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

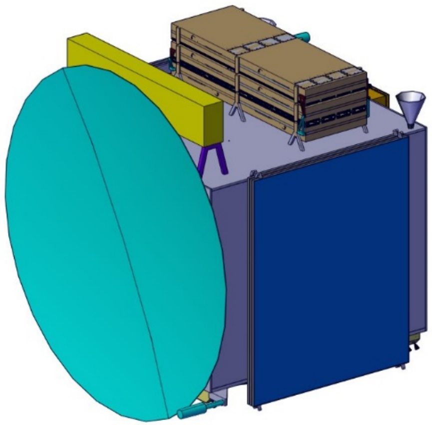
1. Design-to-cost a reference mission, spacecraft design and mission profile
   - Accommodation of the instruments
   - Orbital / mission trajectory design
   - Science operations plan
2. Assess and consolidate potential NASA contributions to the mission
   - *Details for NASA-provided contributions 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

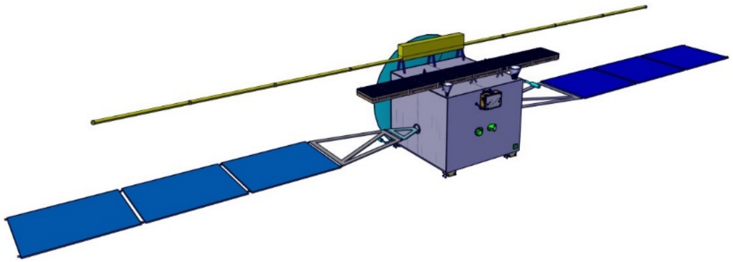
Mission Summary - Chemical Propulsion

Science Case	• Is Venus geologically active ? • How has Venus geologically evolved with time ? • How Venus atmosphere is linked to its geology ? • How does Venus interior work ?
Measurement Principle	• cm-scale surface change detection mapping by radar interferometry over the most likely active regions of interest (~20% of the surface) • Nearly-global Topography, mineralogy, thermal emissivity, sub-surface and gravity field mapping by complementary measurements • Nearly-global atmosphere characterization
Mission Profile	• Launch with A6.2 into HEO then Escape • Baseline launch date 2032 / back-up 2033 • 0.5 years transfer, 2 years aerobraking (3kW/m^2, 0.3 N/m^2 – TGO envelope) • 2.66 years of science (4 Venus cycles) • Science orbit: 220-470 km nearly-polar "frozen ecc. Orbit"

Payload	Total mass: 254 kg (incl. 30% payload margin) Synthetic Aperture Radar (VenSAR) Subsurface Radar (SRS) Spectrometer (VenSpec) Radio Science Experiment (No payload equip.)
Spacecraft	• 15.7 m^2 Solar Arrays incl. 40% OSR • Battery 67 kg • Fixed 3m HGA, Ka-Band (science), 100W TWTA • 2*3.35 m^2 radiators on opposite faces • Reaction-wheel based slews for science target acquisitions and Earth pointing • Bi-propulsion system, with Large Apogee Engine for Escape and VOI, and 16 10N thrusters • 2+2 Tbit SSMM included in OBC • 242 Tbit data return
Mass (with 20% system margin)	Dry mass 1277 kg Wet mass 2537 kg Total (wet + adapter) 2607 kg
Power	Peak: 2.3kW

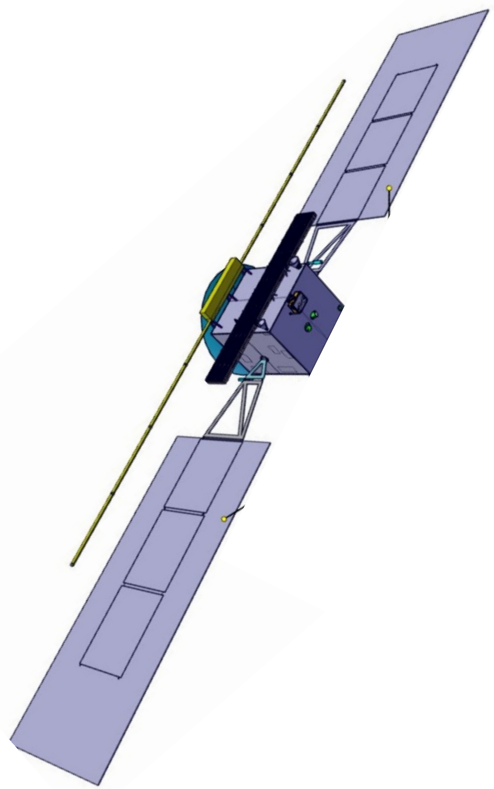
Spacecraft Design – Chemical Propulsion





Mass	Dry mass 1277.5 kg Wet mass 2537kg 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 m^2), 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

	Coverage	Repeat passes	Constraints
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% with most interest in South hemisphere		- Antenna pointed to Earth - No maneuvers - At least 6 hours tracking per day - 250-300km altitude

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Operations planning

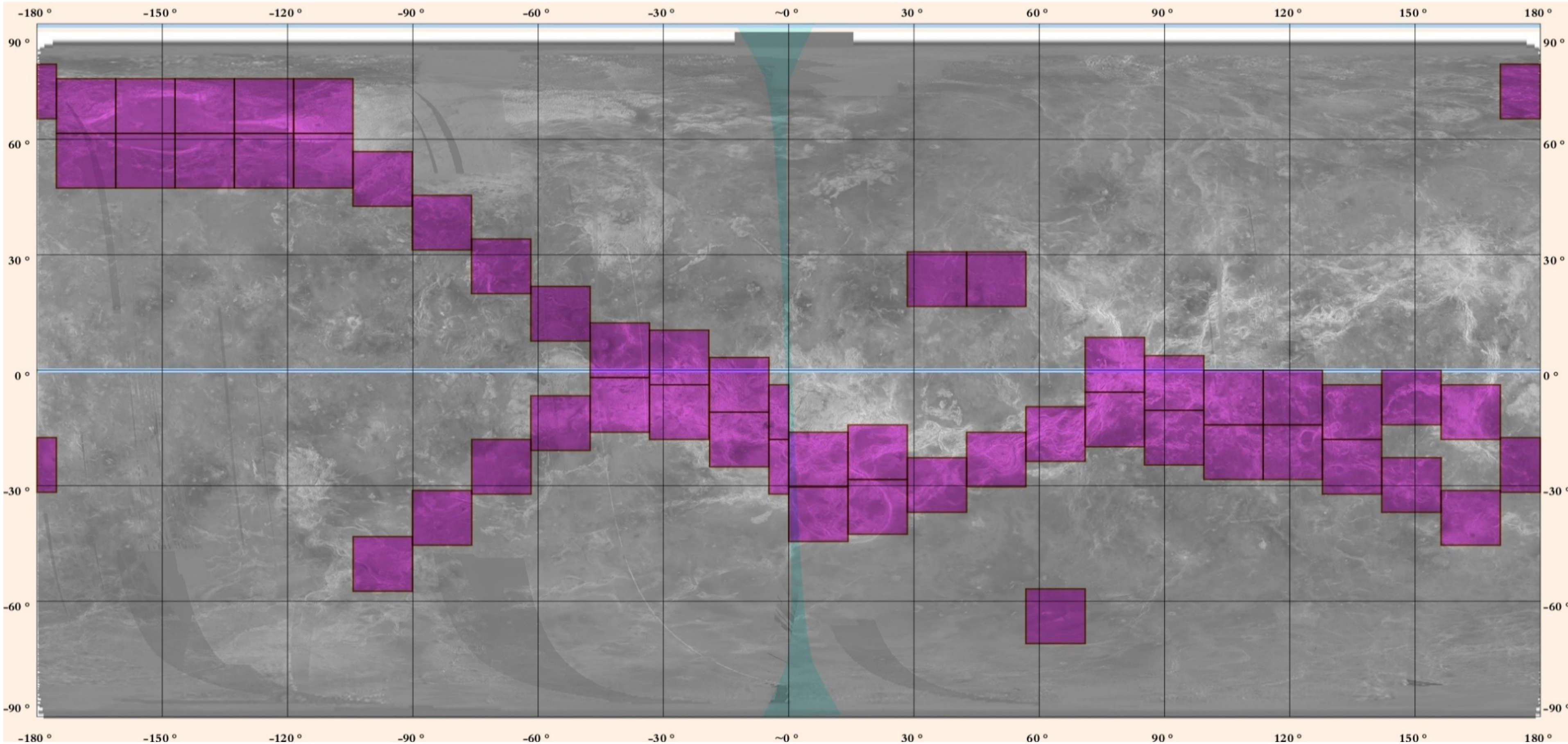
Reaction wheels, operations

Data volume (SSMM and communications)

Power (Solar arrays and battery)

Orbit

Areas of Most Interest for VenSAR



Expected Data Return

To fulfill all instruments data return requirements (related to coverage) a total of 278Tbits: 118Tbits (basic profile) + 160Tbits (enhanced profiles)

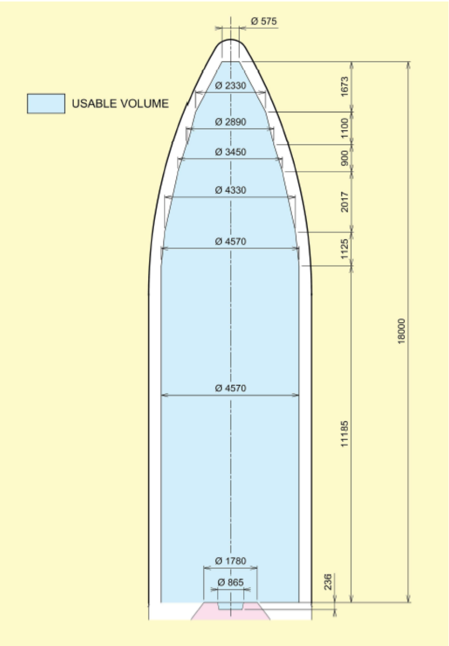
- "Basic" mission profile: **<u>118Tbits</u> (123Gbits/day over mission duration – requirement is over at least two cycles)**
  - InSAR, VenSpec, SRS and radio science (assumed in || to communications)
- "Enhanced" mission profile(s): **<u>160Tbits</u> (to be spread over mission duration)**
  - To fulfil 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)

