VADER

Venus Atmosphere, Descent, and Environmental Researcher

Jennifer Hanley and Erik Larson

JPL Planetary Science Summer School 2012
Session 2

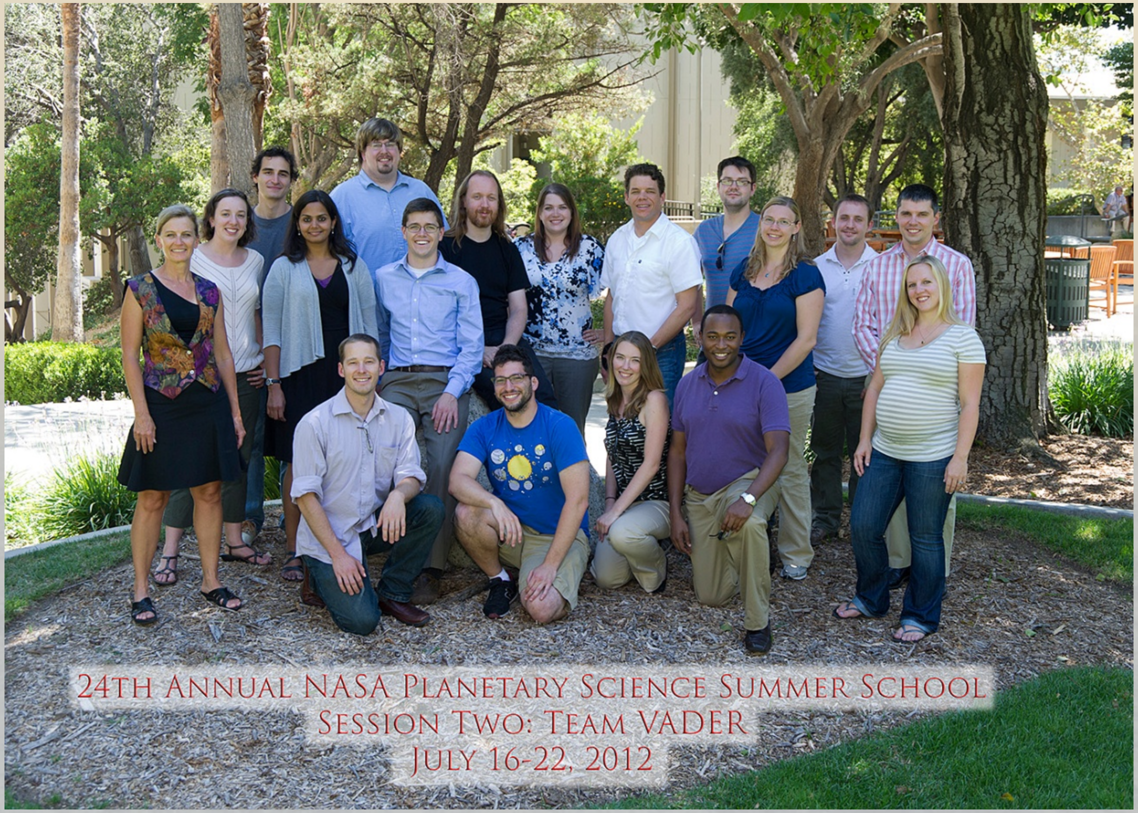
JPL CL#12-3967

Planetary Science Summer School

JPL's Team X - Design a "New Frontiers" class mission

One week "bootcamp"

Respond to the 2009 AO

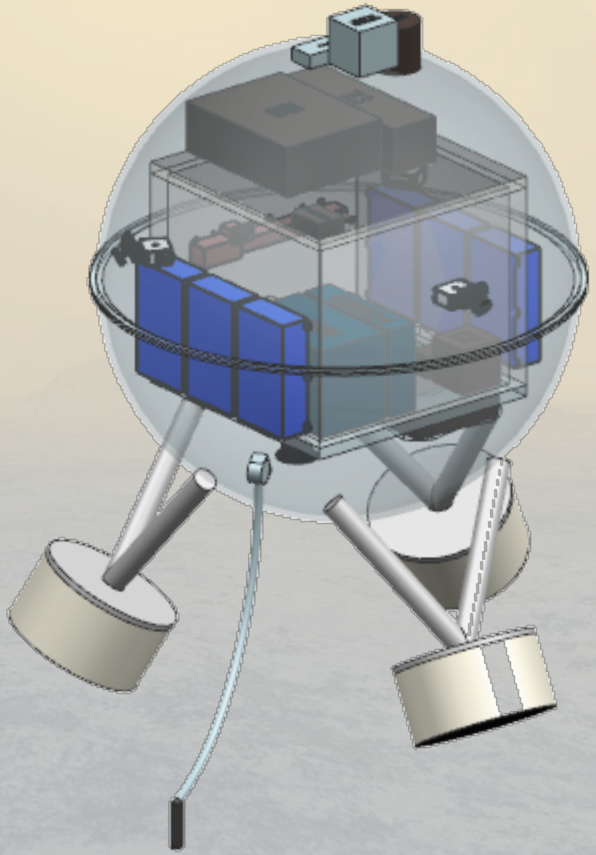


Mission Concept Overview

Nuding, Ozhogin

VADER – **V**enus **A**tmosphere, **D**escent, and **E**nvironmental **R**esearcher

