WEGENER

SOLID BODY DYNAMICS INVESTIGATION OF VENUS

2014-07-24

Summer School Alpbach 2014 – Team Orange

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Wegener: From Earth to Venus

Alfred Wegener, first scientist to propose the theory of continental drift

"It is only by combing the information furnished by all the earth sciences that we can hope to determine 'truth' here, that is to say, to find the picture that sets out all the known facts in the best arrangement and that therefore has the highest degree of probability."

Taken from Wegener's 'The Origins of Ocean and Continents'

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Science community views on Venus

- From the ESA Cosmic Vision:
  - "following the heritage established by Venus Express, the exploration of Venus should be pursued, with ***special emphasis on its surface*** and interior. ***In particular, a high-resolution radar on an orbiter*** should allow us to make significant progress in the search for active volcanism"
- From the NASA Decadal Survey:
  - **Venus is highlighted in 2/3 of the identified crosscutting themes**: Building New Worlds and Workings of Solar Systems
  - Venus is identified for in 3 goals for inner planets research:
    - Understanding the origin and diversity of terrestrial planets
    - Understanding how the evolution of terrestrial planets enables and limits the origin and evolution of life
    - Understanding the processes that control climate on Earth-like planets
  - VEXAG highlighted that ***orbital high-resolution imagery, topographic***, polarimetric and interferometric measurements are ***critical in enabling future landed missions***

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The wider science context

- What are the heat loss mechanisms on Venus?
- Does Venus have active volcanic and tectonic activity?
- Did Venus have a dynamo-driven magnetic field?
- Can atmospheric interactions with the surface drive tectonics?
- How different is tectonic and volcanic activity on Venus from Earth?

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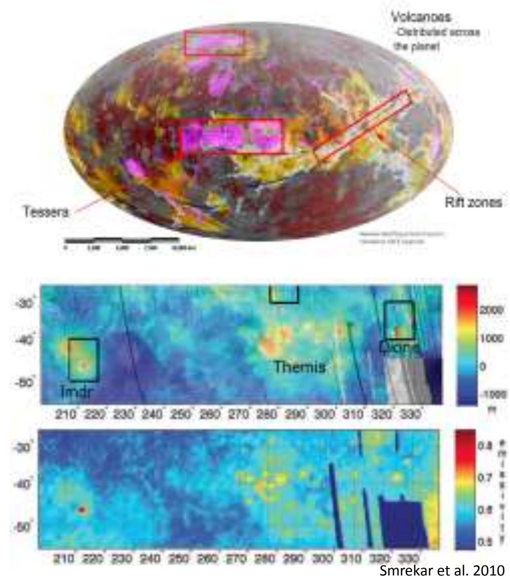
Background

- Previous observations of the Venus surface indicated the **possibility for tectonics and volcanics** [Nimmo and McKenzie, 1998]
- IR emissivity measurements over Venus **hot spots** from Venus Express VIRTIS ***suggests* recent volcanism** [Smrekar et al., 2010]
- ***However*** **no tectonic or volcanic activity has been observed**



Smrekar et al. 2010

Background

- In addition, distribution of impact craters observed by Magellan suggested a resurfacing event ~500-700 Ma
- Any theory for Venus' volcanic and tectonic activity has to address: (1) impact crater population and (2) surface observations of volcanic/tectonic features

Competing Theories:

- **Episodic resurfacing** [e.g. Turcotte, 1993; Basilevsky et al. 2000]
- **Plate-like movement** [e.g. Schubert and Sandwell, 1995; Ghail, 2002]
- **Mantle-derived plume related volcanic activity and localized tectonic activity** [e.g. Campbell, 1999; Guest and Stofan, 1999; Johnson and Richards, 2003]

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Mission objectives

Investigating the solid body dynamics of Venus

Search for evidence of tectonic activity

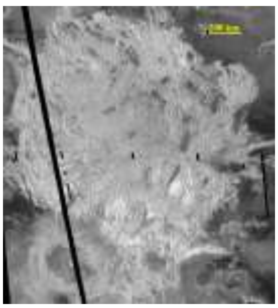


Image Credit: LPI/NASA

Search for evidence of volcanic activity

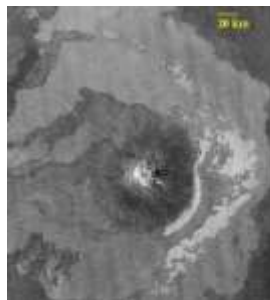


Image Credit: LPI/NASA

Understand geomorphological processes modifying the surface

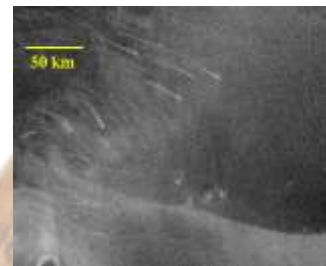


Image Credit: LPI/NASA

Mission objective: tectonic activity

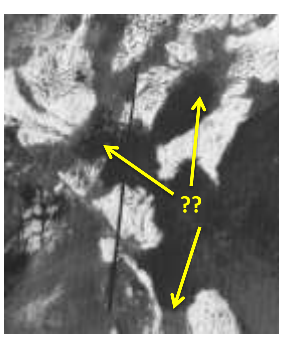
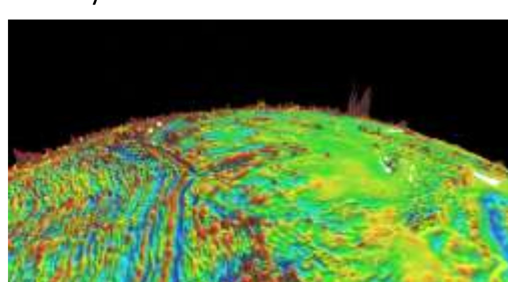


Image Credit: Strom et al. 1994

Primary Objective: Search for evidence of (1) resurfacing and (2) crust movement in tessera and rift zones

Secondary Objective: Search for evidence of a dynamo



Magnetic anomaly map looking north-west at Portugal/Spain from the Atlantic. Image Credit: CIRES/NOAA

Science Requirements:

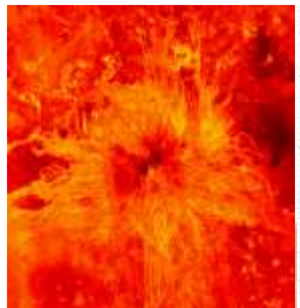
A. 3D deformation of the surface
B. Topography of the planet
C. Refined structure of the crust

Mission Objective: Volcanic Activity

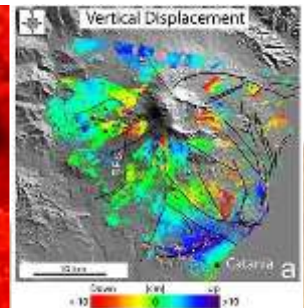
Primary Objective: Search for evidence of (1) eruption and (2) inflation in volcanic edifices

Science Requirements:

A. 3D deformation of the surface
B. Topography of the planet
C. Refined structure of the crust
D. Distinguish between mass wasting, aeolian activity and surface materials that result from volcanic processes



Ushas Mons 'Hot Spot'
Image Credit: JPL NASA



Mount Etna
Image Credit: ESA

Mission objective: geomorphological processes

Objective: Understanding geomorphological processes modifying the surface by searching for mass wasting and aeolian activity

Landslide in Navka Region.
Image Credit: NASA/JPL

Fortuna-Meshkenet dune fields
Image Credit: Greeley et al. 1992

Science Requirements:

A. 3D deformation of the surface
B. Topography of the planet
C. Distinguish between landslides, dunes and surface materials that result from volcanic processes

Mission requirements

1. ***Obtain topographic data*** from the archive to serve as a baseline for our observations

2. ***Make repeated topographic measurements*** of key surface features

3. ***Choose a measurement type to analyse the influence of physical properties*** of key surface features

4. ***Improve the orbit knowledge*** to below 1 m and optional to below 10 cm

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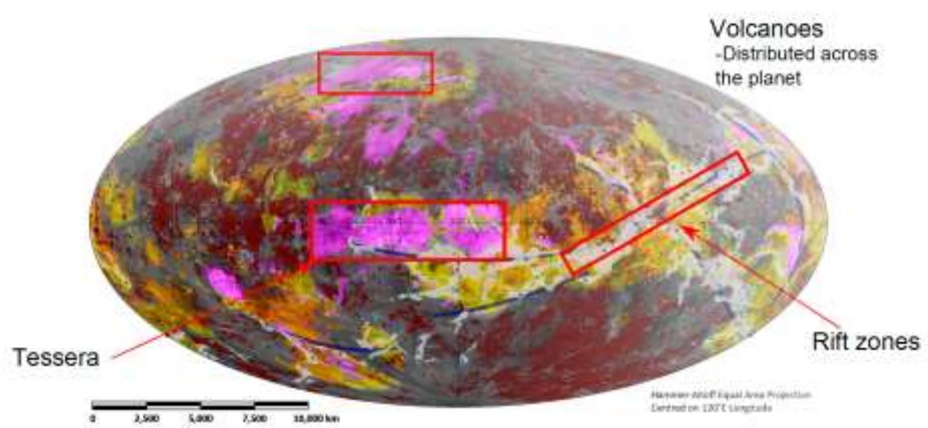
Key features



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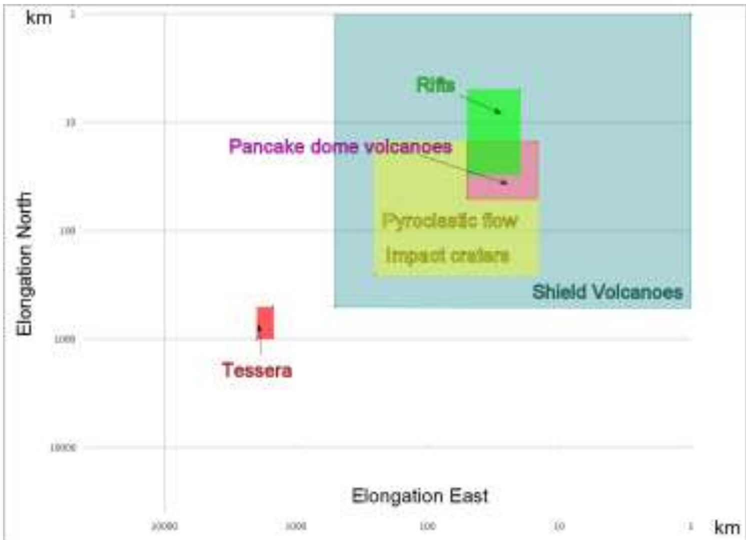
Spatial scale of key features



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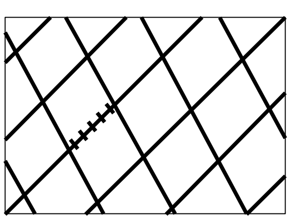
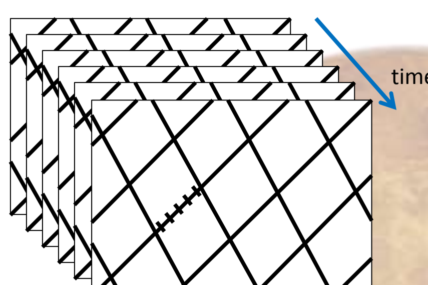
Deformation tracking

Maximum expected movement ~10mm p.a.

