EnVision

CDF Study – Executive Summary

Prepared by ESA Study and CDF* Teams

(*) ESTEC Concurrent Design Facility
Outline

- Introduction
- CDF Study Objectives
- Mission and System Design Summary
- Driving requirements and constraints
- Payload
- System trade-offs, system options
- Concept of operations
- System design
- Mass budgets
- Conclusions
- Points for attention for phase A (spacecraft platform)
Introduction
Introduction

- The Call for M5 Mission Proposals was issued in April 2016. ESA received 25 valid proposals that underwent a selection process that has led the recommendation of three ESA-led candidates missions by the Space Science Advisory Committee (SPC(2018)17):
  - EnVision, to determine the nature and current state of geological activity on Venus, and its relationship with the atmosphere, in collaboration with NASA
  - SPICA, the Space Infrared observatory for Cosmology and Astrophysics using a 2.5 m cryogenic telescope, in collaboration with JAXA
  - THESEUS, a transient high energy sky and early universe surveyor, to explore the early universe with Gamma-ray bursts and to monitor the X-ray transient universe.

- ESA Phase 0 internal studies were carried out for all 3 missions within ESA’s Concurrent Design Facility, between June 2018 (SPICA) and November 2018 (ENVISION).

- Note: Envision original M5 proposal is publicly available on https://www2.physics.ox.ac.uk/sites/default/files/2011-07-07/envisionm5_proposal_without_annexes_pdf_12334.pdf
Context for Envision

- Envision is a Venus orbiter mission addressing the following science questions:
  - Is Venus geologically active? How has Venus geologically evolved with time?
  - How Venus atmosphere is linked to its geology? How does Venus interior work?

- Carrying 6 experiments (an S-band Synthetic Aperture Radar performing Interferometry SAR, a Subsurface Radar Sounder, a suite of 3 spectrometers, a Radio Science Experiment), Envision will answer these questions by a set of complementary measurements:
  - cm-scale surface change detection mapping by radar interferometry (InSAR) over the most likely active regions of interest (~20% of the surface)
  - Nearly-global Topography, mineralogy, thermal emissivity, sub-surface and gravity field mapping
  - Nearly-global atmosphere characterization

- The mission is studied in collaboration with NASA, with the potential sharing of responsibilities currently under assessment
CDF Study objectives
CDF Study Objectives

1. Design-to-cost a reference mission, spacecraft design and mission profile
   - Accommodation of the instruments
   - Orbital / mission trajectory design
   - Science operations plan

2. Assess and consolidate potential NASA contributions to the mission
   - Details for NASA-provided contributions were not available at the time of the CDF
   - CDF technical assessment was performed with the initially proposed radar instrument concept
   - CDF outcomes were used to derive requirements towards potential NASA provisions

3. Identify technology development activities

4. Estimate the cost of the mission, its development time, and risks
### Mission Summary - Chemical Propulsion

<table>
<thead>
<tr>
<th>Science Case</th>
<th>Payload</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Is Venus geologically active?</td>
<td>Total mass: 254 kg (incl. 30% payload margin)</td>
</tr>
<tr>
<td>• How has Venus geologically evolved with time?</td>
<td>Synthetic Aperture Radar (VenSAR)</td>
</tr>
<tr>
<td>• How Venus atmosphere is linked to its geology?</td>
<td>Subsurface Radar (SRS)</td>
</tr>
<tr>
<td>• How does Venus interior work?</td>
<td>Spectrometer (VenSpec)</td>
</tr>
<tr>
<td></td>
<td>Radio Science Experiment (No payload equip.)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement Principle</th>
<th>Spacecraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>• cm-scale surface change detection mapping by radar interferometry over the most likely active regions of interest (~20% of the surface)</td>
<td>15.7 m² Solar Arrays incl. 40% OSR</td>
</tr>
<tr>
<td>• Nearly-global Topography, mineralogy, thermal emissivity, sub-surface and gravity field mapping by complementary measurements</td>
<td>• Battery 67 kg</td>
</tr>
<tr>
<td>• Nearly-global atmosphere characterization</td>
<td>• Fixed 3m HGA, Ka-Band (science), 100W TWTA</td>
</tr>
<tr>
<td></td>
<td>• 2*3.35 m² radiators on opposite faces</td>
</tr>
<tr>
<td></td>
<td>• Reaction-wheel based slews for science target acquisitions and Earth pointing</td>
</tr>
<tr>
<td></td>
<td>• Bi-propulsion system, with Large Apogee Engine for Escape and VOI, and 16 10N thrusters</td>
</tr>
<tr>
<td></td>
<td>• 2+2 Tbit SSMM included in OBC</td>
</tr>
<tr>
<td></td>
<td>• 242 Tbit data return</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mission Profile</th>
<th>Mass (with 20% system margin)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Launch with A6.2 into HEO then Escape</td>
<td>Dry mass 1277 kg</td>
</tr>
<tr>
<td>• Baseline launch date 2032 / back-up 2033</td>
<td>Wet mass 2537 kg</td>
</tr>
<tr>
<td>• 0.5 years transfer, 2 years aerobraking (3kW/m², 0.3 N/m² – TGO envelope)</td>
<td>Total (wet + adapter) 2607 kg</td>
</tr>
<tr>
<td>• 2.66 years of science (4 Venus cycles)</td>
<td></td>
</tr>
<tr>
<td>• Science orbit: 220-470 km nearly-polar “frozen ecc. Orbit”</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak: 2.3kW</td>
<td></td>
</tr>
</tbody>
</table>
# Spacecraft Design – Chemical Propulsion

| **Mass**       | Dry mass 1277.5 kg  
|                | Wet mass 2537 kg  
|                | Total (wet + adapter) 2607 kg |
| **Mission Duration** | 4.5 – 6.3 years |
| **Data Handling**   | OBC with SSMM (2 Tbit + 2 Tbit in cold red.), RTU |
| **AOCS**           | 2x star trackers  
|                    | 2x gyros 4x reaction wheels  
|                    | 2x sun sensors  
|                    | 2x accelerometers |
| **Communications** | HGA, 2x LGA, Ka-band TWT/EPC, X-band TWT/EPC, RF harness, 2x transponders |
| **Chemical Propulsion** | Bipropulsion System: MON/MMH  
|                        | 420 N Main Engine  
|                        | 8 + 8 10 N thruster for AOCS |
| **Mechanisms**     | SADE, 2x SADM, SRS deployable dipole antenna |
| **Power**          | Solar array (total 15.7 m²), 67 kg battery, PCDU 25 kg |
| **Structures**     | Assembly panels, adapter ring and mountings, bottom panel, HGA bracket, radiator panel, SA attachment frame, SAR mounting brackets, shear panels, SRS mounting brackets, substrate SA, substrate SAR, top panel, tank struts |
| **Thermal Control**| Black paint, constant conductance heat pipe, high temperature MLI, heater, Multi Layer Insulation 10 layer, Optical Solar Reflector, thermal filler, doubler, thermistor, thermal strap, thermal washer |
## Spacecraft Design – Electric Propulsion