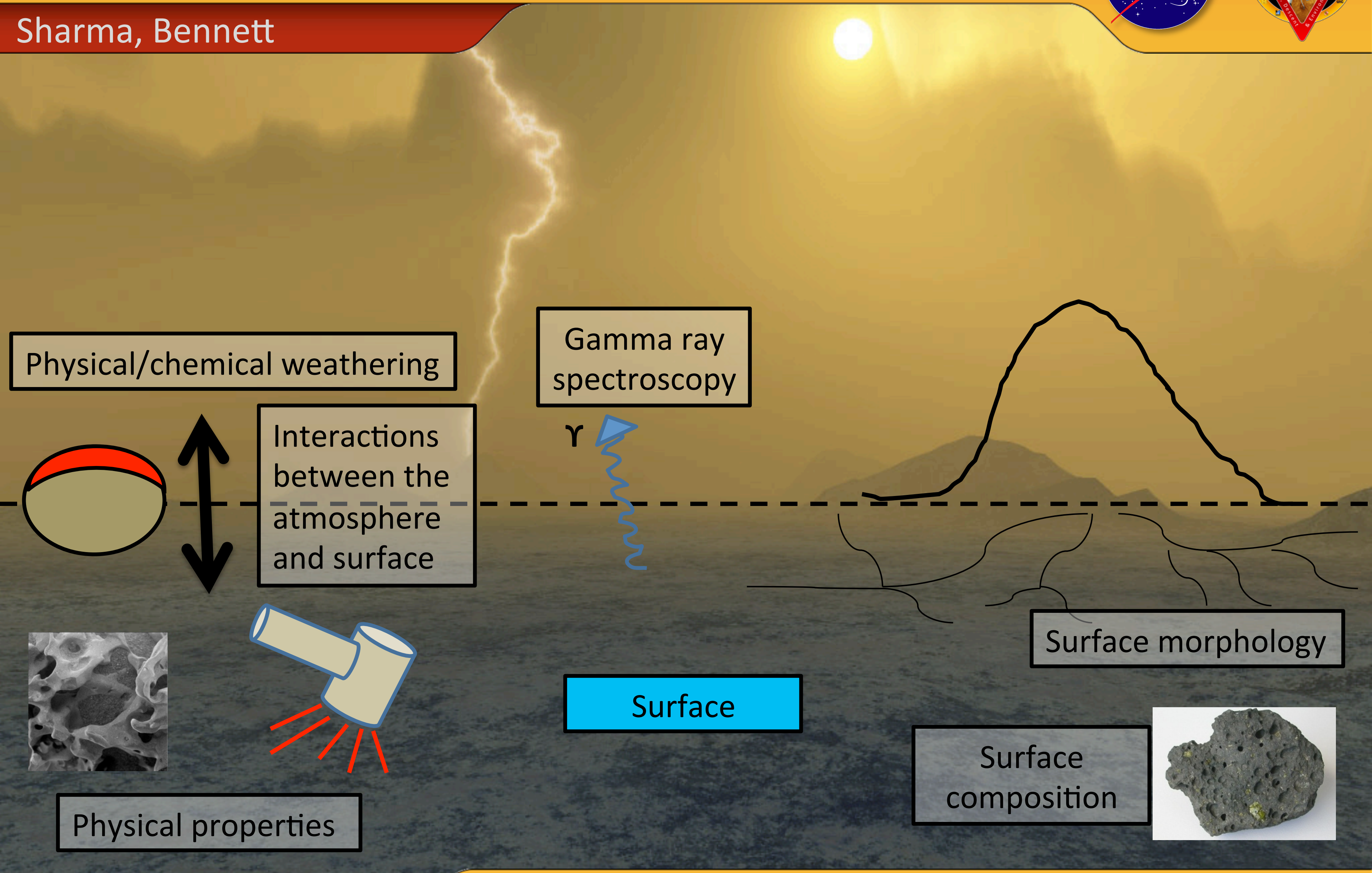
- Launch vehicle: Atlas 411
- Launch mass: 1354 kg
- Launch date: July 8, 2020



Response to the AO calling for a Venus science mission

Surface Science Schematic

Sharma, Bennett



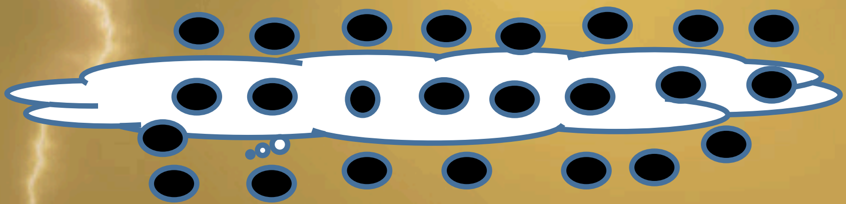
Atmospheric Science Schematic

Sharma, Bennett

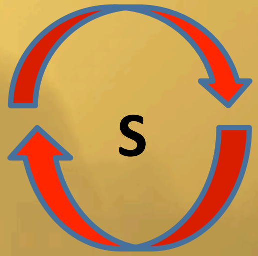
$^{36}Ar/^{38}Ar$, $^{15}N/^{14}N$, $^{21}Ne/^{22}Ne$, $^{34}S/^{33}S$