Minimum detectable movement is determined by the quality of topography and number of measurements

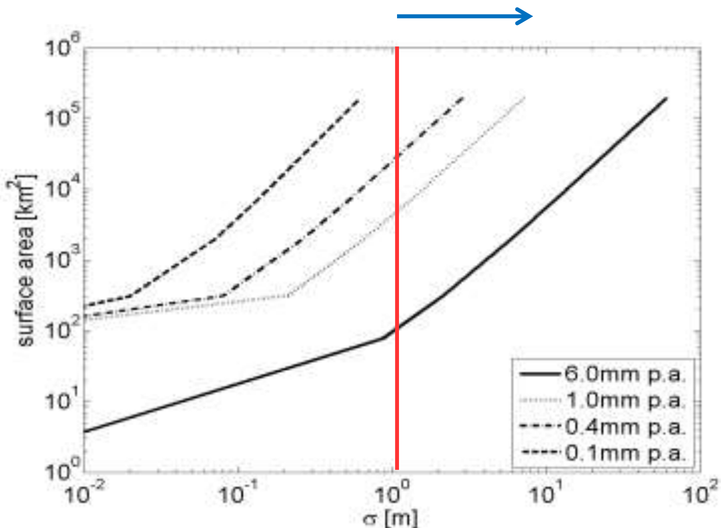
$$\sigma_{feature} \sim \frac{\sqrt{\sigma_{orbit}^2 + \sigma_{rest}^2}}{\sqrt{N}}$$



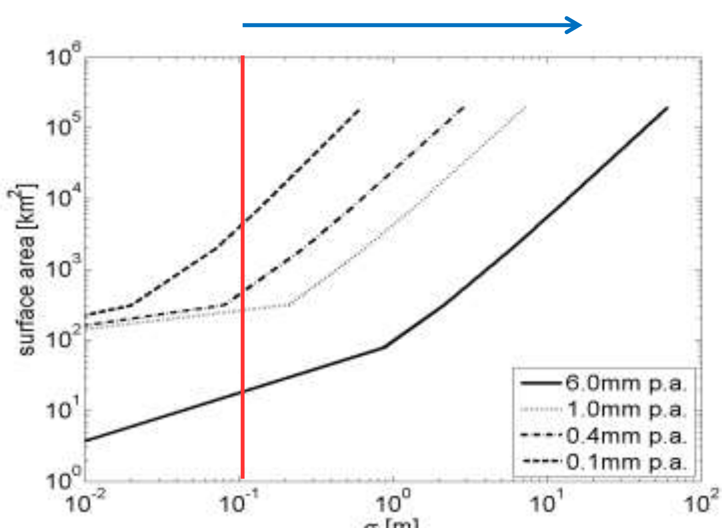


N samples in one repeat period assuming little to no change

Baseline scenario study



Target scenario study



Mission Requirements

5. ***Map the potential weak magnetic field*** originating from remnant magnetic crust and/or potentially from the core

6. ***Achieve global coverage of magnetic and gravity fields***

7. ***Choose a near polar orbit height of 400-500 km*** (to trade loss of sensitivity to gravity versus increase of atmospheric drag)

8. **Optional:** ***gravity gradients for crustal modelling and improvement of existing gravity model*** (accuracy and resolution)

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Magnetic measurements

Goal: **Detect possible remnant magnetic stripes in the crust, and/or a weak magnetic field from the core.**

-Presence of a magnetic field in crust of Venus is unknown
→ no exact observational requirements can be derived

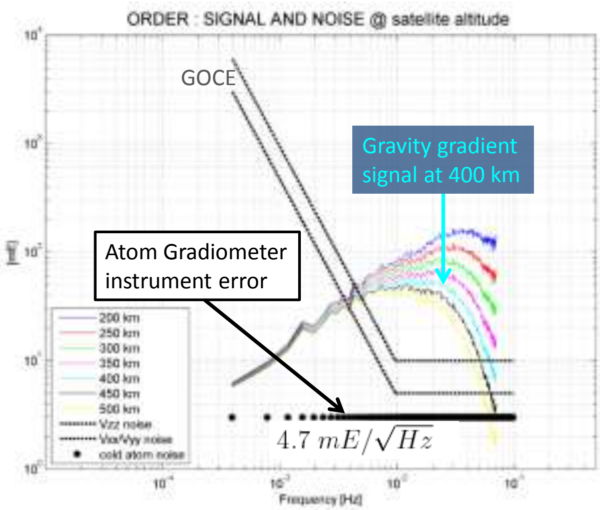
Better resolution (1nT) and **less noise** (~200 nT) than magnetic instrument on Venus Express:

- **Strength** of the magnetic field in the range: 0 nT – 512 nT
- **Vector** magnetic field range: ± 512 nT with a resolution of 0.0156 nT

Gravity gradiometry

Signal below noise at 22 sec ≈ 160 km:

polar gap of app. 1.5° allowed



Source: M. Rexer, team red

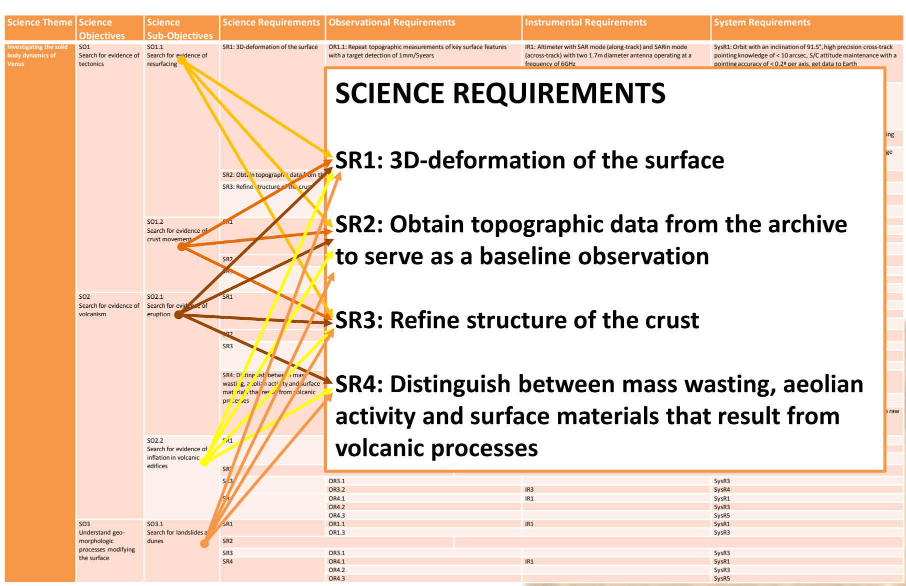
Satellite orbit knowledge

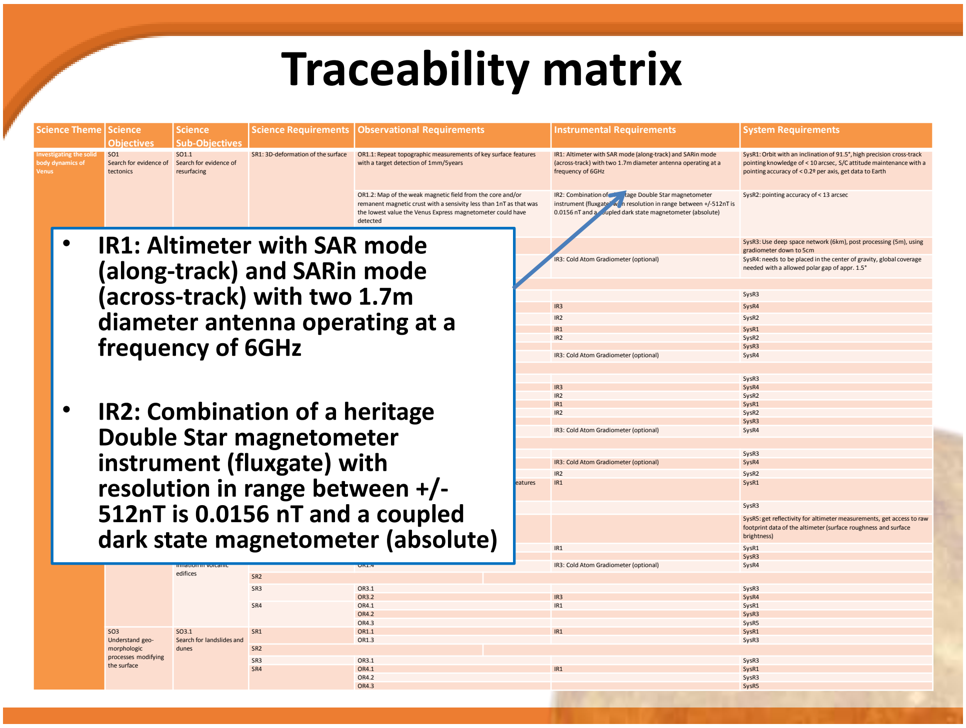
Method for estimating orbit position	Accuracy
From Earth tracking	6 km
From existing gravity fields and error calculations	4 m
Including crossover constraints (like satellite altimetry for Earth)	50 cm (internal consistency)
Velocity (from Doppler information from altimeter)	? Never done
Total baseline	**50 cm – 1 m**
With gradiometer (conservative)	**5-10 cm**