### Mass
- Dry mass 1619.5 kg
- Wet mass 2368 kg
- Total (wet + adapter) 2438 kg

### Mission Duration
- 7-8 years

### Data Handling
- OBC with SSMM (2 Tbit + 2 Tbit in cold red.), RTU

### AOCS
- 2x star trackers
- 2x gyros 4x reaction wheels
- 2x sun sensors
- 2x accelerometers

### Communications
- HGA, 2x LGA, Ka-band TWT/EPC, X-band TWT/EPC, RF harness, 2x transponders

### Chemical Propulsion
- Bipropulsion System: MON/MMH
  - 420 N Main Engine
  - 8 + 8 10 N thruster for AOCS

### Mechanisms
- SADE, 2x SADM, SRS deployable dipole antenna

### Power
- Solar array (total 53.4 m²), 79 kg battery, PCDU 62 kg

### Structures
- Assembly panels, adapter ring and mountings, bottom panel, HGA bracket, radiator panel, SA attachment frame, SAR mounting brackets, shear panels, SRS mounting brackets, substrate SA, substrate SAR, top panel, tank struts

### Thermal Control
- Black paint, constant conductance heat pipe, high temperature MLI, heater, Multi Layer Insulation 10 layer, Optical Solar Reflector, thermal filler, doubler, thermistor, thermal strap, thermal washer
Driving requirements & constraints
## Driving Requirements and Constraints

<table>
<thead>
<tr>
<th></th>
<th>Coverage</th>
<th>Repeat passes</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>InSAR</strong> <em>(30m resolution)</em></td>
<td>20%</td>
<td>min. 2</td>
<td>- roll-up max. 35deg.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- angular baseline 1.4deg</td>
</tr>
<tr>
<td><strong>StereoPol SAR</strong> <em>(30m resolution)</em></td>
<td>20%</td>
<td></td>
<td>- roll-up max. 35deg.</td>
</tr>
<tr>
<td><strong>HiRes SAR</strong> <em>(6m resolution)</em></td>
<td>2%</td>
<td></td>
<td>- roll-up max. 35deg.</td>
</tr>
<tr>
<td><strong>Spotlight SAR</strong> <em>(1m resolution)</em></td>
<td>0.1%</td>
<td></td>
<td>- roll-up max. 35deg.</td>
</tr>
<tr>
<td><strong>SRS</strong></td>
<td>Global</td>
<td></td>
<td>- Night side</td>
</tr>
<tr>
<td><strong>VenSpec-M &amp; H</strong></td>
<td>60%</td>
<td></td>
<td>- Night side</td>
</tr>
<tr>
<td><strong>VenSpec-U</strong></td>
<td>50%</td>
<td></td>
<td>- Day side</td>
</tr>
<tr>
<td><strong>Radio Science</strong></td>
<td>&gt;50% with most interest in South hemisphere</td>
<td></td>
<td>- Antenna pointed to Earth</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- No maneuvers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- At least 6 hours tracking per day</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- 250-300km altitude</td>
</tr>
<tr>
<td>Coverage</td>
<td>Repeat passes</td>
<td>Constraints</td>
<td>Operations planning</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
<td>-------------</td>
<td>---------------------</td>
</tr>
</tbody>
</table>
| InSAR (30m resolution) | 20% | min. 2 | - roll-up max. 35deg.  
- angular baseline 1.4deg | Reaction wheels, operations |
| StereoPol SAR (30m resolution) | 20% | Data volume (SSMM and communications) | - roll-up max. 35deg. |
| HiRes SAR (6m resolution) | 2% | Power (Solar arrays and battery) | - roll-up max. 35deg. |
| Spotlight SAR (1m resolution) | 0.1% | | - roll-up max. 35deg. |
| SRS | Global | | - Night side |
| VenSpec-M & H | 60% | | - Night side |
| VenSpec-U | 50% | | - Day side  
- Observations on several consecutive orbits |
| Radio Science | >50% with most interest in South hemisphere | | - Antenna pointed to Earth  
- No maneuvers  
- At least 6 hours tracking per day  
- 250-300km altitude |

**Driving Requirements and Constraints**

- Radio Science: Antenna pointed to Earth, No maneuvers, At least 6 hours tracking per day, 250-300km altitude
- VenSpec-U: Day side, Observations on several consecutive orbits
- SRS: Night side
- VenSpec-M & H: Night side
- Spotlight SAR: Roll-up max. 35deg.
- HiRes SAR: Roll-up max. 35deg.
- StereoPol SAR: Roll-up max. 35deg.
- InSAR: Roll-up max. 35deg., Angular baseline 1.4deg.
Areas of Most Interest for VenSAR
To fulfill all instruments data return requirements (related to coverage) a total of 278Tbits: 118Tbits (basic profile) + 160Tbits (enhanced profiles)

- “Basic” mission profile: **118Tbits** (123Gbits/day over mission duration – requirement is over at least two cycles)
  - InSAR, VenSpec, SRS and radio science (assumed in || to communications)

- “Enhanced” mission profile(s): **160Tbits** (to be spread over mission duration)
  - To fulfil the coverage requirements for StereoPol, HiRes and Spotlight SAR
  - HiRes and SpotLight SAR observations are mostly at the expense of VenSpec-U
Additional Design Drivers

- Mission cost ceiling 550MEuros
  - Design to cost approach

- Launcher interface
  - Fairing max. diameter 4.570m
  - VenSAR antenna: 5.47m
  - HGA: 3m
  - SRS antenna: 16m (launched stowed)

- Launcher performance
  - Launch mass (depending on orbit)
  - Aerobraking is enabling the mission (chemical)
Payload overview
Payload overview

