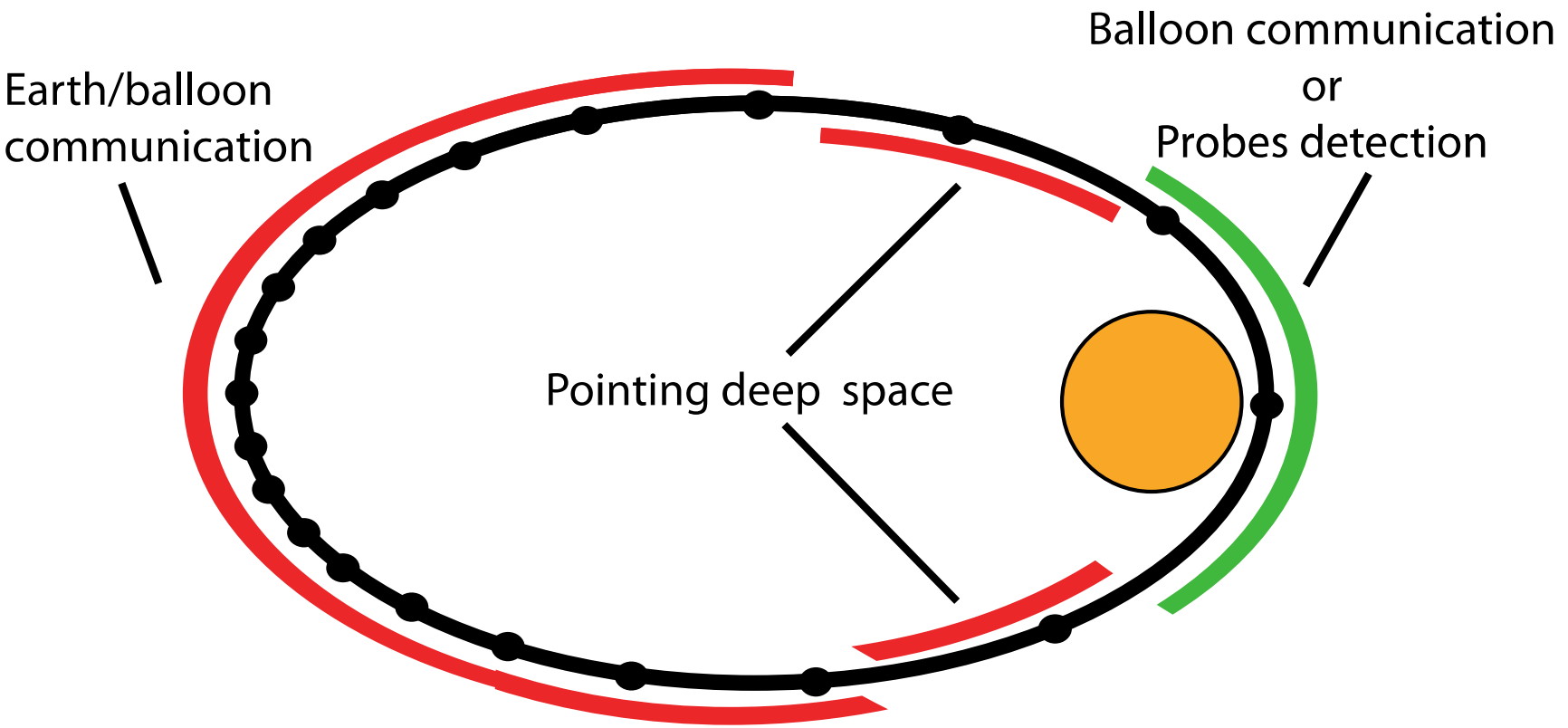
# Operational Strategy

Science investigation orbital mode (16h/day):



# Operational Strategy

Communication orbital mode (8h/day):



# Operational Strategy

**Orbiter Communication System**

- X-Band High Gain Antenna Diameter: 2 m
- Transmitting Power: 65 W to Earth
- Minimum Downlink (at 1.72AU): 76.59 kbps
- Low Gain X- Band Antenna as a back-up

Ground Station Network:

- ESTRACK (8 hour slot)
- Cebreros, New Norcia, Marlargüe
- 35 m antennas
- X-Band frequency

Mission Control Centre:

- ESOC

# Operational Strategy

- Downlink for Average Distance Range (0.99 AU): 233.43 kbps
- Data Transmission to Earth for 6 hrs/day (2 hrs of no data generation)
  ➔ 840 Mb/hr (5040 Mb daily data transmission)

| | Instruments | Data Rates (kbps) | Operational Time (%) | kb Generation /orbit |
|---|---|---|---|---|
| **Orbiter** | GPR | 375 | 10 | 364 500 |
| | Spectral Imager | 80 | 50 | 388 800 |
| | Accelerometer | 0.32 | 100 | 3 110.4 |
| **Balloon** | Neutral Mass Spectrometer | 1.50 | 10 | 0.15 |
| | Nephelometer | 2 | 10 | 0.20 |
| | Atmosphere Science Package | 2.55 | 10 | 0.255 |
| | Camera | 2 | 10 | 0.20 |
| **Total** | | 464 kbps | | 756 Mb/orbit |

- Data Generation for 16 hrs/day
  ➔ 756 Mb/orbit (4480 Mb daily data storage)