Traceability matrix

Science Theme	Science Objectives	Science Sub-Objectives	Science Requirements	Observational Requirements	Instrumental Requirements	System Requirements
Investigating the solid body dynamics of Venus	SO1 Search for evidence of tectonics	SO1.1 Search for evidence of resurfacing	SR1: 3D-deformation of the surface	OR1.1: Repeat topographic measurements of key surface features with a target detection of 1mm/5years	IR1: Altimeter with SAR mode (along-track) and SARin mode (across-track) with two 1.7m diameter antenna operating at a frequency of 6GHz	SysR1: Orbit with an inclination of 91.5°, high precision cross-track pointing knowledge of < 10 arcsec, S/C attitude maintenance with a pointing accuracy of < 0.2º per axis, get data to Earth
				OR1.2: Map of the weak magnetic field from the core and/or remanent magnetic crust with a sensivity less than 1nT as that was the lowest value the Venus Express magnetometer could have detected	IR2: Combination of a heritage Double Star magnetometer instrument (fluxgate) with resolution in range between +/-512nT is 0.0156 nT and a coupled dark state magnetometer (absolute)	SysR2: pointing accuracy of < 13 arcsec
				OR1.3: Measure orbital position accurately		SysR3: Use deep space network (6km), post processing (5m), using gradiometer down to 5cm
				OR1.4: Measure gravity field accurately (optional)	IR3: Cold Atom Gradiometer (optional)	SysR4: needs to be placed in the center of gravity, global coverage needed with a allowed polar gap of appr. 1.5°
			SR2: Obtain topographic data from the archive to serve as a baseline observation			
			SR3: Refine structure of the crust	OR3.1: Measure orbital position accurately		SysR3
				OR3.2: Measure gravity field accurately (optional)	IR3	SysR4
				OR3.3: Measure magnetic field accurately	IR2	SysR2
		SO1.2 Search for evidence of crust movement	SR1	OR1.1	IR1	SysR1
				OR1.2	IR2	SysR2
				OR1.3		SysR3
				OR1.4	IR3: Cold Atom Gradiometer (optional)	SysR4
			SR2			
			SR3	OR3.1		SysR3
				OR3.2	IR3	SysR4
				OR3.3	IR2	SysR2
	SO2 Search for evidence of volcanism	SO2.1 Search for evidence of eruption	SR1	OR1.1	IR1	SysR1
				OR1.2	IR2	SysR2
				OR1.3		SysR3
				OR1.4	IR3: Cold Atom Gradiometer (optional)	SysR4
			SR2			
			SR3	OR3.1		SysR3
				OR3.2	IR3: Cold Atom Gradiometer (optional)	SysR4
				OR3.3	IR2	SysR2
			SR4: Distinguish between mass wasting, aeolian activity and surface materials that result from volcanic processes	OR4.1: Repeat topographic measurements of key surface features with a target detection of 1mm/5years	IR1	SysR1
				OR4.2: Measure orbital position accurately		SysR3
				OR4.3 Surface property measurements		SysR5: get reflectivity for altimeter measurements, get access to raw footprint data of the altimeter (surface roughness and surface brightness)
		SO2.2 Search for evidence of inflation in volcanic edifices	SR1	OR1.1	IR1	SysR1
				OR1.3		SysR3
				OR1.4	IR3: Cold Atom Gradiometer (optional)	SysR4
			SR2			
			SR3	OR3.1		SysR3
				OR3.2	IR3	SysR4
			SR4	OR4.1	IR1	SysR1
				OR4.2		SysR3
				OR4.3		SysR5
	SO3 Understand geo-morphologic processes modifying the surface	SO3.1 Search for landslides and dunes	SR1	OR1.1	IR1	SysR1
				OR1.3		SysR3
			SR2			
			SR3	OR3.1		SysR3
			SR4	OR4.1	IR1	SysR1
				OR4.2		SysR3
				OR4.3		SysR5

Traceability matrix

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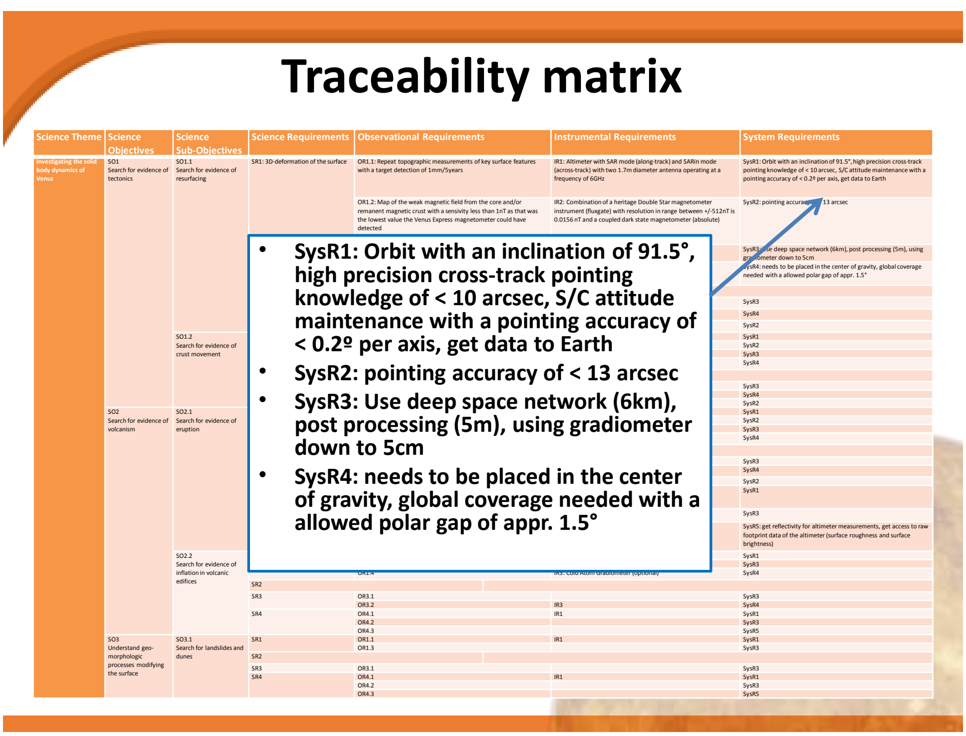
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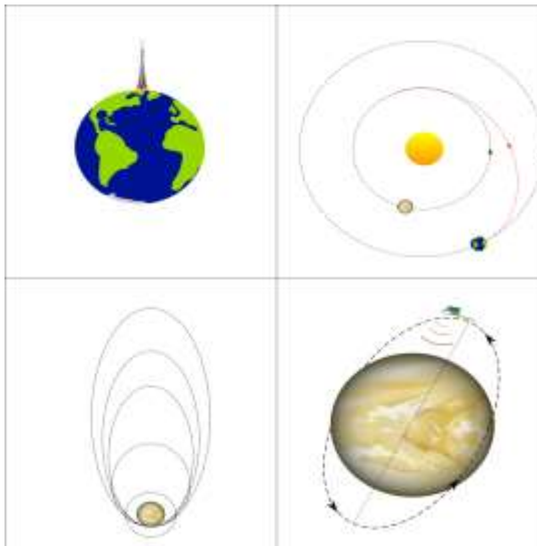
Mission scenario

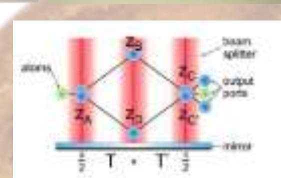


Payload

Altimeter

Magnetometers

Gradiometer

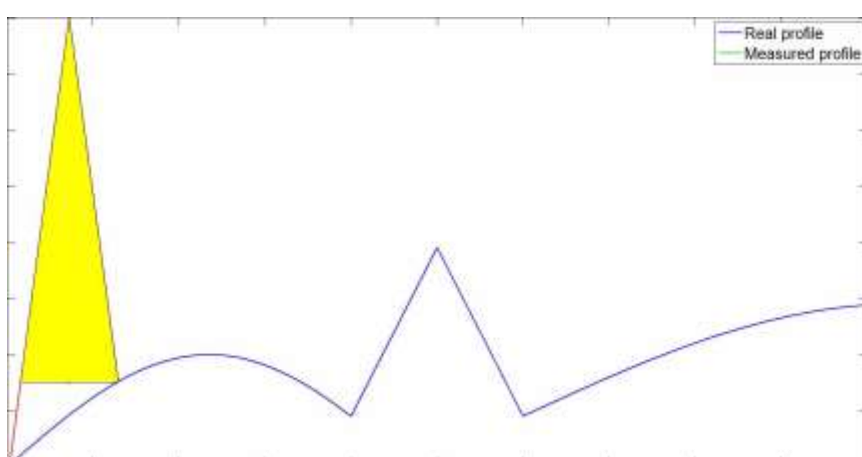


https://eoportal.org/web/eoportal/satellite-missions/c-missions/cryosat-2

Payload overview

Payload	Altimeter	Magnetometer absolute & relative	Gradiometer
Task	Topography measurement	potential remnant magnetism in the crust, measurement of electric currents in the ionosphere	Measurement of the gravity gradients
Duty cycle	Mission operation centre plans measurement scenarios in line with downlink contacts	Every 5s except while transferring data to earth.	Every 10s except while transferring data to earth.
Power	690W peak for SARIn mode, 5W data processing	Absolute magnetometer 3W Relative magnetometer 4W	10W
Mass	70kg	Absolute magnetometer 1.2kg Relative magnetometer 3kg	app. 60 kg
Data rate	280 kbps	0.5 kbps	1 kbps
	1.6 Gb per orbit	2 Mb per orbit	400 kb per orbit
Downlink	2.2 Gb per orbit (30% of orbit time for data downlink with ~ 380kbps)		