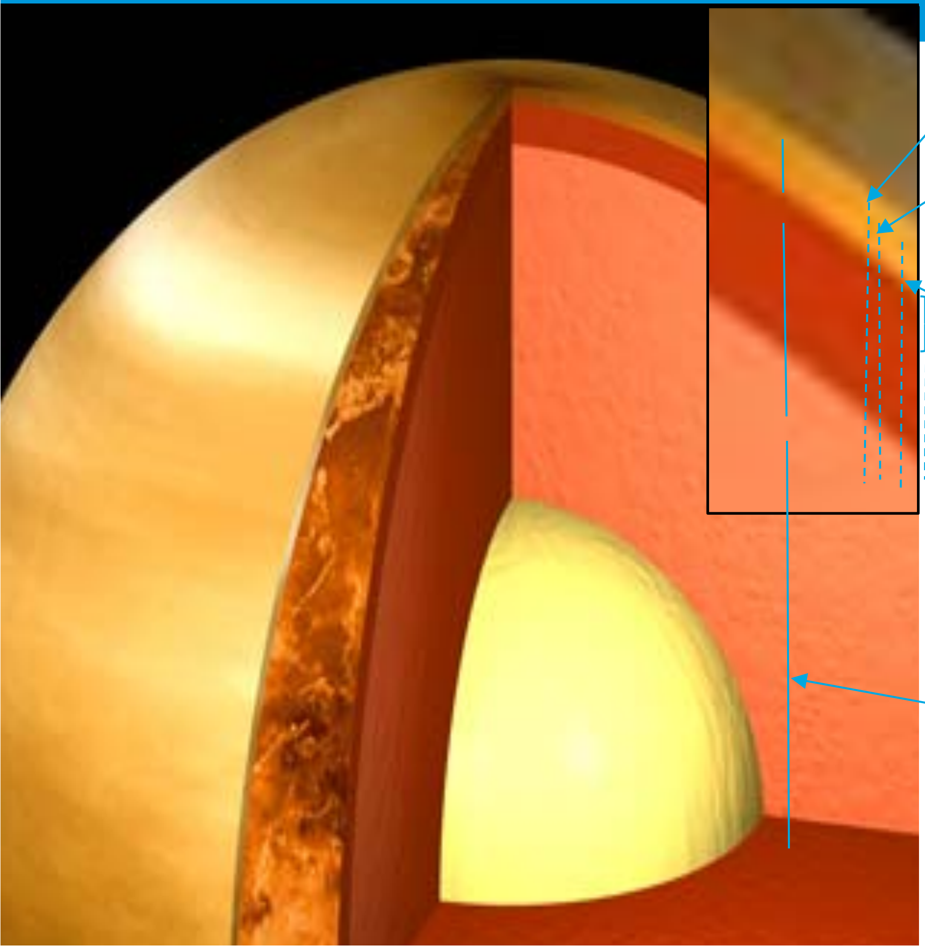


Payload overview

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

Higher atmosphere

VenSpec-U
Mapping SO, SO_2 and UV absorber at cloud top. @210-240nm (0.2nm), @190-380 (2nm), ~100 km spatial resolution

Lower atmosphere

VenSpec-H
Mapping of near surface atmosphere H2O, HDO at 0-15 km @1.08-1.2 µm, H2O, HDO, OCS, SO2 at 30-40 km @ 2.44-2.47 µm, ~100 km spatial resolution

Surface

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

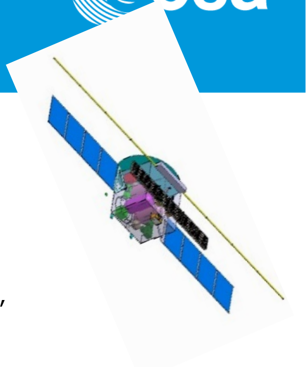
VenSAR
Surface morphology, 1-30 m, cm changes by inter-ferometric measurements, @ 3.2 GHz, radiometry with relative precision of 1K at 5x38 km resolution

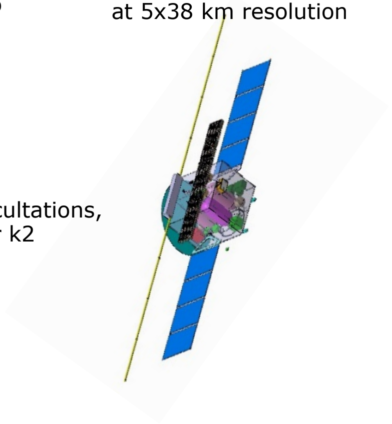
Crust profile

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

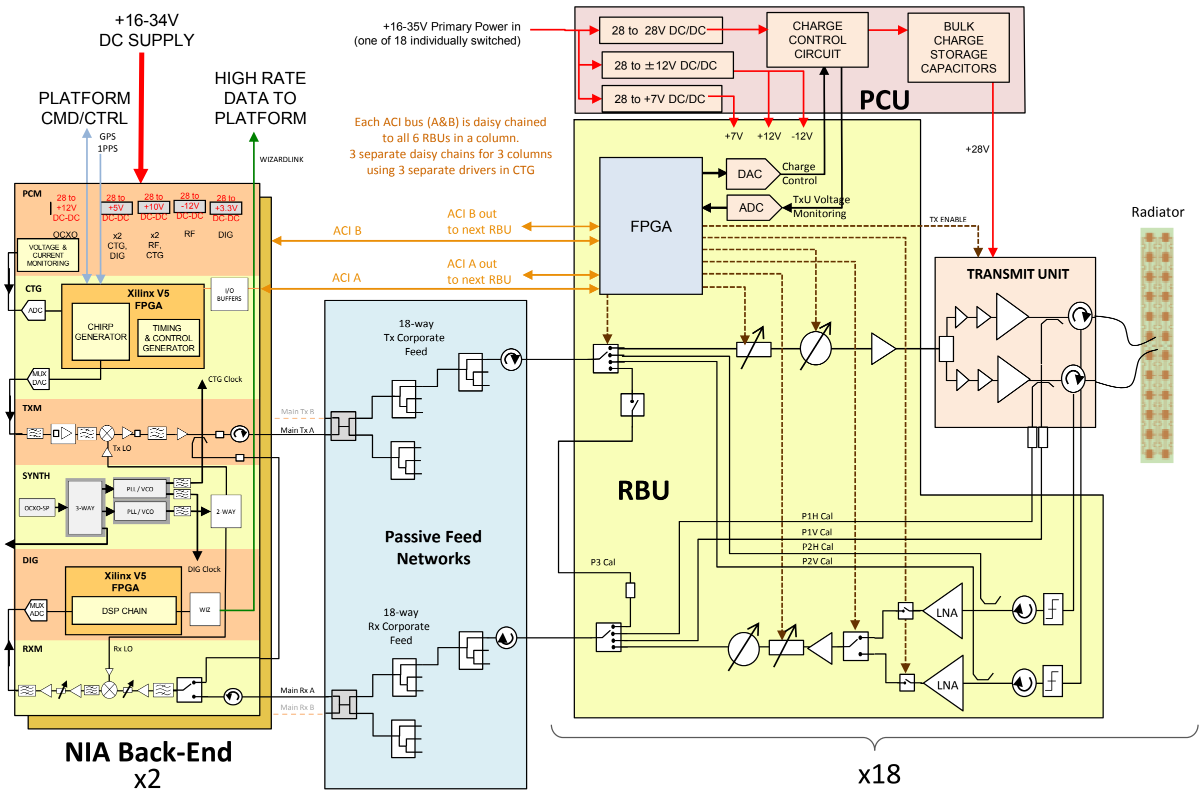
atmosphere, crust, planet mantle and core

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



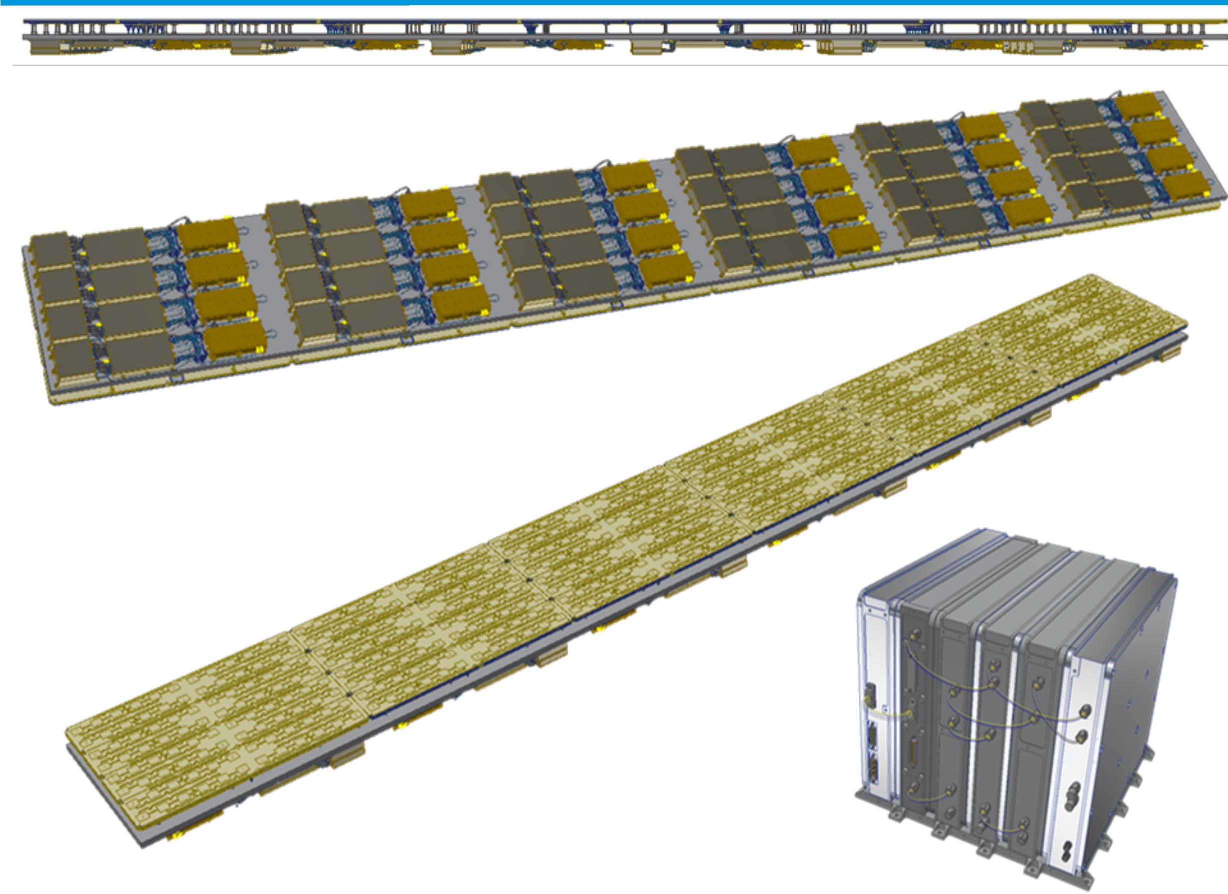


VenSAR – Synthetic Aperture Radar



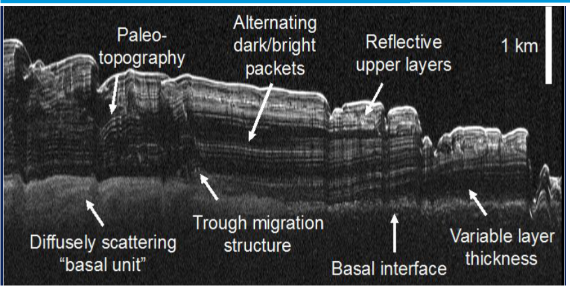
- A synthetic aperture radar
- Heritage from NovaSAR-S (GaN hi-power amplifiers), launched in September 2018
- S-band at 3.2 GHz (182 MHz bandwidth)
- The instrument consists of 3 units
  - The NIA backend x2 (cold redundant)
  - The antenna unit incl. front end electronics, TX/RX and radiator
  - Harness
- 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