# Hephaestos Power System

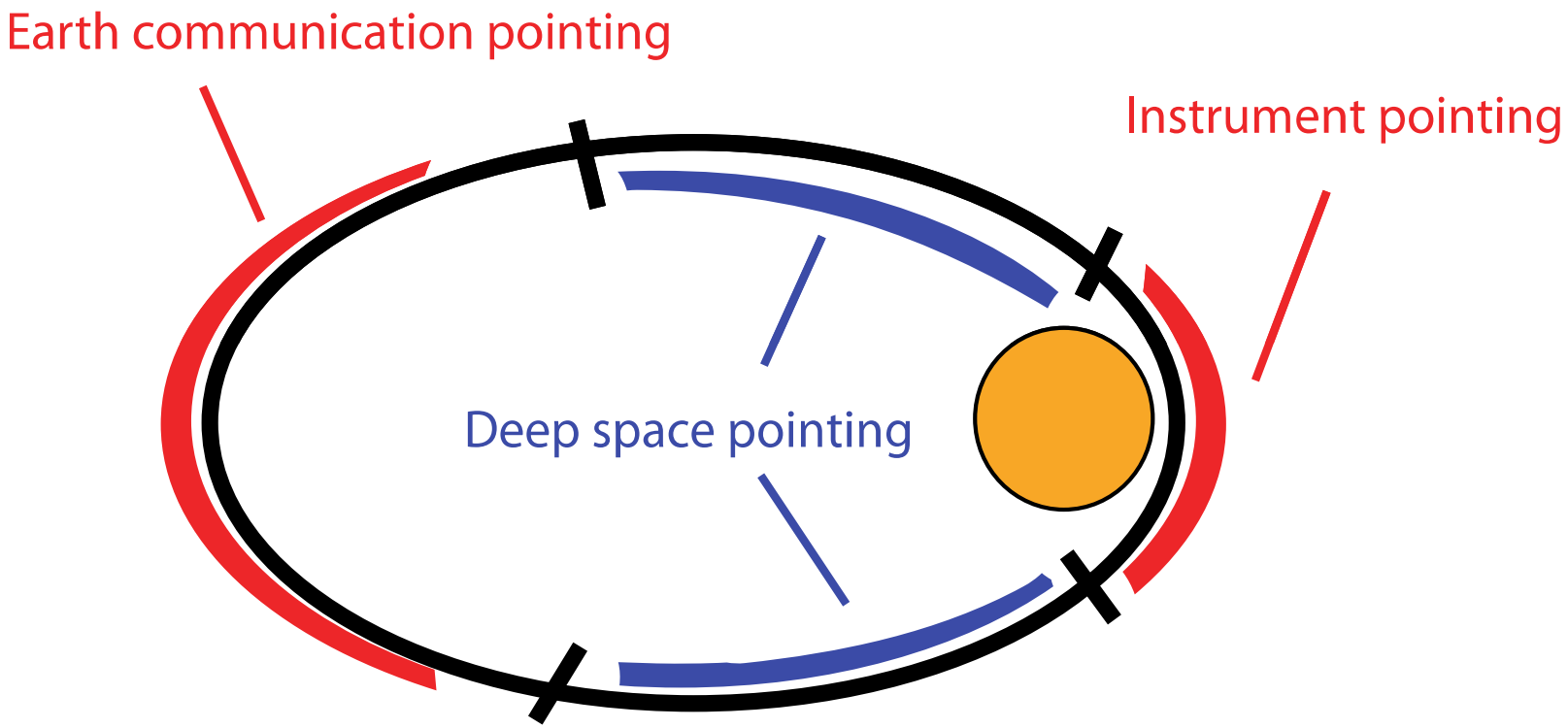
| | Power (including margins) (W) | Duty Cycle | Average Power per orbit |
|---|---|---|---|
| Payload | | | |
| GPR operational | 34 | 10% | 9 |
| GPR heater + stdby | 12 | 90% | 29 |
| Spectral Imager | 43 | 50% | 58 |
| Submm sounder | 25 | 50% | 34 |
| Accelerometer | 18 | 100% | 49 |
| Probe Detection Package | 240 | 1% | 6 |
| AOCS | 72 | 75% | 233 |
| OBDH | 18 | 100% | 49 |
| Comms | 180 | 30% | 146 |
| Power dist. + thermal ctl. | 36 | 100% | 97 |
| Total (W) | | | 711 |

# Hephaestos Power System

- Solar array
  - Large voltage range due to the wide range of temperatures
  - Improved Triple Junction GaAs
    - Efficiency EOL 24.3%
    - Reiforced because of aerobraking
    - Total size and mass: 6 $m^2$; 35 kg
- Battery
  - Low-mass 24 Ah Li-ion
  - Specific energy density : 70-110 Wh/kg
- Power distribution system

# Thermal control (1)

- Spacecraft pointing for radiate cooling



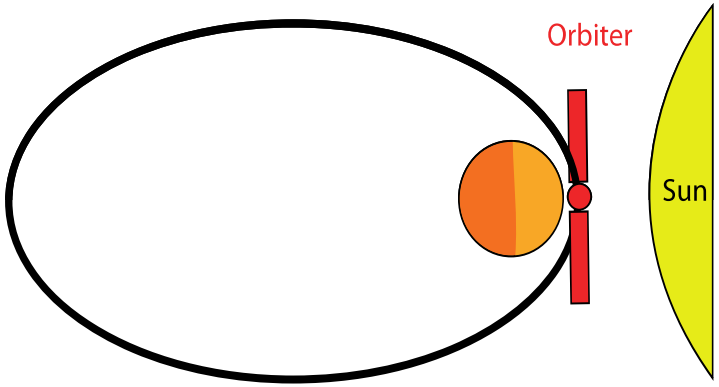

Solar power intensity : $J_s$=1320-2655 W/m$^2$ (Earth - Venus)

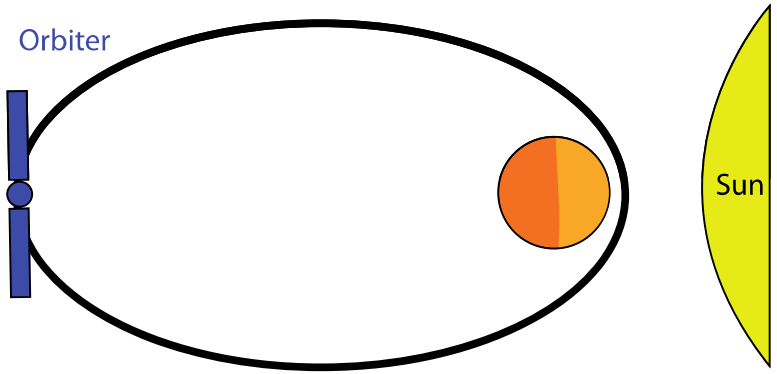
Avg Venus albedo a = 0.61

# Thermal control (2)

- Hot case at venus
  - Max albedo from Venus
  - Max sun radiation

- Cold case at venus
  - Nigh time
  - Furthest from the sun




- excess heat needs to be evacuated
batteries < 25 °C,
hydrazine tanks and lines < 50°C

- Orbiter components and structure must be heated

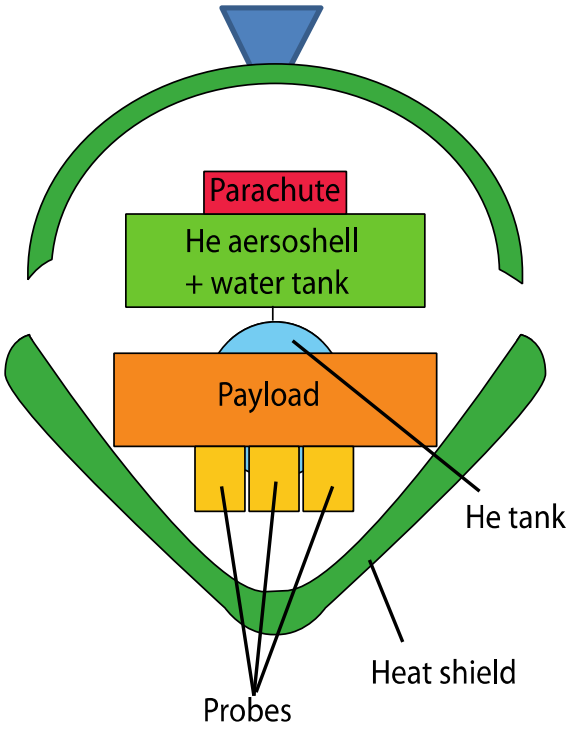
***Passive thermal control***
-Radiators and caloriducs
-Multi-Layer Insulation (MLI) blankets
***Active thermal control*** Spectral Imager (operating temperature of 60K) and spacecraft