Altimetry
basic measurement principle

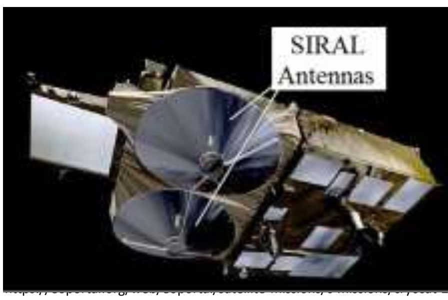


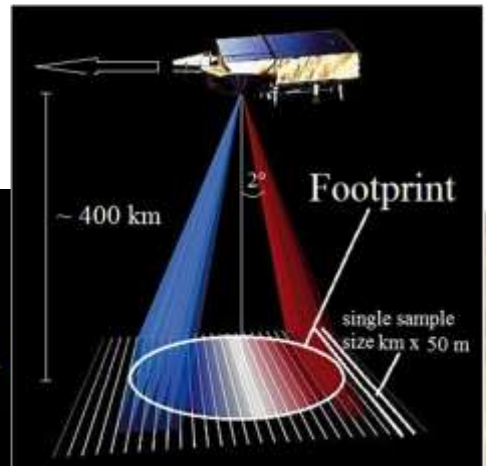
Altimeter in SAR mode

Instrument design based on SIRAL SAR instrument of CryoSat-2

- Altimeter with CryoSat-2 geometry
- 1st active antenna sending and receiving frequency modulated waves (chirps)
- 2nd antenna only receiving

Wegener concept

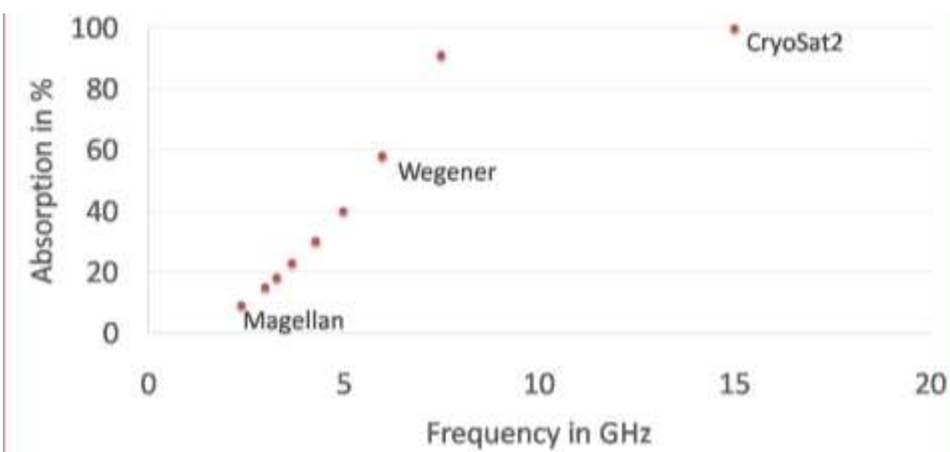




Altimeter in SAR mode

Selection of radar signal frequency

Venus atmospheric transmittance profile

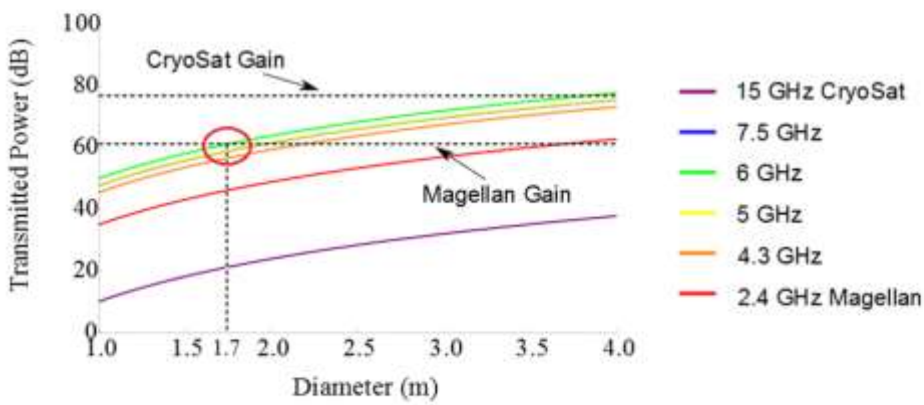


Altimeter in SAR mode

Selection of radar signal frequency

Adaption of the antenna diameter regarding the lower gain at lower frequencies and the atmospheric transmittance profile

✓ Select frequency of 6 GHz (C-Band)



The magnetometers

2 magnetometers

Fluxgate magnetometer: heritage from Double Star mission

Absolute magnetometer: Coupled Dark State Magnetometer.

Will be flown on China Seismo-Electromagnetic Satellite.
Launching at the end of 2016.

Gradiometer

Principle of cold atom gradiometry

1. Laser cooled and trapped cloud of atoms
2. Release atoms -> acceleration
3. Measure position by atom interferometry
   (represents gravitational effect on atom cloud)
4. Expected accuracy for 0-0.1Hz:

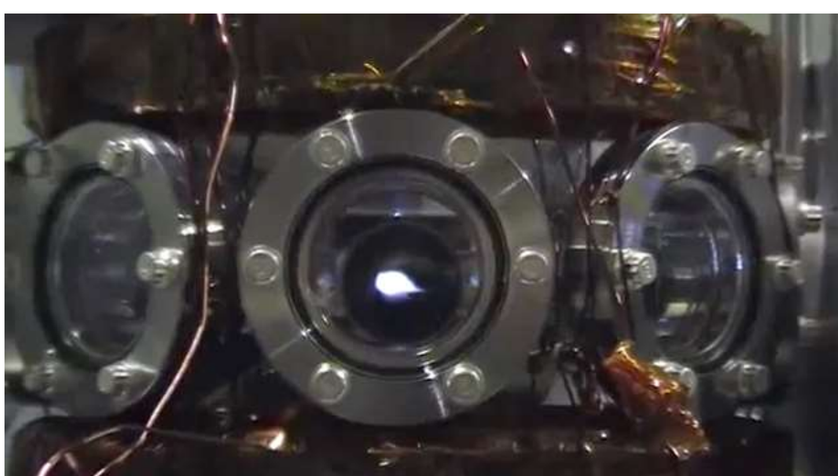
$$\Delta\gamma = 4.7\ mE/\sqrt{Hz}$$
$$\Delta\omega = 35\ prad.s^{-1}/\sqrt{Hz}$$

Estimated TRL = 2-4

"Some developments already worked in zero-g environment in the drop tower facility in Bremen, Germany" – Carraz et.al 2014

Note: Interferometry with Bose-Einstein condensates in space: MAIUS rocket experiment planned November 2014. TRL = 4. Link

Cold atom gravity principle



Payload power budget

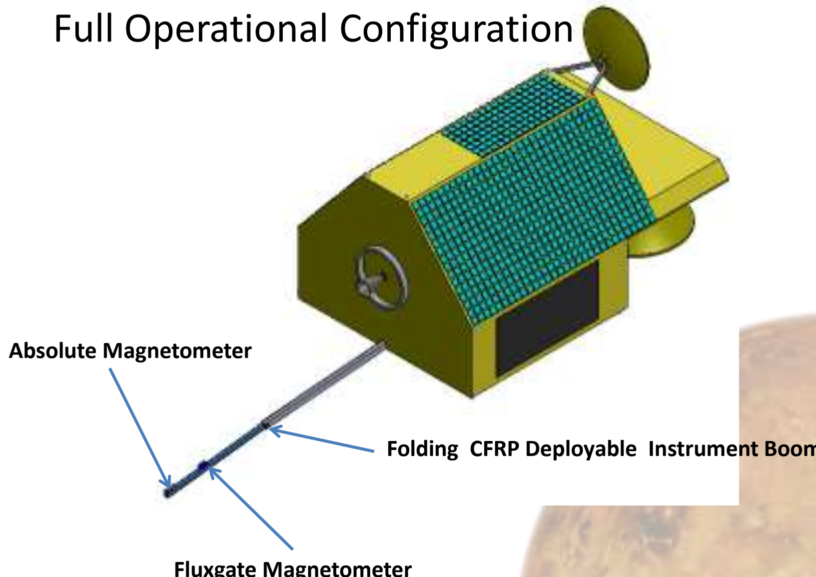
Payload	Power [W]	Margin [%]	Power with margin [W]
Altimeter in SARIn mode	295	10	325
Fluxgate magnometer	3	5	3.2
Cold Atom Gradiometer	10	50	15
Absolute magnetometer	4	20	4.8
Total	**317**		**350**

Payload mass breakdown

Payload	Mass [kg]	Margin [%]	Mass with margin [kg]
Altimeter in SARIn mode	70	10	77
Fluxgate Magnometer	2.86	5	3.0
Cold Atom Gradiometer	15	50	22.5
Absolute magnetometer	1.2	20	1.44
Total	**89.1**		**103.9**

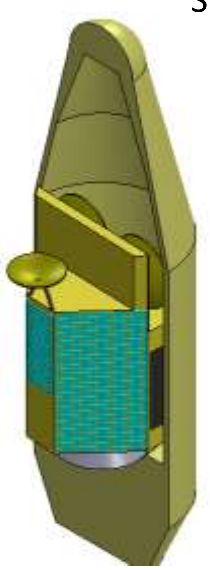
Spacecraft Design

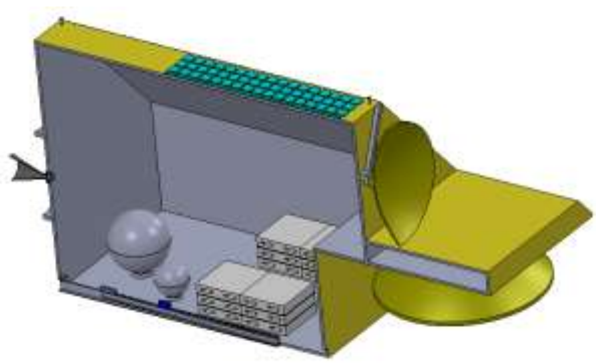
Full Operational Configuration



Spacecraft Design

Stowed Launch Configuration (Soyuz) & Cutaway





Design driver: magnetic field

To achieve good enough signal-to-noise ratio we have limits on the magnetic noise from spacecraft.