D/H

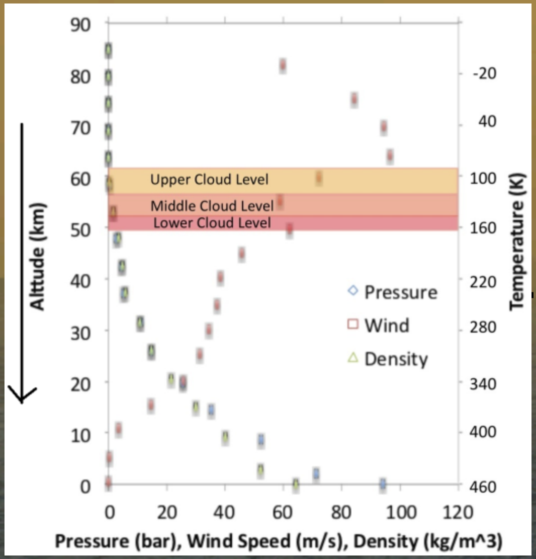
Atmosphere



Aerosol size distribution and composition



Sulfur cycle

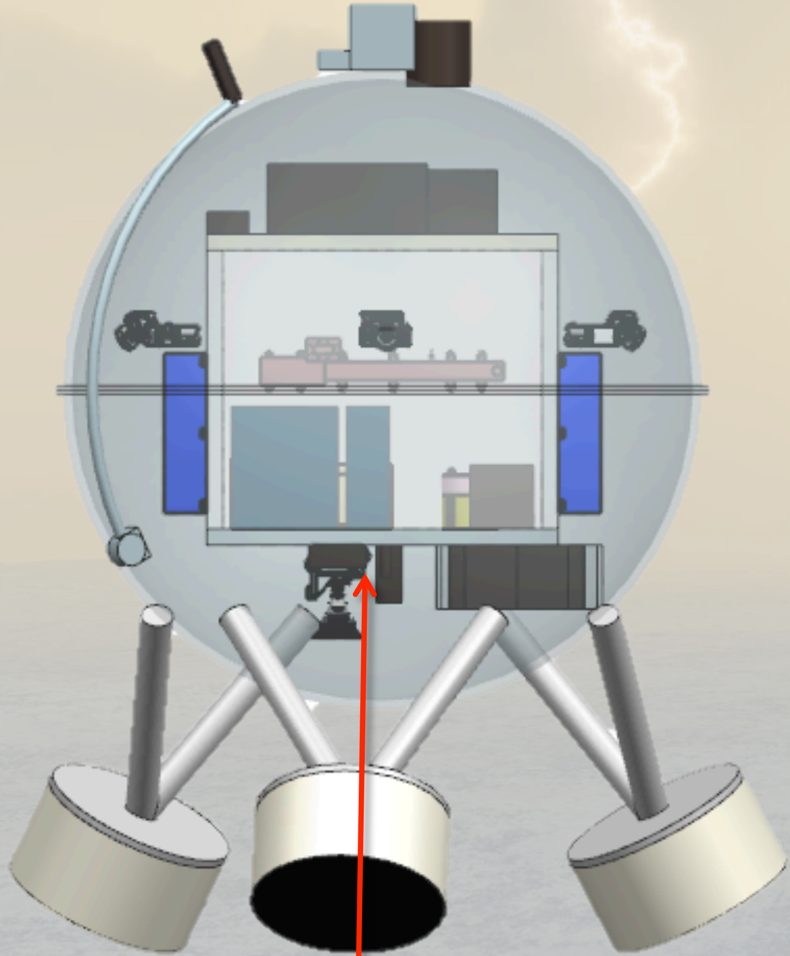


Pressure, temperature, density, wind speeds

Radiative balance

Imaging Systems Suite

Byrne



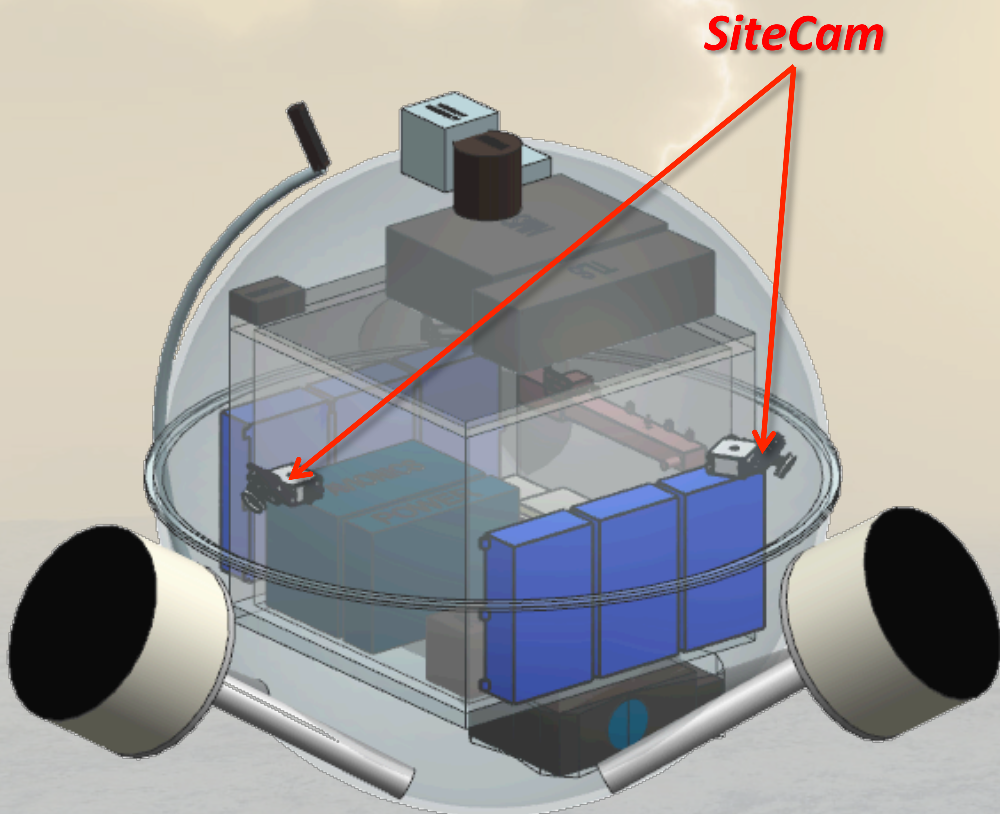
Descent Imaging System

	Visible Camera	Near-IR Camera
Mass (kg)	1	2
Power (W)	3	2.5
Image Resolution	8 m at 10 km <1 m at 100 m	48 m at 60 km 7 m at 5 km
Band(s) (mm)	0.55, 0.7, 0.8	2.3
Data Volume (Mb)	454	338

- ***Physical/chemical weathering***
- ***Physical properties***
- ***Surface composition***
- ***Surface morphology***
- ***Cloud structure***