- Scientific context of instruments
- VenSAR – synthetic aperture radar
- SRS – subsurface radar
- VenSpec – the spectrometer suite
- Radio Science – radio science experiment
- Resource budgets
- Follow-up tasks
Detecting active geologic processes on Venus -past and today-

**Measurement**

**VenSpec-U**
Mapping SO, SO$_2$ and UV absorber at cloud top. @210-240nm (0.2nm), @190-380 (2nm), ~100 km spatial resolution

**VenSpec-H**
Mapping of near surface atmosphere H$_2$O, HDO at 0-15 km @1.08-1.2 µm, H$_2$O, HDO, OCS, SO$_2$ at 30-40 km @ 2.44-2.47 µm, ~100 km spatial resolution

**VenSpec-M**
Mapping mineralogy by surface emission at 6 channels 0.82-1.2 µm at <50 km resolution

**SRS**
Subsurface radar down to 1000 m depth and ~10m resolution @ 9 MHz

**VenSAR**
Surface morphology, 1-30 m, cm changes by interferometric measurements, @ 3.2 GHz, radiometry with relative precision of 1K at 5x38 km resolution

**RadioScience**
2-way mapping, radio occultations, gravity field, love number k2

**Higher atmosphere**

**Lower atmosphere**

**Surface**

**Crust profile**

atmosphere, crust, planet mantle and core
VenSAR – Synthetic Aperture Radar

- A synthetic aperture radar
- Heritage from NovaSAR-S (GaN hi-power amplifiers), launched in September 2018
- S-band at 3.2 GHz (182 MHz bandwidth)
- The instrument consists of 3 units
  - The NIA backend x2 (cold redundant)
  - The antenna unit incl. front end electronics, TX/RX and radiator
  - Harness
- 5.47m x 0.60m antenna (VenSAR)
- 300x270x220 mm backend end (2x)
- 254.4 - 2352.0 W (different modes)
- 154 kg (no antenna structure, no deployment device)
- Data rate 0.25 kb/s – 513 Mb/s
- Pointing (RPE) 300 arcsec 1000 s
VenSAR – Synthetic Aperture Radar

- VenSAR uses 24 separately controllable phase centres (6x4)
- Antenna length driven by imaging requirements
  - Reduction in length is not consistent with (low) pulse repetition frequency required by the swath width of 50 km. A shorter antenna illuminates a wider zone in along track direction (ie wider Doppler spectrum) which this PRF cannot sample adequately. This would result in azimuth ambiguities
  - A narrower antenna would not deliver enough power through thick atmosphere resulting in too low S/N
- Chosen frequency is a good compromise between:
  - H2SO4 droplet causes phase shift and drives towards lower frequencies
  - Too low frequency are less sensitive to surface displacements
- Front surface coated by RF transparent Ge-coated sunshield, inner side of the honeycomb panel covered with MLI to thermal isolate the unit from the S/C (NovaSAR-S approach)
  - Implementing antenna support structure
  - Implementing of folding mechanism
SRS – Subsurface Radar

- A subsurface radar sounder
- Heritage from RIME (JUICE)
- 9 MHz with 6 MHz bandwidth
- The instrument consists of 4 units
  - Receiver and digital subsystem
  - Transmitter
  - Matching network
  - Deployable antenna
- RDS (256x180x140 mm), TX (362x182x140 mm), MN (280x142x50 mm), antenna (16 m)
- 120.0 W (different modes)
- 12 kg (RDS/TX/MN)
- 14 kg antenna (CDF choice)
- Data rate 3.14 Mb/s – 12.6 Mb/s
- Pointing (APE) 5 degree  RPE n/a
SRS – subsurface radar antenna

- 16 m deployable boom, stowed 1.85 m
- Mass 14.4 kg
- Synchronized deployment
- Spring actuated first segment
- BeCu segments
- Preferred solution wrt to current RIME antenna heritage due to more challenging Venus thermal environment
- First assessment indicates compatibility to aerobraking and thermal load
- Design has reached TRL4
VenSpec – The Spectrometer Suite

- Suite of spectrometers
  - VenSpec-M
  - VenSpec-H
  - VenSpec-U
  - CCU
- Strong heritage from various precursor mission
- Physically separated instrument boxes, controlled by a single control unit (CCU)
- Total mass 31.63 kg
- Power 45.2 W
- M (590x215x204 mm)
  - H (380x144x173 mm)
  - U (500x200x200 mm)
  - CCU (200x200x200 mm)
VenSpec – M

- Pushbroom multispectral imaging system, nadir pointing
- Telecentric design with 3 lenses
- FOV of 45° results in 207km swath width, 50 km spatial res.
- 14 strip filter array at intermediate focus, covering all 5 surface windows between 0.8 and 1.2 μm
- APE 1 mrad, RPE 0.5 mrad over 90 msec

Camera including optics and detector
- Baffle functionally dedicated to the camera including the transparent window unit
- Electronics including PCB’s for power supply and instrument control and internal harness
- InGaAs detector by Xenics with TEC
- Heritage from Mertis and breadboarding

### Design Parameter

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOV (°) ACTxALT</td>
<td>46.4×37.8</td>
</tr>
<tr>
<td>Entrance pupil diameter (mm)</td>
<td>8</td>
</tr>
<tr>
<td>Effective focal length (mm)</td>
<td>16.4</td>
</tr>
<tr>
<td>F/#</td>
<td>2.04</td>
</tr>
</tbody>
</table>

### Accommodation item

<table>
<thead>
<tr>
<th>Accommodation item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg) CBE/CBE+contingency</td>
<td>5.00/5.85</td>
</tr>
<tr>
<td>Power (W) CBE/CBE+contingency</td>
<td></td>
</tr>
<tr>
<td>Peak (Science, Test, Diagnostic, Science_idle modes)</td>
<td>15.0/19.5</td>
</tr>
<tr>
<td>Average (Science, Test, Diagnostic, Science_idle modes)</td>
<td>11.5/15.0</td>
</tr>
<tr>
<td>Standby (Diagnostic safe mode)</td>
<td>8.0/10.5</td>
</tr>
<tr>
<td>Dimensions (mm³) Incl. baffle Instrument body</td>
<td></td>
</tr>
<tr>
<td></td>
<td>590 × 215 × 204</td>
</tr>
<tr>
<td></td>
<td>380 × 144 × 173</td>
</tr>
<tr>
<td>Unobstructed FOV</td>
<td>46.4° × 37.8°</td>
</tr>
<tr>
<td>Data interface/ rate</td>
<td>SpaceWire, 500 kb/s</td>
</tr>
<tr>
<td>Data rate (kbps) 33×33, 5×5 binning</td>
<td>190, 850</td>
</tr>
<tr>
<td>Data rate, raw (kbps)</td>
<td>4500</td>
</tr>
<tr>
<td>Temperature range (°C) Operational / Nonoperational</td>
<td>0 to 35 / -20 to 50</td>
</tr>
</tbody>
</table>
VenSpec-H

- 1.08-1.2 µm @ R=2000
- 2.44-2.47 µm @ R=40000
- Heritage SPICAV-SOIR/VEX, NOMAD/TGO
- 19.17 kg, 21.74 W
- Data rate 37 kb/s
- APE 3.5 mrad, RPE 3.0 mrad over 60 sec
- Nadir pointing, 100 km spatial res.