Noise at end of boom:
- Max strenght: 0.1 nT (after characterisation ~0.01 nT)
- Max frequency: 0.05 nT in 100 seconds

Magnetic cleanliness and spacecraft field characterisation program during building of the spacecraft (like CHAMP, Swarm etc.)

AOCS

Actuators

Attitude control and orbit control:

1. Five reaction wheel assembly
2. Twelve 10-Newton thrusters:
   Also used for reaction wheel momentum off-loading.

Sensors

Attitude measurement:

Two Inertial Measurement Units (IMU).

Celestial position measurement:

Three Star Tracker assembly (STRs) (1-3 arcsec) on boom
One Star Tracker on spacecraft body

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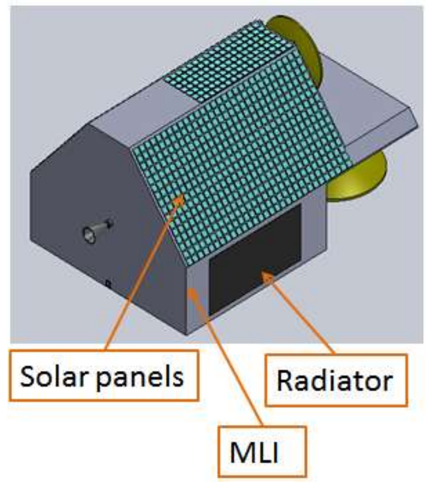
Thermal design

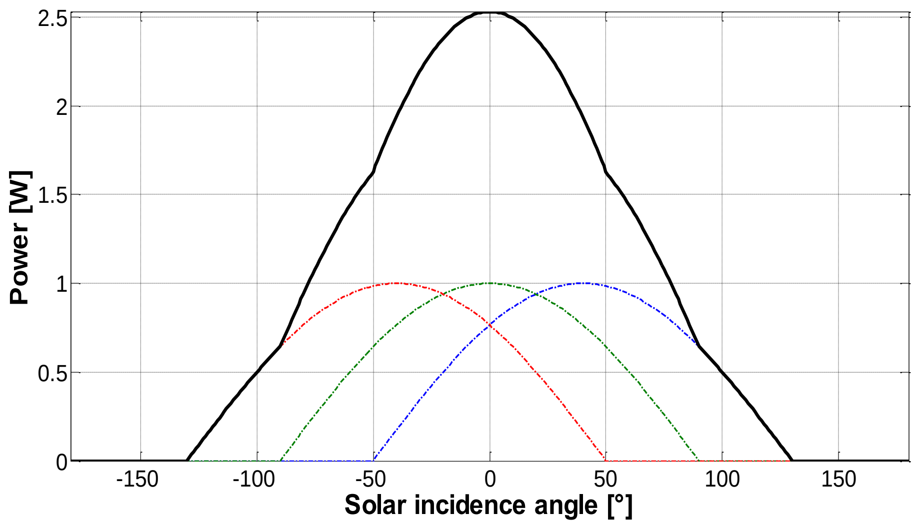
- Components based on Venus Express, but requires some modifications
- **Heat load: 2.6 W/m²** (twice big as on Earth)
- **Radiation dose: 20 krad** (2 mm of Aluminium shielding required)
- Altimeter antennas – **high mechanical stability required**



Power components

- **Solar Panels**
  - Solar arrays: Gallium Arsenide cells (more resistive for the higher heat flux and radiation dose – base on the Venus express solar panels design)
  - Effective area: about **3 m²** required to supply the spacecraft with **1233 W** of power while operating and recharge the batteries
- **Batteries**
  - Venus express heritage
  - Requires two batteries (**1 kWh**)

Power components



Power budget

	Subsystems' margin [%]	Power - nominal [W]	Power - including margin [W]
Payload	n/a	347	347
Subsystems			
Propulsion	5%	60	63
AOCS	5%	39	41
Communications	5%	65	68
C&DH	5%	42	44
Thermal	5%	55	58
Power	5%	412	433
Total		**1018**	**1054**
With overall 20% margin		**1221**	**1265**

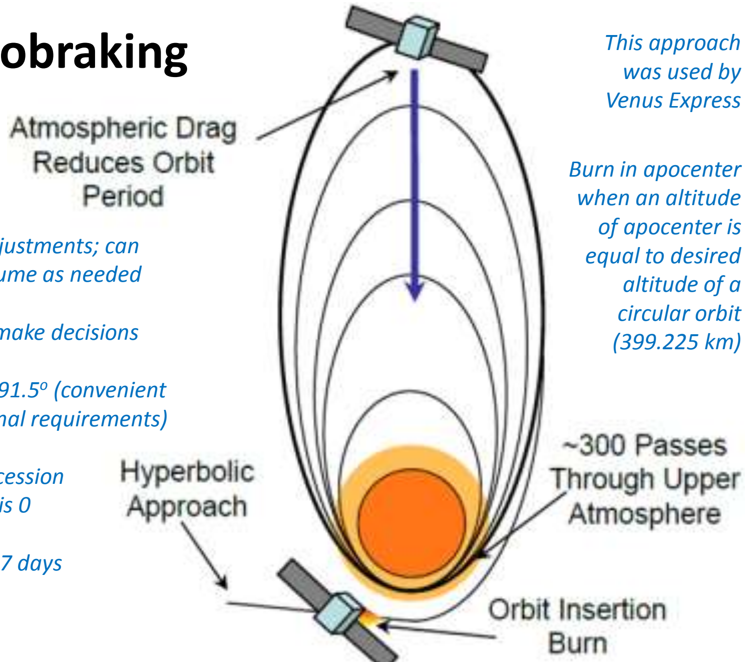
Mass budget

	Subsystems' margin	Mass - nominal [kg]	Mass with the margin [kg]
Payload	n/a	171	171
Subsystem			329
Propulsion	5%	51	54
AOCS	5%	12	13
Communications	5%	15	16
C&DH	5%	11	12
Thermal	5%	25	26
Power	5%	52	55
Structure & mechanisms	10%	140	154
Total with 20% margin (S/C dry mass)		500	566
Total with Propellant mass			**937**
Mass of the Soyuz launcher [kg]			**1650**
Mass for the Venus orbiting [kg]			**1100**

Flight Phases

1. Launch to a parking orbit with a Soyuz-rocket
2. Hohmann transfer orbit
   - ΔV_1 = 3.17 km/s
   - ΔV_2 = 1 km/s
3. Deep space maneuver
   - $i = 91.5^o$
4. Aerobraking
5. Acsent to circle orbit
   - apogee altitude = 399.2 km

Aerobraking



- *Gradual adjustments; can pause and resume as needed*
- *Operators make decisions*
- *Inclination 91.5º (convenient for observational requirements)*
- *Orbital precession around Venus is 0*
- *Duration: 47 days*

This approach was used by Venus Express

Burn in apocenter when an altitude of apocenter is equal to desired altitude of a circular orbit (399.225 km)

Comparison of mass available in final orbit

	Soyuz	Ariane-5
Pure Chemical	550 kg	1500 kg
Aerobraking	1100 kg	3200 kg

Venus Orbits

Circular Orbit

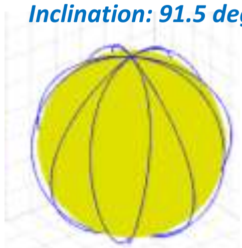
Constant resolution of the image.

Altitude: 399.225 km

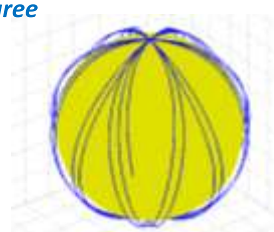
After one Venus day an exact repeat of the tracks is required. So only certain altitude can be chosen.

At this altitude, *1m* drift in altitude causes about *9m* drift of the trace after one Venus day.

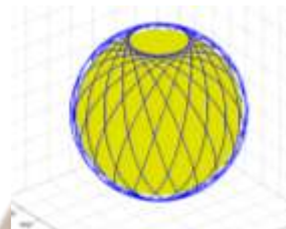
Inclination: 91.5 degree



Correct altitude



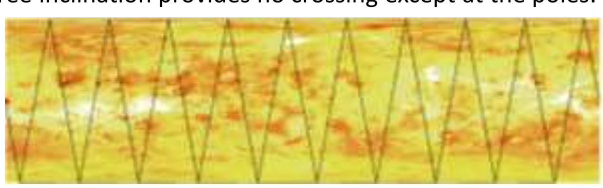
Wrong altitude



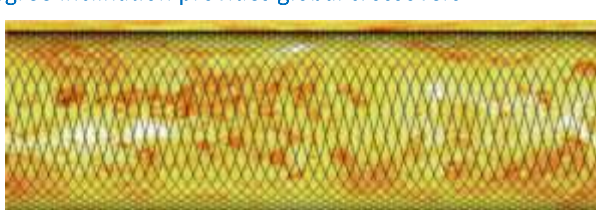
Blind-zone of none-90 inclination

Venus orbit trade off

90 degree inclination provides no crossing except at the poles:



91.5 degree inclination provides global crossovers



The largest distance at the equator after 1 Venus day is 5.17 km.

Satellite data budget

- Able to send around 9 Gb/day

Instrument	Raw data rate [kbps]
Altimeter	280
Magnetometer	0.4
Gradiometer	1 (est.)