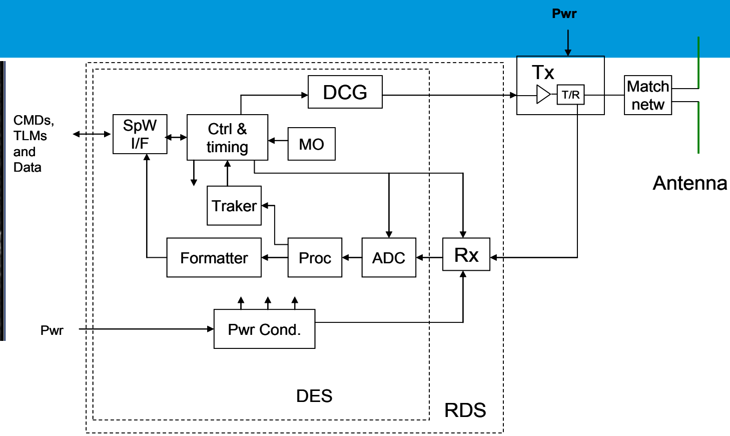
VenSAR – Synthetic Aperture Radar

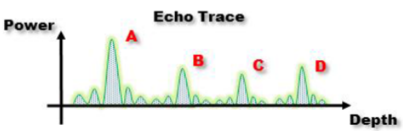


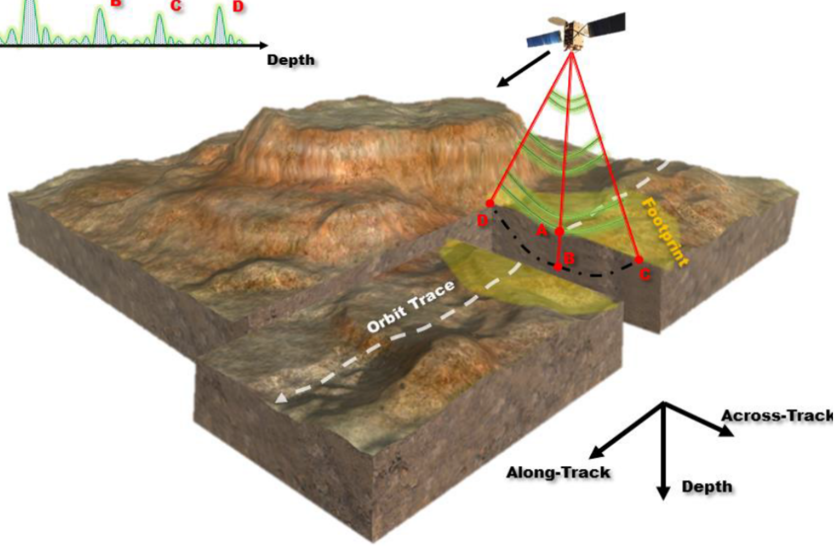
- VenSAR uses 24 separately controllable phase centres (6x4)
- Antenna length driven by imaging requirements
  - Reduction in length is not consistent with (low) pulse repetition frequency required by the swath width of 50 km. A shorter antenna illuminates a wider zone in along track direction (ie wider 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





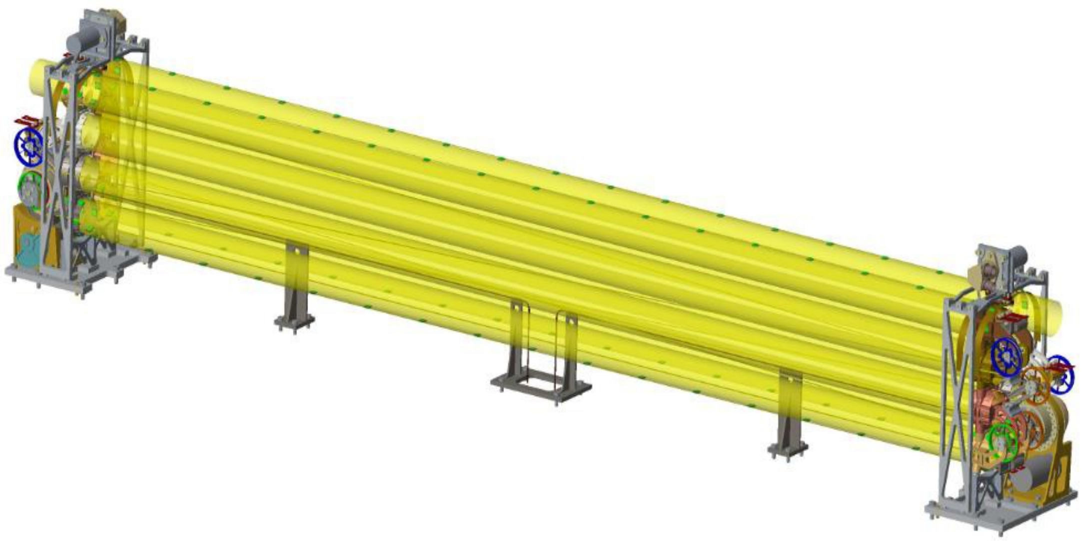




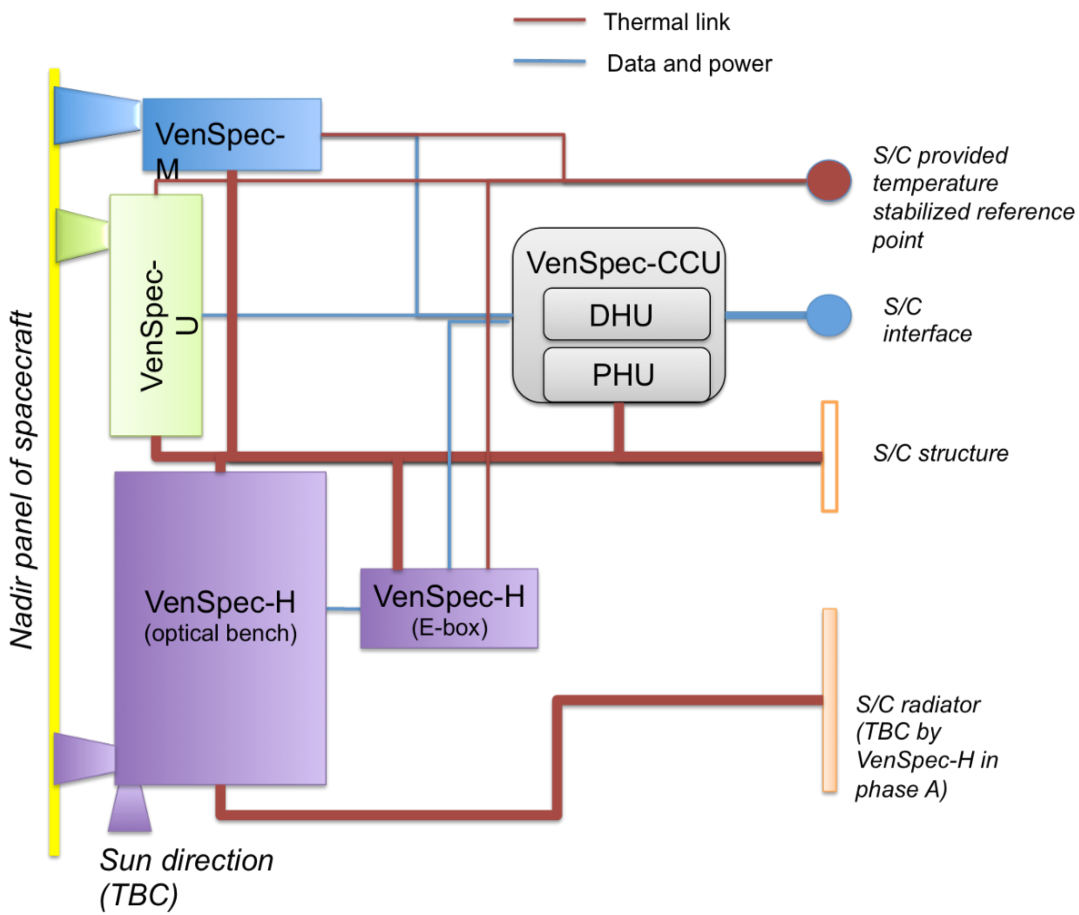
- A subsurface radar sounder
- Heritage from RIME (JUICE)
- 9 MHz with 6 MHz bandwidth
- The instrument consists of 4 units
  - Receiver and digital subsystem
  - Transmitter
  - Matching network
  - Deployable antenna
- RDS (256x180x140 mm), TX (362x182x140 mm), MN (280x142x50 mm), antenna (16 m)
- 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

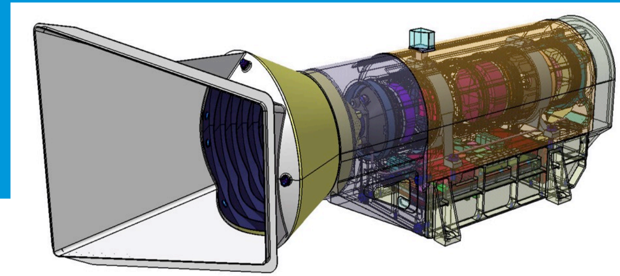


VenSpec – The Spectrometer Suite



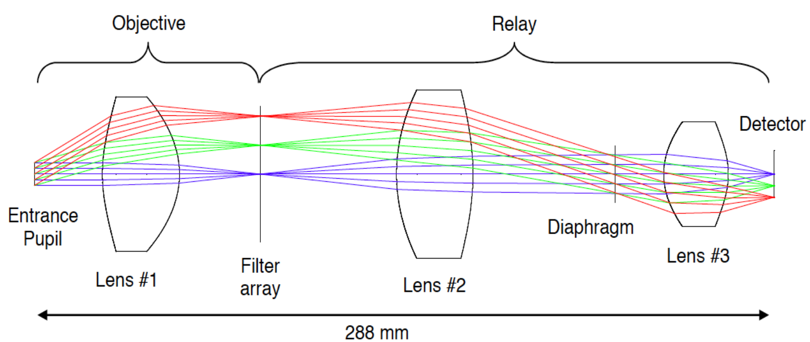
- Suite of spectrometers
  - Venspec-M
  - VenSpec-H
  - VenSpec-U
  - CCU
- Strong heritage from various precursor mission
- Physically separated instrument boxes, controlled by a single control unit (CCU)
- Total mass 31.63 kg
- Power 45.2 W
- -M (590x215x204 mm)
  -H (380x144x173 mm)
  -U (500x200x200mm)
  -CCU (200x200x200mm)

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	Value
Optics	
FOV (°) ACTxALT	46.4×37.8
Entrance pupil diameter (mm)	8
Effective focal length (mm)	16.4
F/#	2.04

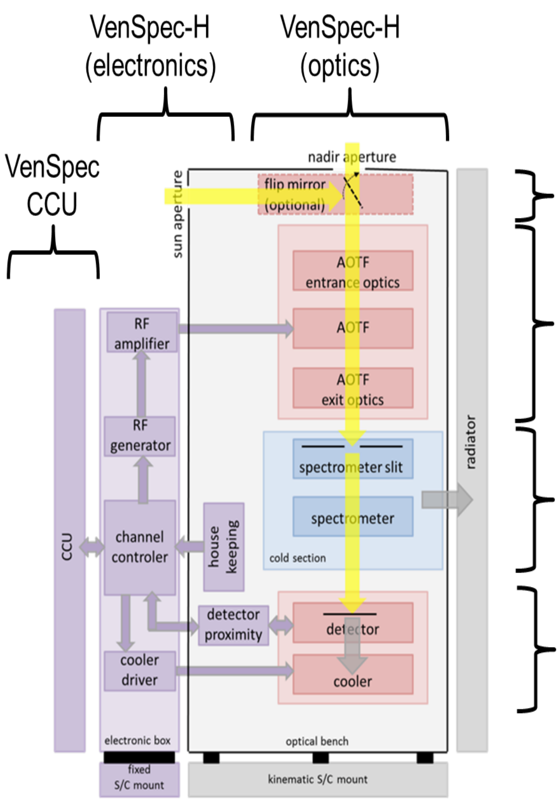
Accommodation item	Value
Mass (kg) CBE/CBE+contingency	5.00/5.85
Power (W) CBE/CBE+contingency Peak (Science, Test, Diagnostic, Science_idle modes) Average (Science, Test, Diagnostic, Science_idle modes) Standby (Diagnostic safe mode)	 15.0/19.5 11.5/15.0 8.0/10.5
Dimensions (mm³) Incl. baffle Instrument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