- a hi-res infrared Echelle spectrometer with AOTF (tbc)
- Sofradir HgCdTe detector in a modified integrated detector dewar cooler assembly (detector temperature at 150 k)

Entrance optics

AOTF: selection of spectral region of interest

Spectrometer

Detector
VenSpec-U

- Dual channel UV spectral imager, nadir
- Low-res 190-380nm, hi-res 210-240
- Spectr. res. 1.5 nm and 0.2 resp.
- Heritage from SPICAM/Mex, SPICAV/Vex and PHEBUS/BepiC
- Mass 4.11 kg, 14.4 W, data rate: 20 kb/s
- 100km spatial resolution
- APE 10 mrad, RPE 1 mrad over ½ orbit

**Entrance objective**

- 2 aspheric lenses, UV grade fused silica
- Focal length: 25.14mm
- F-#: 10
- Front lens diameter: 50mm

**Detector**

- Customized CMOS CAPELLA 2nd generation from Teledyne/E2V with innovative “AR” UV coating
- Useful area [mm²]: 24 (spatial) × 12 (spectral)
- Pixel size: 40µm×40µm
- Full well charge: 45 ke⁻
- Readout noise: ~6e⁻
- Power [W]: 4

PHEBUS on BepiColombo
VenSpec – CCU

- Two subunits
  - data handling unit (DHU)
  - power handling unit (PHDU)
- Partial heritage from MERTIS/BepiC and Cheops
- 200x200x200 mm
- 2.5 kg (incl 50% margin)
Radio Science – The Gravity Experiment

- Radio-navigation tracking data, relying on the spacecraft TT&C system
- No additional H/W required
- 2-way tracking x-band up / x-band down, x-up / Ka-band down
- Observations during communication paths
- Experiment requirement 4 successive orbits per day
- Gravity field measurements to cover 100% of the planet
- Coverage better than 50% at spatial resolution better than 200 km
- Scientifically more interesting region on the southern hemisphere

- Current S/C sub-system performance matches requirements
  - ESTRACK reaching an accuracy of at least 0.1 mm/sec (including all error contributors, like troposphere, clocks, station coordinates knowledge, solar plasma and more), when integrating the Doppler observable over a count interval of 60 seconds.
  - parasitic deltaV after wheel offloading ~0.2 mm/s, measurements also during wheel offloading sequence
## Top level requirements – Resource Budgets (incl. support equipment)

<table>
<thead>
<tr>
<th></th>
<th>VenSAR</th>
<th>Radio Science</th>
<th>VenSpec</th>
<th>SRS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass</strong></td>
<td>154 kg</td>
<td>Experiment, no H/W</td>
<td>31.63</td>
<td>10.0</td>
</tr>
<tr>
<td></td>
<td>22.56 kg (support)</td>
<td></td>
<td></td>
<td>14.4 (antenna)</td>
</tr>
<tr>
<td></td>
<td>22.40 kg (deployment)</td>
<td></td>
<td></td>
<td>Σ 254.99 kg (incl. instrument maturity margin)</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>254-2352 (InSAR: 641-977)</td>
<td>--</td>
<td>45.25</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2352 W max (sequenced operations)</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>300x270x220 (backend x2)</td>
<td>--</td>
<td>590x215x204 (-M)</td>
<td>256x180x140 (RDS)</td>
</tr>
<tr>
<td></td>
<td>5470x600 (antenna/front end)</td>
<td></td>
<td>655x463x275 (-H)</td>
<td>362x182x140 (TX)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>500x200x200 (-U)</td>
<td>280x142x50 (MN)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>200x200x200 (-CCU)</td>
<td>16000 (2x8000) (ant.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>256x180x140 (RDS)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>362x182x140 (TX)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>280x142x50 (MN)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>16000 (2x8000) (ant.)</td>
<td></td>
</tr>
<tr>
<td><strong>Data rate</strong> (nominal)</td>
<td>0.25 kb/s – 513 Mb/s (no compression)</td>
<td>--</td>
<td>-H 37 kb/s -U 20 kb/s -M 500 kb/s (different compression factors)</td>
<td>3.8 Mb/s (low res. compressed)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Next steps in (pre)-industrial phase

- **Accommodation**
  - SRS antenna orientation to be re-assessed
  - Position of VenSpec-H wrt cold face during entire operations to be assessed, thermally analysed on S/C level and instrument level
  - All spectrometer straylight analysis
  - Slanted SAR accommodation

- **Operations**
  - In principle surface/atmospheric coverage requirements are achieved but require optimisation
  - VenSAR spotlight and SRS high res. coverage is on the low side, VenSpec-U observation time is short due to VenSAR operations
  - Implications of frozen eccentricity orbit to be further analysed by RadioScience, VenSAR, VenSpec, SRS
  - Proposed is a task force of SEWG/SST and ESA until industrial KO, boundary conditions distributed by ESA, regular telecons throughout this phase with science/instrument consolidation workshop

- **Thermal environment and aerobraking**
  - More detailed work on thermal modelling all instruments
  - Specifically VenSAR and SRS antenna and VenSpec-H thermal design, mechanical load on SRS antenna

- **Contamination**
  - Mainly VenSpec-U

- **Instrument specification & detailed development**
  - All instruments/experiments

- **EMC**
  - To be assessed
System trade-offs and options
System Trade-Offs and Critical Areas