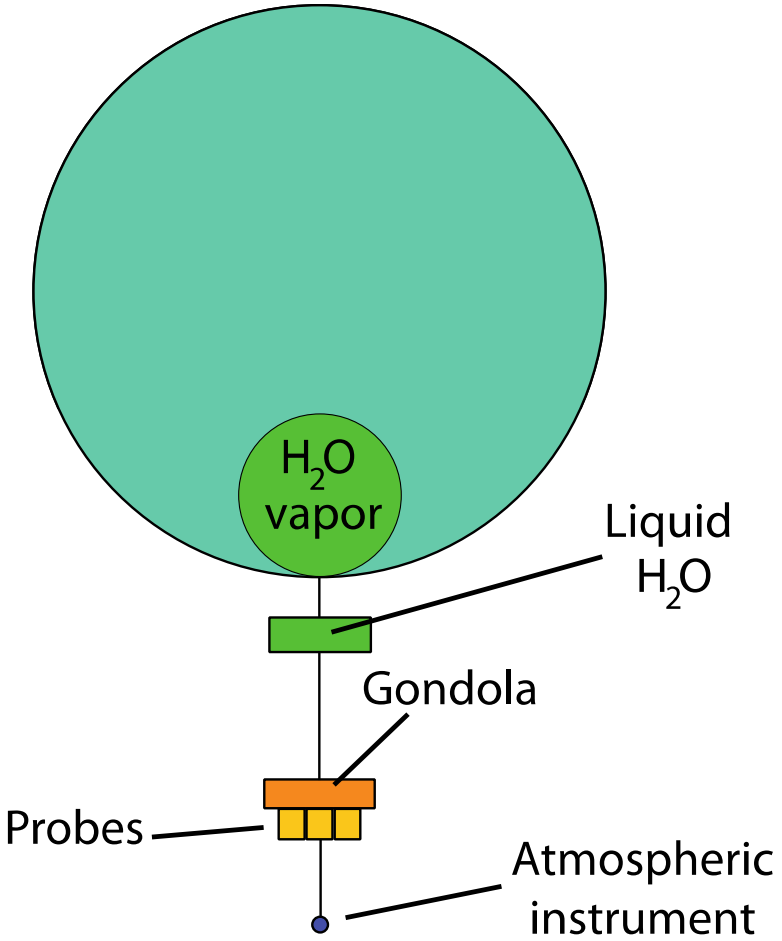
Total mass estimation: 76,5 kg

# Hephaestos mass budget

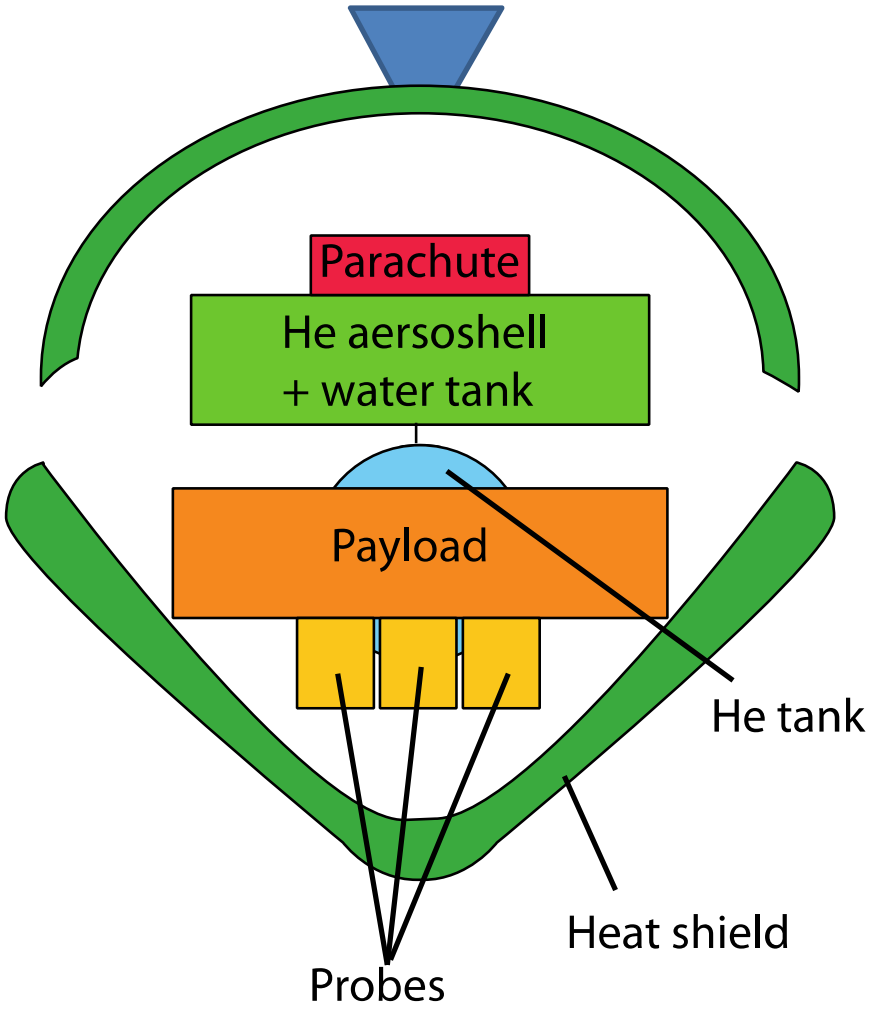
| | Weight including margins (kg) | TRL |
|---|---|---|
| Payload | | |
| Spectral Imager | 32 | 6 |
| GPR | 21 | 8 |
| Submm sounder | 8 | 6 |
| Accelerometer | 18 | 8 |
| Probe Detection Package | 4 | 4 |
| AOCS | 34 | |
| Comms | 24 | |
| OBDH | 2 | |
| Engine+ tank | 55 | |
| Structure + thermal | 504 | |
| Power system | 64 | |
| Total | 756 | |