System

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)

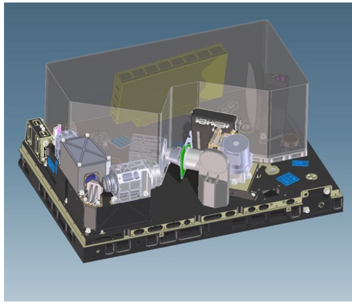


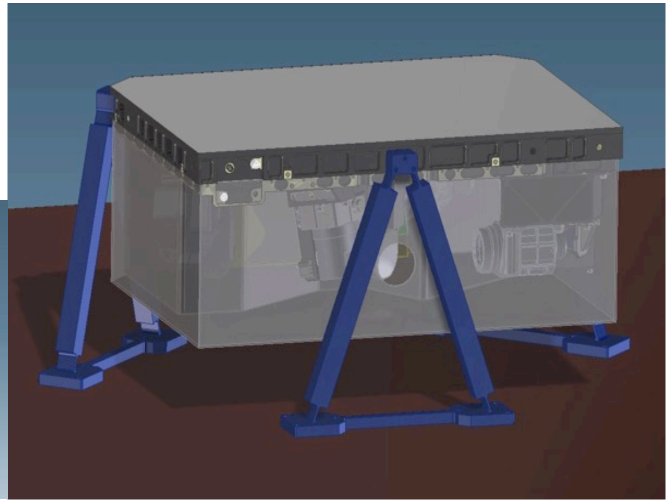
Entrance optics

AOTF : selection of spectral region of interest

Spectrometer

Detector



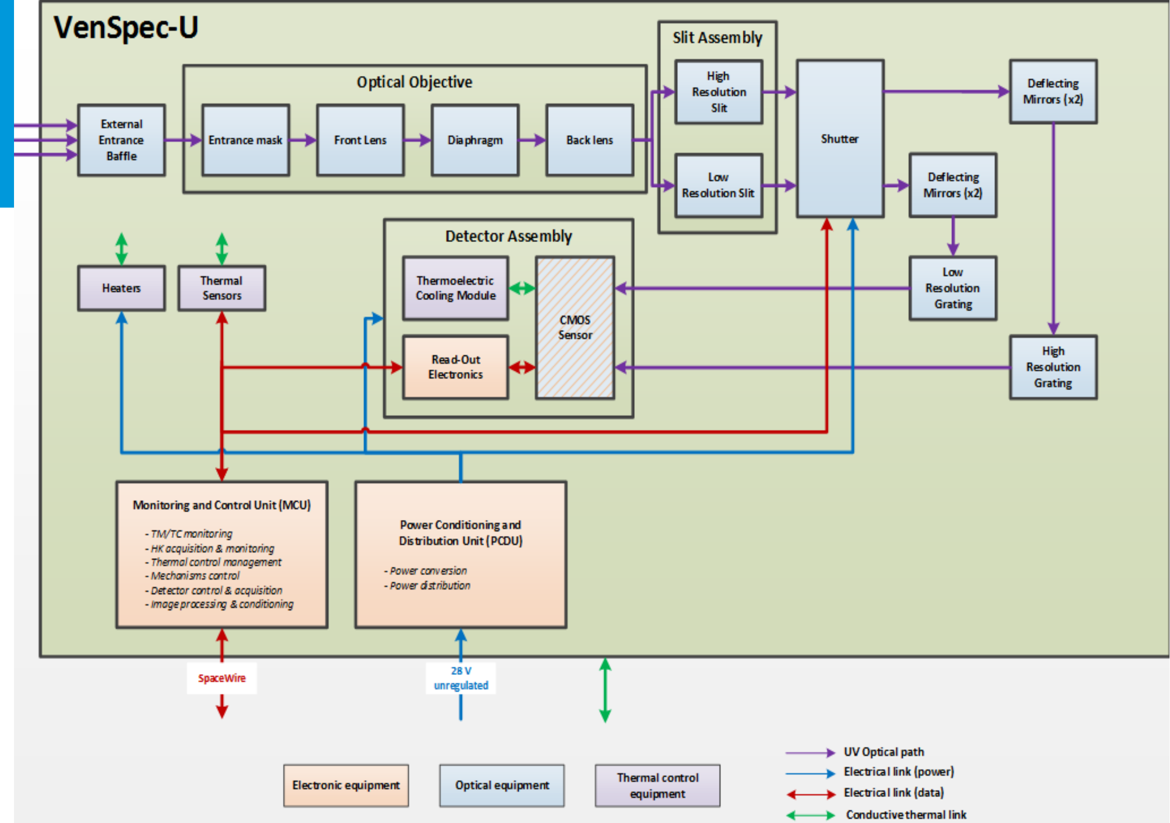


System

VenSpec-U

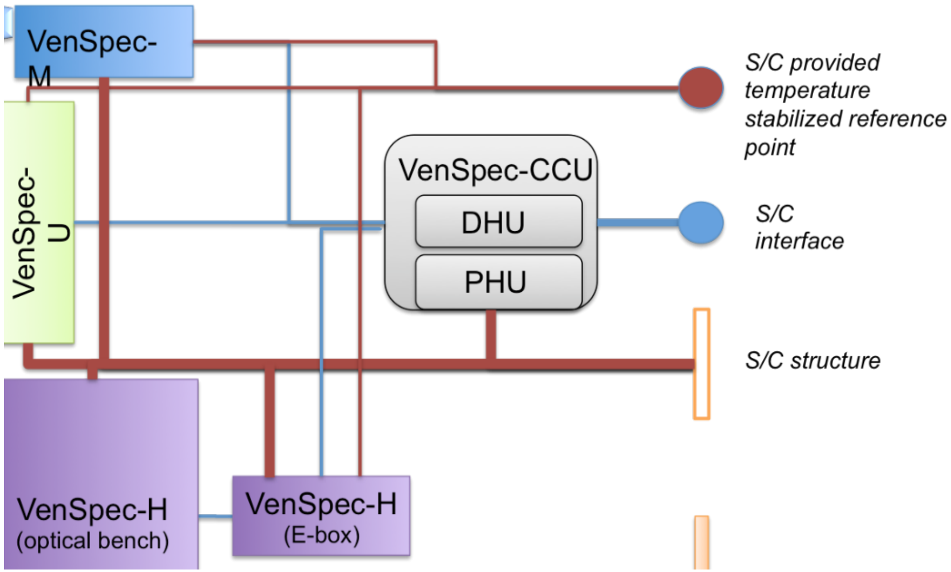
- Dual channel UV spectral imager, nadir
- Low-res 190-380nm, hi-res 210-240
- Spectr. res. 1.5 nm and 0.2 resp.
- Heritage from SPICAM/Mex, SPICAV/Vex and PHEBUS/BepiC
- Mass 4.11 kg, 14.4 W, data rate: 20 kb/s
- 100km spatial resolution
- APE 10 mrad, RPE 1 mrad over ½ orbit

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

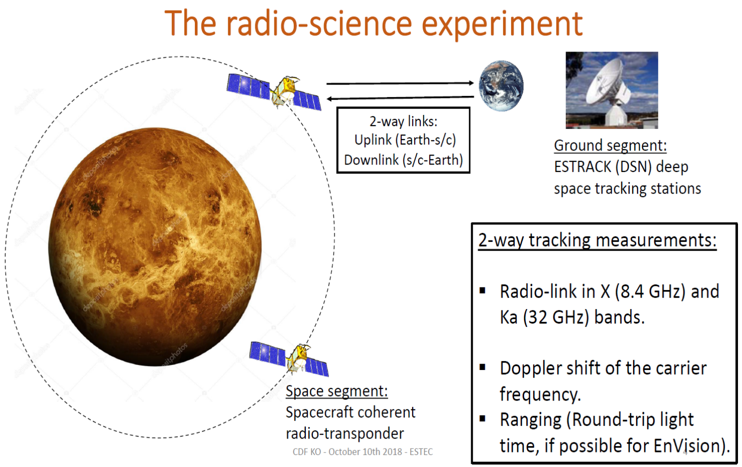
VenSpec – CCU



- 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)

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

Next steps in (pre)-industrial phase

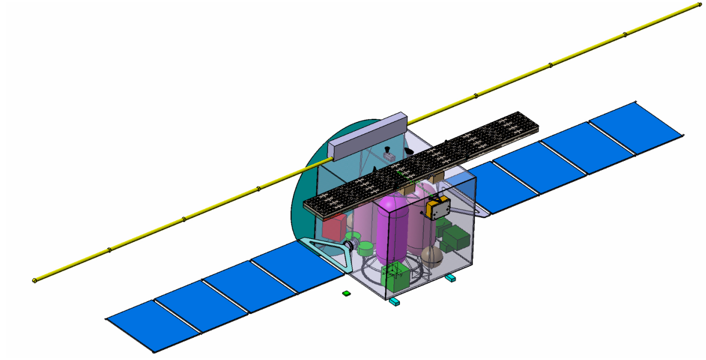
- **Accommodation**
  - SRS antenna orientation to be re-assessed
  - position of VenSpec-H wrt cold face during entire operations to be assessed, thermally analysed on S/C level and instrument level
  - all spectrometer straylight analysis
  - Slanted SAR accommodation
- **Operations**
  - In principle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

