EvolVe

Evolution of **Ve**nus

Alpbach Summer School 2014

Team Red

esa

FFG

Overarching Theme

ESA

1. Conditions for planet formation and emergence of life?

1.3. Life and habitability in the Solar System, explore environmental conditions that make life possible

NASA

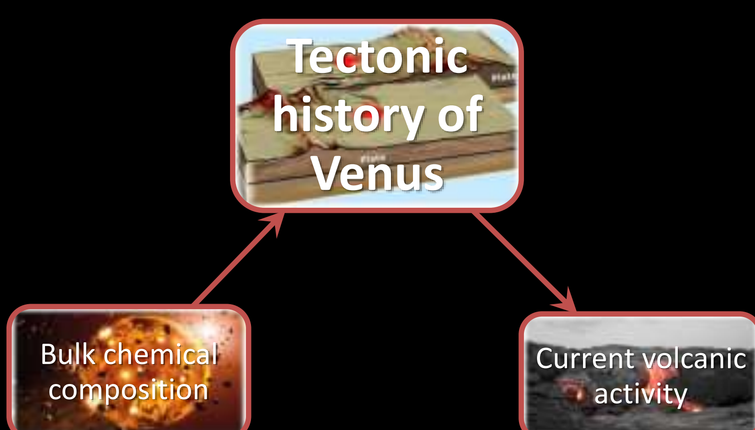
Building New Worlds: Accretion, water, chemistry, internal differentiation of inner planets, evolution of atmospheres?

Planetary Habitats: Did Mars or Venus had environments conducive for life in the past? Evidence that life emerged?

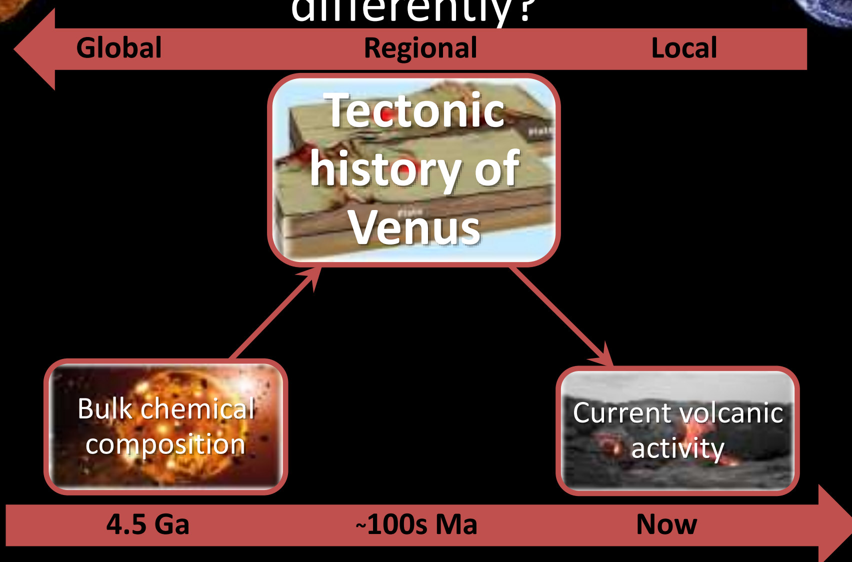
Why did Venus and Earth evolve differently?

properties	Venus	Earth
radius [km]	6050	6378
mass [kg]	4.87×10^{24}	5.97×10^{24}
heliodistance [AU]	0.73	1
surface pressure [bar]	92	1
atmosphere comp [vol%]	CO_2 (96.5), N_2 (3.5)	N_2 (78), O_2 (21), Ar (1)
surface temp. [°C]	462	14
axial tilt [°]	177	23

Why did Venus and Earth evolve differently?



Why did Venus and Earth evolve differently?



Thursday, July 24, 2104 EvolVe / Alpbach Summer School 2014 5

Why did Venus and Earth evolve differently?

Is the tectonic history of Venus comparable to that of Earth?

What is the level of current volcanic activity of Venus?

Is the bulk chemical composition of Venus and Earth different?

Thursday, July 24, 2104 EvolVe / Alpbach Summer School 2014 6

Tectonics; present knowledge

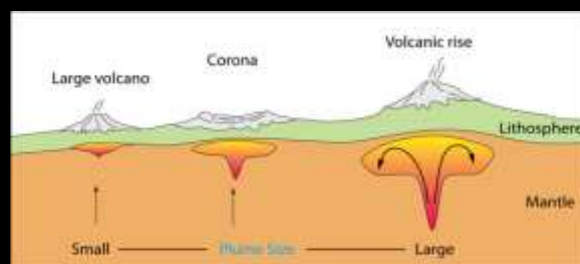
- Faults and rifts
- "Stagnant lid"-theory
- Subduction vs. obduction

Tectonics; present knowledge

- Faults and rifts
- "Stagnant lid"-theory
- Subduction vs. obduction

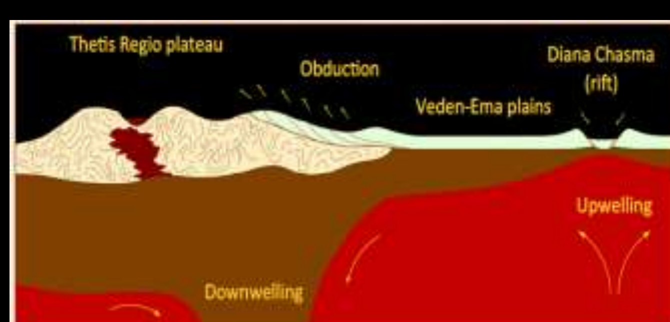
Tectonics; present knowledge

- Faults and rifts
- "Stagnant lid"-theory
- Subduction vs. obduction



Tectonics; present knowledge

- Faults and rifts
- "Stagnant lid"-theory
- Subduction vs. obduction




Tectonics; observations

- Subsurface structure
  - Gravity field
    - ✓ global Bouguer anomalies
    - ✓ resolution 80km, accuracy ~ 5mG
    - ✓ orbital perturbations
  - Magneto-telluric (MT) sounding
    - ✓ lithosphere thickness
    - ✓ H_2O content
  - Radiogenic isotopes
    - ✓ noble gases (3He, 4He, 40Ar, 35Ar, 38Ar)
- Surface mapping
  - Topography
    - ✓ determined areas
    - ✓ spatial resolution ~ 10m, accuracy ~1m

Thursday, July 24, 2104 EvolVe / Alpbach Summer School 2014 11


Tectonics; observations

- Subsurface structure
  - Gravity field
    - ✓ global Bouguer anomalies
    - ✓ resolution 80km, accuracy ~ 5mG
    - ✓ orbital perturbations
  - Magneto-telluric (MT) sounding
    - ✓ lithosphere thickness
    - ✓ H_2O content
  - Radiogenic isotopes
    - ✓ noble gases (3He, 4He, 40Ar, 35Ar, 38Ar)
- Surface mapping
  - Topography
    - ✓ determined areas
    - ✓ spatial resolution ~ 10m, accuracy ~1m

Thursday, July 24, 2104 EvolVe / Alpbach Summer School 2014 12

Tectonics; observations

- Subsurface structure
  - Gravity field
    - ✓ global Bouguer anomalies
    - ✓ resolution 80km, accuracy ~ 5mG
    - ✓ orbital perturbations
  - Magneto-telluric (MT) sounding
    - ✓ lithosphere thickness
    - ✓ H_2O content
  - Radiogenic isotopes
    - ✓ noble gases (3He, 4He, 40Ar, 35Ar, 38Ar)
- Surface mapping
  - Topography
    - ✓ determined areas
    - ✓ spatial resolution ~ 10m, accuracy ~1m

Tectonics; observations

- Subsurface structure
  - Gravity field
    - ✓ global Bouguer anomalies
    - ✓ resolution 80km, accuracy ~ 5mG
    - ✓ orbital perturbations
  - Magneto-telluric (MT) sounding
    - ✓ lithosphere thickness
    - ✓ H_2O content
  - Radiogenic isotopes
    - ✓ noble gases (3He, 4He, 40Ar, 35Ar, 38Ar)
- Surface mapping
  - Topography
    - ✓ determined areas
    - ✓ spatial resolution ~ 10m, accuracy ~1m


Tectonics; observations

- Subsurface structure
  - Gravity field
    - ✓ global Bouguer anomalies
    - ✓ resolution 80km, accuracy ~ 5mG
    - ✓ orbital perturbations
  - Magneto-telluric (MT) sounding
    - ✓ lithosphere thickness
    - ✓ H_2O content
  - Radiogenic isotopes
    - ✓ noble gases (3He, 4He, 40Ar, 35Ar, 38Ar)
- Surface mapping
  - Topography
    - ✓ determined areas
    - ✓ spatial resolution ~ 10m, accuracy ~1m


Tectonics; observations

- Subsurface structure
  - Gravity field
    - ✓ global Bouguer anomalies
    - ✓ resolution 80km, accuracy ~ 5mG
    - ✓ orbital perturbations
  - Magneto-telluric (MT) sounding
    - ✓ lithosphere thickness
    - ✓ H_2O content
  - Radiogenic isotopes
    - ✓ noble gases (3He, 4He, 40Ar, 35Ar, 38Ar)
- Surface mapping
  - Topography
    - ✓ determined areas
    - ✓ spatial resolution ~ 10m, accuracy ~1m

Volcanism; present knowledge

- Basic cooling history of Venus and Earth
- Volcano-like features and basalts
- Age of the surface
- Variation in SO_2 abundance
- Surface heat flux

Thursday, July 24, 2104 EvolVe / Alpbach Summer School 2014 17

Volcanism; present knowledge

- Basic cooling history of Venus and Earth
- Volcano-like features and basalts
- Age of the surface
- Variation in SO_2 abundance
- Surface heat flux

Thursday, July 24, 2104 EvolVe / Alpbach Summer School 2014 18

Volcanism; present knowledge

- Basic cooling history of Venus and Earth
- Volcano-like features and basalts
- Age of the surface
- Variation in SO_2 abundance
- Surface heat flux

Thursday, July 24, 2104 EvolVe / Alpbach Summer School 2014 19

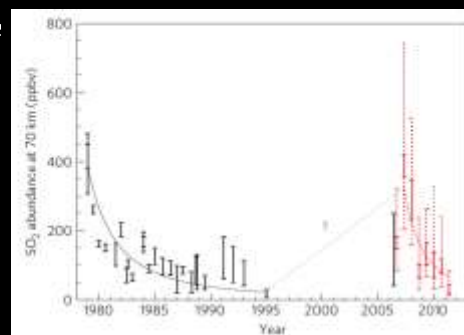
Volcanism; present knowledge

- Basic cooling history of Venus and Earth
- Volcano-like features and basalts
- Age of the surface
- Variation in SO_2 abundance
- Surface heat flux

Thursday, July 24, 2104 EvolVe / Alpbach Summer School 2014 20

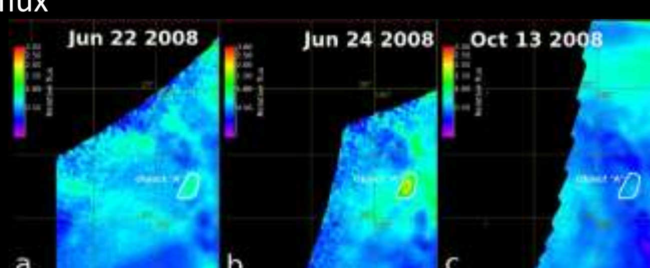
Volcanism; present knowledge

- Basic cooling history of Venus and Earth
- Volcano-like features and basalts
- Age of the surface
- Variation in SO_2 abundance
- Surface heat flux



Volcanism; present knowledge

- Basic cooling history of Venus and Earth
- Volcano-like features and basalts
- Age of the surface
- Variation in SO_2 abundance
- Surface heat flux




Volcanism; observations

- Abundance and ratios of sulfur and water
  - Global coverage
    - ✓ UV 0.11-0.31 µm, resolution 0.8 nm, resolving power 100
  - In-situ
    - ✓ twice a day, continuous, <70km, accuracy 1%
- Locate and observe activity
  - Irradiance of ground
    - ✓ IR: 0.7-5.0 µm, resolution 0.8nm, resolving power 200
    - ✓ spatial resolution 50km, nighttime
  - Elevation changes
    - ✓ spatial resolution <40m,
    - ✓ accuracy inflation <1cm, accuracy for eruptions <1m


Volcanism; observations

- Abundance and ratios of sulfur and water
  - Global coverage
    - ✓ UV 0.11-0.31 µm, resolution 0.8 nm, resolving power 100
  - In-situ
    - ✓ twice a day, continuous, <70km, accuracy 1%
- Locate and observe activity
  - Irradiance of ground
    - ✓ IR: 0.7-5.0 µm, resolution 0.8nm, resolving power 200
    - ✓ spatial resolution 50km, nighttime
  - Elevation changes
    - ✓ spatial resolution <40m,
    - ✓ accuracy inflation <1cm, accuracy for eruptions <1m

Volcanism; observations

- Abundance and ratios of sulfur and water
  - Global coverage
    - ✓ UV 0.11-0.31 μm, resolution 0.8 nm, resolving power 100
  - In-situ
    - ✓ twice a day, continuous, <70km, accuracy 1%
- Locate and observe activity
  - Irradiance of ground
    - ✓ IR: 0.7-5.0 μm, resolution 0.8nm, resolving power 200
    - ✓ spatial resolution 50km, nighttime
  - Elevation changes
    - ✓ spatial resolution <40m,
    - ✓ accuracy inflation <1cm, accuracy for eruptions <1m

Volcanism; observations

- Abundance and ratios of sulfur and water
  - Global coverage
    - ✓ UV 0.11-0.31 μm, resolution 0.8 nm, resolving power 100
  - In-situ
    - ✓ twice a day, continuous, <70km, accuracy 1%
- Locate and observe activity
  - Irradiance of ground
    - ✓ IR: 0.7-5.0 μm, resolution 0.8nm, resolving power 200
    - ✓ spatial resolution 50km, nighttime
  - Elevation changes
    - ✓ spatial resolution <40m,
    - ✓ accuracy inflation <1cm, accuracy for eruptions <1m


Composition; present knowledge

- Inference from meteorites
- Atmosphere from interior
  - Noble gases (He, Ne, Ar, Xe) abundance and isotopic ratios with too large errors
  - Proxy for volatiles
- Internal structure
  - Iron as a proxy for refractory


Composition; present knowledge

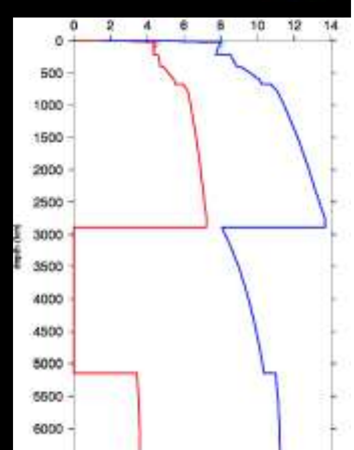
- Inference from meteorites
- Atmosphere from interior
  - Noble gases (He, Ne, Ar, Xe) abundance and isotopic ratios with too large errors
  - Proxy for volatiles
- Internal structure
  - Iron as a proxy for refractory