Imaging Systems Suite

Byrne



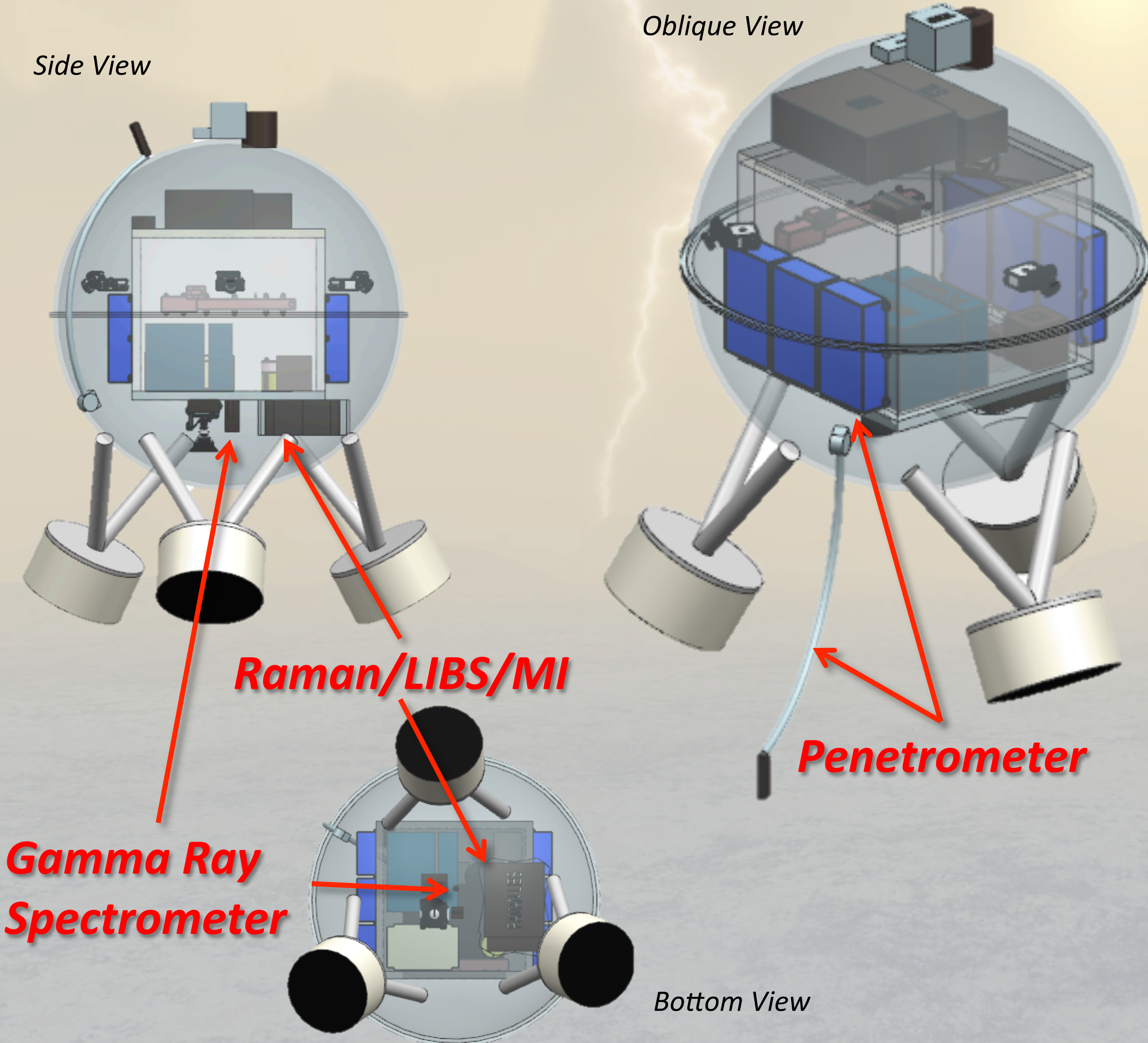
SiteCam

Mass (kg)	0.735
Power (W)	6.45
Sensor Size (pixels)	1024 x 1024
Band(s) (mm)	0.55, 0.7, 0.8
Data Volume (Mb)	92

- ***Physical/chemical weathering***
- ***Surface composition***
- ***Surface morphology***

Surface Composition Suite

Pendleton, Bennett



Surface Composition Suite

Mass (kg)	16.8
Power (W)	66
Data Volume (Mb)	790

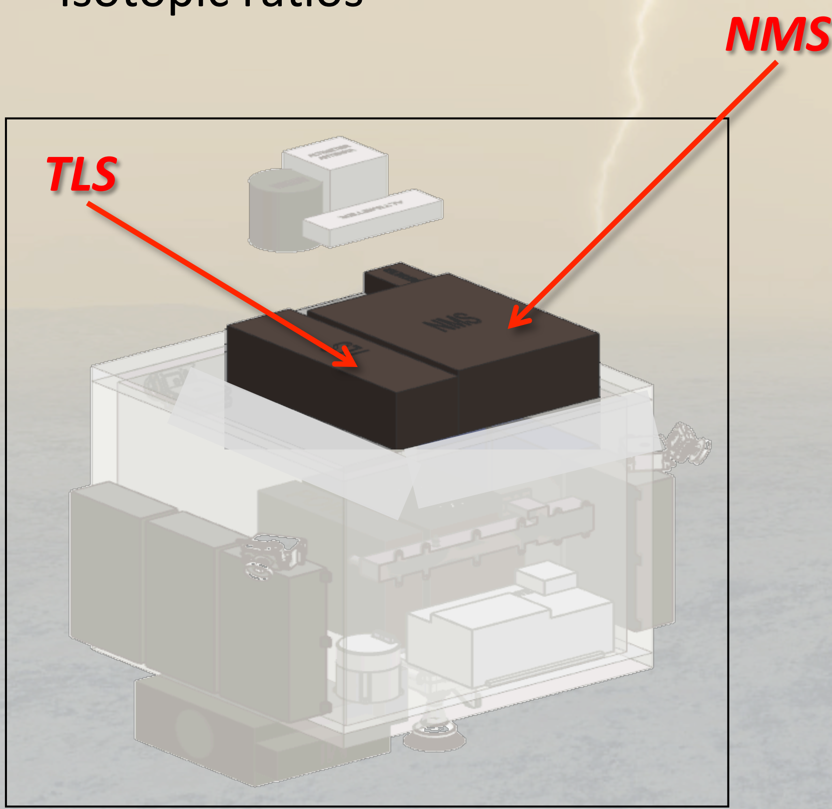
- ***Physical/chemical weathering***
- ***Physical properties***
- ***Gamma ray spectroscopy***
- ***Surface composition***

Atmospheric Composition Suite

Bell

The atmospheric composition suite (ACS) enables the measurement of:

- Abundances of sulfuric compounds and water vapor
- Aerosol composition
- Isotopic ratios



Atmospheric Composition Suite	Neutral Mass Spectrometer (NMS) and Aerosol Collector	Tunable Laser Spectrometer (TLS)
Mass (kg)	3	4.5
Power (W)	5	25
Data Volume (Mb)	0.435	0.289