- Onboard processing needed
- Storage needed until communication opportunity

Link budget


Source: ESA

X-Band Antenna

- 1.2m diameter, 60W High Gain Antenna
- X-Band transmission frequency of 8500 MHz

X-Band Downlink Data Rates:

- Minimum (Super Conjunction) = 130Kbps (3.7 GB/day over 8 hour downlink)
- Maximum (Inferior Conjunction) = 4Mbps (115 GB/day over 8 hours downlink)

S-Band Antenna

- 5W Low Gain S-Band Antennas - communication backup over short distances.
- S-Band transmission frequency of 2296 MHz

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Risk assessments

Risk	Consequence	P	S	PxS	Mitigation plan
More than one reaction wheel fails during the five-year mission.	Reduced pointing quality	C	4	Medium	Redundant system with five reaction wheels.
Malfunction of one radar channel.	No SARIng	A	4	Very low	Primary mission goal still possible.
Malfunction of the absolute vector magnetometer.	No detection of remnant magnetic crust	A	5	Low	Mission still possible to continue.
Scalar magnetometer failure	Loss in accuracy,	A	4	Very low	Does not endanger primary mission goal
Gradiometer not flight ready.	Cannot be used	E	2	Medium	Instrument not needed for reaching the threshold of the Primary mission objective.

Probability (P)	1	2	3	4	5
E	low	medium	high	very high	very high
D	low	low	medium	high	very high
C	very low	low	low	medium	high
B	very low	very low	low	low	medium
A	very low	very low	very low	very low	low
	Severity (S)				

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Risk Reduction and Descope

Risk Reduction option

– Start instrument predevelopment to increase the total TRL of payload. (cold atom gradiometer partly under ESA control).

- *In case of non-feasibility remove the cold atom gradiometer*
  - – Primary objective is still feasible to the treshhold requirements.
  - – Unable to improve the knowlege of the fine structure of the crust.
  - – Interior structure studies need to rely on the relativly poor existing gravity model.

Descope option

- Removing the Coupled Dark State Magnetometer
  - – Still possible to detect magnetic stripping but not possible to improve the model data
  - – Unable to improve the knowlege of the fine structure of the crust.

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Costs

- M-class (Medium size) mission
- Launch by a Soyuz rocket

		Costs	[M€]	Risk reduction	[M€]
Launcher			75		75
Payload			176		76
	Radar altimeter		70		70
	Gradiometer		100 *		0
	Magnetometer		6		6
S/C			280		235
MOC&SOC			100		100
Contingency			65		50
Long TDA			50		0
			Total: 637		Total: 533

** This is an estimated price since the gradiometer is still at largely TRL level 2 and parts are at TRL level 4 [November 2014].*

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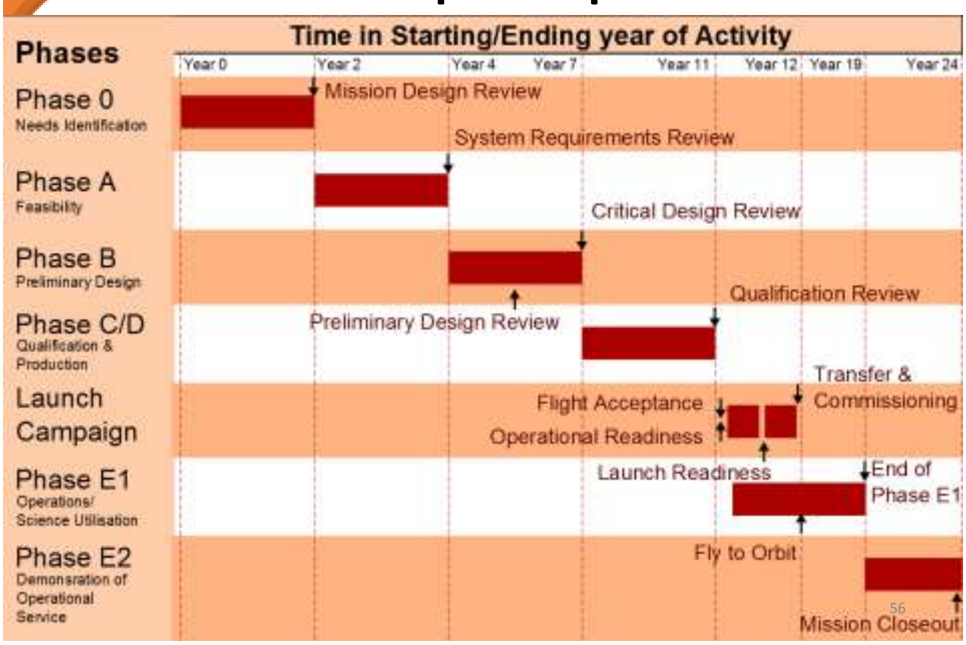
Development plan



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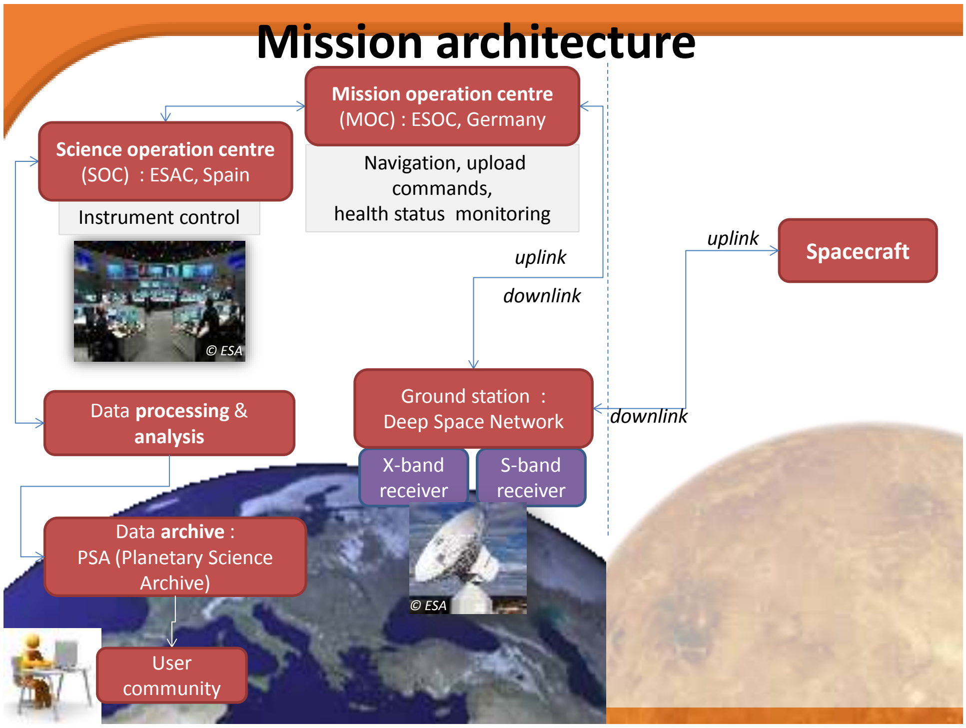
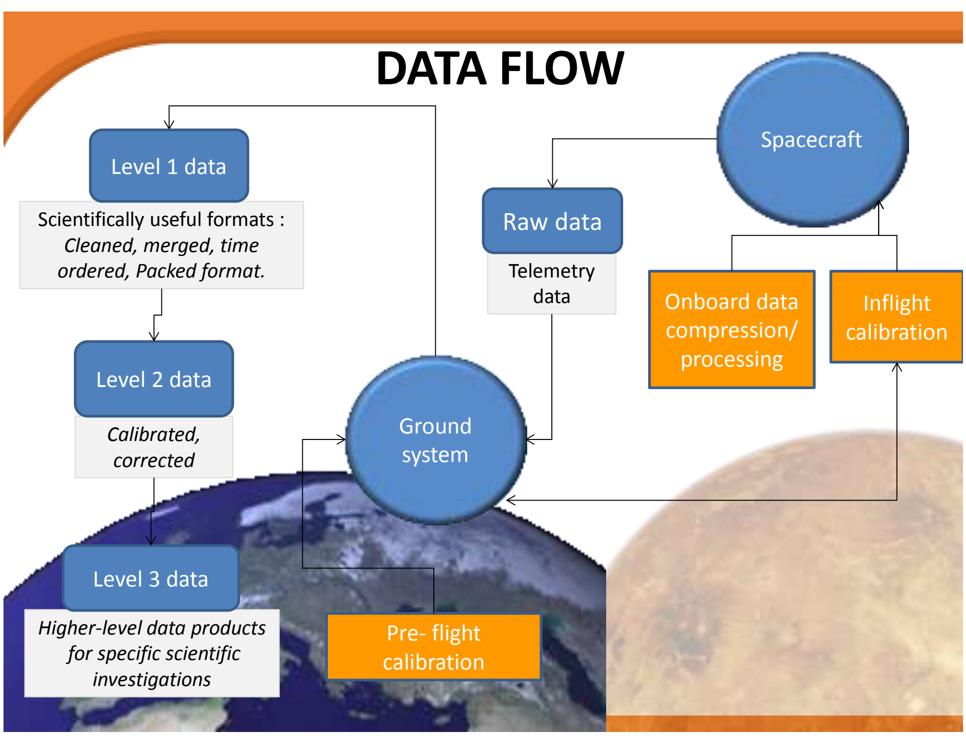


Mission architecture
Mission operation centre (MOC) : ESOC, Germany
Navigation, upload commands, health status monitoring
Science operation centre (SOC) : ESAC, Spain
Instrument control
© ESA
uplink
downlink
uplink
Spacecraft
Data processing & analysis
Ground station : Deep Space Network
downlink
X-band receiver
S-band receiver
Data archive : PSA (Planetary Science Archive)
© ESA
User community



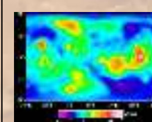
DATA FLOW
Spacecraft
Level 1 data
Scientifically useful formats : Cleaned, merged, time ordered, Packed format.
Raw data
Telemetry data
Onboard data compression/ processing
Inflight calibration
Level 2 data
Calibrated, corrected
Ground system
Level 3 data
Higher-level data products for specific scientific investigations
Pre- flight calibration

DATA PRODUCTS

Data product	Characteristics	Main use	Data volume
Altimeter	Ranges & accuracy	Topography and compare changes during the mission life time	280 kbps (Onboard computing needed)
Vector Magnetic field	3 components of the magnetic field	Detection potential relative variations (positive/negative anomalies) of remnant magnetic field	384 bps
Scalar Magnetometer	High precision of the magnetic field magnitud	- Calibration of the vector magnetometer - Support the analysis of the Vector Magnetometer. => Includes ionospheric studies (day side)	32 bps
Gravity field data		- Improve orbit knowledge & position → increase precision of gravity field measurement - Direct use of the gravity gradients → more precise structure of the surface	1 kbps

Example of SAR data.
© Magellan

Example of magnetic signature in oceanic ridge.
© CNES_Mioara MANDEA



Example of Venus surface gravity
© Magellan

DATA PRODUCT example : altimeter

Data product	Characteristics	Main use	Data volume
Altimeter Level 0 (Raw data)			280 kbps (Onboard computing needed)
Processing step : Convolution of the raw data with the range reference function			
Altimeter Level 1	Raw telemetry source packets: • filtered for [illegible] • time ordered; • time and telemetry quality information.		
Processing step : Convolution with the azimuth reference function, which changes from near to far range.			
Altimeter Level 2	Ranges & accuracy	Topography and changes during the mission life time.	