# Balloon and Entry System Design



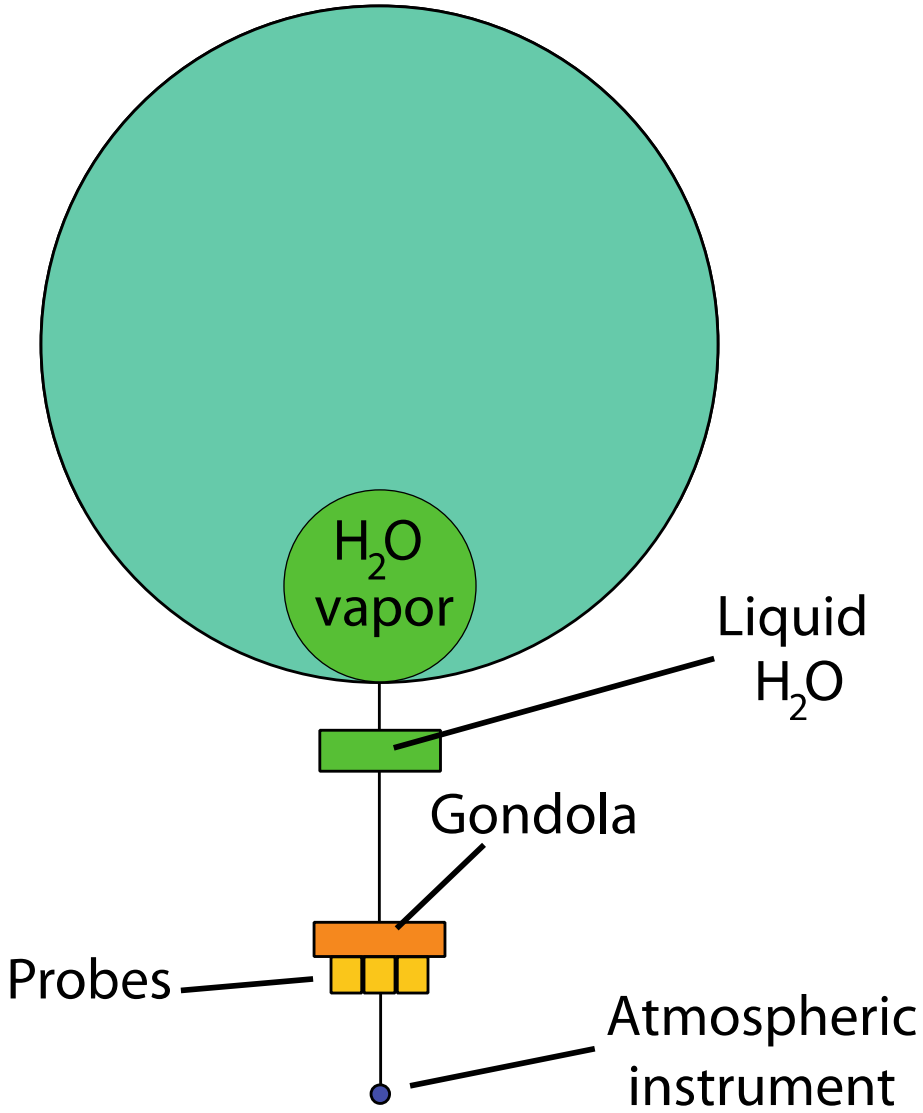



# Entry system




- Entry thruster:
  1N Isp=220 ΔV=36m/s
- Thermal Protection Shell
- releasable Helium tank

# Balloon Adonis




- Primary envelope 5m
  - He gas

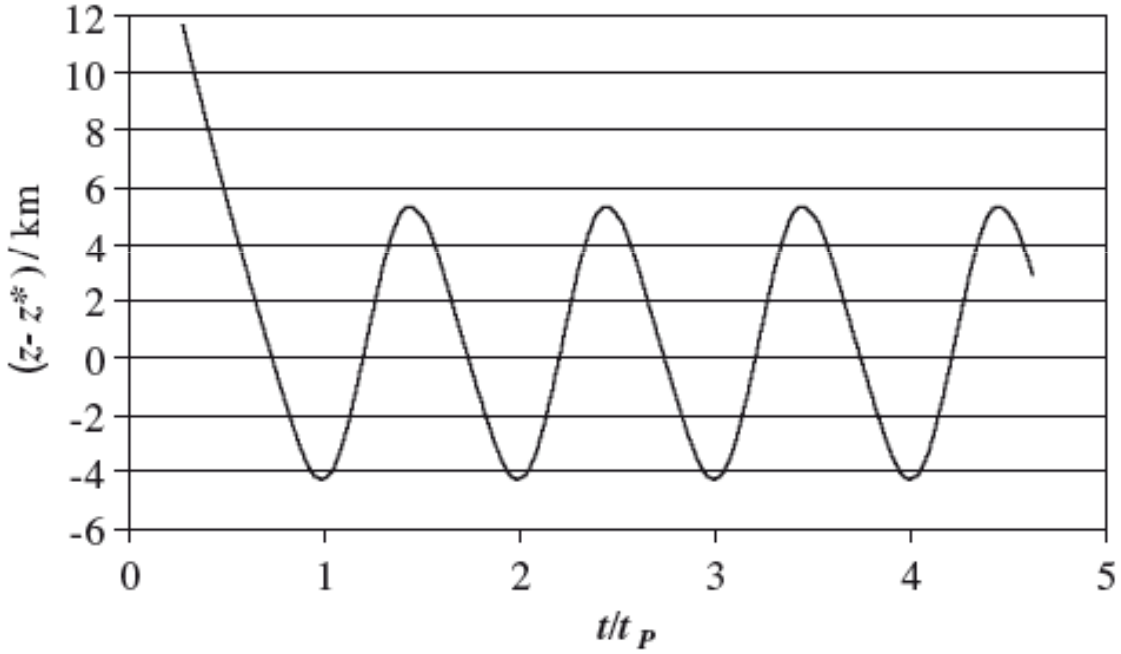
  ➔Stability around 40km
- Secondary envelope 1.5m
  - Phase change balloon

  ➔16km increased altitude

- 40-56km cycling range

# Balloon Adonis

Predicted oscillations around z*= saturation altitude




[Dorrington G.E.]

- When z < z*

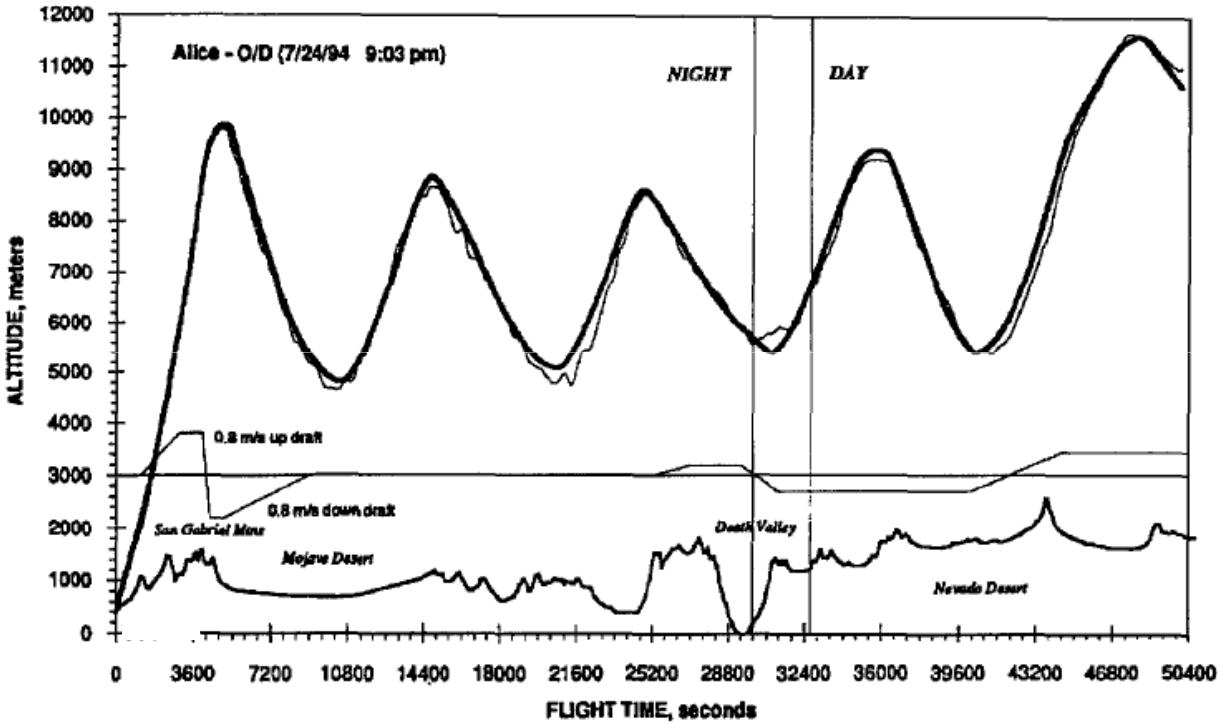
Liquid H2O boils causing an increase in buoyancy