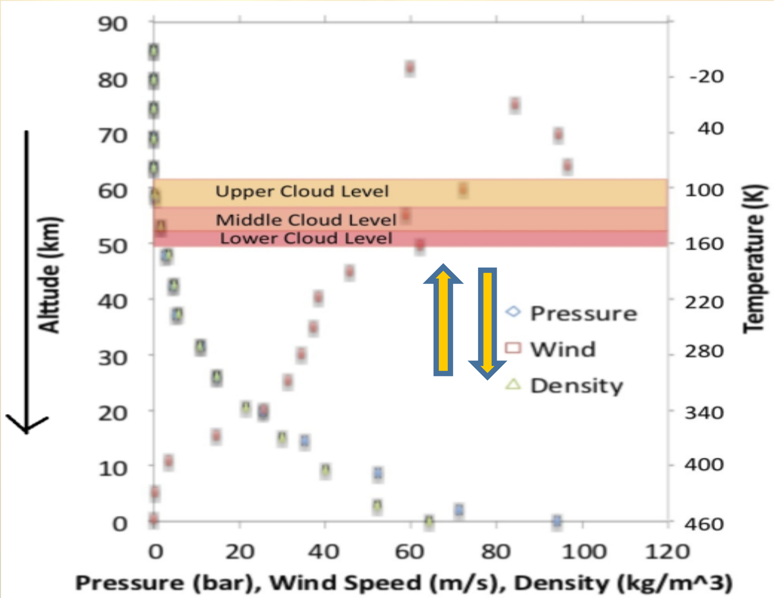
- ***Atmospheric composition***
- ***Atmospheric evolution***

Atmospheric Dynamics Suite

Broiles

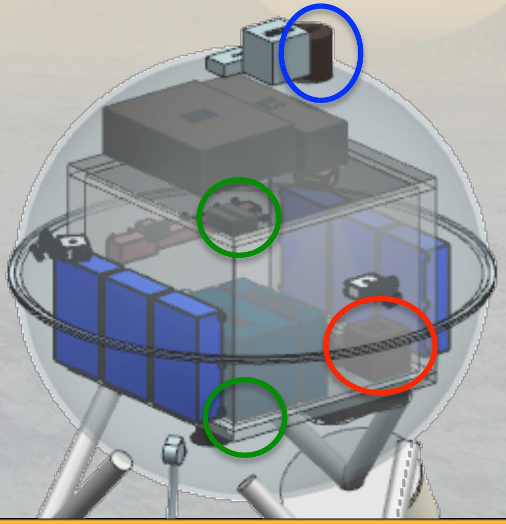
ADS is uniquely qualified to address these objectives

- Atmospheric Structure Instrument
  - Thermocouples
  - Barometer
  - Accelerometer
- Nephelometer
- Upward and downward pointing spectral radiometers
- Doppler Wind Investigation



Atmospheric Dynamics Suite

	ASI	Nephelometer	Radiometer
Mass (kg)	1	0.5	0.4
Power (W)	3	1.2	2.5
Measurement Freq.	0.3/0.03 Hz	4 bands/s	20 bands/s
Data Volume (Mb)	17.7	0.384	0.192