Composition; present knowledge

- Inference from meteorites
- Atmosphere from interior
  - Noble gases (He, Ne, Ar, Xe) abundance and isotopic ratios with too large errors
  - Proxy for volatiles
- Internal structure
  - Iron as a proxy for refractory

Composition; present knowledge

- Inference from meteorites
- Atmosphere from interior
  - Noble gases (He, Ne, Ar, Xe) abundance and isotopic ratios with too large errors
  - Proxy for volatiles
- Internal structure
  - Iron as a proxy for refractory



Composition; observations

- Noble gases
  - Fractionation of isotopes of noble gasses
    - ✓ origin and external changes
    - ✓ accuracy of abundance and ratios ±3%
    - ✓ minimum 1 measurement pr species
- Core size
  - Orbital perturbations
    - ✓ Doppler tracking
    - ✓ moment of inertia
  - Magnetic measurement
    - ✓ eventual possibility

Composition; observations

- Noble gases
  - Fractionation of isotopes of noble gasses
    - ✓ origin and external changes
    - ✓ accuracy of abundance and ratios ±3%
    - ✓ minimum 1 measurement pr species
- Core size
  - Orbital perturbations
    - ✓ Doppler tracking
    - ✓ moment of inertia
  - Magnetic measurement
    - ✓ eventual possibility

Composition; observations

- Noble gases
  - Fractionation of isotopes of noble gasses
    - ✓ origin and external changes
    - ✓ accuracy of abundance and ratios ±3%
    - ✓ minimum 1 measurement pr species
- Core size
  - Orbital perturbations
    - ✓ Doppler tracking
    - ✓ moment of inertia
  - Magnetic measurement
    - ✓ eventual possibility

Observables

1) Tectonic history
- Gravity field
- Lithospheric thickness and H_2O content
- Topography
- Radiogenic isotopes

2.1) Current volcanism
- Delta-topography
- Composition
- Thermal gradient

2.2) Bulk chemical composition
- Noble gas ratios
- Core size

Observables ⟶ Instruments

1) Tectonic history

Observables	Instruments
– Gravity field	Gradiometer + altimeter
– Lithospheric thickness and H_2O content	Magnetometer + dipoles
– Topography	InSAR
– Radiogenic isotopes	Mass spectrometer

2.1) Current volcanism

Observables	Instruments
– Delta-topography	InSAR
– Composition	UV + Mass spectrometer
– Thermal gradient	IR spectrometer

2.2) Bulk chemical composition

Observables	Instruments
– Noble gas ratios	Mass spectrometer
– Core size	Magnetometer

Payload

Gradiometer

- Geodesy for tectonics question

  - measures gravity field (3-D gradient tensor) from medium to short-scales in order to reveal litospheric feature

  - GOCE-type (TRL = 7)

- *Science requirements*:

  - low orbit (h =250 – 300 km)

  - MBW: 5 MHz – 0.1 Hz (noise : 10 mE $Hz^{-1/2}$)

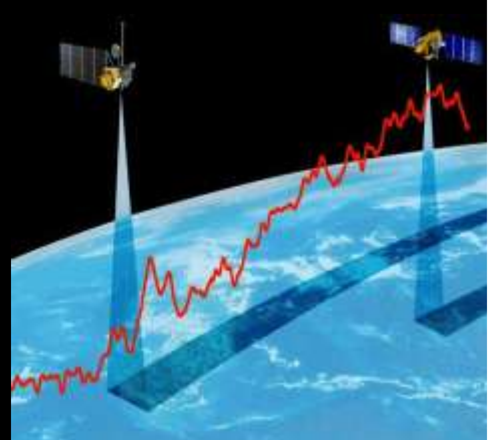
  - drag needs to be compensated

  - attitude accuracy (0.15 rad)

MBW = Measurement Band Width

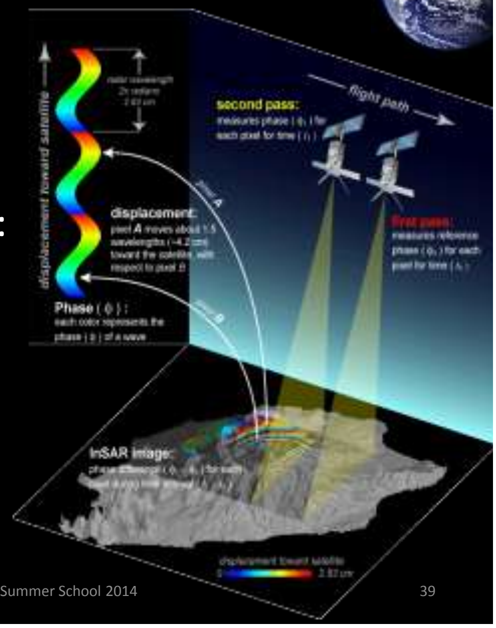
Radar Altimeter

- Goal: support orbit measurements during geodesy phase
- *Scientific requirements:*
  - Altitude Accuracy : 1 m
  - Sample rate: 50 Hz
  - Backscattering coefficient: 0.7 dB
  - Beam width: 1.3 degrees
  - Pulse repetition frequency: 1020 Hz



SAR- InSAR

- Goals: tectonics, volcanism
- Scientific requirements:
  - Local coverage (10% duty cycle)
  - Single antenna (repeat pass)
  - S band (λ≈ 12 cm)
  - Look angle: 25-45°
  - Swath Width ≈ 40 -70 Km
  - Spatial Resolution ≈ 40 m
  - Vertical accuracy ≈ cm



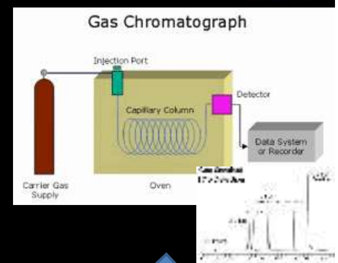
IR/UV spectrometer

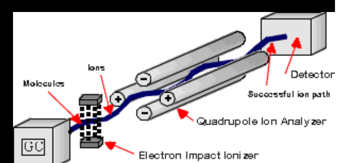
- Goals: volcanism through detection of S02 (cloud top) and freshly erupted lava flows (surface).
- *Scientific requirements*:
  - Spectral range (µm): 0.11-0.31 and 0.7-5
  - Spectral resolution: 0.8 nm and 0.5-1nm
  - Spectral resolving power λ/Δλ: ~100-200
  - Field of view (rad) 64x64
  - Spatial resolution: ~50 km

High TRL. Based on: SPICAV and VIRTIS on Venus Express

Gas Chromatograph Mass Spectrometer

- Goals: composition, volcanism to measure isotopic ratios and abundances
- *Scientific requirements*:
  - Resolution: 0.1 AMU
  - Range of measurement: 2 - 150 AMU
  - Frequency of measurement: at least 1 measurement of every noble gass isotopic ratio
  - Sensitivity: 0.1 ppb Xe, Kr
  - Accuracy: Abundance and isotope ratios of He, Ne, Ar, Kr, Xe, H_2O, SO_2 to ±1%



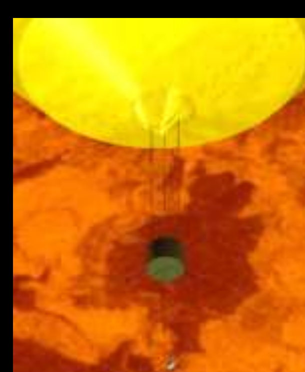


Based on: GCQMS with gas enrichement line from SAM experiment on Curiosity rover and GCMS on Huygens.

MT sounding device

- Goals: tectonics through thickness of lithosphere and H_2O content
- *Scientific requirements*:
  - Measurements must be done within ionosphere
  - 1 - 100 Hz sampling
  - Balloon attitude determination

Based on dipoles and space-qualified magnetometer



Fluxgate magnetometer

- Used in MT sounding for tectonics and to experimentally address the bulk composition question:
  - Core size estimate
- *Scientific requirements*:
  - 50 pT accuracy
  - Balloon attitude determination
  - > 3m from any electrical device or metal (boom mounting)

How do we improve on current data?

Comparison of EvolVe and Magellan

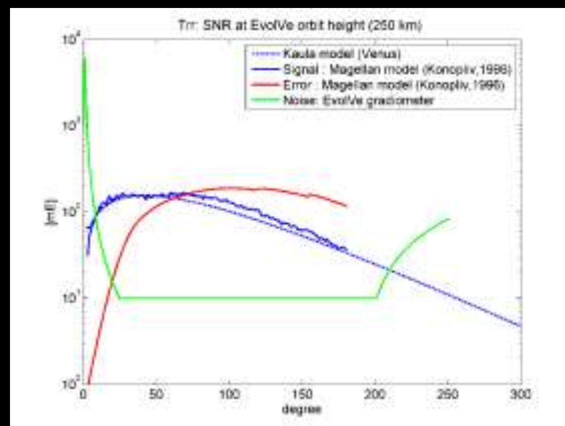
	Magellan	EvolVe
Gravity measurements		
Resolution:	300 - 700 km	80 km
High resolution topography	(SAR stereo)	(SAR stereo / InSAR)
Coverage:	20%	10%
Spatial resolution:	1-2 km	40 m TBC
Vertical precision:	50 m	<4 m
Radar imaging		
Coverage:	global (96%)	20 %
Spatial resolution:	100 m	10 m TBC

How do we improve on current data?

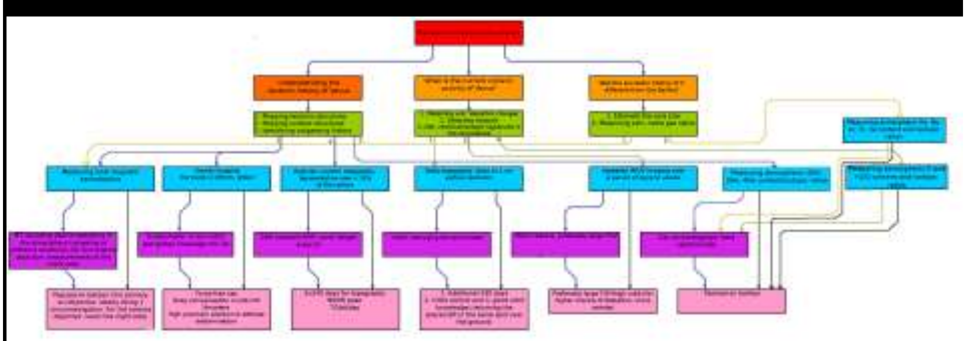
Gravity field improvement w.r.t Magellan (SNR)

spatial resolution:

- Magellan: **700** km (resolution varies)
- EvolVe: **80** km (global, homogeneous)
- Improvement of long wavelengths expected (polar orbit, dynamic orbit analysis)



Traceability



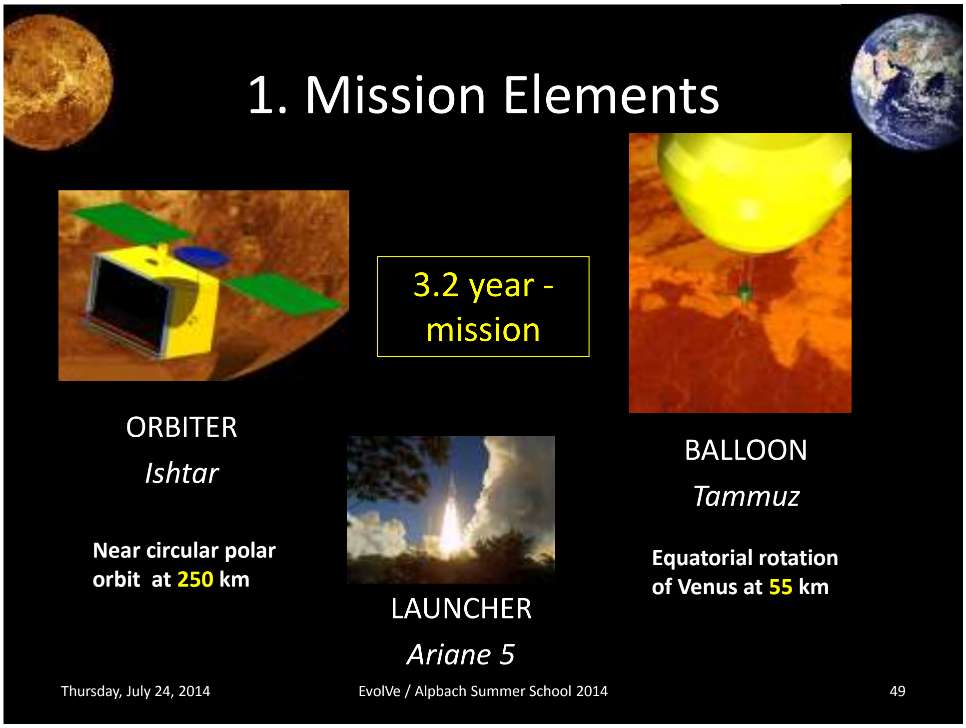
Mission Architecture

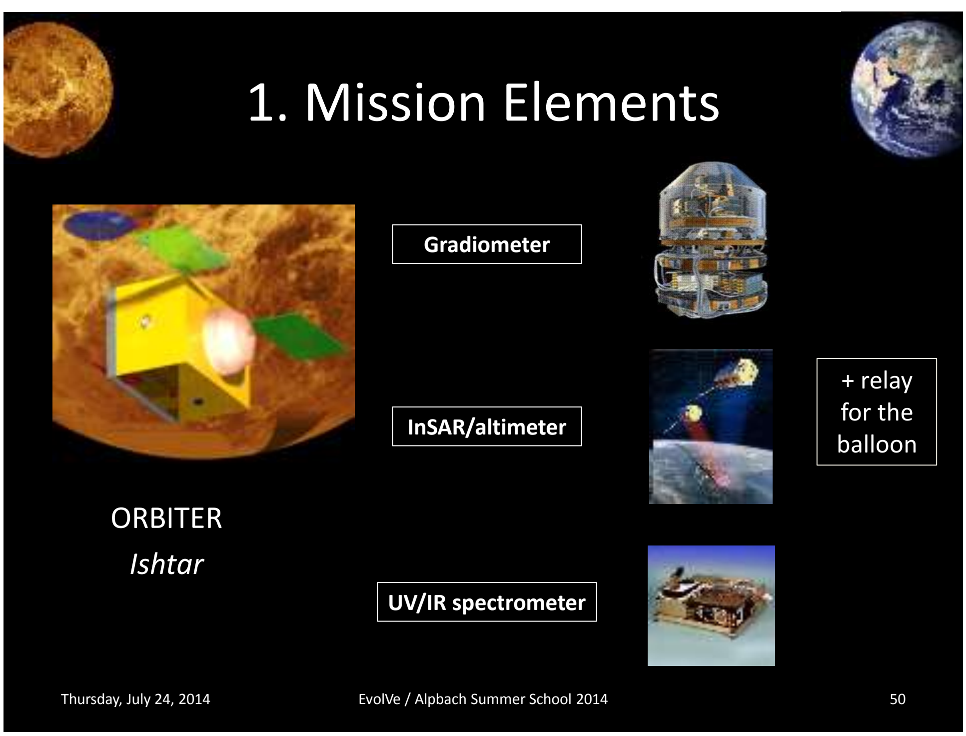
Mission Architecture

1. Mission Elements

2. Orbit Design

3. Mission Phases


1. Mission Elements
3.2 year - mission
ORBITER
Ishtar
Near circular polar orbit at 250 km
BALLOON
Tammuz
Equatorial rotation of Venus at 55 km
LAUNCHER
Ariane 5
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
49