- When z > z*

H2O vapor condenses causing a decrease in buoyancy.

# Balloon Adonis

Earth tests: ALICE (1993-1994)

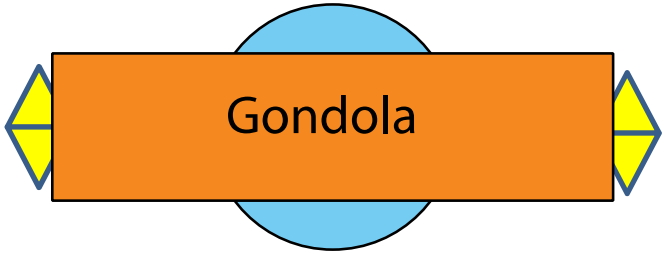



[Cutts J.A. et al.]

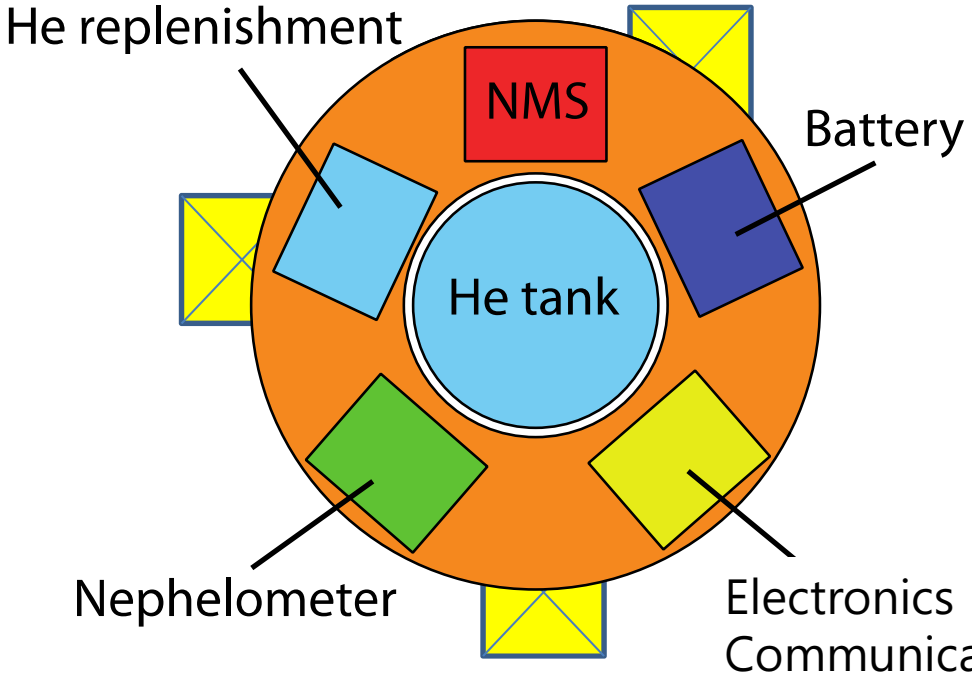
Bold line: model results
Thin line: data test

Results:
- Increasing amplitudes during day
- Decreasing amplitudes during night

# Gondola




Side view




Top view

# Adonis design

- Operation modes:
  - Entry Descent and Inflation mode: COM and inflation mechanisms active
  - Nominal: science measurements from operations list previously sent by orbiter. (22h/day)
  - Com mode: data upload to orbiter (2h/day)
  - Safe mode: temperature is critical (30km), all instruments powered off. He replenishment active (10kg)

# Adonis Power Budget

| | | Science Operations (22h/day) | | Telecom Mode (2h/day) | |
|---|---|---|---|---|---|
| | Power with margins (W) | duty cycle | W-hr | duty cycle | W-hr |
| Payload | | | | | |
| Neutral Mass Spectrometer | 33 | 10% | 73 | 0% | 0 |
| Nephelometer | 2 | 10% | 3 | 0% | 0 |
| Atmoshpere Science Package | 4 | 10% | 8 | 0% | 0 |
| Camera | 1 | 10% | 1 | 0% | 0 |
| Microflown | 1 | 10% | 1 | 0% | 0 |
| Inflation | 24 | 0% | 0 | 0% | 0 |
| OBDH | 5 | 100% | 106 | 100% | 10 |
| Telecom | 12 | 0% | 0 | 100% | 24 |
| | | total (per day) | 192 | total (per day) | 34 |

**Total** for 25 day nominal mission (including EDI phase) **5700 Whr**

# Balloon Power design

Total Energy required for 25 day mission time = 5700 W/hr

Maximum power output = 72W

- Choice:

Li-SOCl2 non rechargeable battery 90A/hr

With 2.5kg packaging and electronics and 20% overall mar gin ➔ 31kg

DOD at end of nominal mission = 91%

# Communication System

**Balloon**

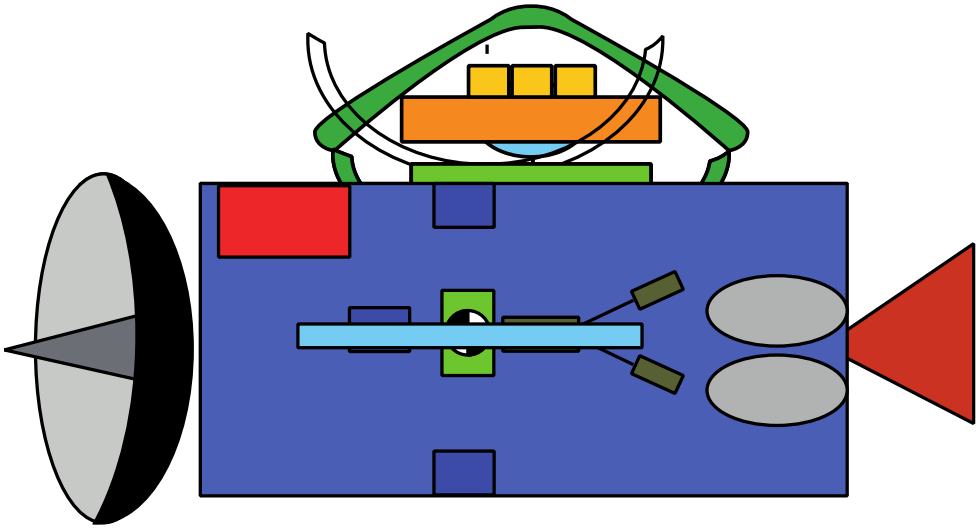
- X-band Helix Antenna
- Minimum transmission (at 6 000 km): 4.80 Mbps
- Balloon Data Rate Contribution to Orbiter: 805.2 bits

  – Fast data download. Communication time with orbiter especially necessary for balloon tracking

# Adonis Mass Budget

| | Total (incl. contingency) (kg) | TRL |
|---|---|---|
| Payload | | |
| Atmosphere Package | 2 | 8 |
| Nephelometer | 1 | 4 |
| Neutral mass spectrometer | 11 | 6 |
| Camera | 1 | 8 |
| Microflown | 1 | 8 |
| Probes (3 pieces) | 18 | 2 |
| OBDH | 2 | |
| Power system | 30 | |
| Gondola + balloon | 91 | |
| Comms | 5 | |
| Thermal | 2 | |
| Gas replenishment | 12 | |
| Total | 176 | |

# Orbiter + Entry System



- Entry system embedded on the top of the spacecraft

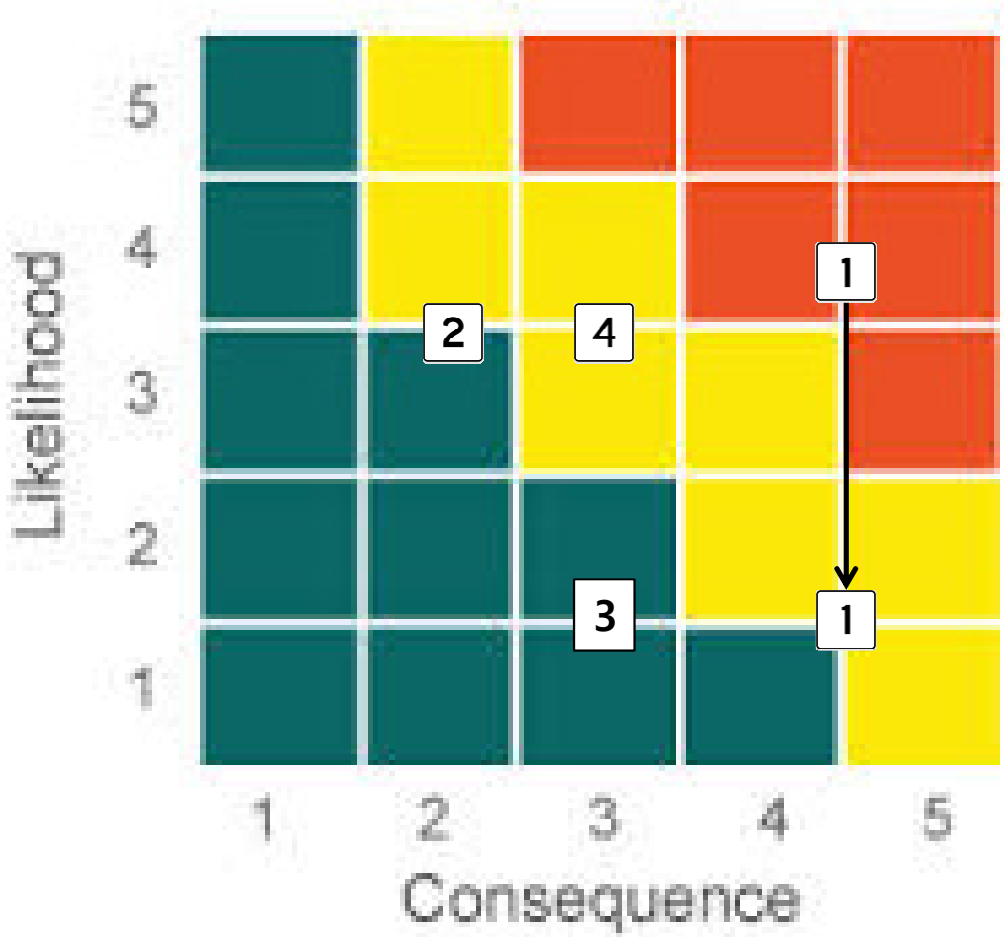
# Aphrodite Mass Budget

| Hephaestos | | Adonis | | Adonis Entry system |
|---|---|---|---|---|
| Payload | 83 kg | Payload | 34 kg | |
| Systems | 683 kg | Systems | 142 kg | |
| Total: | 766kg | Total: | 176 kg | Total: 107kg |