Onboard processing (Cryosat heritage)

Example of SAR data.
© Magellan

Data Analysis and Integration

Science Requirement: Track 3D deformation of the surface

Topography

1. Map key features (rifts, tesserae, volcanoes):
   a. Maps from previous missions.
   b. Obtain new maps, over multiple orbits
2. Detect changes in x-y positions and heights of features

Yes – Dynamics on surface observed

Surface deformation not occurring or below observation limits

Magnetic field

1. Map key features (tesserae, highlands) with surface materials proposed to have high curie temperatures

Yes – Remnant crustal field observed Possible Dynamo

No remnant magnetic field at observation limits

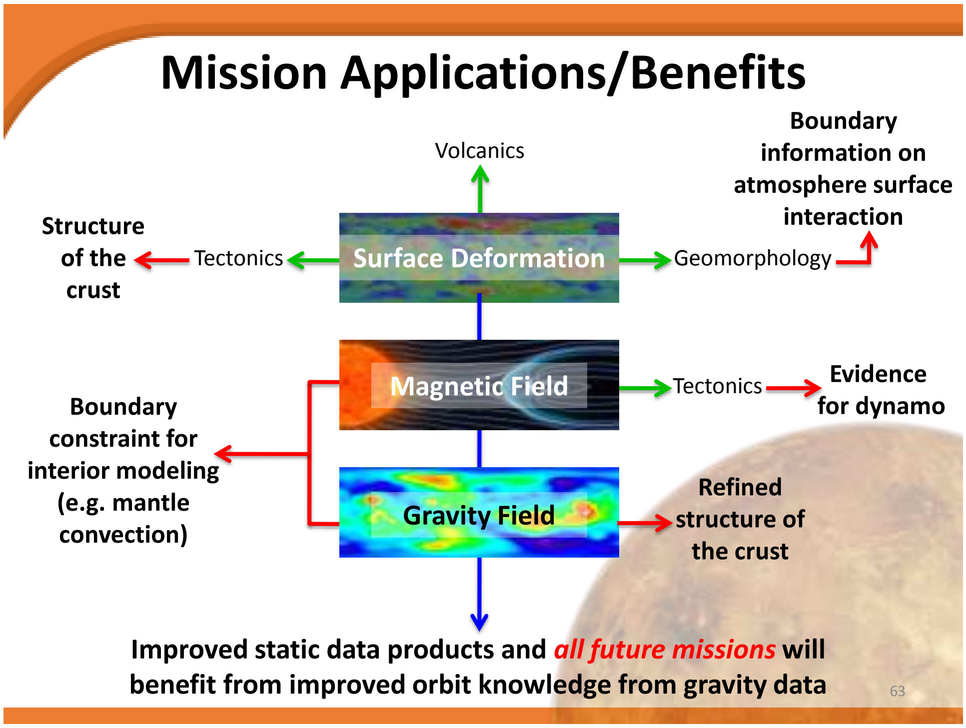
Optional Gravity data

1. Use improved gravity model to constrain (1) accuracy of spacecraft position and (2) structure of the crust

Example: gravity gradients for refining crustal structure

[redacted]

Ebbing et al., 2013, The Leading Edge, 902-906


Mission Applications/Benefits
Volcanics
Boundary information on atmosphere surface interaction
Structure of the crust
Tectonics
Surface Deformation
Geomorphology
Magnetic Field
Tectonics
Evidence for dynamo
Boundary constraint for interior modeling (e.g. mantle convection)
Gravity Field
Refined structure of the crust
Improved static data products and all future missions will benefit from improved orbit knowledge from gravity data
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esa
• Explain interest of Space Science (human, science, technology…) and Venus exploration.
• Show how it is realized (European context, collaboration, challenges…).
• ESA contribution + Make people feel part of it as European citizens.
OUTREACH PROJECTS
For public
- Chronological view of the mission conception (from Alpbach to Venus!)
- Contest for the selection of the spacecraft name.
=> Space Center visit/attend the mission launch.
- Interactive 3D maps.
For educator & students
- Teacher training.
- Panels in science and technology museums.
- Students projects : (create mission to Venus/data interpretation.)
- Ground observations.
For media
- Mission website :
historical exploration of Venus
follow the mission
main mission results.
- Press releases :
launch, arrival, first results…
For scientists
- Special workshop sessions (during international conferences) : data products & tools…

Further descope options ?

- **Wegener around the Moon**
  - Should funding prove difficult the payload can be easily adapted to a mission investigating the solid body dynamics of the Moon.

Image Credit: The last threads of sanity left in team Orange

Even further descope options ?

- **Wegener around the Earth**
  - Should funding prove extremely difficult the payload can be easily adapted to a mission investigating the solid body dynamics of the Earth.

Image Credit: Holiday album from Alfred Wegener

Team orange

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Thank you for your attention!

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Backup slides

ΔV orbit

	dV	margin	added dV	dV new	
dV total	1.22	km/s		1.68	km/s
dV delivered by S/C apogee kick motor				1.050	km/s
dV delivered by S/C attitude thrusters				0.621	km/s

Altimeter in SARIn mode

Synthetic Aperture Radar Interferometry

Antenna parameters
for optimal atmospherical transmittance and gain:

- Antenna diameter 1.7 m
- Operating frequency 6 GHz

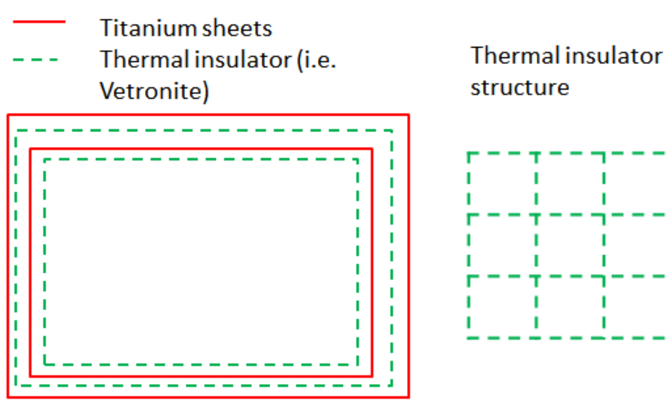
Height resolution dependent on

- Accuracy of orbit height (~ several km due to tracking from earth to several 10cm after refining orbit hight with, e.g., doppler measurement and gradriometry)
- Pulse time
- Accuracy of distance between Antennas (~ cm)
- Wavelength (~5cm)
- Orbit height (~ 400km) and antenna design leading to sample size of 50 m x several km

Height resolution of several cm possible!

Backup/Thermal

- Antennas as a sandwich
- Highly reflective coating
- MLI – on low conductive mesh, Titanium sheets



C&DH

- Onboard calculations needed - Compact computer based on ESAs LEON4 or LEON3 (30 W, 4 kg)
- Storage unit - Flash Mass Memory Unit eg. NEMO (0.5 Tb, 6.5 kg, 10W)

Propulsion

Required:

- apogee kick motor for insertion into orbit around Venus
- 16 control thruster for attitude and orbit control

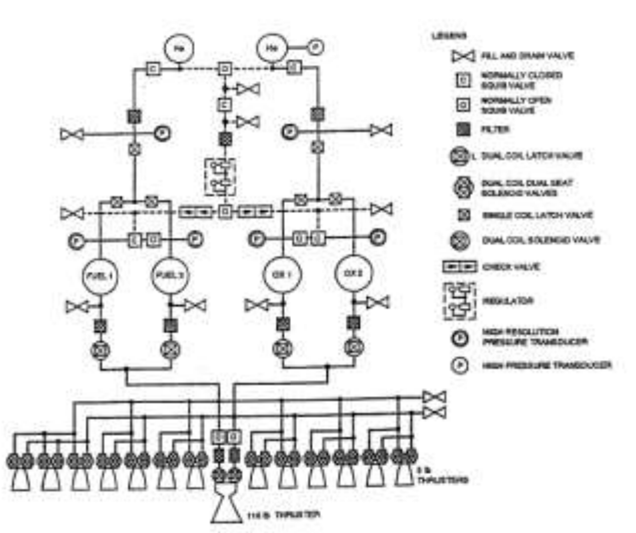
Constraints:

- no cryogenics
- heritage systems
- high specific impulse

Characteristics chosen systems:

- Fuel: MMH + NTO
- Pressure regulated feed system

Propulsion



Propulsion

Attitude control thruster

model	S10-26
nominal thrust	10N
specific impulse	291s
thruster mass	0.35kg
propellant	MMH + NTO
heritage	>130 flights