- Launch strategy
  - Direct escape vs. **HEO**
- Orbit
  - Quasi-circular vs. **Frozen eccentricity** vs. Highly elliptical
- Mission operations profile
  - Accommodate all instrument requirements and constraints
  - Minimize data storage
- Configuration
  - VenSAR and SRS antennas wrt. HGA
  - VenSAR launched in final configuration
  - Solar arrays and radiators position
- Propulsion
  - **Chemical** vs. **Electric** vs. Hybrid
1. Launch into HEO with Ariane 62
   B/L: 24/11/2032; B/U: 12/05/2033

2. Escape Sequence Manoeuvre 1

3. Escape Sequence Manoeuvre 2
   B/L: 24/12/2032

4. Interplanetary transfer
   B/L: 134 days;

5. VOI
   B/L: 7/5/2033

6. Apocyclethion lowering

7. Aerobraking
   B/L: ~25 months
   Note: 4 months margin applied

8. Science Operations
   2.66 yrs / 4 Venus cycles

Total mission duration
B/L: 5.1 yrs; B/U: 6.3 yrs
Post-VOI Lowering for Aerobraking

- After VOI: Periapsis altitude 250 km, apoapsis radius 250,000 km
- 24 hour orbit period assumed at start of aerobraking
- Lowering manoeuvre cost: 290 m/s
Aerobraking assumptions

- Three sample cases, varying peak dyn. Pressure (dp) ballistic coefficient B=m/(CD*A):
  1. Peak dp=0.3 N/sqm, B=25 kg/sqm
  2. Peak dp=1 N/sqm, B=25 kg/sqm
  3. Peak dp=0.3 N/sqm, B=12.5 kg/sqm
  - Example for B: m=1000 kg, aerodynamic cross section A=20 sqm, CD=2, B=25 kg/sqm

- Results:
  - 1 kW/sqm peak free stream heat flux for every 0.1 N/sqm peak dp
  - Duration depends linearly on peak dp and B
  - Total delta-v cost of AEB around 120 m/s incl. 100% margin on pericentre control
  - Pericentre control cost depends linearly on duration
  - Additional delta-v required for conjunction hopping and safe modes
  - Delta-v after VOI: 290 + 120 + X m/s
## Aerobraking Scenarios

<table>
<thead>
<tr>
<th>Case</th>
<th>1 (dp 0.3, B 25)</th>
<th>2 (dp 1.0, B 25)</th>
<th>3 (dp 0.3, B12.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak free stream heat flux [kW/sqm]</td>
<td>3</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Duration [d]</td>
<td>574</td>
<td>185</td>
<td>285</td>
</tr>
<tr>
<td>Pericentre control [m/s]</td>
<td>44</td>
<td>14</td>
<td>22</td>
</tr>
<tr>
<td>Final pericentre raising [m/s]</td>
<td>33</td>
<td>35</td>
<td>33</td>
</tr>
</tbody>
</table>

- Three sample cases, varying peak dyn. Pressure (dp) ballistic coefficient B=m/(CD*A):
  1. Peak dp=0.3 N/sqm, B=25 kg/sqm
  2. Peak dp=1 N/sqm, B=25 kg/sqm
  3. Peak dp=0.3 N/sqm, B=12.5 kg/sqm

- Results:
  - Total delta-v cost of AEB around 120 m/s incl. 100% margin on pericentre control
  - Pericentre control cost depends linearly on duration
  - Delta-v after VOI: 290 + 120 + X m/s

- **Case 1 = CDF design case**, resulting in an aerobraking duration of ~2 years including 4 months margin for operational contingencies (e.g. conjunction, non favourable thermal geometry, etc).
CP Scenario: Aerobraking Example
## Transfer - Chemical Propulsion

<table>
<thead>
<tr>
<th></th>
<th>T2 2031</th>
<th>T2 2032 (baseline)</th>
<th>ET2 2033 (backup)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Orbit</td>
<td></td>
<td>250 x 300000 x 7deg</td>
<td></td>
</tr>
<tr>
<td>Wet Mass Limit [kg]</td>
<td></td>
<td>2800</td>
<td></td>
</tr>
<tr>
<td>Launch Date</td>
<td>27/04/2031</td>
<td>24/11/2032</td>
<td>12/05/2033</td>
</tr>
<tr>
<td>Escape Date</td>
<td>27/05/2031</td>
<td>24/12/2032</td>
<td>12/06/2033</td>
</tr>
<tr>
<td>Escape Man. 1 [m/s]</td>
<td>41</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Escape Man. 2 [m/s]</td>
<td>505</td>
<td>491</td>
<td>983</td>
</tr>
<tr>
<td>VOI [m/s]</td>
<td>879</td>
<td>850</td>
<td>611</td>
</tr>
<tr>
<td>Total ∆V [m/s]</td>
<td>1425</td>
<td>1371</td>
<td>1614</td>
</tr>
<tr>
<td>Arrival Date</td>
<td>28/10/2031</td>
<td>07/05/2033</td>
<td>28/11/2034</td>
</tr>
<tr>
<td>Post-VOI Lowering [m/s]</td>
<td>&gt; 290 (more is better in terms of duration)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerobraking</td>
<td>120 (+ more for conjunction hopping and safe modes)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Science Orbit

- Frozen eccentricity at [220, 470] km altitude
  - The eccentricity vector (ecc. & arg. of pericentre) evolves in time, but the initial value is such that at the end of the cycle it is back to initial point
Concept of Operations
Basic Data Return Profile

- Opposite look SAR (365s)
- Normal look SAR (365s)
- SRS (low res)*
- VenSpec M, H*
- VenSpec U*
- TT&C (incl RSE)
- Slew
- Wheel offloading

*incl. Radiometry with SAR
**Enhanced Data Return Profile**

**Chemical Propulsion Option**

- Opposite look SAR (365s)
- Normal look SAR (365s)
- SRS (low res)*
- VenSpec M, H*
- VenSpec U*
- TT&C (incl RSE)
- StereoPol (254s)
- 6 x HiRes (50s)
- ROI: 100km x 60km
- 16 x Spotlight (20s)
- Slew

*incl. Radiometry with SAR

50 km

Approx 24 hours

Wheel offloading
Data Return Budget

... With proposed system baseline

- SSMM 2Tbits (Plato capability – SSMM in OBC, 2Tbits+2Tbits cold redundancy)
- Communications: 3m antenna, 100W TWTA

all longitudes are covered over at least two cycles for InSAR

The downlink capacity is not used in full at closest distances → opportunity to optimize ground station allocation (less downlink time, more operational flexibility)
Overall Data Return Profile Over Mission Duration