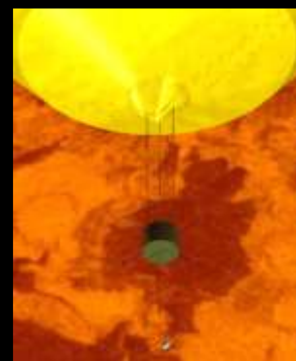

1. Mission Elements
Gradiometer
InSAR/altimeter
+ relay for the balloon
ORBITER
Ishtar
UV/IR spectrometer
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
50

1. Mission Elements

Gas Chromatograph Mass Spectrometer

Double Star magnetometer

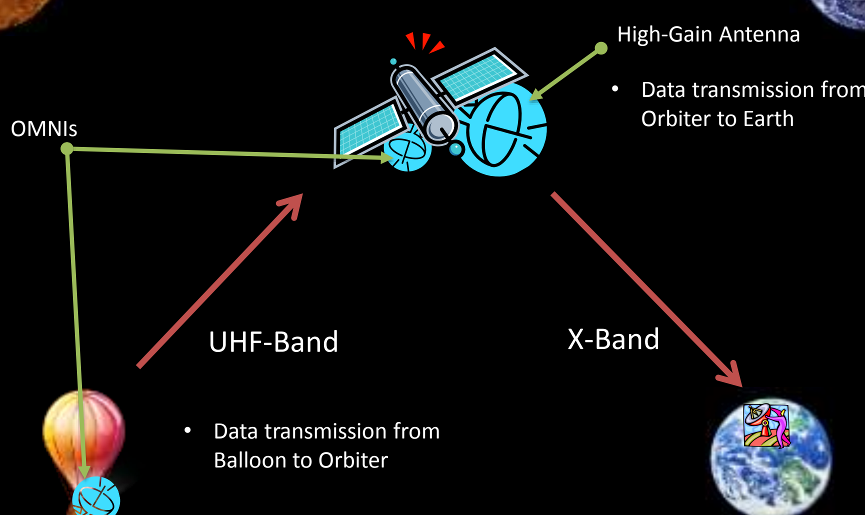
MT sounding device



BALLOON

Tammuz

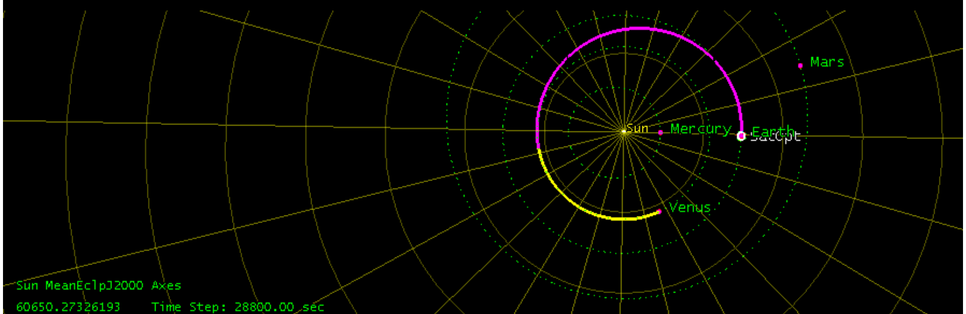
1. Mission Elements



2. Orbit Design

Mission requirement :

Polar near-circular orbit @250 km above Venus



Launch Window	06/12/2032 ± 5 days	06/12/2032 ± 5 days
Dv1+Dv2	5.8959 km/s	5.8224 km/s
Transfer time	157.52 days	155.40 days

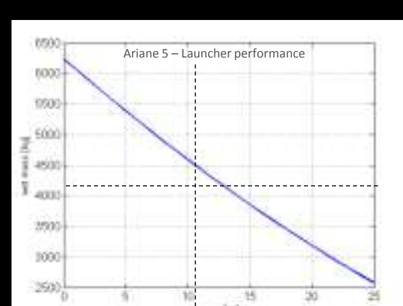
2. Orbit Design

Launcher *($C3 = 10.6\ km^2/s^2$)*

- Ariane 5 (4500 kg payload mass)

Options for orbit insertion @250 km

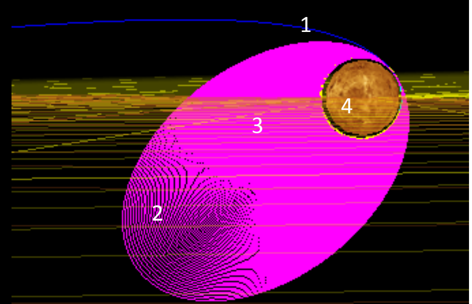
- Chemical propulsion
  - DeltaV= 3.286 km/s
  - Total mass = 1472 kg
- ***AeroBraking***
  - ***DeltaV= 1.510 km/s***
  - ***Total mass = 2690 kg***
- AeroCapture
  - DeltaV= 0.9 km/s
  - Total mass = 3300 kg



2. Orbit Design

Aerobraking@130 km, 1-6 months:

1. Polar orbit insertion : 14-05-2033
   apoapsis@17369 km , e=0.571
2. Preliminary SAR obs : 16.05.2033
   apoapsis@6617 km , e=0.329
3. Balloon release : 23.06.2033
   apoapsis@405 km , e=0.022
4. Final orbit: 24.06.2033
   apoapsis@250 km , e=0.001



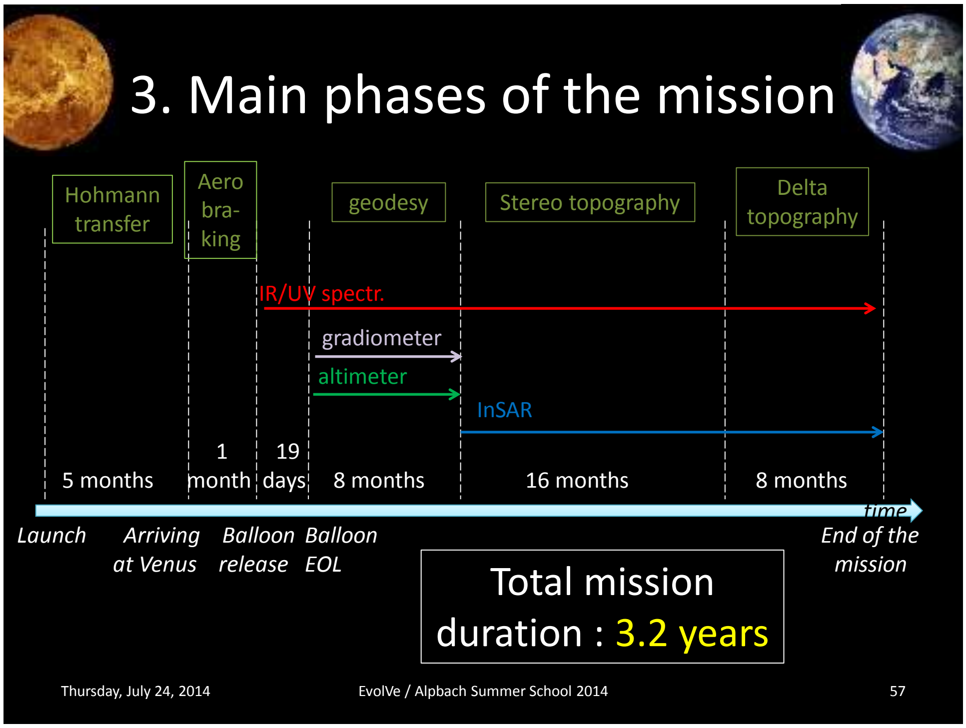
Force model:

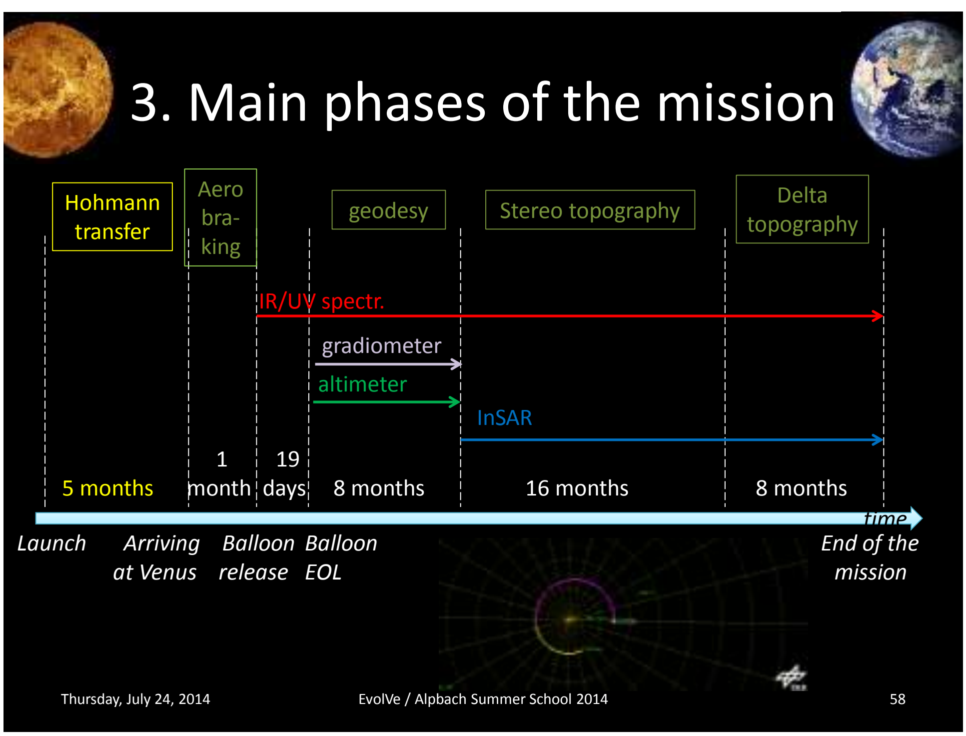
- Atmospheric density model [Seiff A. et al., 1980] (test at higher altitudes) (consistent with Magellan and Venus Express measurements)
- Venus gravity field up to degree and order 4
- Sun as third body (point mass)

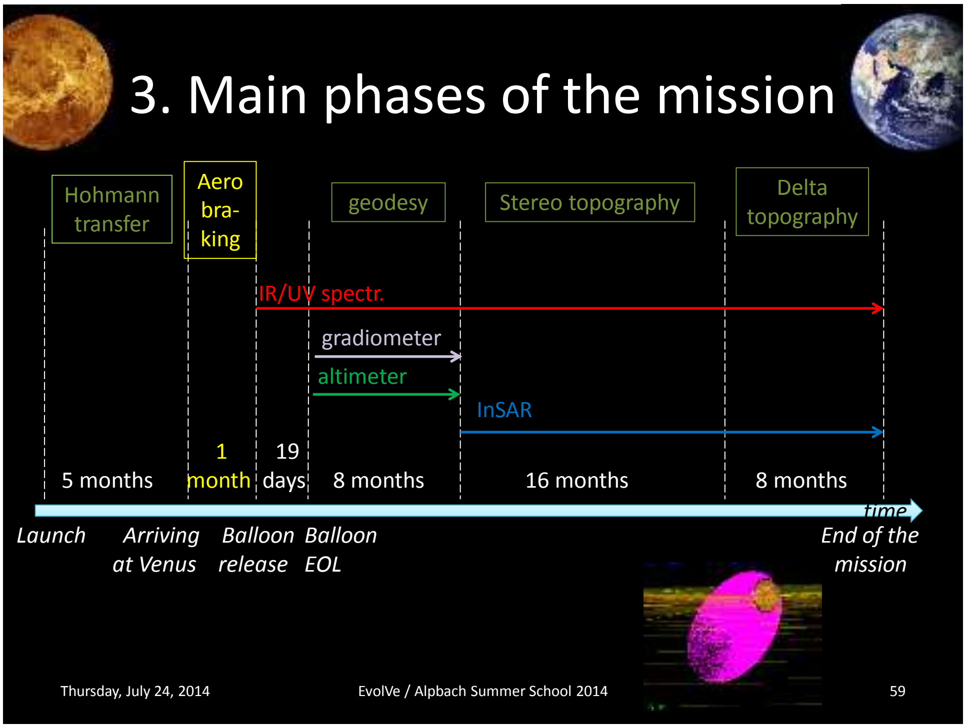
2. Orbit Design

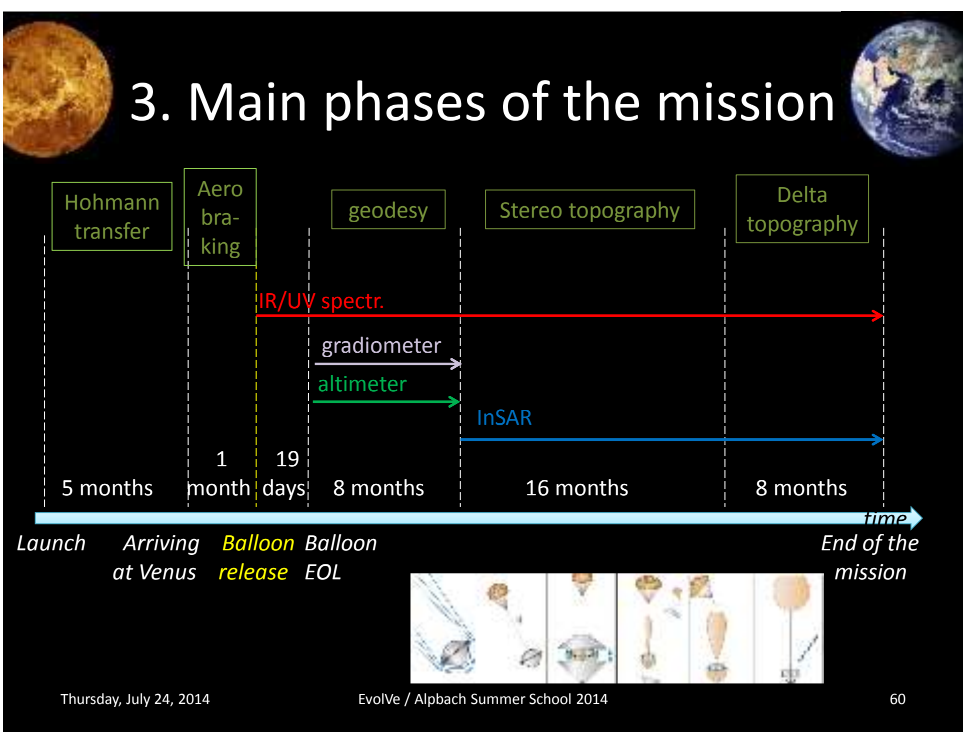
- Orbit maintenance (2.8 years science operation)
  - DeltaV : 500 m/s
  - Fuel : 230 kg
- ESTRACK
  - 8 h/day
  - 35 % visibility / station