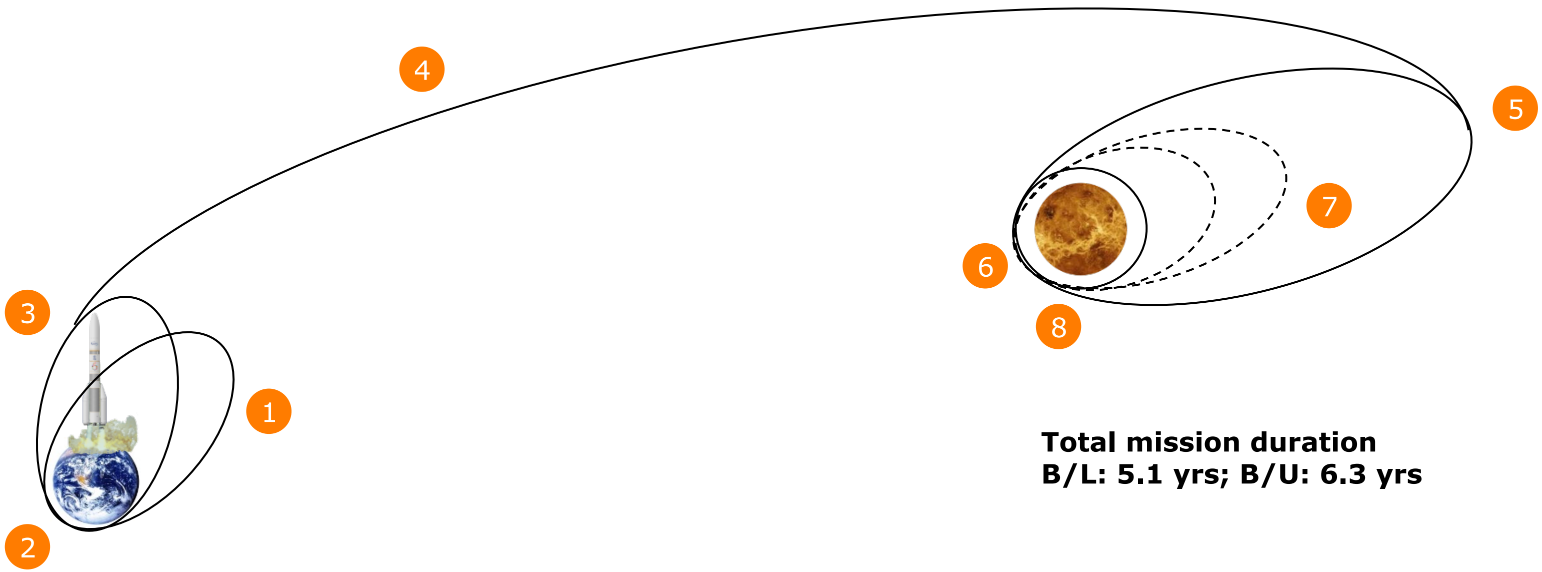
System Trade-Offs and Critical Areas

- 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

System Options



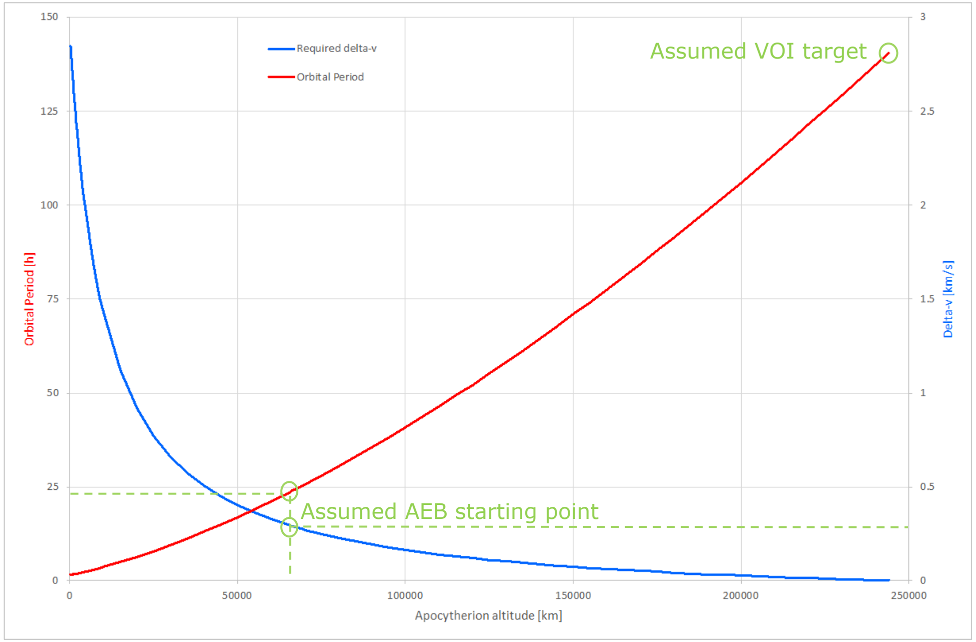
Mission Timeline - Chemical Propulsion



Total mission duration
B/L: 5.1 yrs; B/U: 6.3 yrs

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. Apocytherion lowering
7. Aerobraking
   B/L: ~25 months
   Note: 4 months margin applied
8. Science Operations
   2.66 yrs / 4 Venus cycles

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

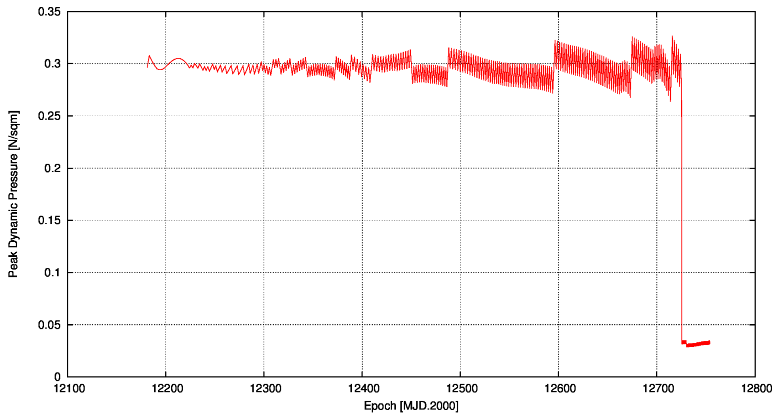
- Three sample cases, varying peak dyn. Pressure (dp) ballistic coefficient B=m/(CD*A):
    1. Peak dp=0.3 N/sqm, B=25 kg/sqm
    2. Peak dp=1 N/sqm, B=25 kg/sqm
    3. Peak dp=0.3 N/sqm, B=12.5 kg/sqm
    - Example for B: m=1000 kg, aerodynamic cross section A=20 sqm, CD=2, B=25 kg/sqm
- Results:
 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

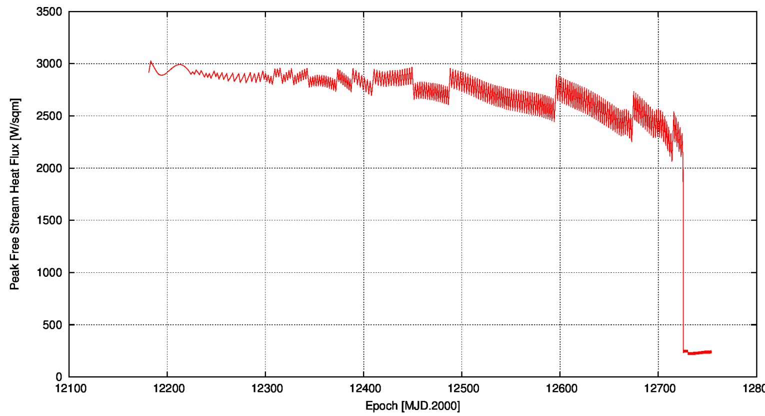
Aerobraking Scenarios

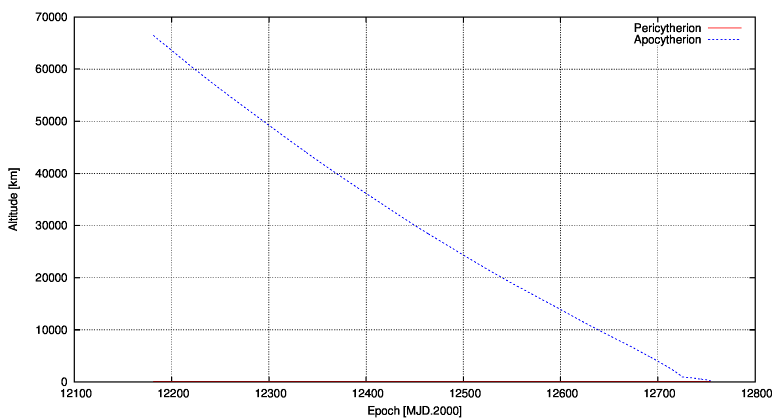
Case	1 (dp 0.3, B 25)	2 (dp 1.0, B 25)	3 (dp 0.3, B12.5)
Peak free stream heat flux [kW/sqm]	3	10	3
Duration [d]	574	185	285
Pericentre control [m/s]	44	14	22
Final pericentre raising [m/s]	33	35	33

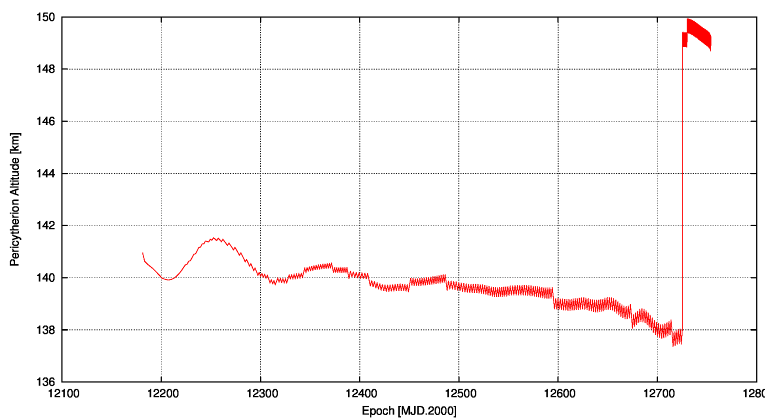
- Three sample cases, varying peak dyn. Pressure (dp) ballistic coefficient B=m/(CD*A):
    1. Peak dp=0.3 N/sqm, B=25 kg/sqm
    2. Peak dp=1 N/sqm, B=25 kg/sqm
    3. Peak dp=0.3 N/sqm, B=12.5 kg/sqm
- Results:
    - Total delta-v cost of AEB around 120 m/s incl. 100% margin on pericentre control
    - 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







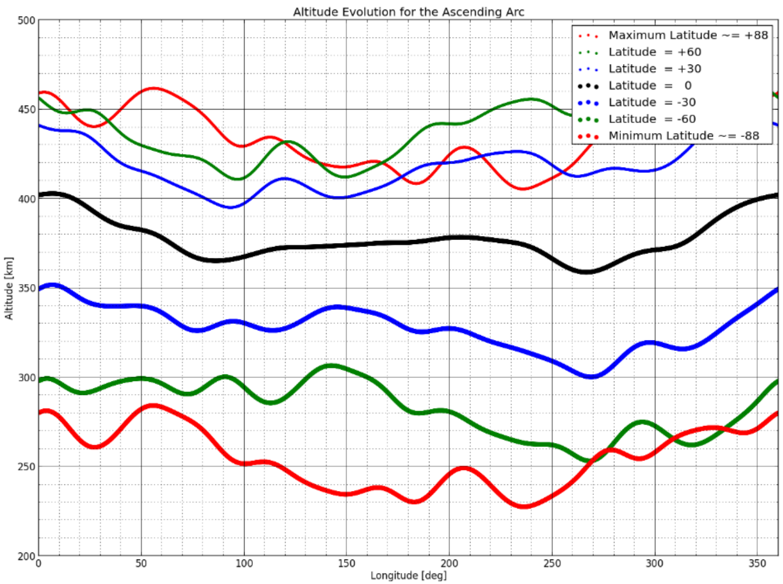


Transfer - Chemical Propulsion

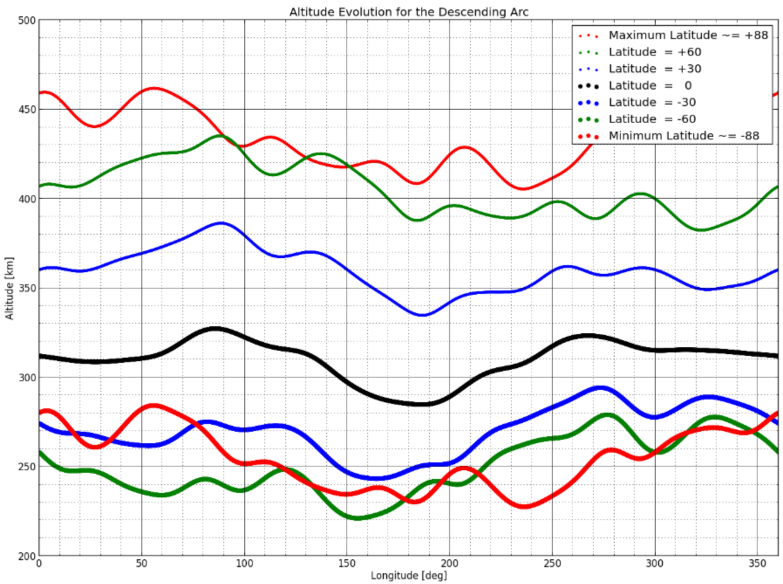
	T2 2031	T2 2032 (baseline)	ET2 2033 (backup)
Launch Orbit	250 x 300000 x 7deg		
Wet Mass Limit [kg]	2800		
Launch Date	27/04/2031	24/11/2032	12/05/2033
Escape Date	27/05/2031	24/12/2032	12/06/2033
Escape Man. 1 [m/s]	41	30	20
Escape Man. 2 [m/s]	505	491	983
VOI [m/s]	879	850	611
Total ΔV [m/s]	1425	1371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