Propulsion

Apogee kick motor

model	S400-12
nominal thrust	420N
specific impulse	318s
thruster mass	3.6kg
propellant	MMH + NTO
heritage	>80 flights

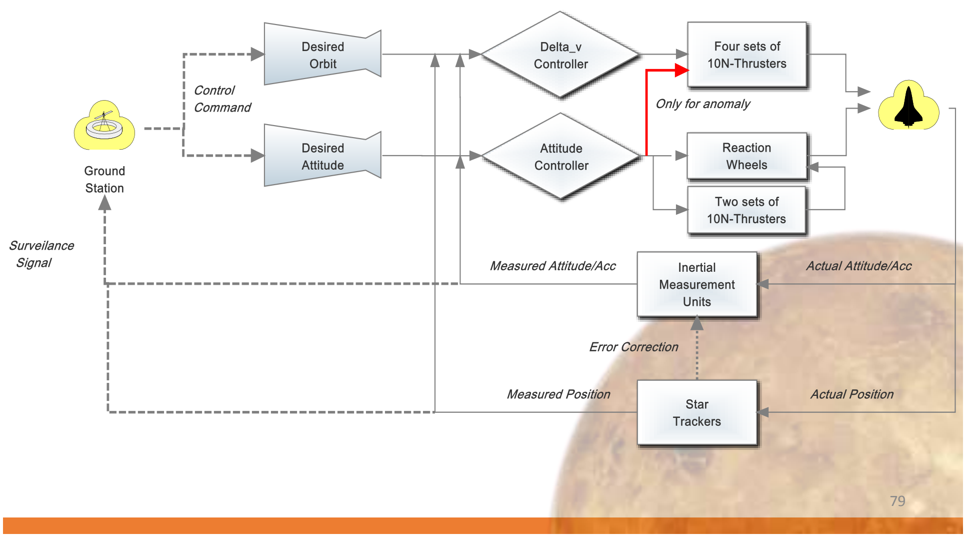
Data budget

- Able to send around 9 Gb/day

Instrument	Raw data rate [kbps]
Altimeter	280
Magnetometer	0.4
Gradiometer	1 (est.)

- Sample every 50 m: max 24 doubles (32-bit) per sample area
- Sample every 100 m: max 48 doubles (32-bit) per sample area
- Onboard processing needed
- Storage needed until sending opportunity

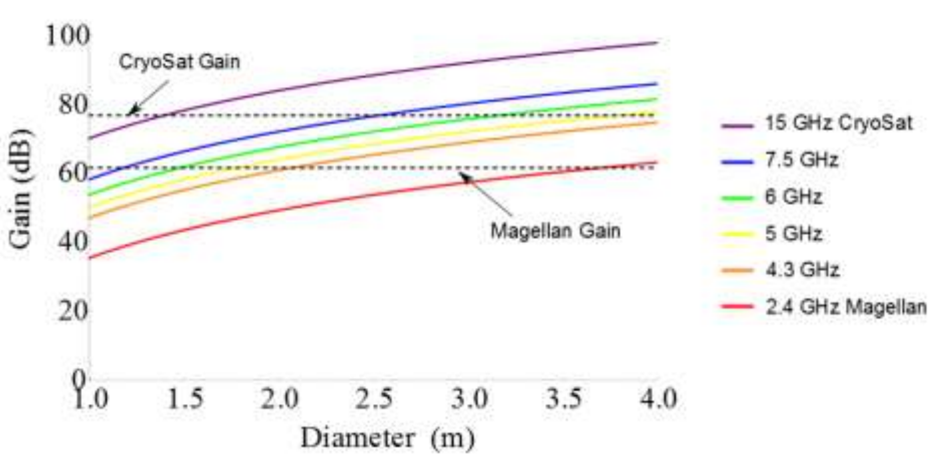
Flow chart for the AOCS Equipment



Altimeter in SARIn mode

Selection of radar signal frequency

Adaption of the antenna diameter
regarding the reduced antenna gain with lower frequencies

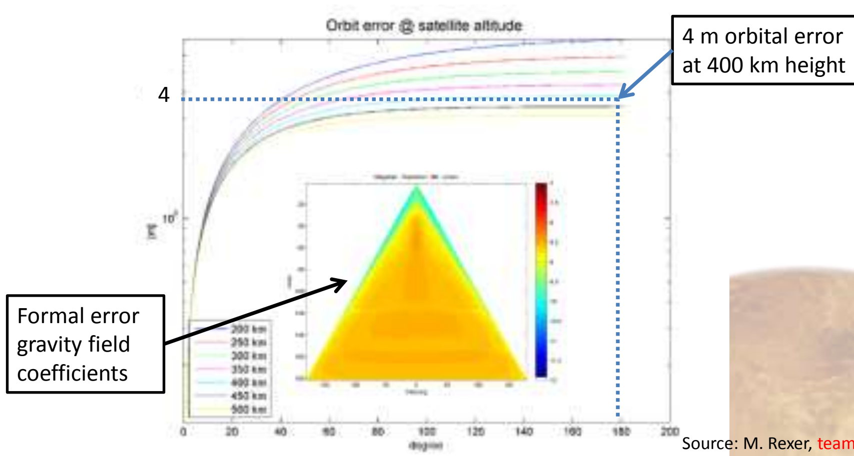


How do the absolute scalar magnetometer work?

Coupled Dark State Magnetometer (CDSM)

- optically-pumped magnetometer based on two-photon spectroscopy of free alkali atoms (87-Rubidium).
- working principle is similar to previous optically pumped vapour magnetometers.
- Instrument is better than previous versions:
  - fiber optic laser (less loss)
  - less rubidium needed (just a few micrograms)
  - More reliable instrument

Orbit error with existing gravity field model



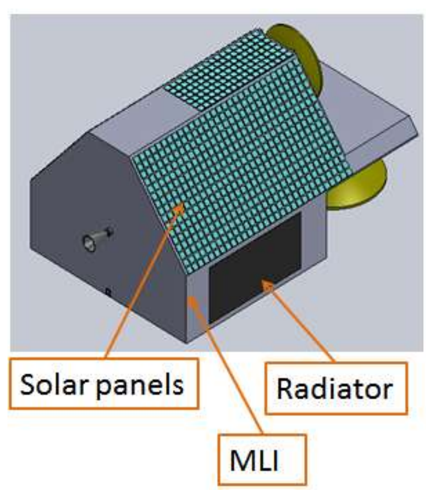
Source: M. Rexer, team red

Instrument: Gradiometer

- From the results one can also calculate the position of the satallite
  - High accuracy, **current estimate 5-10 cm**
  - No need to rely on star trackers etc.
- Need low drag (< few mN)
  - Should not be a problem at our altitude [Keating et.al 1985]
- Vibrations are rejected by the system
- 60 kg, 10 W

Subsystems/Thermal

- **Heat load: 2.6 W/m²** (twice big as on Earth)
- **Radiation dose: 20 krad** (2 mm of Aluminium shielding required)
- Altimeter antennas – **high mechanical stability required**
- Components (based on Venus Express, but requires some modifications)
  - MLI – kapton layers, gold plated externally – covers whole S/C structure except radiators and solar panels – **the stiff structure required by gradiometer**
  - Radiators (minimal radiative area of **3 m²**)
  - Heaters (based on the Venus Express)



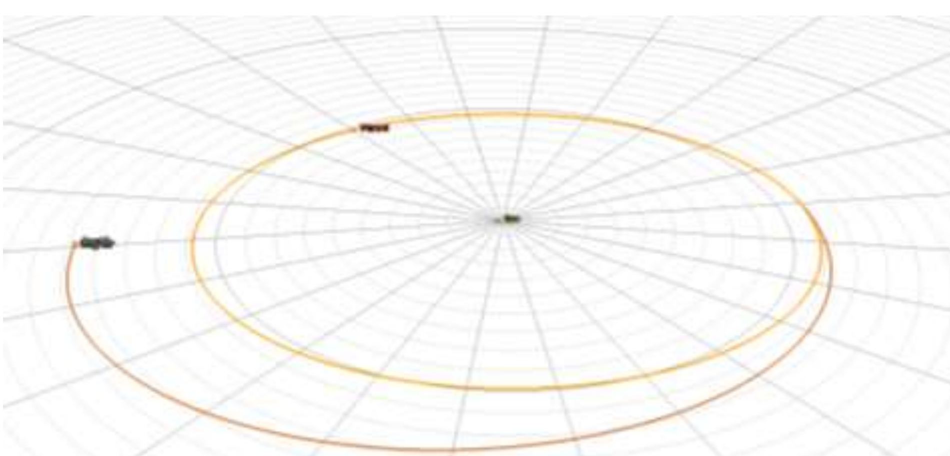
Power budget and mission scenarios

	Subsystems' margin [%]	Power - nominal [W]	Power - including margin [W]	Transfer Scenario [W]	Science and Communication [W]	Science [W]	Eclipse [W]	Maintenance [W]	Safe mode [W]
Payload	n/a	312	347	0	347	347	295	0	0
Subsystems									
Propulsion	5%	60	63	63	0	0	0	0	0
AOCS	5%	39	41	41	41	41	41	41	0
Communications	5%	65	68	0	68	0	0	68	0
C&DH	5%	42	44	0	44	44	44	0	0
Thermal	5%	55	58	0	58	58	58	58	0
Power	5%	412	433	0	433	433	0	0	0
Total [W]		**985**	**1054**	**104**	**991**	**923**	**437**	**167**	**0**
With overall 20% margin		**1182**	**1265**	**124**	**1189**	**1107**	**525**	**200**	**0**

Two-impulsive transfer

ΔV_1 = 3,17 km/s — *C3 = 10.09 km^2/s^2*

Transfer Time: 157,52 days — *Performance for escape mission = 1650 kg*



DATA PRODUCTS : backup slide

Topography validation from SAR mode

- In-orbit verification of the use of SAR mode vs SARin mode.

- Commissioning phase :
  - Run SARin mode for test.
  - Compare with SARin results, with the results obtained with the SAR mode when a topography based correction is applied for the cross track profile.