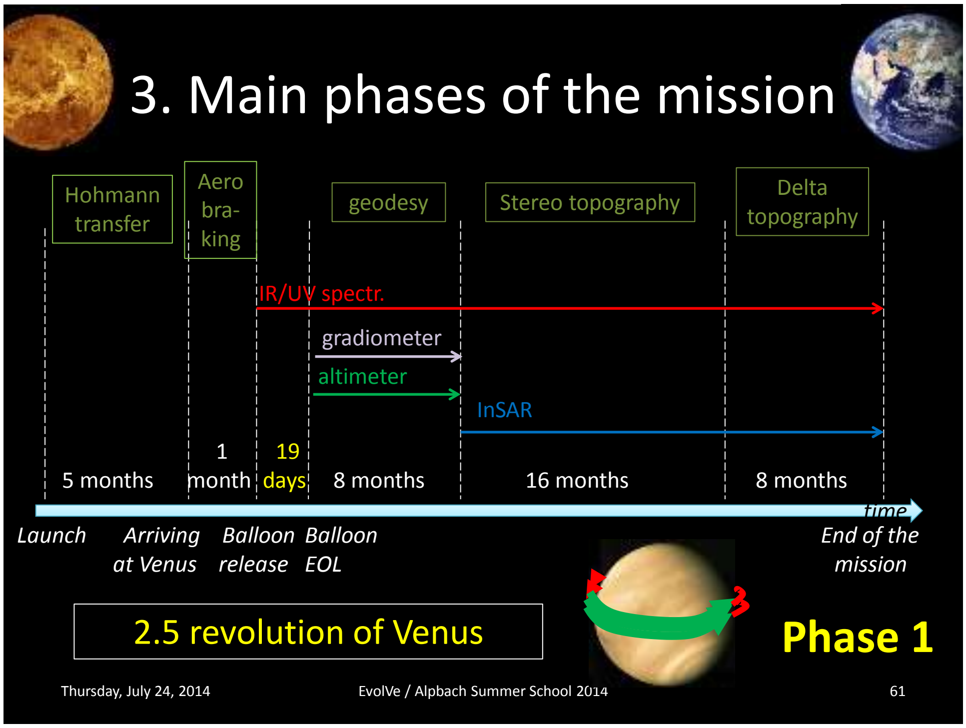
	DeltaV [m/s]
Orbit Insertion	1490
End of Aerobraking (Raise of Pericenter)	30
Orbit Maintenance	500
TOTAL	2200

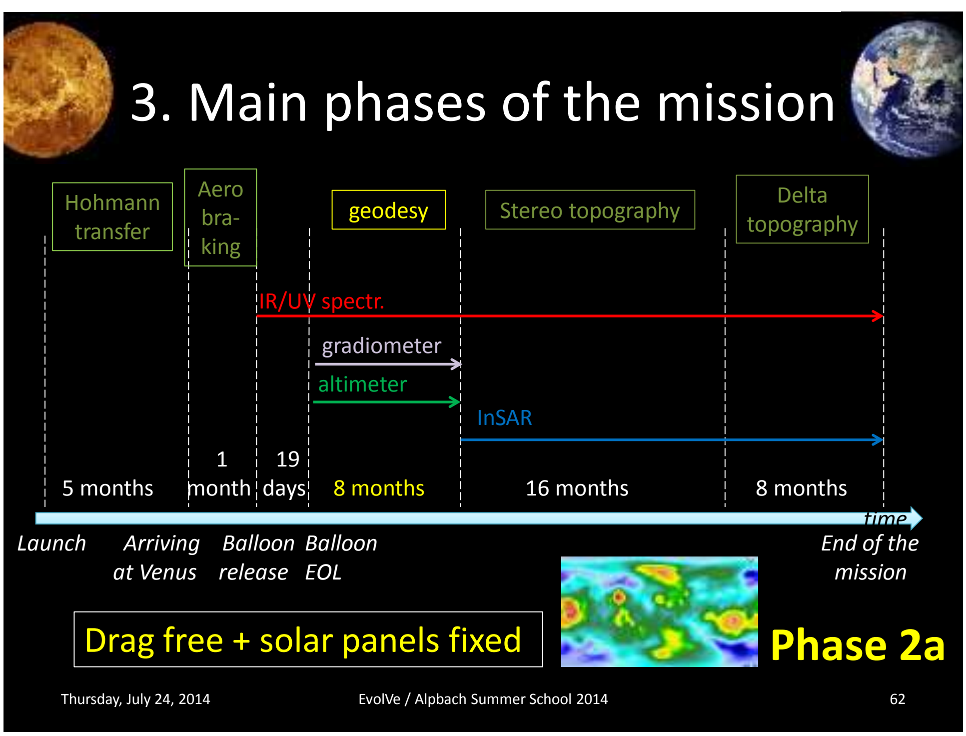

3. Main phases of the mission
Hohmann transfer
Aero bra-king
geodesy
Stereo topography
Delta topography
IR/UV spectr.
gradiometer
altimeter
InSAR
5 months
1 month
19 days
8 months
16 months
8 months
time
Launch
Arriving at Venus
Balloon release
Balloon EOL
End of the mission
Total mission duration : 3.2 years
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
57

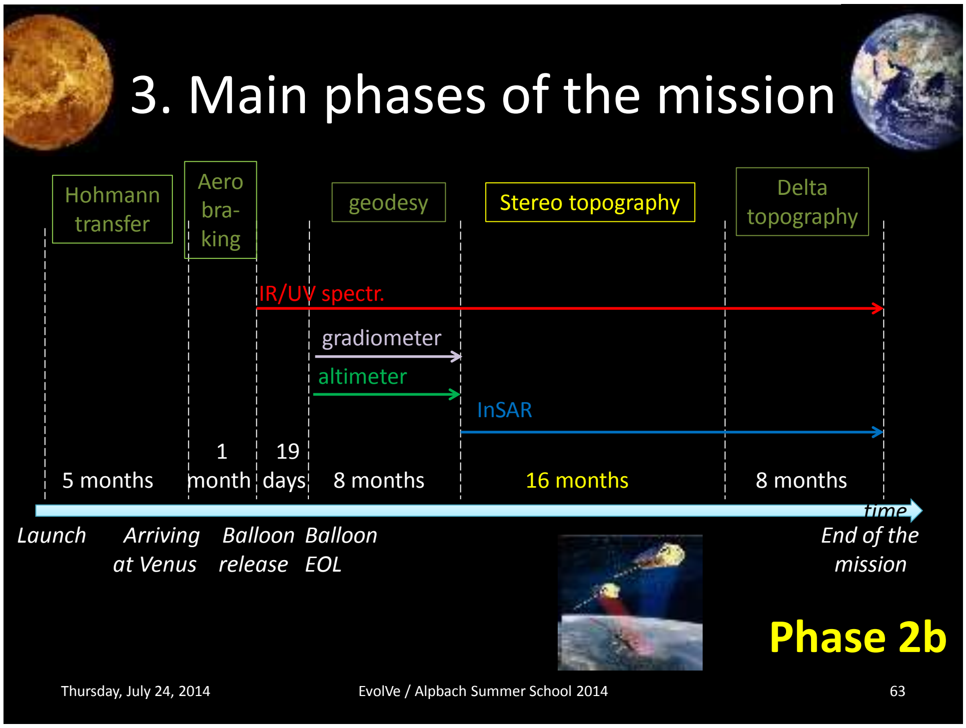

3. Main phases of the mission
Hohmann transfer
Aero bra-king
geodesy
Stereo topography
Delta topography
IR/UV spectr.
gradiometer
altimeter
InSAR
5 months
1 month
19 days
8 months
16 months
8 months
time
Launch
Arriving at Venus
Balloon release
Balloon EOL
End of the mission
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
58


3. Main phases of the mission
Hohmann transfer
Aero bra- king
geodesy
Stereo topography
Delta topography
IR/UV spectr.
gradiometer
altimeter
InSAR
5 months
1 month
19 days
8 months
16 months
8 months
time
Launch
Arriving at Venus
Balloon release
Balloon EOL
End of the mission
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
59

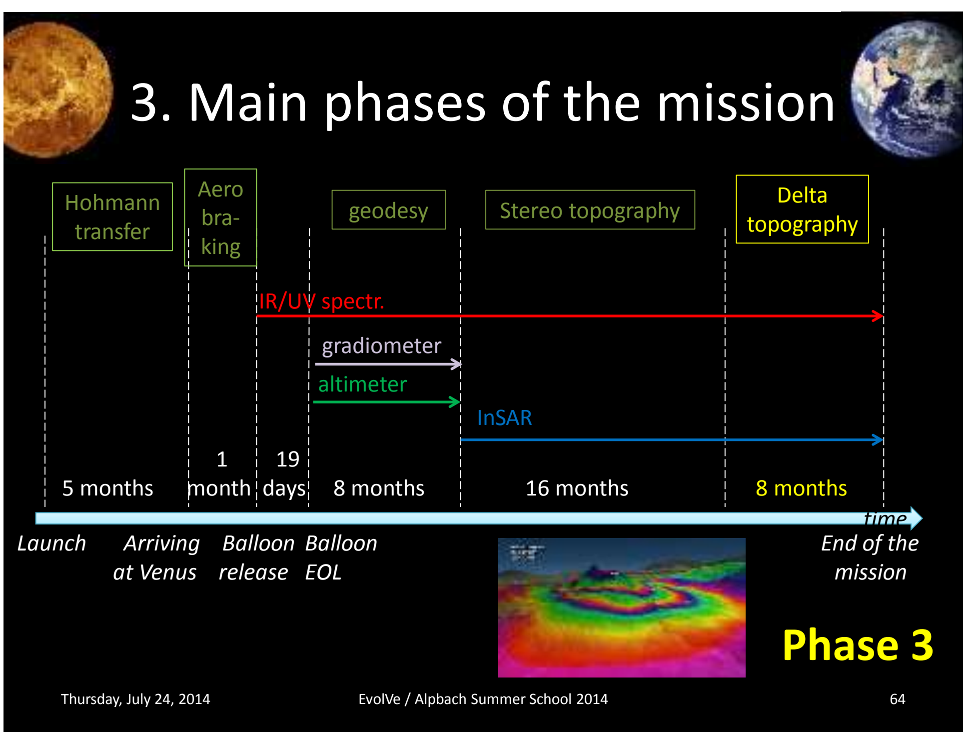

3. Main phases of the mission
Hohmann transfer
Aero bra- king
geodesy
Stereo topography
Delta topography
IR/UV spectr.
gradiometer
altimeter
InSAR
5 months
1 month
19 days
8 months
16 months
8 months
time
Launch
Arriving at Venus
Balloon release
Balloon EOL
End of the mission
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
60


3. Main phases of the mission
Hohmann transfer
Aero bra-king
geodesy
Stereo topography
Delta topography
IR/UV spectr.
gradiometer
altimeter
InSAR
5 months
1 month
19 days
8 months
16 months
8 months
time
Launch
Arriving at Venus
Balloon release
Balloon EOL
End of the mission
2.5 revolution of Venus
Phase 1
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
61


3. Main phases of the mission
Hohmann transfer
Aero bra-king
geodesy
Stereo topography
Delta topography
IR/UV spectr.
gradiometer
altimeter
InSAR
5 months
1 month
19 days
8 months
16 months
8 months
time
Launch
Arriving at Venus
Balloon release
Balloon EOL
End of the mission
Drag free + solar panels fixed
Phase 2a
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
62



3. Main phases of the mission
Hohmann transfer
Aero bra-king
geodesy
Stereo topography
Delta topography
IR/UV spectr.
gradiometer
altimeter
InSAR
5 months
1 month
19 days
8 months
16 months
8 months
time
Launch
Arriving at Venus
Balloon release
Balloon EOL
End of the mission
Phase 2b
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
63



3. Main phases of the mission
Hohmann transfer
Aero bra-king
geodesy
Stereo topography
Delta topography
IR/UV spectr.
gradiometer
altimeter
InSAR
5 months
1 month
19 days
8 months
16 months
8 months
time
Launch
Arriving at Venus
Balloon release
Balloon EOL
End of the mission
Phase 3
Thursday, July 24, 2014
EvolVe / Alpbach Summer School 2014
64

3. Main phases of the mission

- Phase 1 : Balloon
  - *Balloon relay*
  - *IR/UV spectrometer*
- Phase 2a : geodesy
  - *Gradiometer*
  - *Altimeter*
  - *IR/UV spectrometer*
- Phase 2b + 3: topography
  - *InSAR (10% of the time)*
  - *IR/UV spectrometer*

Power (W)	with margin	Data rate (kbps)	With margin
463	**555**	143	**151**
463	**555**	36	**37**
1211	1423	341	358

Design

Main technological challenges

Area	Challenge	Solution
Main experiment: Gradiometer	Drag free	Electric propulsion
	No oscillations	Panel configuration + different operation phases
InSAR/Altimeter	High data rate	Different operation phases + local coverage
	High power consumption	
Measurement in the atmosphere	Balloon life time	Solar panels + battery
Venus environment	Thermal challenge	Radiator on 1 cold face + turn the orbiter once a Venus year

Antenna pointing during geodesy phase

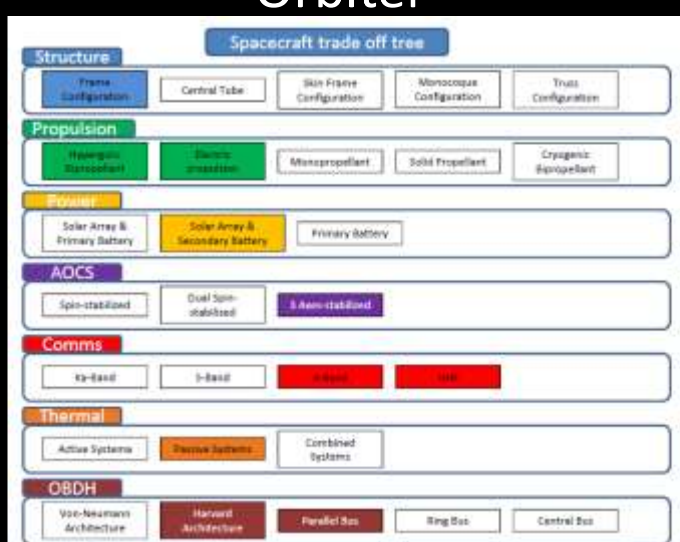
- Conflicting requirements

Continuous Measurement — **Minimal vibrations on spacecraft** ⟷ **Pointing of antenna** — *Data Transmission*, *Doppler Tracking*