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



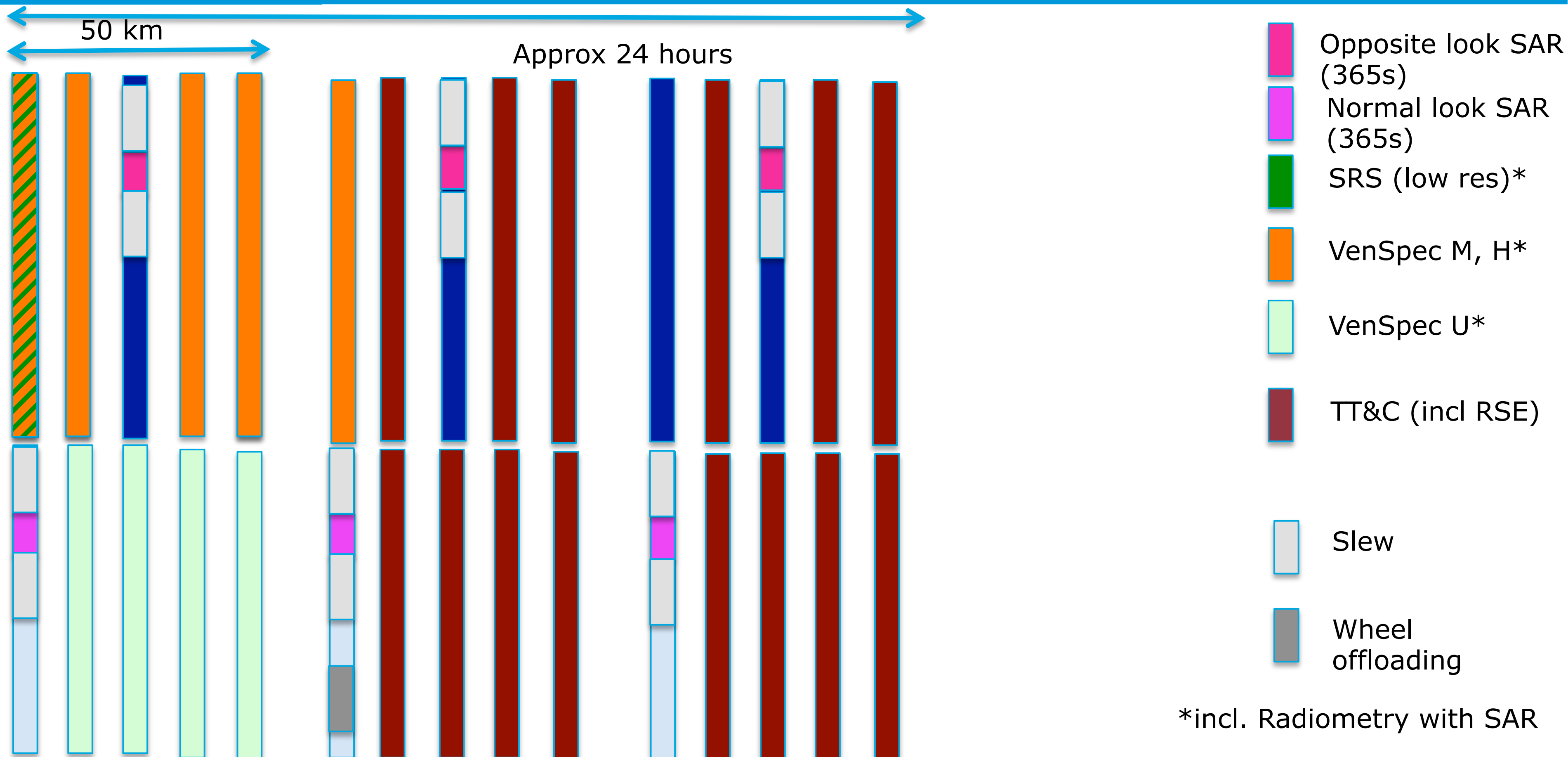
Ascending Arc (South to North)



Descending Arc (North to South)