Total Dry mass : 1049 kg
Fuel : 526 kg

Total Wet mass : 1575 kg

# Risk Analysis

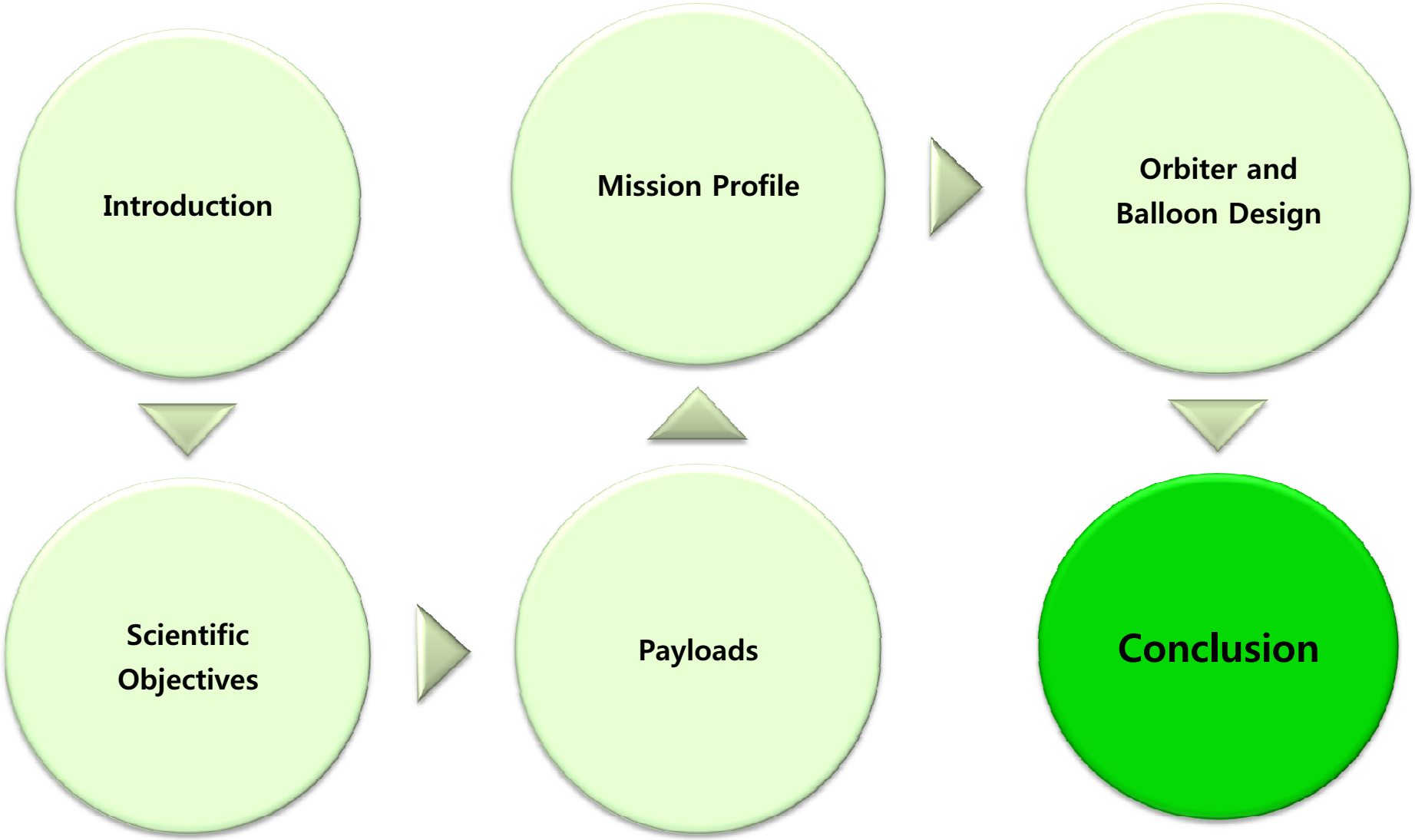



1. Balloon Separation & Insertion
2. Balloon Development
3. Low TRL payloads
4. Failure of Aglaea reflector

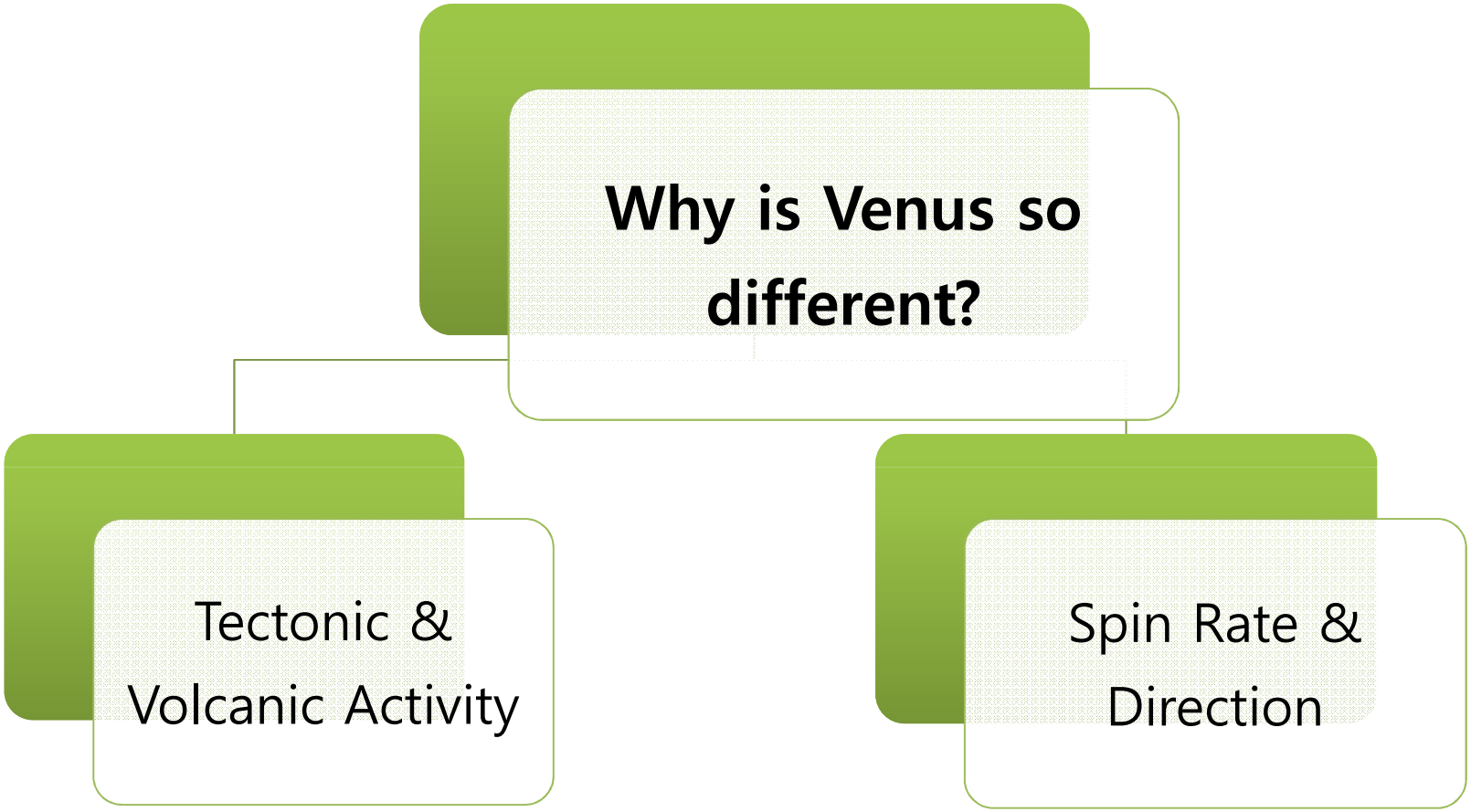
# Cost Analysis

| | Cost (M€) |
|---|---|
| 1) Ground Segment & Operations | 85 |
| 2) Management & Facilities | 75 |
| 3) Spacecraft Development | 165 |
| 4) Payload development | 100 |
| 5) Balloon & Entry System | 350 |
| Total | 775 |
| **Total including contingency (15%)** | **891** |
| Launcher | 75 |
| **Total including launcher** | **966** |