- Possible solutions
  - consecutive observation and pointing sequences (e.g. 3:1 cycles)
  - pointing over the poles (dense ground-tracks)
  - stabilize orbit determination via altimeter cross-over analysis and gradiometer angular rates
  - Phased-Array Antenna with electronic pointing (TRL=3)

Orbiter Design

Orbiter

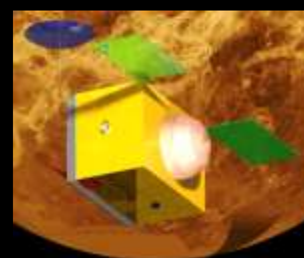


Orbiter

Structure

Frame Configuration | Central Tube | Skin Frame Configuration | Monocoque Configuration | Truss Configuration

- Rectangular shape, Aluminium
- Primary struts: 170 kg
- Secondary structure: 67 kg
- Mechanisms: 15 kg, 61 W
  - Solar Array Drives
  - HGA Drive
  - Deployment Systems
- High design margins, detailed design required



Orbiter

Propulsion

Hypergolic Bipropellant | Electric propulsion | Monopropellant | Solid Propellant | Cryogenic Bipropellant

- ***400 N bi-propellant***

× 1 Model S400-12

Nominal flow rate: 135g/s

- ***10 N bi-propellant***

× 12 Model S10-18

Nominal flow rate: 3.5 g/s

- ***MiniRIT (electrical micropropulsion)***

Drag compensation

40μN-500μN

× 2 an operational version of LISA´s

Nominal flow rate: 2.5 μg/s

Orbiter

Power

Solar Array & Primary Battery | Solar Array & Secondary Battery | Primary Battery

Primary source:
Solar panels
Triple junction Ga As
2.25 kW/m² and 26%
Surface = 4 m²

Secondary source:
Battery Li SoCl2
(rechargeable)
133 Wh/kg
Weight = 12 kg

Eclipse worst case : 30 min

Orbiter

AOCS

Spin-stabilized | Dual Spin-stabilized | 3 Axes-stabilized

Sensors

3 stars trackers : A-STR
(Venus express,
Rosetta,..)

3 sun sensors (baseline Bradfort)
2 gyroscopes (baseline Honeywell)

accuracy

Attitude	10^{-3} rad
Angular rate	10^{-5} rad/s
Angular acc.	10^{-7} rad/s^2

Actuators

3-axis stabilized
4 reaction
wheels

12 thrusters

-> Scientific requirements ok
-> safe mode ok
-> redundancy ok

Orbiter

Comms

Ka-Band | S-Band | X-Band | UHF

- Required data rate from **orbiter to Earth**: 55.3 kbps (Phase 1), 1.85 Mbps (Phases 2a, 2b, 3)
- Antenna size on orbiter: 2.0 m , 30.1 kg (to 35 m receiver on Earth)
- Power: 230 W
- Frequency: 8.5 GHz, X-band
- Maximum possible Data Rate E/N : 1.924 Mbps

Orbiter

Thermal

Active Systema | Passive Systems | Combined Systems

One of the main design drivers

Heat sources

Sun (Solar flux ~2.6 kW/m^2)
Venus (Albedo ~0.8, IR flux ~ 153 W/m^2)
Internal Power (Total budget – emitted power ~1150 W)

Control elements

20 layers MLI (golden Kapton)
1 „cold face" + radiator -> S_area = 4 m^2

Target

Maintain S/C temperature ~297 K

Area cross section	4	m2
QInternal	1150	W
Qexternal x Area	224.82	W
Qradout x Area	1376.58	W
BALANCE = Qext + QInt - Qrad	-1.76	W

-> Operational requirements ok

Orbiter

OBDH

Von-Neumann Architecture | Harvard Architecture | Parallel Bus | Ring Bus | Central Bus

- Commercial Off The Shelf (COTS)
- Includes:
  - Data Storage
  - Telemetry and Tele-command processing
- 10.5 kg
- 21 W

Orbiter - Mass Budget

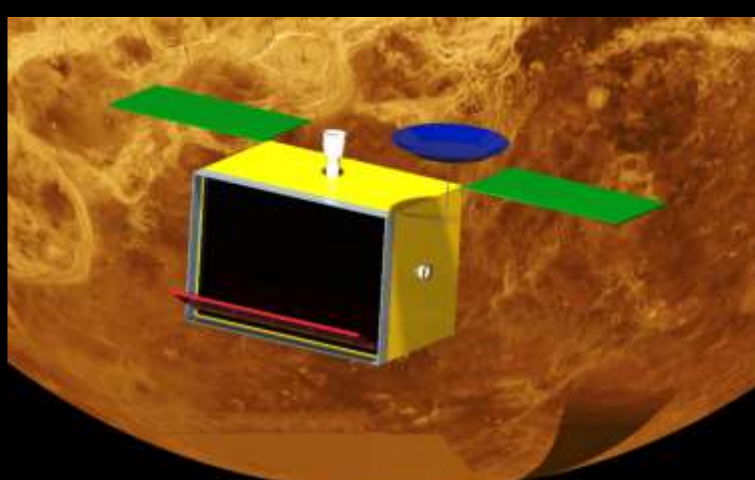
Ishtar Orbiter	
MASS BUDGET	***Mass (Kg)***
Payload	460
Structure	170
Propulsion	130
AOCS	60
Thermal control	35
Power + solar arrays	35
Comms	30
OBDH	10
Platform mass	**930**
Platform system margin	20%
Total dry mass	**1116**
Propellant	2040
Propellant margin	20%
Total propellant	**2448**
TOTAL MASS	3564

Orbiter - Power Budget

Ishtar Orbiter	
POWER BUDGET	***W***
Payload	818
Structure	47
Propulsion	70
AOCS	133
Thermal control	-
Power + solar arrays	28
Comms	230
OBDH	20
Required Power	**1346**
System margin	10%
TOTAL POWER	**1480**

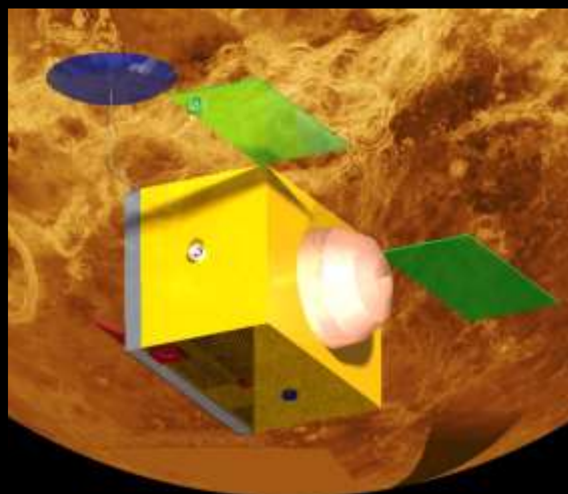
Thursday, July 24, 2014 EvolVe / Alpbach Summer School 2014 80

Orbiter Architecture



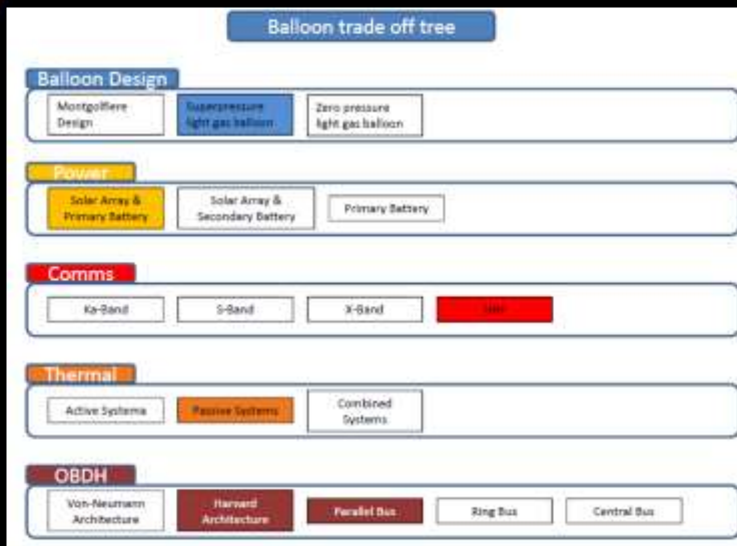
Thursday, July 24, 2014 EvolVe / Alpbach Summer School 2014 81

Orbiter Architecture



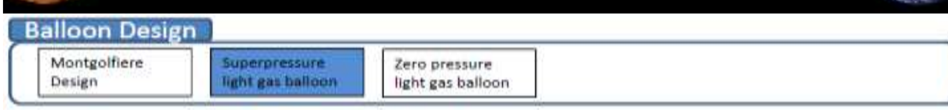
Balloon Design

Balloon



Thursday, July 24, 2014 EvolVe / Alpbach Summer School 2014 84

Balloon



- Superpressure light gas
- Approx. 7 m diameter
- Gas generated at deployment

Thursday, July 24, 2014 EvolVe / Alpbach Summer School 2014 85

Balloon

Power

Solar Array & Primary Battery	Solar Array & Secondary Battery	Primary Battery

Primary source:

Solar panels to extent operation

Triple junction morphous

600 W/m² of solar radiance at 55 km

Surface = 2 m²

Secondary source:

Battery Li SoCl2 (non rechargeable)

680 Wh/kg

Weight = 18 kg

Life-time of the balloon : 19 days

Balloon

Comms

Ka-Band	S-Band	X-Band	UHF

- Required data rate from **balloon to orbiter**: 22.5 kbps
- Antenna size on balloon: 0.1 m , 0.8 kg (identical on orbiter)
- Power: 10 W
- Frequency: 0.45 GHz, UHF
- Maximum possible Data Rate E/N : 35.6 kbps


Balloon

Other Systems

- Entry and Descent System (EDS)
  - Released from orbiter during aerobraking phase
  - Retro rockets
  - Heat shield
- Structural
- Attitude System
  - Sun Sensor
- Thermal System
  - Passive
- OBDH


Balloon – Mass Budget

Tammuz Balloon	
MASS BUDGET	***Mass (Kg)***
Payload	28
Structure	20
Thermal control	1
Power + solar arrays	24.5
Comms	0.8
OBDH	4
Entry probe	127
Gas storage	50
Balloon	21
Gas	16
Balloon mass	**292.3**
Platform system margin	20%
Total dry mass	**350.76**
TOTAL MASS	**351**


Balloon – Power Budget

Tammuz Balloon	
POWER BUDGET	***(W)***
Payload	46
Structure	0
Thermal control	-
Power + solar arrays	5
Comms	10
OBDH	5
Balloon power requirements	**66**
Platform system margin	10%
TOTAL POWER	**73**

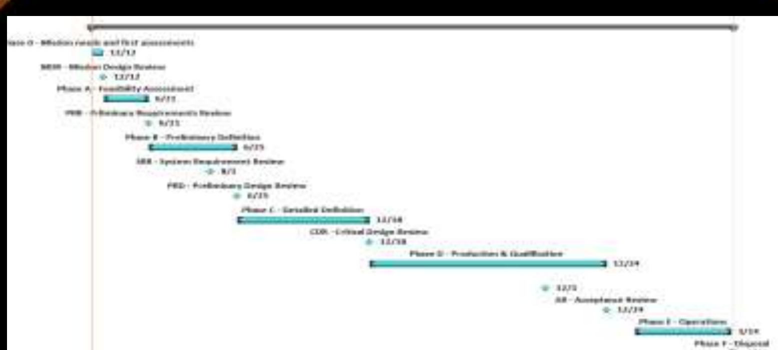

Cost, Risk & Management


Enabling technologies

- Balloon system
- Entry probe
- Drag reduction aerodynamic design

➔ Increased development time


Mission Development Plan



Phase 0 Now - 12/2014	Phase A 12/2014 - 6/2016	Phase B 6/2016 - 6/2019	Phase C 6/2019 - 12/2023	Phase D 12/2023 - 12/2031	Phase E 12/2032 - 3/2036	Phase F 3/2036 - 4/2036

Risk Analysis

Severity						
5	B, M	N	A			
4		E, I	G	H		
3	K	C	F	L		
2	J	D		O		
1						
	1	2	3	4	5	Probability

- Main Risks:
  - A: Drag in Orbit too high for Measurement
    - Mitigate: design margins
  - H: Insufficient Orbit Determination
    - Mitigate: development time

Cost Analysis

ELEMENTS	[M€]
LAUNCHER (Ariane 5)	175
SPACECRAFT (Dry mass ~ 1115 Kg + propellant ~ 2450 Kg)	350
ENTRY PROBE (Including balloon, ~290 Kg)	300
SMOC	110
PROJECT MANAGEMENT	80
INDUSTRIAL MARGIN (10%)	65
PROGRAM MARGIN (15%)	136
PROGRAM COST TO ESA	**1216**
PAYLOAD (~500 Kg)	500
TOTAL COST (including margin)	**1716**

Conclusion & Recommendations

Downscaling

- Minimum Working Example: Gradiometer w/ Altimetry

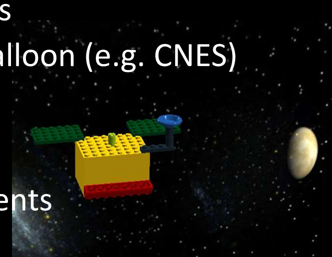
All values in [kg]	SMAD Remote Sensing	SMAD Average All
Payload	143	143
Dry Mass	388	529
Total Launch Mass	**1253**	**1710**
Soyuz to Venus	1650	1650
Ariane V to Venus	4500	4500

Recommendations (1)

- Refine subsystems
  - More powerful injection engine
  - Investigate Ka-band design change
- Detailed structural design
- Detailed balloon design
- Refine operational concept, duty cycles
- Additional downsizing options

Recommendations (2)

- Potential for Co-operations
  - Different launcher (e.g. Delta)
  - Instrument development (national space agencies)
  - Ground station network, tracking (e.g., NASA DSN)
  - Synergy with future missions
  - Separate development of balloon (e.g. CNES)
- Outreach
  - Education program for students
  - Flyers, exhibitions