- **Cycle 1**:
  - Generation rate:
    - Gb/day basic (123Gbits/day)
- **Cycle 2**:
  - Gb/day basic + 127 StereoPol/Hires/spot
  - Gb/day basic + 362 StereoPol/Hires/spot
  - Gb/day basic + 417 StereoPol/Hires/spot
### Fulfilled Requirements and Constraints

<table>
<thead>
<tr>
<th></th>
<th>Coverage</th>
<th>Repeat passes</th>
<th>Constraints</th>
</tr>
</thead>
</table>
| **InSAR** (30m resolution) | 20% ✓    | min. 2 ✓      | - roll-up max. 35deg.  
- angular baseline 1.4deg ✓  |
| **StereoPol SAR** (30m resolution) | 20% ✓    |               | - roll-up max. 35deg.  |
| **HiRes SAR** (6m resolution) | 2% ✓     |               | - roll-up max. 35deg.  |
| **Spotlight SAR** (1m resolution) | 0.1% ✓   |               | - roll-up max. 35deg.  |
| **SRS**          | Global ✓ |               | - Night side ✓                                |
| **VenSpec-M & H**| 60% ✓    |               | - Night side ✓                                |
| **VenSpec-U**    | 50% ✓    |               | - Day side  
- Observations on several consecutive orbits ✓ |
| **Radio Science**| >50% ✓   |               | - Antenna pointed to Earth  
- No maneuvers  
- At least 6 hours tracking per day  
- 250-300km altitude ✓ |
System Design and Budgets
### Mission and System Summary

**CDF Baseline / Chemical Propulsion**

**HEO T2 2032**

<table>
<thead>
<tr>
<th><strong>Launch vehicle</strong></th>
<th>Ariane 6.2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Launch date</strong></td>
<td>Baseline: 2032 / Backup: 2033</td>
</tr>
<tr>
<td><strong>Lifetime</strong></td>
<td>Nominal science 2.66 years</td>
</tr>
<tr>
<td><strong>Orbit</strong></td>
<td>Frozen eccentricity</td>
</tr>
<tr>
<td><strong>Altitude</strong></td>
<td>220-470 km</td>
</tr>
<tr>
<td><strong>Inclination</strong></td>
<td>88</td>
</tr>
<tr>
<td><strong>Ground stations</strong></td>
<td>X-Band (TT&amp;C) and Ka-Band (Science downlink) communication based ground station capability provided by 35m antennas: Malargüe, New Norcia (NNO-1), Cebreros</td>
</tr>
<tr>
<td></td>
<td>Access to, and use of NASA DSN ground station contribution.</td>
</tr>
<tr>
<td></td>
<td>Additional smaller 15m ground station coverage support: Kourou (15m), New Norcia 2 (4.5m)</td>
</tr>
<tr>
<td><strong>Mass (with margin)</strong></td>
<td>Dry mass 1277.5 kg</td>
</tr>
<tr>
<td></td>
<td>Wet mass 2535 kg</td>
</tr>
<tr>
<td></td>
<td>Total (wet + adapter) 2607 kg</td>
</tr>
<tr>
<td></td>
<td>Launcher performance 2870 kg</td>
</tr>
<tr>
<td><strong>Payload</strong></td>
<td>Synthetic Aperture Radar (VenSAR)</td>
</tr>
<tr>
<td></td>
<td>Subsurface Radar (SRS)</td>
</tr>
<tr>
<td></td>
<td>Spectrometer (VenSpec)</td>
</tr>
<tr>
<td></td>
<td>Radio Science Experiment (No payload equip.)</td>
</tr>
<tr>
<td><strong>Data Handling</strong></td>
<td>OBC with SSMM (2 Tbit + 2 Tbit in cold red.), RTU</td>
</tr>
<tr>
<td><strong>AOCS</strong></td>
<td>2x star trackers</td>
</tr>
<tr>
<td></td>
<td>2x gyro 4x reaction wheels</td>
</tr>
<tr>
<td></td>
<td>2x sun sensors</td>
</tr>
<tr>
<td></td>
<td>2x accelerometers</td>
</tr>
<tr>
<td><strong>Communications</strong></td>
<td>HGA, 2x LGA, Ka-band TWT/EPC, X-band TWT/EPC, RF harness, 2x transponders</td>
</tr>
<tr>
<td><strong>Chemical Propulsion</strong></td>
<td>Bipropulsion System: MON/MMH</td>
</tr>
<tr>
<td></td>
<td>420 N Main Engine</td>
</tr>
<tr>
<td></td>
<td>8 + 8 10 N thruster for AOCS</td>
</tr>
<tr>
<td></td>
<td>Isp &lt; 319 s for main engine</td>
</tr>
<tr>
<td></td>
<td>Isp ~ 290 s for smaller thrusters</td>
</tr>
<tr>
<td><strong>Mechanisms</strong></td>
<td>SADE, 2x SADM, SRS deployable dipole antenna</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Solar array (total 15.7 m²), 67 kg battery, PCDU</td>
</tr>
<tr>
<td><strong>Structures</strong></td>
<td>Assembly panels, adapter ring and mountings, bottom panel, HGA bracket, radiator panel, SA attachment frame, SAR mounting brackets, shear panels, SRS mounting brackets, substrate SA, substrate SAR, top panel, tank struts</td>
</tr>
<tr>
<td><strong>Thermal Control</strong></td>
<td>Black paint, constant conductance heat pipe, high temperature MLI, heater, Multi Layer Insulation 10 layer, Optical Solar Reflector, thermal filler, doubler, thermistor, thermal strap, thermal washer</td>
</tr>
</tbody>
</table>
Communications Subsystem

• Bitrates:
  – Uplink/Downlink X-Band TT&C, 4 kbps @ 1.7 AU
  – Uplink X-Band safe-mode 28 bps @ 1.7 AU
  – Downlink X-Band safe-mode:
    • HGA w/o APM nominally
    • Backup in case STR failure: LGA+TWTA in X-band: 7 bps
  – Ka-Band downlink (3m, 100W)
    • 4.2 Mbps @ 1.7AU
    • 75 Mbps @ 0.3AU (transponder saturation limit)