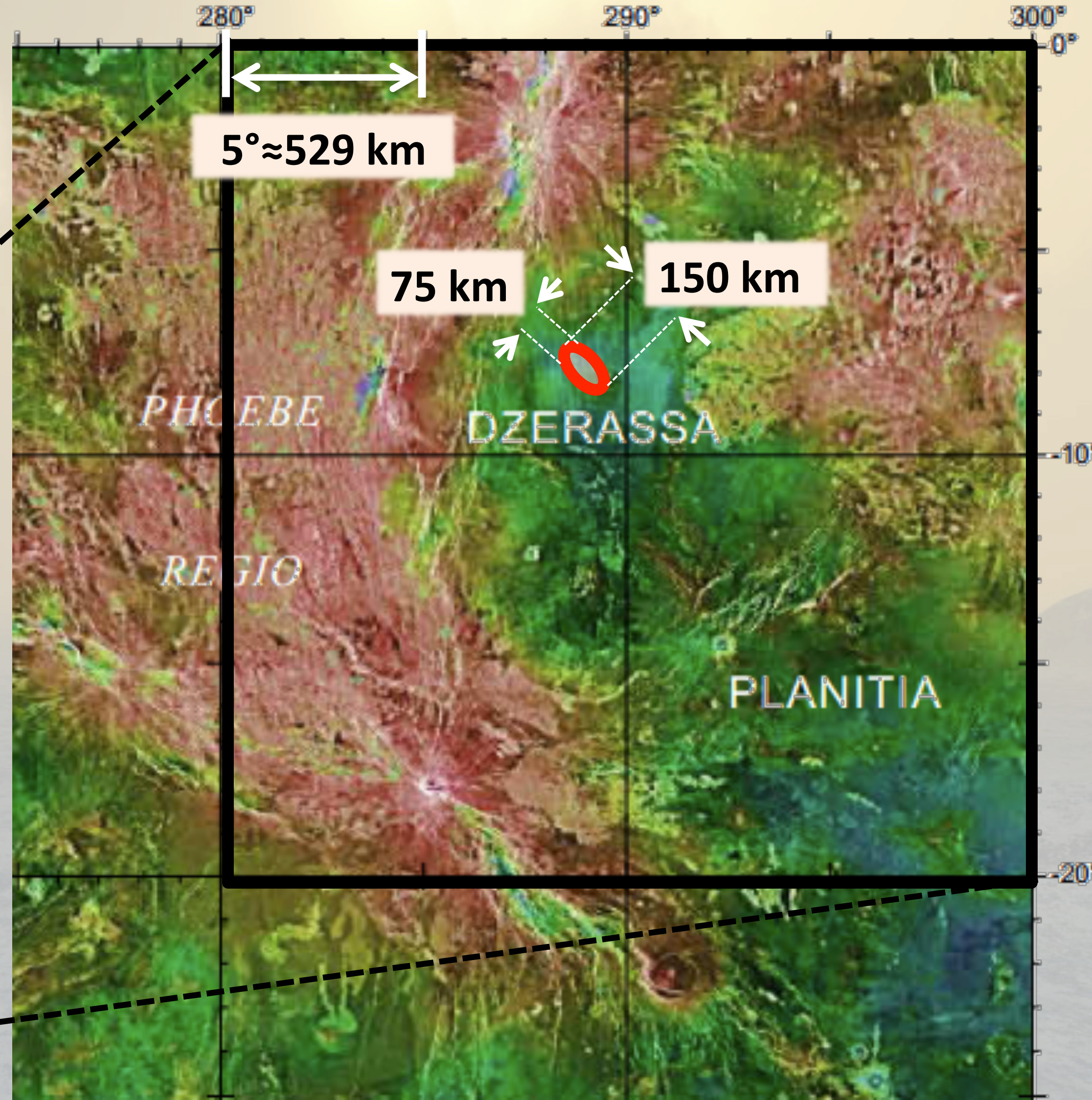


Proposed Landing Site

Bell

- The landing site is located at 8° S, 289° E, on the flanks of Phoebe Regio.
- This site offers potential to sample material that has eroded off of the highlands.

min G	280	285	290	295	300	305	310	315	320	325	330	335	340
30						55	53	51	53	56	57	59	89
25					59	53	53	53	56	58	77		
20					56	53	55	57	72	105			