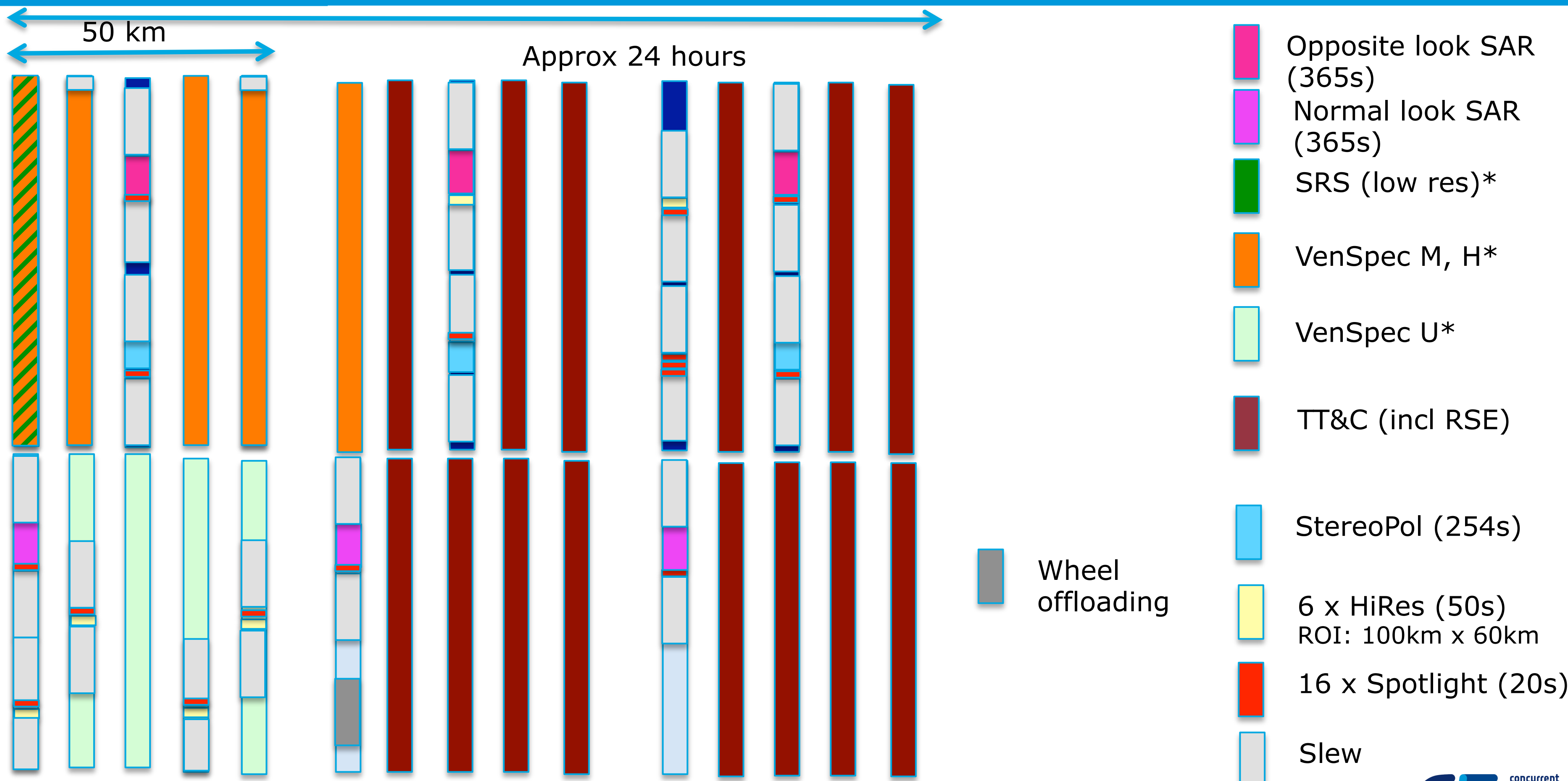
Concept of Operations

Basic Data Return Profile



Enhanced Data Return Profile
Chemical Propulsion Option

*incl. Radiometry with SAR



Data Return Budget

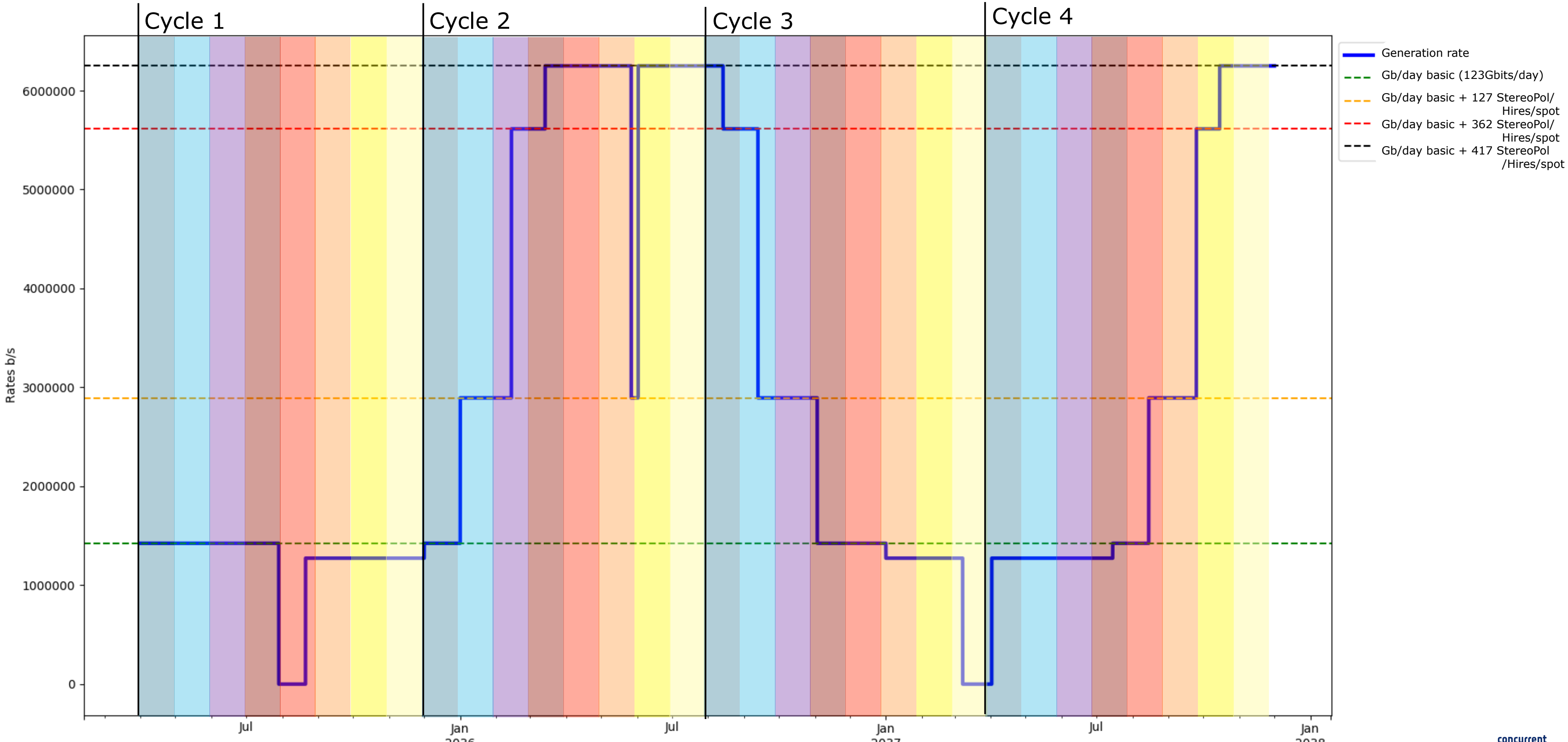
… With proposed system baseline

- 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



Fulfilled Requirements and Constraints

	Coverage	Repeat passes	Constraints
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 √ lowRes		- 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

System Design and Budgets

Mission and System Summary
CDF Baseline / Chemical Propulsion
HEO T2 2032

Launch vehicle	Ariane 6.2
Launch date	Baseline: 2032 / Backup: 2033
Lifetime	Nominal science 2.66 years
Orbit	Frozen eccentricity
Altitude	220-470 km
Inclination	88
Ground stations	X-Band (TT&C) and Ka-Band (Science downlink) communication based ground station capability provided by 35m antennas: Malargüe, New Norcia (NNO-1), Cebreros Access to, and use of NASA DSN ground station contribution. Additional smaller 15m ground station coverage support :Kourou (15m), New Norcia 2 (4.5m)
Mass (with margin)	Dry mass 1277.5 kg Wet mass 2535 kg Total (wet + adapter) 2607 kg Launcher performance 2870 kg
Payload	Synthetic Aperture Radar (VenSAR) Subsurface Radar (SRS) Spectrometer (VenSpec) Radio Science Experiment (No payload equip.)

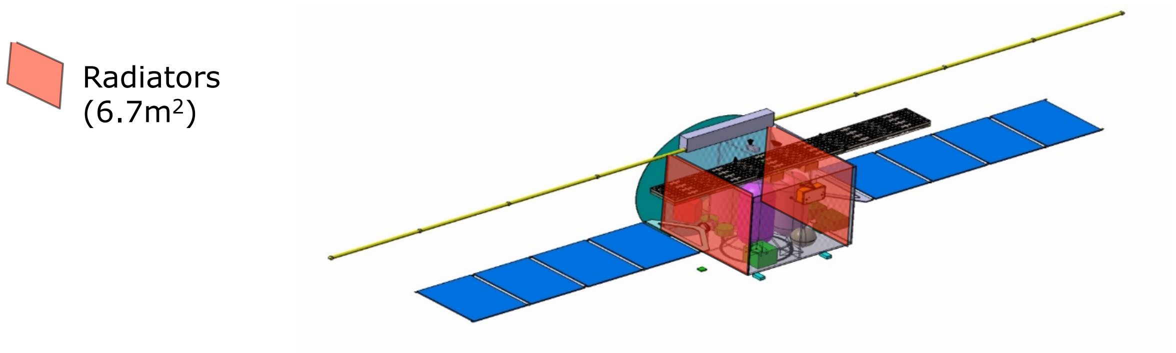
Data Handling	OBC with SSMM (2 Tbit + 2 Tbit in cold red.), RTU
AOCS	2x star trackers 2x gyros 4x reaction wheels 2x sun sensors 2x accelerometers
Communications	HGA, 2x LGA, Ka-band TWT/EPC, X-band TWT/EPC, RF harness, 2x transponders
Chemical Propulsion	Bipropulsion System: MON/MMH 420 N Main Engine 8 + 8 10 N thruster for AOCS Isp < 319 s for main engine Isp ~ 290 s for smaller thrusters
Mechanisms	SADE, 2x SADM, SRS deployable dipole antenna
Power	Solar array (total 15.7 m²), 67 kg battery, PCDU
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

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)



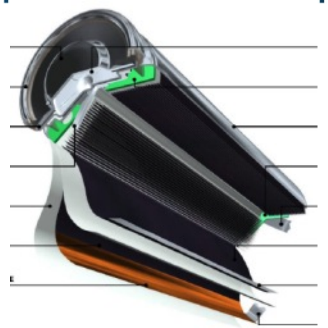
- Internal configuration:
  - Most of payload units shall be installed close to both radiator faces and NADIR face
  - Platform units shall be installed preferably on radiator faces to minimize use of straps/HP (bottom part)

Power Subsystem Concept

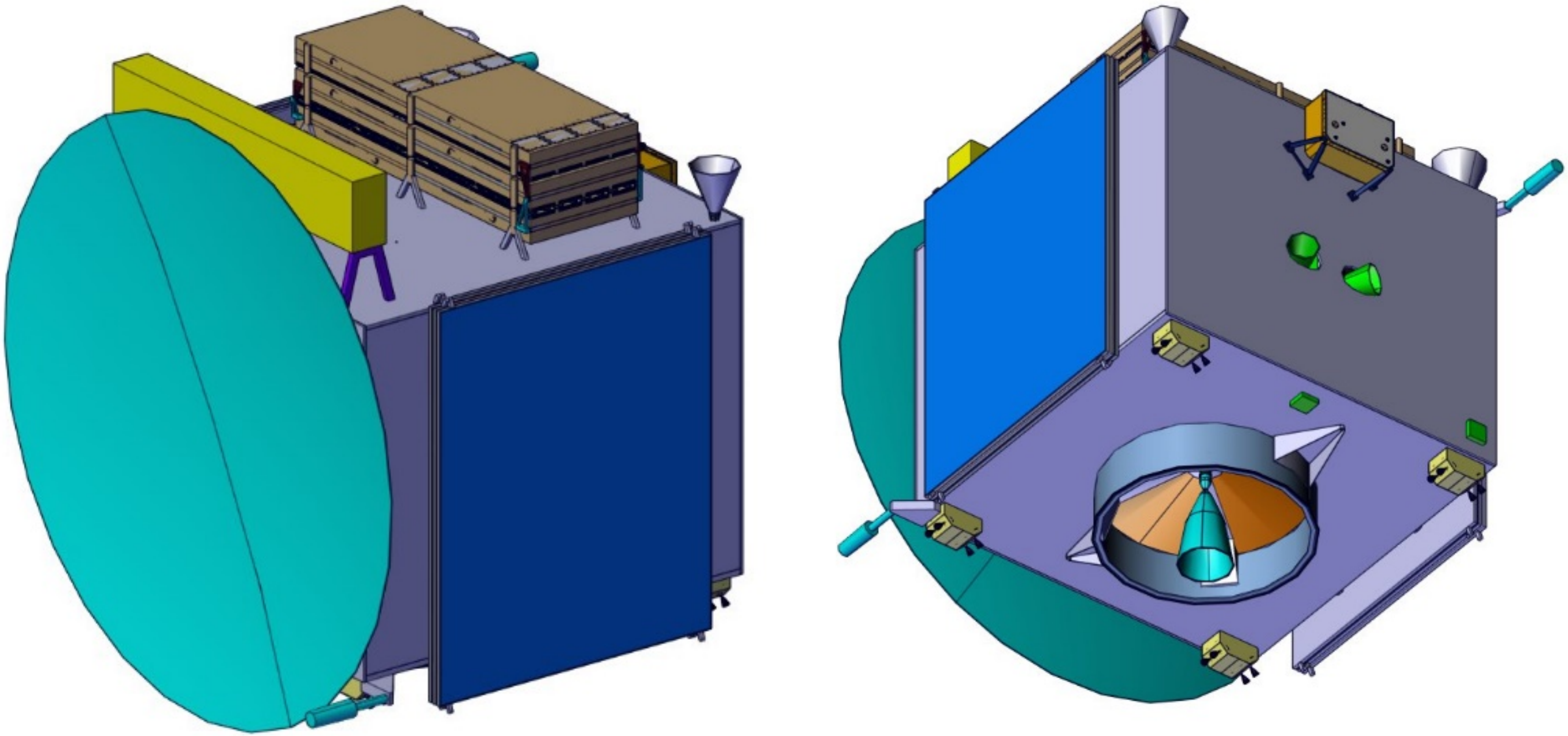
- 50V regulated bus with BCR/BDR → **PCDU 25 kg**
- **Solar arrays: 97 kg**
  - 2 wings, 56 strings of 40 cells in parallel
  - Area: 15.7 m^2 (57% solar cells, 40% optical reflectors)
- **Battery: 67 kg**
  - Maximum allowed Depth of Discharge (DoD)
    - for repeated cycling < 15%
    - for occasional occurrences (Launch) < 60%

Power Budget: CP Option Power (W)	LM	CM	MAN	COM	SciH	SciL	ABM	SM
	P_avg	P_avg	P_avg	P_avg	P_avg	P_avg	P_avg	P_avg
AOGNC	14.0	98.9	296.9	98.9	98.9	98.9	98.9	14.0
Comms	21.6	30.8	30.8	221.3	30.8	30.8	32.3	45.8
Data Handling (DHS)	48.0	88.0	88.0	88.0	88.0	88.0	88.0	48.0
CPROP	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9
MECH	2.5	0.0	0.0	0.0	0.0	3.5	0.0	0.0
THES	51.8	672.9	776.4	659.9	375.3	401.1	1138.7	659.9
INS	0.0	211.8	211.8	211.8	392.7	295.0	211.8	211.8
PWR	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Total consumption P(W)	175.7	1140.3	1441.8	1317.8	1023.5	955.2	1607.6	1017.4
Losses (PDU, Harness, Distribution)	5	34	43	40	31	29	48	31
BAT charging		0	0	1096	852	795	1337	846
TOTAL S/C	181	1174	1485	2454	1906	1779	2993	1894
Total Power Budget With Margin P(W)	217	1409	1782	2944	2287	2134	3592	2273
Energy Requirement: Energy (Wh)								
Duration Eclipse (min):	240	0	0	42	42	42	42	42
Battery Energy Requirement (Wh)	869	0	0	1140	886	826	1391	880