• Equipments:
  – Transponders
  – **Ka-Band TWT (100W)** and EPC
  – X-Band TWT and EPC
  – **Fixed HGA: 3m (requires dedicated slews)**
  – LGA: 8cm
Thermal Design Concept

• External configuration:
  - Radiators accommodated on velocity & anti-Velocity sides (Solar Arrays)

  ![Radiator Diagram](Image)
  - Radiators (6.7m²)

• Internal configuration:
  - Most of payload units shall be installed close to both radiator faces and NADIR face
  - Platform units shall be installed preferably on radiator faces to minimize use of straps/HP (bottom part)
Power Subsystem Concept

• 50V regulated bus with BCR/BDR → PCDU 25 kg

• Solar arrays: 97 kg
  – 2 wings, 56 strings of 40 cells in parallel
  – Area: 15.7 m² (57% solar cells, 40% optical reflectors)

• Battery: 67 kg
  – Maximum allowed Depth of Discharge (DoD)
    • for repeated cycling < 15%
    • for occasional occurrences (Launch) < 60%

<table>
<thead>
<tr>
<th>Power Budget: CP Option Power (W)</th>
<th>LM</th>
<th>CM</th>
<th>MAN</th>
<th>COM</th>
<th>SciH</th>
<th>SciL</th>
<th>ABM</th>
<th>SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CM (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAN (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COM (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SciH (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SciL (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABM (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total consumption (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Losses (PDU, Harness, Distribution)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Power Budget With Margin (W)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Energy Requirement: Energy (Wh)    |    |    |     |     |      |      |     |    |
| Duration Eclipse (min)             |    |    |     |     |      |      |     |    |
| Battery Energy Requirement (Wh)    |    |    |     |     |      |      |     |    |
Configuration – in Ariane 6.2 Fairing
Configuration - Deployed
## Mass Budget

**Chemical Option/ Baseline Date HEO T2 2032**

### Instruments Mass Budget

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Switch</th>
<th>Mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>INS</td>
<td>Product</td>
<td>195.63</td>
</tr>
</tbody>
</table>

- **Dry Mass w/o Payload Margin**: 195.63 kg
- **Payload Margin**: 30% of 195.63 kg = 58.69 kg
- **Dry Mass incl. Payload Margin**: 254.32 kg

### S/C Mass Budget

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Switch</th>
<th>Mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AOGNC</td>
<td>Product</td>
<td>51.77</td>
</tr>
<tr>
<td>COM</td>
<td>Product</td>
<td>69.29</td>
</tr>
<tr>
<td>CPROP</td>
<td>Product</td>
<td>108.11</td>
</tr>
<tr>
<td>DH</td>
<td>Product</td>
<td>33.60</td>
</tr>
<tr>
<td>EPROP</td>
<td>Not used</td>
<td>0.00</td>
</tr>
<tr>
<td>MEC</td>
<td>Product</td>
<td>57.96</td>
</tr>
<tr>
<td>PWR</td>
<td>Product</td>
<td>208.45</td>
</tr>
<tr>
<td>STR</td>
<td>Product</td>
<td>206.04</td>
</tr>
<tr>
<td>SYE</td>
<td>Not used</td>
<td>0.00</td>
</tr>
<tr>
<td>TC</td>
<td>Product</td>
<td>64.50</td>
</tr>
</tbody>
</table>

**Harness**: 5% of 852.67 kg = 52.70 kg

- **Dry Mass w/o System Margin**: 852.67 kg
- **System Margin**: 20% of 852.67 kg = 170.53 kg
- **Dry Mass incl. System Margin**: 1023.20 kg

### Total dry mass Budget

- **Instrument dry mass with payload margin**: 254.32 kg
- **S/C dry mass with system margin**: 1023.20 kg
- **Total dry mass incl. Margins**: 1277.52 kg

### Baseline Launch Window HEO T2 2032

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPROP Fuel Mass</td>
<td>472.70</td>
</tr>
<tr>
<td>CPROP Oxidizer Mass</td>
<td>780.00</td>
</tr>
<tr>
<td>CPROP Pressurant Mass</td>
<td>7.00</td>
</tr>
<tr>
<td><strong>Total Wet Mass</strong></td>
<td><strong>2537.22</strong></td>
</tr>
<tr>
<td>Launcher Adapter</td>
<td>70.00</td>
</tr>
<tr>
<td><strong>Launch mass</strong></td>
<td><strong>2607.22</strong></td>
</tr>
<tr>
<td>Target Launch mass</td>
<td>2870.00</td>
</tr>
<tr>
<td><strong>Below Target Mass by</strong></td>
<td><strong>262.78</strong></td>
</tr>
</tbody>
</table>

EnVision| Slide 54
# Mass Budget

**Chemical Option/Back-Up Date HEO ET2 2033**

<table>
<thead>
<tr>
<th>Back-up Launch Window HEO ET2 2033</th>
<th>Mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPROP Fuel Mass</td>
<td>503.20</td>
</tr>
<tr>
<td>CPROP Oxidizer Mass</td>
<td>830.30</td>
</tr>
<tr>
<td>CPROP Pressurant Mass</td>
<td>7.00</td>
</tr>
<tr>
<td><strong>Total Wet Mass</strong></td>
<td><strong>2618.02</strong></td>
</tr>
<tr>
<td>Launcher Adapter</td>
<td>70.00</td>
</tr>
<tr>
<td><strong>Launch mass</strong></td>
<td><strong>2688.02</strong></td>
</tr>
<tr>
<td>Target Launch mass</td>
<td>2870.00</td>
</tr>
<tr>
<td>Below Target Mass by</td>
<td>181.98</td>
</tr>
</tbody>
</table>
Mission Performance Improvements

• Use a 1kN engine to decrease gravity losses
  – Engine mass increase 5 kg
  – Length and diameter
    → Confirm configuration feasibility
    → Revise RCS thruster system (22N vs. the current 10N baseline)
    → Check compatibility of deployed appendages with mechanical loads

• Use the available launch vehicle performance to decrease aerobraking duration (in the order of months)
  – Resizing chemical subsystem tanks
Programmatics
• Spacecraft development duration is evaluated to 7.6 years including
  – 18 months for phase B2, allows for “best practice” approach
  – 60 months for phase C/D assuming STM E(Q)M/PFM model philosophy
  – 6+4 months of ESA schedule margin wrt baseline launch date (November 2032)
  – 3 months for phase E1

• The master schedule includes 6-months built-in margin wrt payload delivery dates

• Assuming KO for phase B2 in April 2025, the mission is compatible with mission adoption in June 2024, a launch in November 2032. The mission is compatible with a back-up launch date in May 2033.