15				59	54	55	69	89	113				
10			53	51	55	71	91	117					
5	54	51	50	52	71	88	114						
0	51	50	51	66	85	108							
-5	52	52	61	80									
-10	52	58	77										
-15	55	75											
-20	78												



Telecommunication

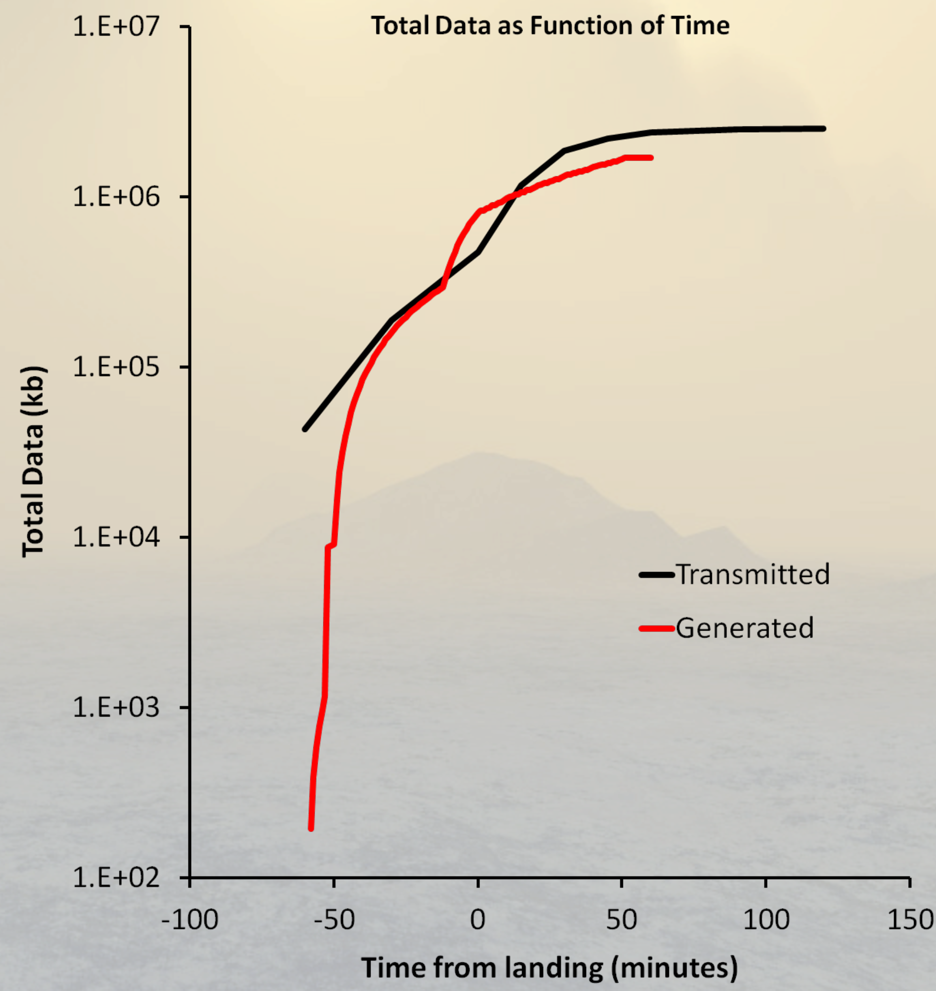
Broiles

This mission would return the largest in-situ dataset of measurements from Venus to date (~1.7 Gb).