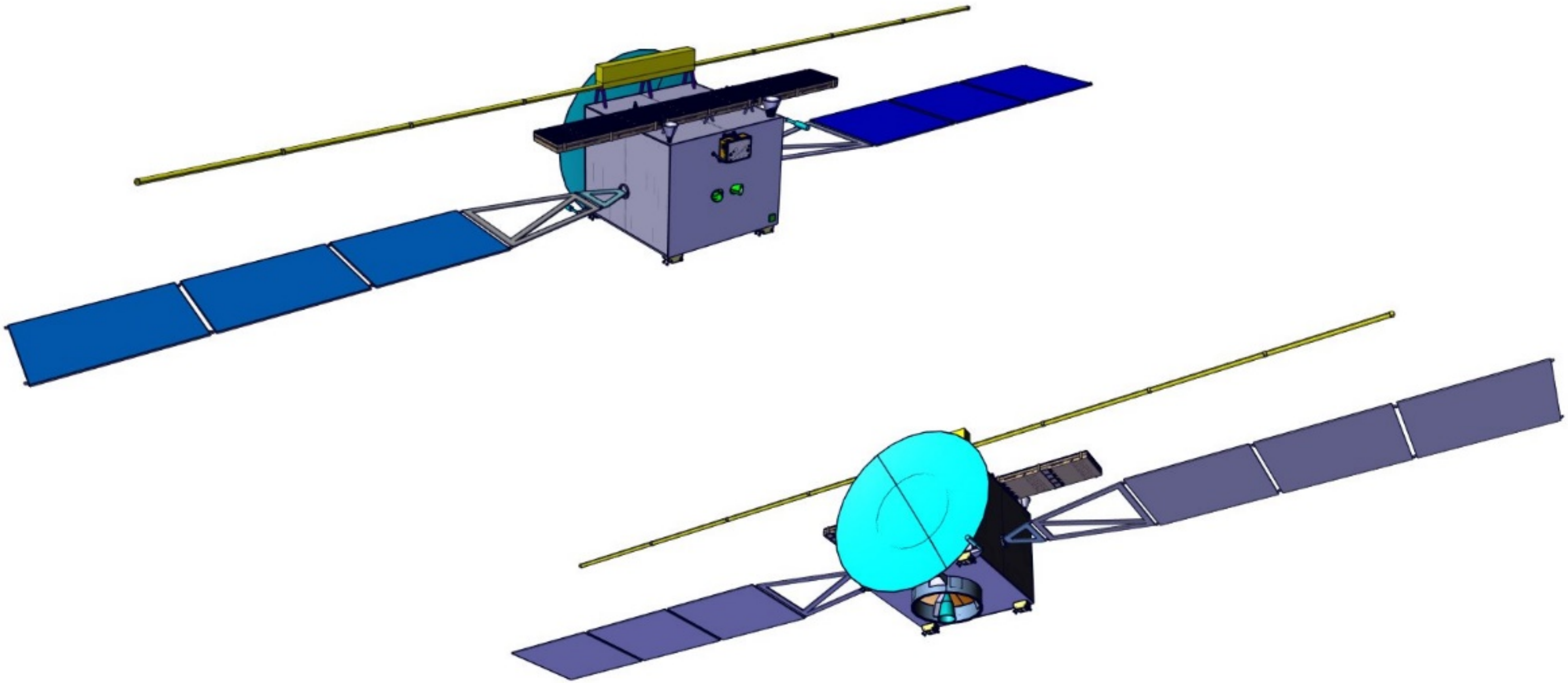
ABSL SPACE PRODUCTS



Configuration – in Ariane 6.2 Fairing



Configuration - Deployed



Mass Budget
Chemical Option/ Baseline Date HEO T2 2032

Subsystem	Switch	Instruments Mass Budget		Mass [kg]
INS	Product			195.63
		Dry Mass w/o Payload Margin		**195.63**
		Payload Margin	30%	58.69
		Dry Mass incl. Payload Margin		**254.32**

Subsystem	Switch	S/C Mass Budget		Mass [kg]
AOGNC	Product			51.77
COM	Product			69.29
CPROP	Product			108.11
DH	Product			33.60
EPROP	Not used			0.00
MEC	Product			57.96
PWR	Product			208.45
STR	Product			206.04
SYE	Not used			0.00
TC	Product			64.50
		Harness	5%	52.70
		Dry Mass w/o System Margin		**852.67**
		System Margin	20%	170.53
		Dry Mass incl. System Margin		**1023.20**

Total dry mass Budget	Mass [kg]
Instrument dry mass with payload margin	254.32
S/C dry mass with system margin	1023.20
Total dry mass incl. Margins	**1277.52**

Baseline Launch Window HEO T2 2032	Mass [kg]
CPROP Fuel Mass	472.70
CPROP Oxidizer Mass	780.00
CPROP Pressurant Mass	7.00
Total Wet Mass	**2537.22**
Launcher Adapter	70.00
Launch mass	**2607.22**
Target Launch mass	2870.00
Below Target Mass by	262.78

Mass Budget
Chemical Option/Back-Up Date HEO ET2 2033

Back-up Launch Window HEO ET2 2033	Mass [kg]
CPROP Fuel Mass	503.20
CPROP Oxidizer Mass	830.30
CPROP Pressurant Mass	7.00
Total Wet Mass	**2618.02**
Launcher Adapter	70.00
Launch mass	**2688.02**
Target Launch mass	2870.00
Below Target Mass by	181.98

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

Programmatics / Master Schedule

- 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

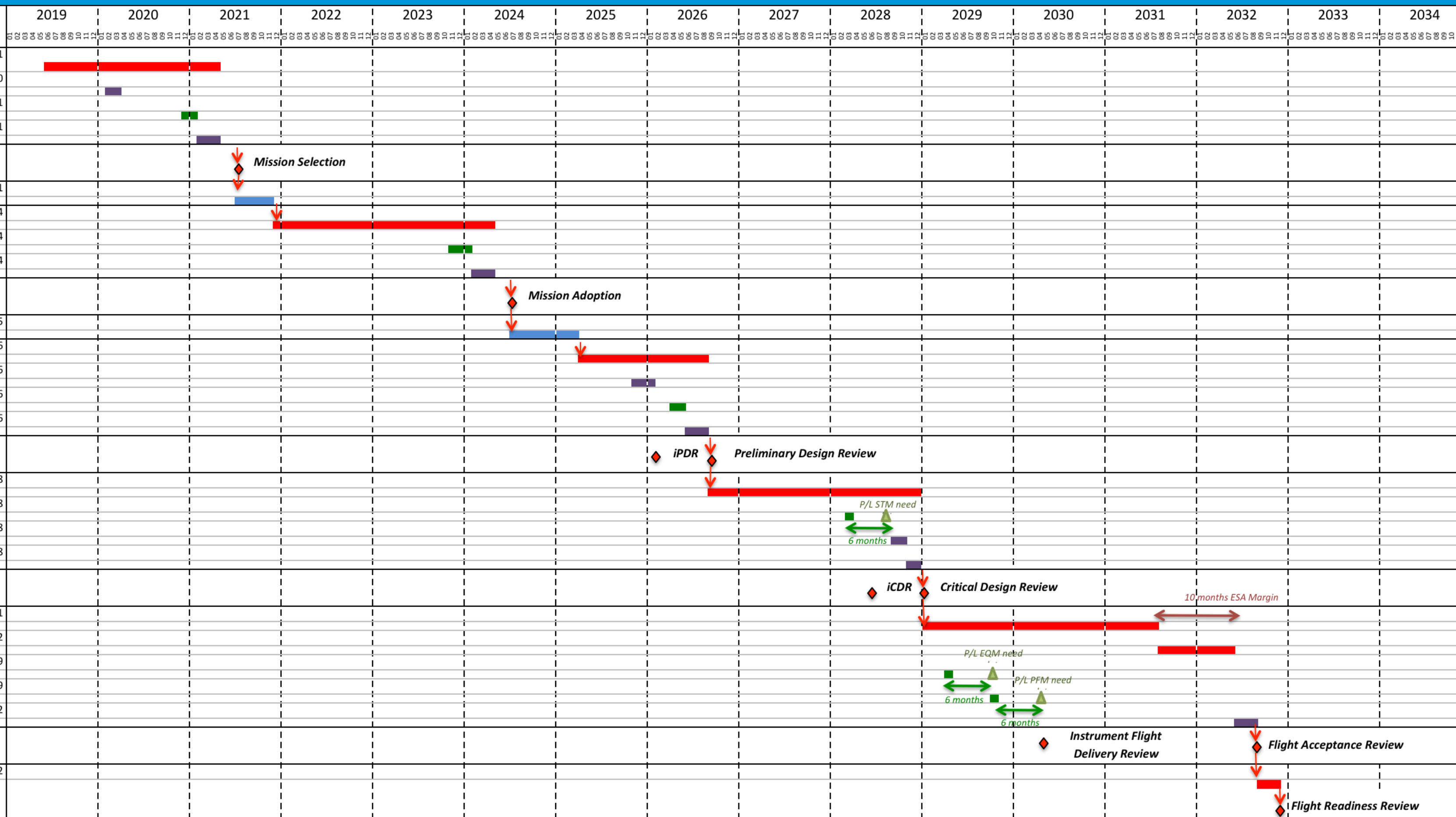
- The master schedule includes 6-months built-in margin wrt payload delivery dates

- 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)

Programmatics / Master Schedule

Task		
Phase A	01/06/2019	30/04/2021
MCR	01/02/2020	01/03/2020
iPRR	01/12/2020	31/01/2021
MSR	01/02/2021	30/04/2021
Post MSR margin	15/06/2021	30/11/2021
Phase B1	01/12/2021	30/04/2024
iSRR	01/11/2023	01/01/2024
MAR	01/02/2024	30/04/2024
Prime selection	15/06/2024	21/03/2025
Phase B2	21/03/2025	06/08/2026
SRR	01/11/2025	31/01/2026
iPDR	31/03/2026	31/05/2026
PDR	01/06/2026	06/08/2026
Phase C	07/08/2026	07/12/2028
P/L STM	15/02/2028	15/03/2028
iCDR	28/08/2028	30/10/2028
CDR	31/10/2028	31/12/2028
Phase D	07/12/2028	03/07/2031
ESA Margin	03/07/2031	03/05/2032
P/L E(Q)M	15/03/2029	15/04/2029
P/L PFM	30/09/2029	31/10/2029
FAR	03/05/2032	03/08/2032
Phase E1	03/08/2032	10/11/2032



Programmatics / Technology Readiness

- 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 Msyms) of ground segment

Programmatics / Technology Readiness

- **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 (⇔ 75 Mbps).

- **TT&C Subsystem :**
  - Ka/Ka/X/X iDST transponder under development allows up to 300 Msyms (⇔ 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.

Programmatics / Technology Readiness

- 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 <u>generic</u> 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).

Programmatics / Risk Register

Severity	A (remote)	B (unlikely)	C (likely)	D (highly likely)	E (near certainty)
5	Low	MI03 S/C mass critical Medium	High	Very high	Very high
4	MI04 missed MAN MI08 missed 2032 launch Low	MI02b SAR adaptation Low	MI09 Aerobraking duration Medium	High	Very high
3	Very low	Low	MI10 DSA availability Low	Medium	High
2	MI07 STR-based safe mode Very low	MI11 SRS antenna adaptation Very low	Low	Low MI06 SRS / SA EMC	Medium
1	Very low	Very low	Very low	Low	Low

Likelihood

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