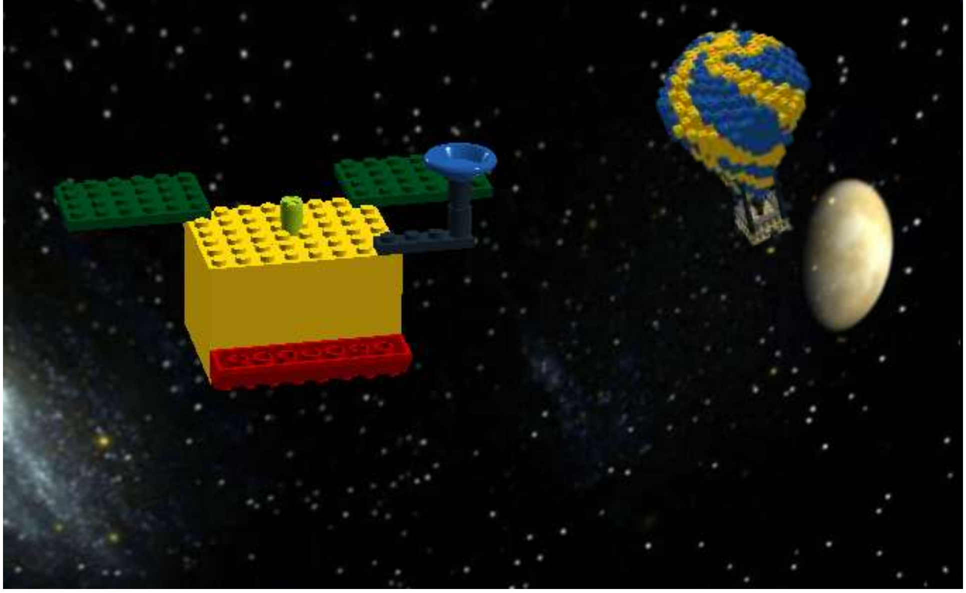
Conclusion

- Science Theme: Difference Venus - Earth
- Primary Objective: Investigate Tectonics
- Secondary objectives: Volcanism, composition
- Payloads: *Gradiometer, InSAR, Altimeter, IR/UV Spectrometer, Mass Spectrometer, MT Sounding*
- Orbiter, Balloon
- Total Launch Mass: 3915 kg (Dry Mass: 1467 kg)
- Ariane V Launch
- Mission Duration: 3.2 yrs

Thank you for your attention!

R. Bailey – Conrad Observatory, ZAMG
S. Bertone – Bern University (CH)
S. Credendino – University of Naples
A.M. Kleinschneider – TU Delft
D. Koronczay – Eotvos University
M. Lanzky - University of Copenhagen
A. Losiak – Polish Science Academy
C. Marcenat – SUPAERO, Toulouse
P. Martin – Trinity College Dublin
I. Muñoz – DLR-GfR
T. Neidhart – University of Vienna
M. Rexer – TU München
H. Wirnsberger – TU Graz

EvolVe For Kids



Observables

1) Tectonics
   - Gravity field
   - Topography
   - Crustal/lithospheric structure
   - H_2O content

2) Volcanism
   - Delta-topo
   - Composition
   - Thermal gradient

3) Accretion
   - Core size
   - Composition, noble gas quantities


Observables – Tectonics (1)
Requirements

- Gravity field
  - Minimal drag/drag compensation
  - Very accurate attitude determination
  - Resolution of 80km
- Topography
  - Deduce subsurface structures from combination of gravity field and topography
- Lithospheric structure
  - Constrain thickness of lithosphere to within 10s of km


Observables – Tectonics (1)
Methods

- Gravity field:
  - ???
- Topography:
  - SAR-InSAR from orbiter
- Lithospheric structure:
  - *In situ* MT sounding using natural EM signals

MT Sounding: Theory

$$D(km) = 0.36\sqrt{\rho/f}$$

- Magneto-telluric sounding
- Past implementations:
  - Used extensively in ground, marine and aerial subsurface explorations on Earth
  - Method has been implemented on magnetic surveying of the moon to gain information on core size
  - Same method used measurement inversion to find possible subsurface oceans on Europa and Callisto
- On Venus:
  - Ideal at height of 55km
  - Use Schumann resonances from lightning as natural sounding signal

Observables – Volcanism (2) *Requirements*

- Variability in isotopic composition of noble gases from He to Xe:
  - Mass resolution: 0.1 AMU
  - Range of measurement: 1 - 150 AMU
  - Frequency of measurement: at least 1 measurement of every noble gas isotopic ratio
  - Sensitivity: 0.1 ppb
  - Accuracy: Abundance and isotope ratios of He, Ne, Ar, Kr, Xe to ± 3%.
- Change in topography:
  - Vertical resolution 5mm, horizontal resolution 1km
- Global variability of volcanic gas SO_2
  - Sensitivity 50 ppbv at the top of clouds
  - 1 month duration and global coverage
  - Measurement at least twice a day during probe life-time
  - Range of measurement 1-150 AMU
  - 0.1% precision
- Thermal flux:
  - Detect relative thermal flux 0.1 W/m^2
  - Spatial resolution: <50 km/px
  - Targeted area of observation size: 1000 km
  - Observation of a targeted area should be repeated in 2-6 days.

Observables – Volcanism (2)
Methods

- Variability in isotopic composition of noble gases:
  - Gas chromatograph mass spectrometer for *in situ* measurements of the atmosphere
- Change in topography:
  - SAR-InSAR for variability over time
  - Detect recently deposited volcanic lava flows
  - Requires re-measurement of area of interest over time
- Global variability of volcanic gas SO_2
  - Gas chromatograph mass spectrometer for long duration measurement in situ variations in isotopic composition of volcanic gases: $^{34}S/^{32}S$ and $^{33}S/^{32}S$ H^2O/HDO
- Thermal flux:
  - IR/UV spectrometer to measure thermal flux of surface

Observables – Accretion (3)
Requirements

- Core size:
  - Gradiometer ?
- Composition

Observables – Accretion (3) *Methods*

- Core size
  - *In situ* MT sounding in combination with orbiter-measured magnetic field values
- Composition
  - Gas chromatograph mass spectrometer to measure surface composition

Thermal calculations

Input Parameters		
Epsilon (radiator emittance)	0.78	*silvered teflon*
Alfa (radiator absorptance)	0.05	*silvered teflon*
Radiator Temperature	297	K
Distance to Sun	0.72	AU
Albedo	0.8	
IR flux	153	W/m2
Fsun	0	
Falbedo	0.25	
Finfrared	0.25	
Total Electric Power budget	1500	W
Antenna Emitted power	350	W
Area cross section	**4**	m2
Qinternal	1150	W
Qexternal x Area	224.82	W
Qradout x Area	1376.58	W
BALANCE = Qext + Qint - Qrad	-1.76	W

What do we know: noble gases

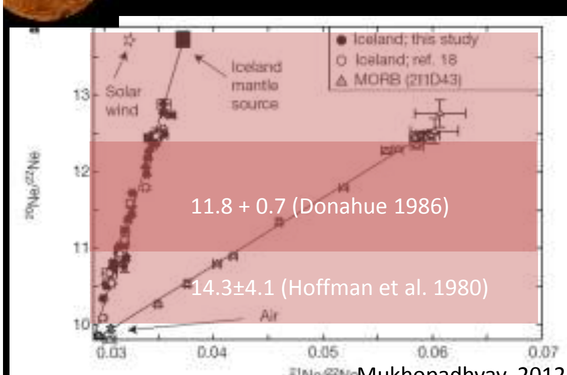
Noble gas abundance	Previous measurements	notes
He	12 (+24,-8) ppm	extrapolated from meas. > 130 km
Ne	7 ± 3 ppm	4 MS measurements
Ar	70 ± 25 ppm	3 MS and 2 GC measurements
Kr	0.4 ± 0.14	Venera 11 and 12 reproduced measurements
	0.2	PV Probe Hoffman analysis
	0.025	PV Probe Donahue analysis
Xe	0.12 upper limit	PV Probe Donahue analysis

Target accuracy <5-10%

Noble gas isotope ratio	Previous measurement	notes
$^3He/^4He$	---	^3He predicted at low ppb level – methane or H_2 could give H_3^+ interference with HD
$^{20}Ne/^{22}Ne$	11.8 ± 0.7	Potential interference from $^{40}Ar^{++}$ at 20 Da and CO_2^{++} at 22 Da
$^{20}Ne/^{21}Ne$	---	
$^{36}Ar/^{38}Ar$	5.56 ± 0.62	PV Probe Donahue analysis
	5.08 ± 0.05	Venera 11/12 MS
$^{40}Ar/^{36}Ar$	1.03 ± 0.04	PV Probe Donahue analysis
	1.19 ± 0.07	Venera 11/12 MS
Kr isotopes	---	
Xe isotopes	---	

Mahaffy et al. 2011

What do we know: noble gases



Mukhopadhyay, 2012

Xe isotopes, $^{36}Ar/^{38}Ar$

- Cometary origin of volatiles
- Atmospheric blowoff
- Comparision between number of large impactors on Venus and Earth

Resolution: 0.1 AMU
Frequency of measurement: at least 1 measurement of every noble gas isotopic ratio
Range of measurement: 1 - 150 AMU
Sensitivity: 0.1 ppb Xe, Kr
Accuracy: Abundance and isotope ratios of He, Ne, Ar, Kr, Xe to ±3%.
Temporal resolution: onece
Gas Chromatograph Mass Spectrometer on Balloon (~55 km altitude)

Is tectonic history of Venus comparable to Earth's?

- **Why it is important and how it relates to the theme?**
  - Plate tectonics could be essential for life
    - Support generation of magnetic fields by effectively cooling the deep interior that serves as shield for radiation and solar wind erosion
    - Recycling carbon is needed to stabilize temperature (on Earth)
  - **It is likely to have water if there is plate tectonics**
    - Near surface rock must be weakened, lowers melting point

[Planetary Interior Evolution and Life, EGU2012, T. Spohn 2012]

Is tectonic history of Venus comparable to Earth's?

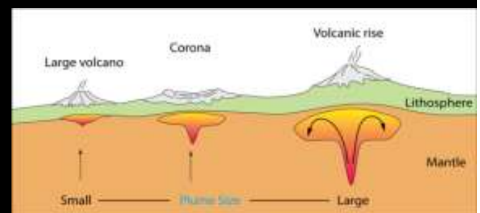
What do we know about the issue raised by the question?

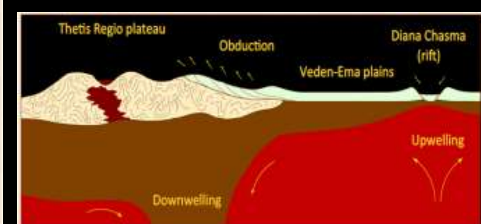
1 .Topographic evidence that point to tectonics and surface movement at Venus (Radar images and Altimetry from Magellan)

2. Magellan topography & gravity seems to confirm "stagnant lid " theory that is different to Earths plate tectonics. [Solomatov and Moresi, 1996]

Is tectonic history of Venus comparable to Earth's?

What do we know about the issue raised by the question?

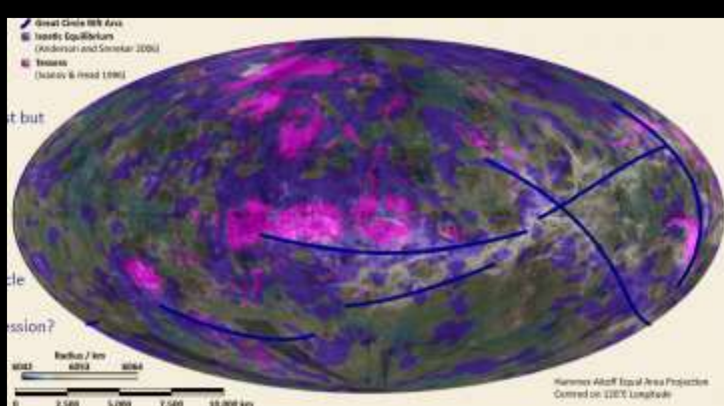




Ghail, 2014

Is tectonic history of Venus comparable to Earth's?

What do we know about the issue raised by the question?



Constant lid vs. plate tectonics

Ghail, 2014


Is tectonic history of Venus comparable to Earth's?

How good do we know the gravity field ?

Models based on Magellan and PVO Doppler data:

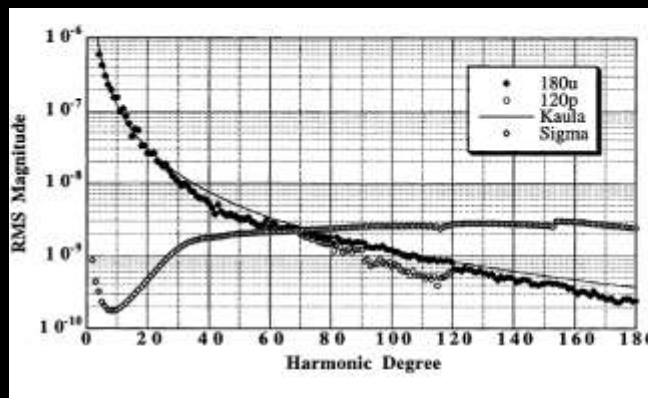
Konopliv (1996): n=120 p

Konopliv (1998): n=180 u

Barriot (1998): n=180

Equator: nmax= 180

Poles: nmax= 40



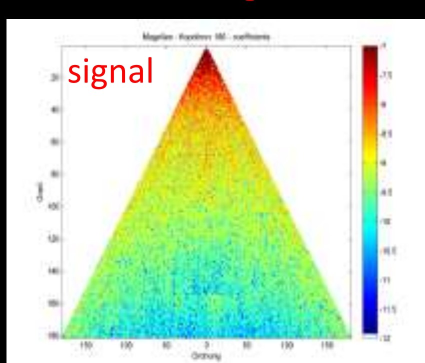
Mostly error supersedes signal approx. at n = 60 (~ 320 km)

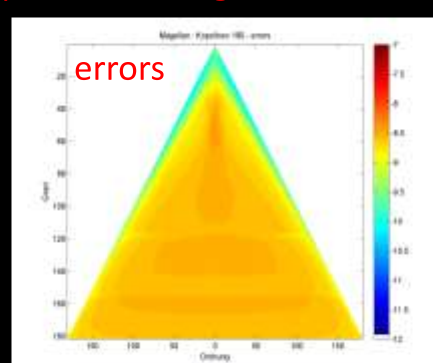
→ Cannot reveal crustal features at few 10s of kilometers


Is tectonic history of Venus comparable to Earth's?

How good do we know the gravity field ?

Magellan results: poor knowledge





→ sectorials SHC's are relatively good determined, zonals are determined weakly

Is tectonic history of Venus comparable to Earth’s?

What do we expect to measure on Venus and what will that mean?