# Aphrodite Mission



# Conclusion


Why is Venus so different?
Tectonic & Volcanic Activity
Spin Rate & Direction

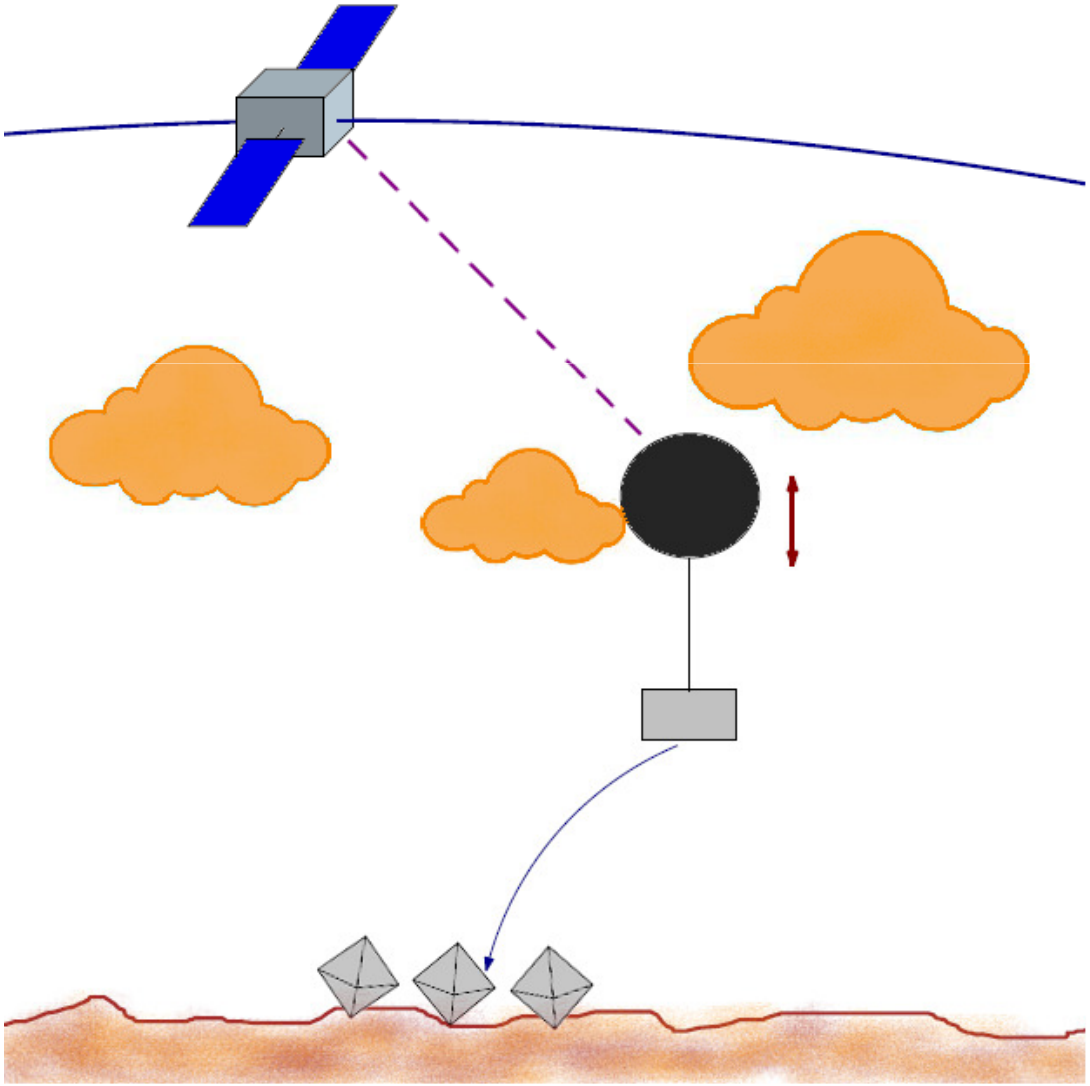
# Conclusion

***Aphrodite Mission***

- Hephaestos
- Adonis
- Aglaea 1-3

- Thank you for your attention!

APHRODITE



# Extra slides

# Thermal Imaging

| | Sensitivity | Range | Frequency | Data rate |
|---|---|---|---|---|
| Spatial | 1 km (min. 5 km) | - | | |
| Temperature | 0.1 K | 740 – 1500 K | | |

# Atmospheric Composition

## Concentration

| Orbiter | Concentration | Sensitivity | Height | Frequency | Data rate |
|---|---|---|---|---|---|
| H20 | | 0.4 ppm | upper atm | | |
| SO2 | | 20 ppb | 70 km | | |

# Atmospheric Composition

## Concentration

| Balloon | Concentration | Sensitivity | Height | Frequency | Data rate |
|---|---|---|---|---|---|
| H20 | | 3 ppm | 45-50 km | 1 /h | 32 bit/s |
| SO2 | | 15 ppm | | 1 /h | 32 bit/s |
| H2SO4 | ~10 ppm<br>< 1 ppm | 1 ppm | ~46.5 km<br>> 51 km | 1/h | 32 bit/s |

# Atmospheric Composition

## Particle Size

| Balloon | Range | Sensitivity | Frequency | Data rate |
|---|---|---|---|---|
| | 0.1 – 10 μm | 0.01 μm | | |

# Atmospheric Composition

## Isotopic Ratios

| Balloon | Ratio | Sensitivity better than | Frequency | Data rate |
|---|---|---|---|---|
| D/H (H2O) | 0.016 +- 0.002 | 5 – 10% | 1 /h | 32 bit/s |
| O-16/O-18 (CO2) | 500 +- 25 | 1 – 2% | 1 /h | 32 bit/s |
| S-32/S-34 (SO2) | - | < 2% | 1 /h | 32 bit/s |

# Physical parameters

| Acoustic Waves | Sensitivity | Range | Height | Frequency | Data rate |
|---|---|---|---|---|---|
| Temperature | 10 K | 200 – 350 K | 130 – 190 km | | |
| Gravity Waves | | | | | |
| Occultation Exp Magellan | ΔT = A = 4 K Vert. λ = 2.5 km | 200-350 K | 65 km | | |

# (Sub)Surface Topography

| | Sensitivity | Range | Frequency | Data rate |
|---|---|---|---|---|
| Horizontal Resolution | 10 km | - | | ~ GByte/orbit |
| Vertical Resolution | 10 m | 100 m (sub) | | |

# Spin rate

| | Sensitivity | Height | Frequency | Data rate |
|---|---|---|---|---|
| Surface Movement | 1.5 m | 250 km | Tracking probe | |
| Accelaration | 10^-5 m/s2 | | 10 Hz (min. 1 Hz) | 40 Byte/s (min 4 Byte/s) |

# Atmospheric Conditions

| balloon | Sensitivity | Range | Frequency | Data rate |
|---|---|---|---|---|
| Temperature | 1 K | 200-400 K | | |
| Pressure | 1 mbar for 10-100 mbar,<br>10 mbar for 100-3000 mbar | 10-2500 mbar | | |
| Wind speed | 5 km/h | 100-800 km/h | | |
| **orbiter** | | | | |
| Temperature | 10 K | 200-400 K | Every 10 km on surface | |
| Wind speed | 10 km/h | 100-800 km/h | | |