• The back-up launch date is 6 months after the baseline launch date
  – 10 months ESA schedule margin in baseline schedule wrt baseline launch date (Nov 2032)
  – 16 months of ESA schedule margin wrt back-up launch date (May 2033)
• A major effort has been put in the phase 0 to streamline the top level science requirements with the science team, e.g. coverage requirements, following a design to cost approach.

• The CDF exercise allowed to derive top-down the “dynamic” daily data return requirements, ranging between 110 Gbits / day (at the farthest Venus distance) and 539 Gbits/day, for a total data return of more than 242 Tbits, with up to 75 Mbps of downlink rate in Ka Band. This data return strategy was deemed compatible with a “small” mass memory unit (2+2 Tbits) which can be integrated with the OBC and a fixed HGA of 3m.

• The science data return requirement is achieved with a combination of:
  – Significant usage of ESA’s DSA (in average ~10 hours daily, with peaks at 13 hours)
  – Cryo-cooling technology at Ground Station level to improve G/T
  – High RF power Ka-band subsystem (100W at TWTA output, 3m fixed HGA)

• The data return strategy is compatible with TRL6 by Mission Adoption at ground and S/C levels for Ka Band (see next slides) and with current data rate saturation limits (300 Msysms) of ground segment.
• **Ground Segment:**
  - cryo-cooling technology (currently TRL 5 at CBO; deployed by 2023/2024 at all 3 DSAs)
  - Ka-band availability at the 3 DSA (currently: only MLG and CBO equipped, NNO planned in 2023/2024)
  - All 3 DSA already compatible with TurboCode and compatible with 300 Msyms of the TT&C ($\approx 75$ Mbps).

• **TT&C Subsystem:**
  - Ka/Ka/X/X iDST transponder under development allows up to 300 Msyms ($\approx 75$ Mbps with Turbo Code, current saturation assumption for Envision)
    - GSTP funded, TRL 6 in 2020
  - The baseline high power RF chain assumes the procurement of a 100W TWTA + EPC from L3 in the US (TRL>6) due to unavailability of technology in Europe.
The platform design relies on mature technology for all subsystems, benefiting in particular from heritage from Venus Express / Bepi Colombo for key subsystems (power, thermal).

- The chosen strategy for aerobraking (3 kW/m², 0.3 N/m²) allows to remain within existing qualification limits (e.g. TGO, Bepi, VEX heritages) for “exposed” subsystems (solar arrays, HGA, MLI, SAR antenna).
- Lowest TRL items identified on the TT&C (iDST : TRL 4) but development from TRL 4 to 6 is already funded with TRL 6 by 2020.
- Future ESA science missions might benefit from a European High RF power TWTA development. A generic CTP activity could be proposed to adapt current technology (40W) to higher power (65-100W).

Some lower TRL Items have been identified for the payload instruments (cf payload presentations)

- TRL 4 overall for all instruments, all benefiting from significant heritage.
- SRS antenna : TDA is in the TDP for the de-risking and adaptation of the SRS to Envision context.
- SAR instrument : carries a risk due to technology adaptation needs (ECSS, radiation-hardening, thermal).
## Programmatic Risk Register

<table>
<thead>
<tr>
<th>Severity</th>
<th>Likelihood</th>
<th>Risk Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Low</td>
<td>MI03 S/C mass critical</td>
</tr>
<tr>
<td>4</td>
<td>Low</td>
<td>MI04 missed MAN, MI08 missed 2032 launch, MI02b SAR adaptation, MI09 Aerobraking duration</td>
</tr>
<tr>
<td>3</td>
<td>Very low</td>
<td>MI07 STR-based safe mode, MI11 SRS antenna adaptation</td>
</tr>
<tr>
<td>2</td>
<td>Very low</td>
<td>MI07 STR-based safe mode, MI11 SRS antenna adaptation, MI06 SRS / SA EMC</td>
</tr>
<tr>
<td>1</td>
<td>Very low</td>
<td>MI07 STR-based safe mode, MI11 SRS antenna adaptation, MI06 SRS / SA EMC</td>
</tr>
</tbody>
</table>

### Likelihood

- **A (remote)**
- **B (unlikely)**
- **C (likely)**
- **D (highly likely)**
- **E (near certainty)**
**Programmatics / Medium Risks**

- (Medium Risk) MI03 (B5) mass-critical mission, the risk is linked to the very high delta V: a 1 kg dry mass increase leads to ~2 kg launch mass increase. An increase of dry mass, or a drop of A62 performance could lead the S/C mass above the Ariane 62 performance, requiring to launch on-board Ariane 64 with >10% EaC cost increase
  - Maintain a positive launchability above 5% (currently: 8%)
  - Monitor Ariane 62 performance evolutions
  - Define HW de-scoping options e.g. for payload elements

- (Medium Risk) MI09 (C4) The nominal aerobraking requires significantly longer duration than expected, with cost impact (operations) and increased risk of failure
  - Increases drag surfaces e.g. dedicated flap to decrease ballistic coefficient and minimize AEB duration
  - Maximize the use of propellant to decrease the period of the starting AEB orbit
  - On-board autonomy to relax ground load over long durations.
Conclusions
Conclusions

• Chemical propulsion baseline in 2032 is feasible with a backup in 2033
• Electric propulsion option is marginally infeasible (4% negative launch margin)

• Mission science requirements are fulfilled
  – InSAR, HiRes SAR, SpotLight SAR, VenSpec, Radio science requirements fully covered
  – Spotlight SAR 0.1% of the surface
  – SRS global coverage fulfilled (high resolution coverage requirement needs to be specified by SST)

• The mission is compatible with the M5 boundaries assuming NASA contribution
Points for Attention for Phase A (Spacecraft Platform)

- Full aerobraking analysis
  - Incl. control corridor definition
  - Incl. aerothermal fluxes, thermal constraints
  - Incl. Slew performance during aerobraking (RWs vs. thrusters)
  - Incl. Configuration optimization for aerobraking (center of pressure vs. center of mass)
- Thermal gradients → need of heaters to be further analyzed
- SADM thermal cycling loads
- SRS mechanical interference with solar arrays
- Safe mode design
- Potential benefits of slanted SAR and/or not flipping the spacecraft