- measure mainly deformation distributions across tens to a few hundred kilometers at possible plate boundaries, along rift systems of some thousand kilometer lengths

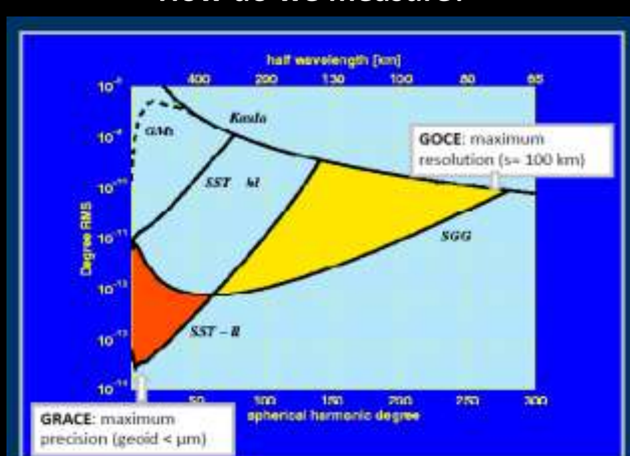
- Venus tectonics could be significantly different to Earth's, which shows rather narrow plate boundaries (few 10 km's).

- expect to retrieve small crustal thickness at rifts, that point to upwelling mantle material. This would tell us that Venus has or recently had tectonic activity.

Thursday, July 24, 2014 EvolVe / Alpbach Summer School 2014 121

Is tectonic history of Venus comparable to Earth’s?

How do we measure?



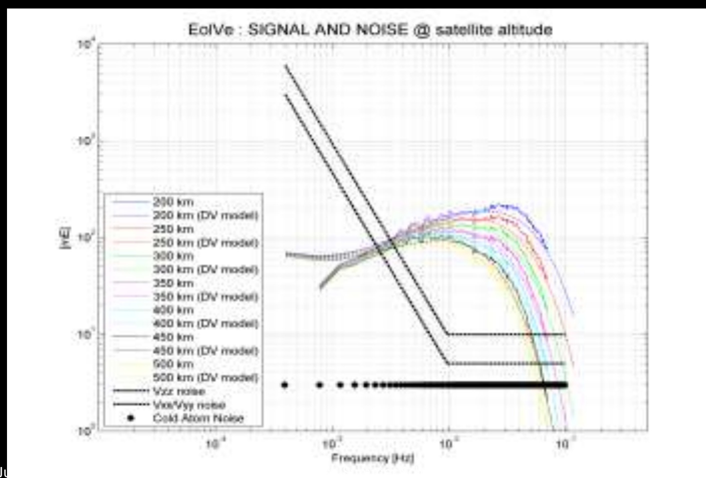
Rummel, 2014

Thursday, July 24, 2014 EvolVe / Alpbach Summer School 2014 122

Gradiometry is suited best to the short-scale scientific requirements

Gradiometer

Gravity field : EvolVe orbit height vs. resolution

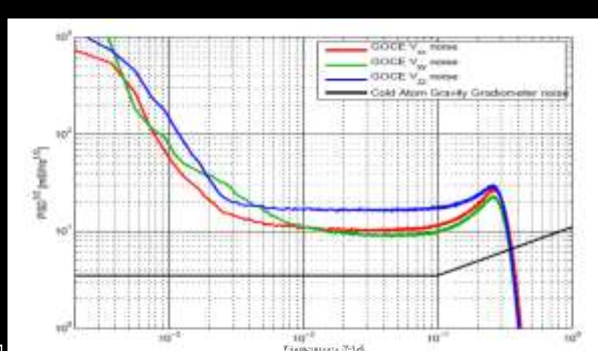


Is tectonic history of Venus comparable to Earth’s?

What instruments – GRAVITY

Option 1: Gravity Gradiometer (GOCE type) (Orbiter, TRL=9)

Option 2: Cold Atom Gradiometer (Orbiter, TRL=3)



Is tectonic history of Venus comparable to Earth's?

Cold Atom Gradiometer

Idea : Cold Atom interferometers instead of accelerometers

Concept: - movement of a cloud of atoms (10^6) is observed

- Interferometry: Raman laser, vacuum chamber
- Cooling of cloud via laser → recoil velocity

Advantages: - white noise over the entire spectrum (3 mE $Hz^{-1/2}$)

→ supercedes both: SST-hl and gradiometry accuracy

- no drag-free system required

Is tectonic history of Venus comparable to Earth's?

What instruments – GRAVITY long wavelengths

Option 1: X/Ka-Band Radar Antenna

STATION-TO-SPACECRAFT-TO-STATION Doppler Tracking

Frequency: 8.43 / ~32 GHz

Accuracies: 20-30cm range

3e-4 cm/s range rate (1000-10000s integ. Time)

[from BepiColombo, based on 1.5m HGA]


Is tectonic history of Venus comparable to Earth's?

What instruments – CRUSTAL/LITHOSPHERIC THICKNESS

Option 1: aerial EM sounding (Ballon, TRL=5)

- Use a balloon at 55km
- On a "dry" Venus should give information on resistivity of the ground at 50km and deeper (taken from models of Grimm 2011)
  - On a "wet" Venus would have information on structures at < 20km depths
  - Greater distances covered (> 104 km) allow for greater reduction of ionospheric effects on the modelled subsurface structures


Is the tectonic history of Venus comparable to Earth's?

- Method: aerial EM sounding
  - Give information on thickness of crust and lithosphere as well as thermal gradient
- EM sounding has been used extensively in ground exploration on Earth, has been done using satellite-based magnetic measurements of Europa and Callisto (Khurana 1998)
- Use naturally-occurring magnetic perturbations (solar wind-ionosphere interactions: < 1 Hz, Schumann resonances from lightning: > 10 Hz)


Is the tectonic history of Venus comparable to Earth's?

- Method: aerial EM sounding
  - Use a balloon at 55km
  - On a "dry" Venus should give information on resistivity of the ground at 50km and deeper (taken from models of Grimm 2011)
  - On a "wet" Venus would have information on structures at < 20km depths
  - Greater distances covered (> 10^4 km) allow for greater reduction of ionospheric effects on the modelled subsurface structures


WHY: Volcanic activity is a surface indicator of interior activity

<u>What do we know?</u>

- V&E Similar size (basic cooling history)
  - But Callisto and Ganymed are simillar size and different properties.
- Geochemical composition (radioisotopes) (Surkov 1997)
  - Age of basalts?
- Young surface age <800 Ma (Romeo and Turcotte 2009)
  - High rates of errosion?
- Morphological volcanoes present
  - Morphology is deceptive
- Variation in SO_2 abundance (Esposito, 1984, Marcq et al. 2013)
  - Can also be caused by long term variation in the circulation \ mesosphere (Clancy and Muhleman 1991).

Marcqet al. 2013

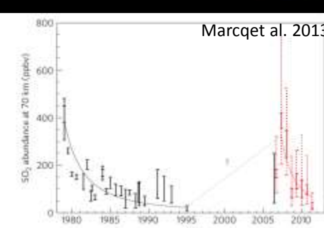
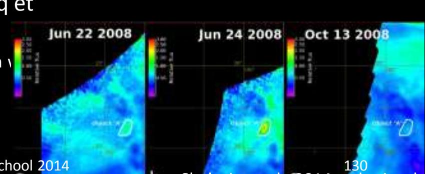


Figure 3 | More than thirty years of SO_2 measurements at Venus's cloud top. Black stands for previously published measurements[26]. Red stands for the 8-month moving average of the retrievals also shown in Fig. 1. Solid red error bars represent 1σ random uncertainty, and dotted red error bars represent measurement dispersion in each temporal bin.



Shalygin et al., 2014, submitted

:asibility of the gravity mapping phase of t mission

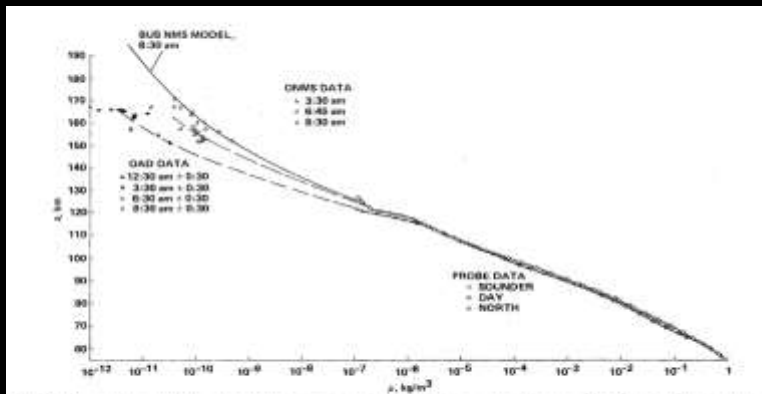


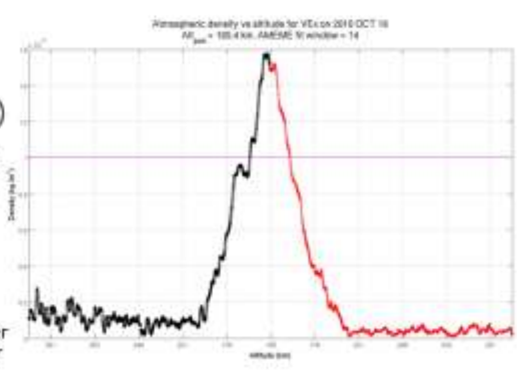
Fig. 14 Entry mode density data from deceleration measurements extended to pass through densities measured by Orbiter and Bus experiments at corresponding local Venus times.

Venus atmospheric models from Pioneer

(Atmospheres of Earth, Mars and Venus as defined by entry probe experiments, Seiff, 1991)

:asibility of the gravity mapping phase of t mission

Density ($\sim 10^{-12}$ to 10^{-10} kg /m^3) – with wave signatures?



Legend

Black – Pre-pericenter

Red – Post-pericenter

Venus atmospheric densities from the VEX drag experiments (VExADE)

(Grotheer, 2013)

:asibility of the gravity mapping phase of t mission

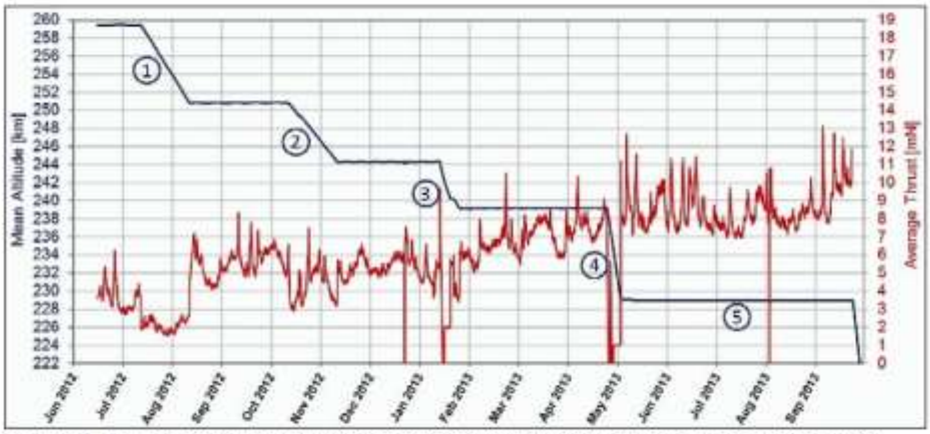


Figure 25: Attitude and average thrust during the low orbit operations campaign (image credit: ESA)

Gas Chromatograph Mass Spectrometer

Power: 41W

Weight: ~17.5 kg

Data rate: 900 bits/s

Based on: GCQMS with gas enrichement line from SAM experiment on Curiosity rover.

(no option for solid sample processing) and GCMS on Huygens

What do we know about Ne isotopes on Venus Earth and Mars?

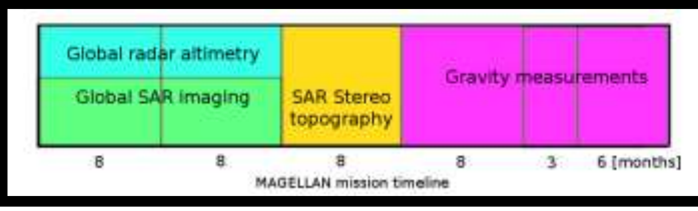
- Noble gas ratios in the upper mantle are similar to those in the modern atmosphere (Ozima and Igarashi 2000): they experienced the same fractionation before Earth was formed (Rollinson 2007:
- There is a profound difference in concentration of noble gases measured by Venera 11-12 and Pioneer Venus e.g., 84Kr from Venera is 0.4 ppm and 0.025 ppm based on Pioneer Venus (Atreya et al. 1989).
- 20Ne/22Ne
  - 14.3±4.1 (from Pioneer Venus Hoffman et al. 1980)
- - 11.8 + 0.7 (later compilation by Donahue 1986)
  - Large error:
  - (Potential interference from 40Ar++at 20 Da and CO2 ++ at 22 Da)

What do we expect on Venus and what would it mean?

- Neon isotopes:
- If the (22Ne/20Ne, 21Ne/20Ne) ratios for Venus and Earth fall on the mass fractionation line predicted by escape processes, it would imply the two planets began as neon twins, sharing the same source of noble gases (and perhaps other volatiles).
- If the observed ratios don't both fall on the fractionation/escape line, then the two planets likely accreted their neons from disparate sources, thus indicating that a variety of formation processes and realms in the parent nebulae helped to create the inner planets.

Current knowledge

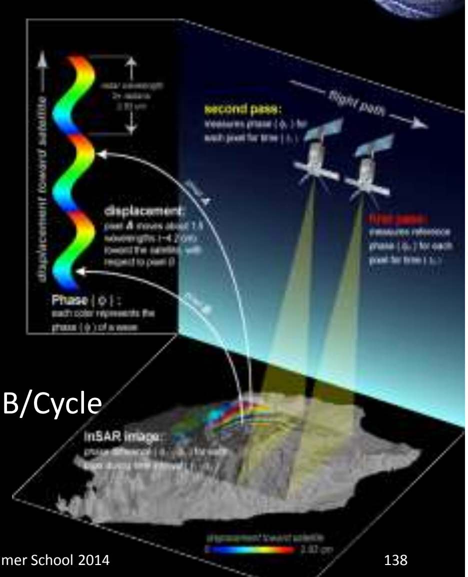
The “state of the art” in topographic information and gravity maps is data from the MAGELLAN mission



Magellan results	
Global SAR coverage:	100-200 m
Global altimetry:	10-20 km horizontal resolution (100 m vertical)
Stereo topography:	20% of planet, 1-2 km horizontal, 50 m vertical
Gravity maps:	300-700 km

SAR- InSAR INSAR

- Single Antenna
- Antenna Size: 2.4m x 0.6m
- Altitude: 250 Km
- Swath Width ≈ 40 -70 Km
- Spatial Resolution <10 m
- Vertical accuracy ≈ cm
- Radar Altimeter data rate 2.74GB/Cycle
- InSAR data rate 6.8 Gb/day



Radar Altimeter- InSAR INSAR

Goals: Topography, Volcanism detection

Idea: Combine Radar Altimeter and InSAR

Measurements

Radar Altimeter works in a continuous mode

InSAR provide a local coverage (10% surface)

S band ($\lambda \approx$ 12 cm)

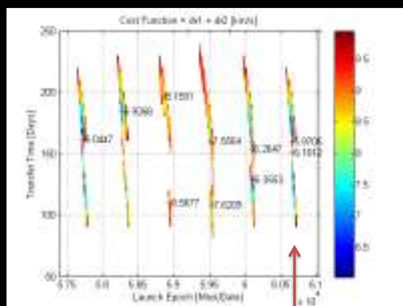
Weight: 120 Kg

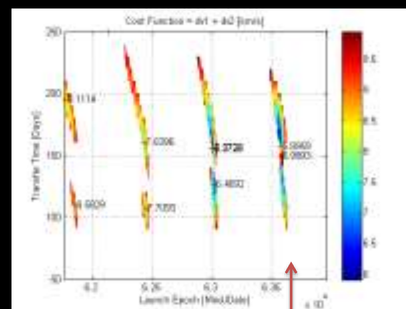
Power Consumption 800W

Phased-Array Antenna

- Electrically steered beam (multiple elements transmit with shifted phase -> constructive/destructive interference)
- 1st 1D high-gain phased array antenna for deep space used in MESSENGER.
- EvolVe requires a 2D antenna -> Difficult to analyze and calibrate.
- New developments are being evaluated
  - Virtual 2D antennas (multiple 1D arrays simultaneously operated)

Orbit design



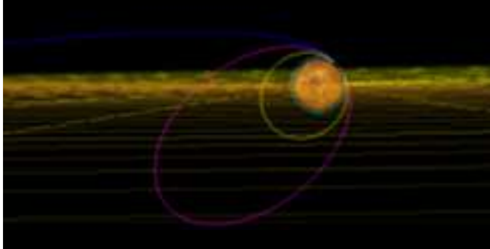


07/12/2024
Optimistic launch window

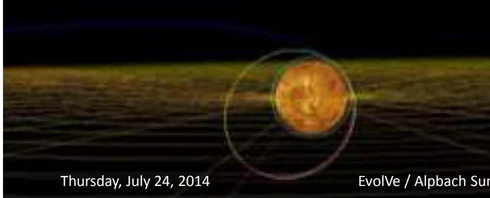
07/12/2032
Alternative launch window

Lambert problem solution
Transfer time and energy optimization

Alternatives for orbit injection

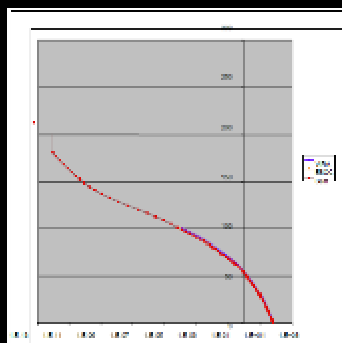


Ariane5	
SatMass@OrbInject	**1472 kg**
deltaV	3.286 km/sec
fuel used	3028 kg
eccentricity	0.0002
periapsis altitude	500 km

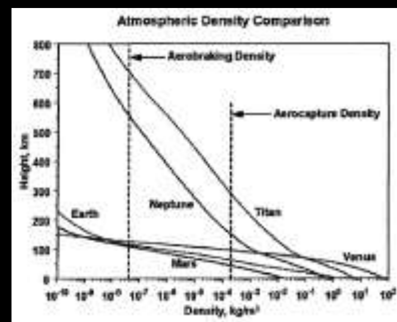


Ariane5	
SatMass@OrbInject	**2787 kg**
deltaV	1.41 km/sec
fuel used	1712 kg
eccentricity	0.007
periapsis altitude	500 km

Orbit design



Credits: CDF Study Report, PEP – ESA 2010



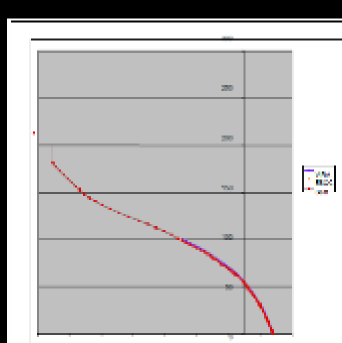
Global reference atmospheric models, including thermospheres, for Mars, Venus and Earth, Just H.L. et al.

Density (kg/m3) as a function of altitude (km) in Venus atmosphere.
Left : the Seiff model, based on the VIRA reference model between 0-100km and extends it up to 200km of altitude. Right: atmospheric density profiles for several planets with indication of aero-braking altitude.

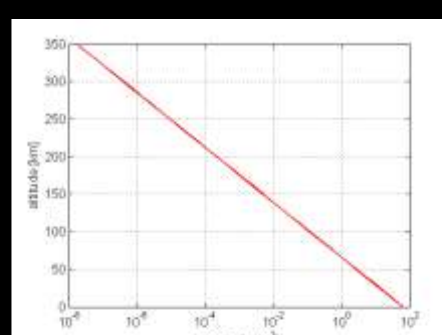
Orbit design

Aero-braking altitude (≈ 10^{-7} kg/m^3 density)

- Seiff model : 130 km
- Exp. density model : 320 km



Credits: CDF Study Report, PEP – ESA 2010



Exponential density profile ρ(0)=65 kg/m3, H=15.9 km

Orbit design

Air-drag acceleration on the satellite/spacecraft

$$a = - 0.5\, \rho\, (C * A / m)\, V^2$$

- ρ : atmospheric density
- C : drag coefficient ≈ 2.2
- A : spacecraft cross-sectional area
- m : spacecraft mass
- V : spacecraft velocity
- a : acceleration

Δv per revolution by air-drag

$$\Delta v_{rev} = - \pi\, \rho\, (C * A / m)\, a * V$$

Orbit maintenance

DeltaV : 0.1769 km/s

Fuel : 210 kg/year

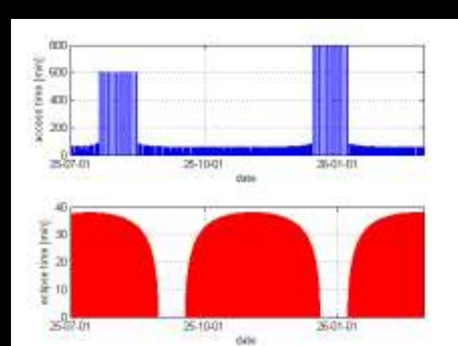
Orbit design

AOS (acquisition of signal) time

(New Norcia DSA to EvolVe, 1 Venus day)

Mean 75 mins

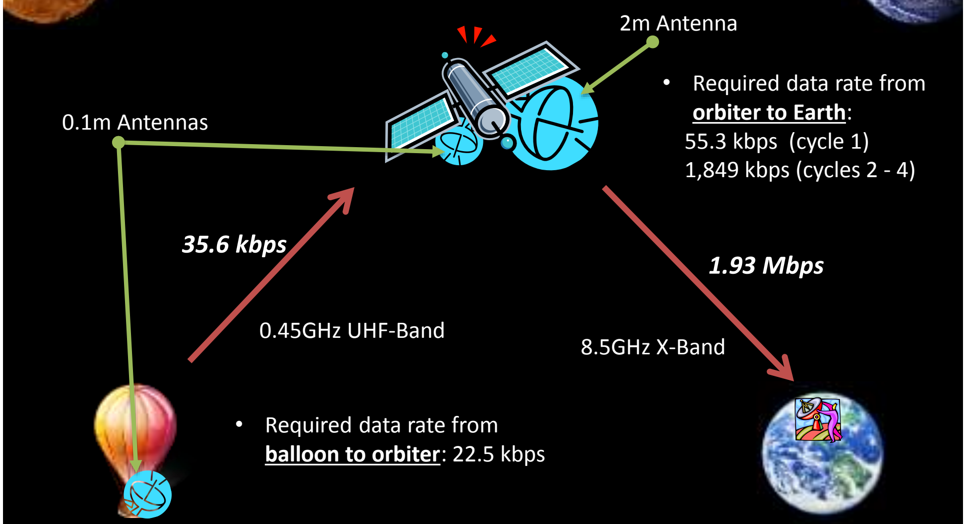
MAX 800 mins



Occultations by : Venus, Sun, Earth rotation

Visibility time for one tracking station: 35%

Communications



- Required data rate from **orbiter to Earth**:
  55.3 kbps (cycle 1)
  1,849 kbps (cycles 2 - 4)

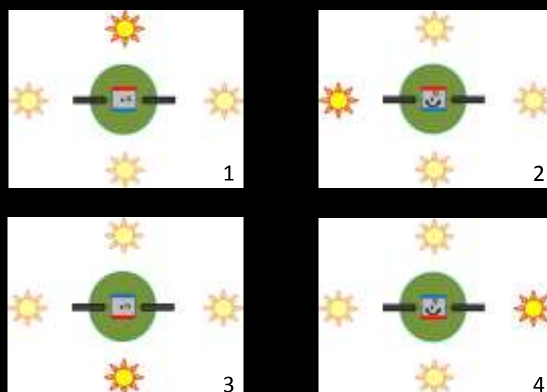
- Required data rate from **balloon to orbiter**: 22.5 kbps

Thermal calculations

Input Parameters		
Epsilon (radiator emittance)	0.78	*silvered teflon*
Alfa (radiator absorptance)	0.05	*silvered teflon*
Radiator Temperature	297	K
Distance to Sun	0.72	AU
Albedo	0.8	
IR flux	153	W/m2
Fsun	0	
Falbedo	0.25	
Finfrared	0.25	
Total Electric Power budget	1500	W
Antenna Emitted power	350	W
Area cross section	4	m2
Qinternal	1150	W
Qexternal x Area	224.82	W
Qradout x Area	1376.58	W
BALANCE = Qext + Qint - Qrad	-1.76	W

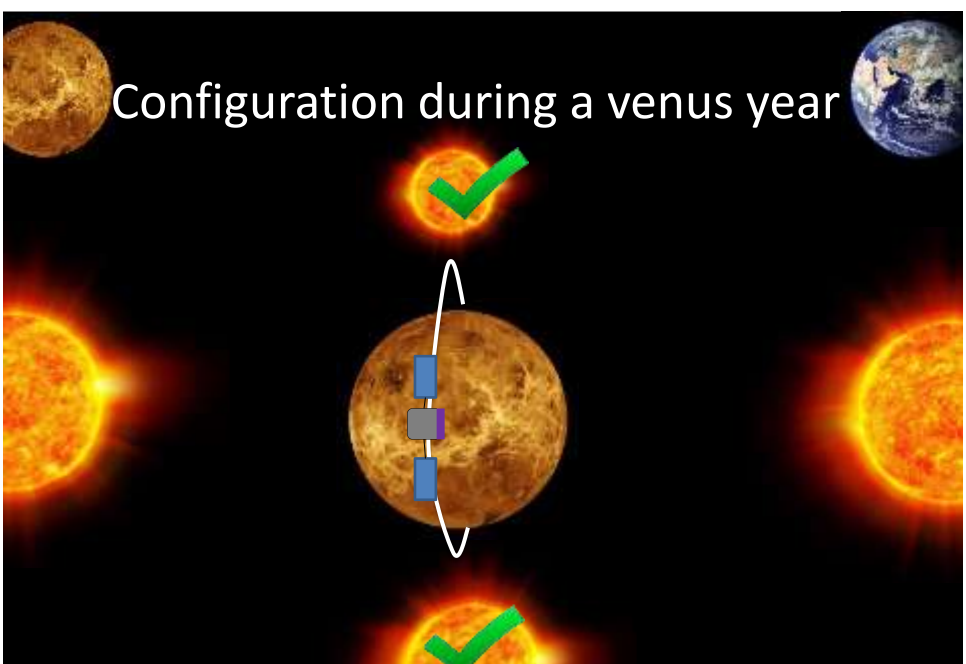
Cold face Orientation

- Always outwards the Sun
- Two singularities per year -> spacecraft turns around ist Z-axis



Thursday, July 24, 2014 EvolVe / Alpbach Summer School 2014 154

Configuration during a venus year



Thursday, July 24, 2014 EvolVe / Alpbach Summer School 2014 155


Venus atmosphere conditions

Venus Environmental conditions					
Balloon altitude	53	55	63	Tolerance	Units
Temperature (K)	323.2	302.3	254.5	plus/minus 4	K
Temperature (°C)	50.05	29.15	-18.65	plus/minus 4	°C
Atmosphere pressure	0.7109	0.5314	0.1659	plus/minus 15%	bar
Zonal speed wind (mean)	60	60	91	plus/minus 40	m/s
Balloon planetary rotation rate	7.4	7.4	4.89	n/a	days
Solar drownwelling flux (0.4-1 micron)	638			n/a	W/m2
Solar drownwelling flux (0.4-1.8 micron)	730			n/a	W/m2
Total upwelling flux	25			n/a	W/m2
Cloud layer	Lower-middle cloud			n/a	n/a
Cloud composition	75% H2SO4 +25% H2O			n/a	n/a
EM radiation	300			n/a	microV/m/sqrt(Hz)


Overview Risk Analysis

Drag in orbit too high for measurements	A
LV failure	B
LV injection error	C
Solar Panel damage	D
Trajectory failure	E
HGA pointing error	F
Loss of Balloon (Reentry, Venus environment)	G
Insufficient Orbit Determination	H
Balloon Deployment Failure	I
Ariane V decommissioned	J
Solar Array pointing error	K
Solar Particle Event	L
Failure to deploy appendices	M
Pointing accuracy insufficient for gradiometer	N
Reduced data transmission rate	O

Cost Analysis

TYPICAL BREAKDOWN OF THE OVERALL COST		
Launcher	~15%	Ariane 5 : ~ 165 M€, Soyuz from Kourou : ~ 75 M€, VEGA ~55 M€
Ground segment & Operations (MOC&SOC)	10-15%	increases with spacecraft distance from the Earth and the mission duration
Management & Facilities	~10%	
Spacecraft Development	60 to to 65 %	what is left !
Contingency	20-25%	(sum (2-4)*M (increase marging with risk)

Downsizing – Medium A

- Gradiometer w/ Altimetry, Balloon

All values in [kg]	SMAD Remote Sensing	SMAD Average All
Payload	386	386
Dry Mass	1047	1429
Total Launch Mass	3382	4616
Soyuz to Venus	1650	1650
Ariane V to Venus	4500	4500

Downsizing – Medium B

- Gradiometer w/ Altimetry and SAR

All values in [kg]	SMAD Remote Sensing	SMAD Average All
Payload	263	263
Dry Mass	713	974
Total Launch Mass	2304	3145
Soyuz to Venus	1650	1650
Ariane V to Venus	4500	4500