- Calculations indicate that we would be able to transmit data at a faster rate than we are able to produce for the majority of the mission

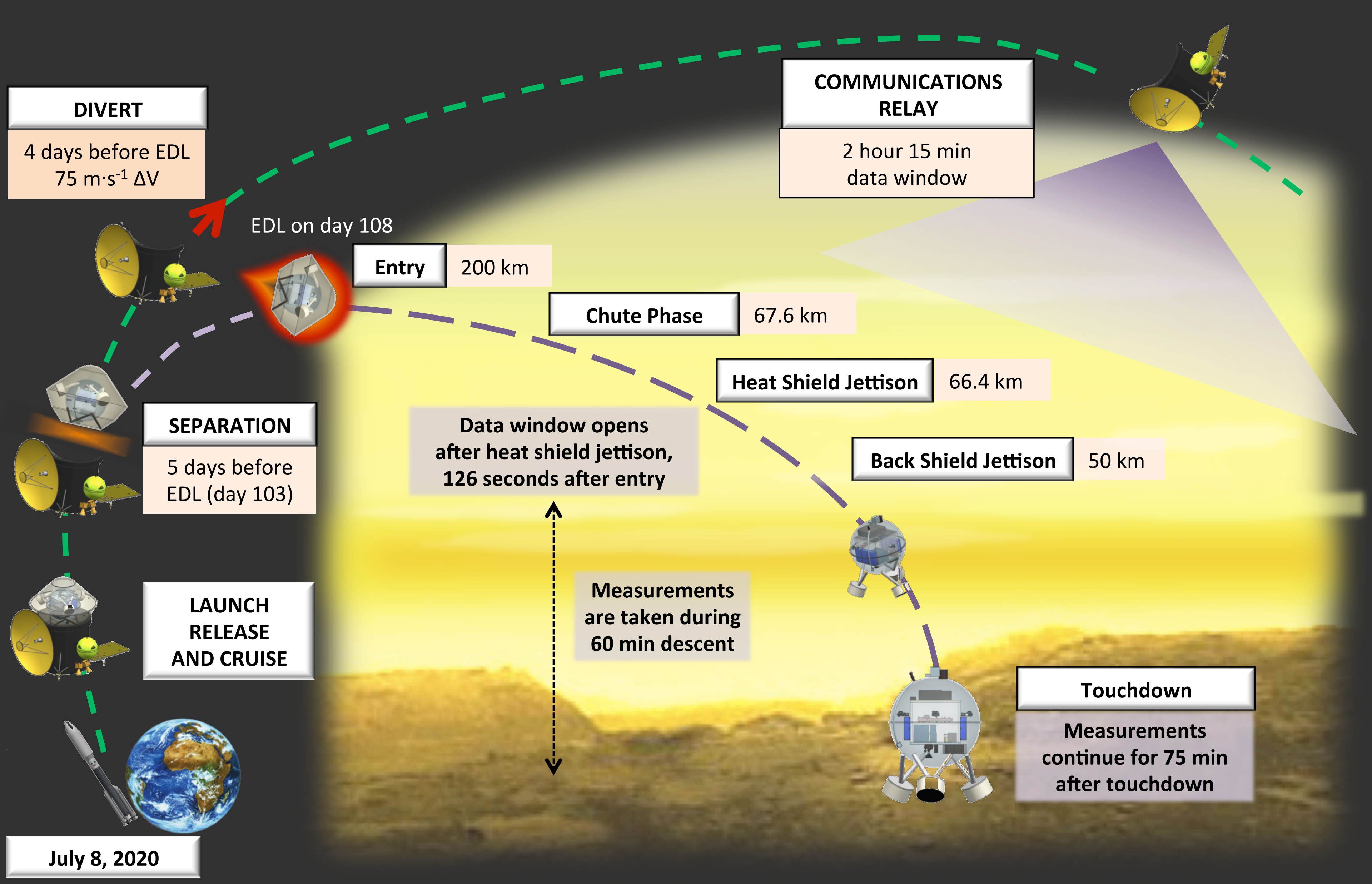
This is due to:

- 100 W Travelling Wave Tube Amplifier (TWTA)
- Relative proximity of carrier spacecraft



Mission Architecture

Bell



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Michael Pugh

Leigh Rosenburg

Evginiy Skylanskiy

Bill Smythe

Ashton Vaughs

Mark Wallace

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Planetary Science Summer School Session 2 2012:

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Jonathan Kay

Erik Larson

Danielle Nuding

Pavel Ozhogin

Matt Pendleton

Stephen Schwartz

Priyanka Sharma

Graham Vixie

VELOCIRAPTOR!

VEnus Landed Observer of Climate, InterioR Atmospheric Properties, Terrain, and ORigin!

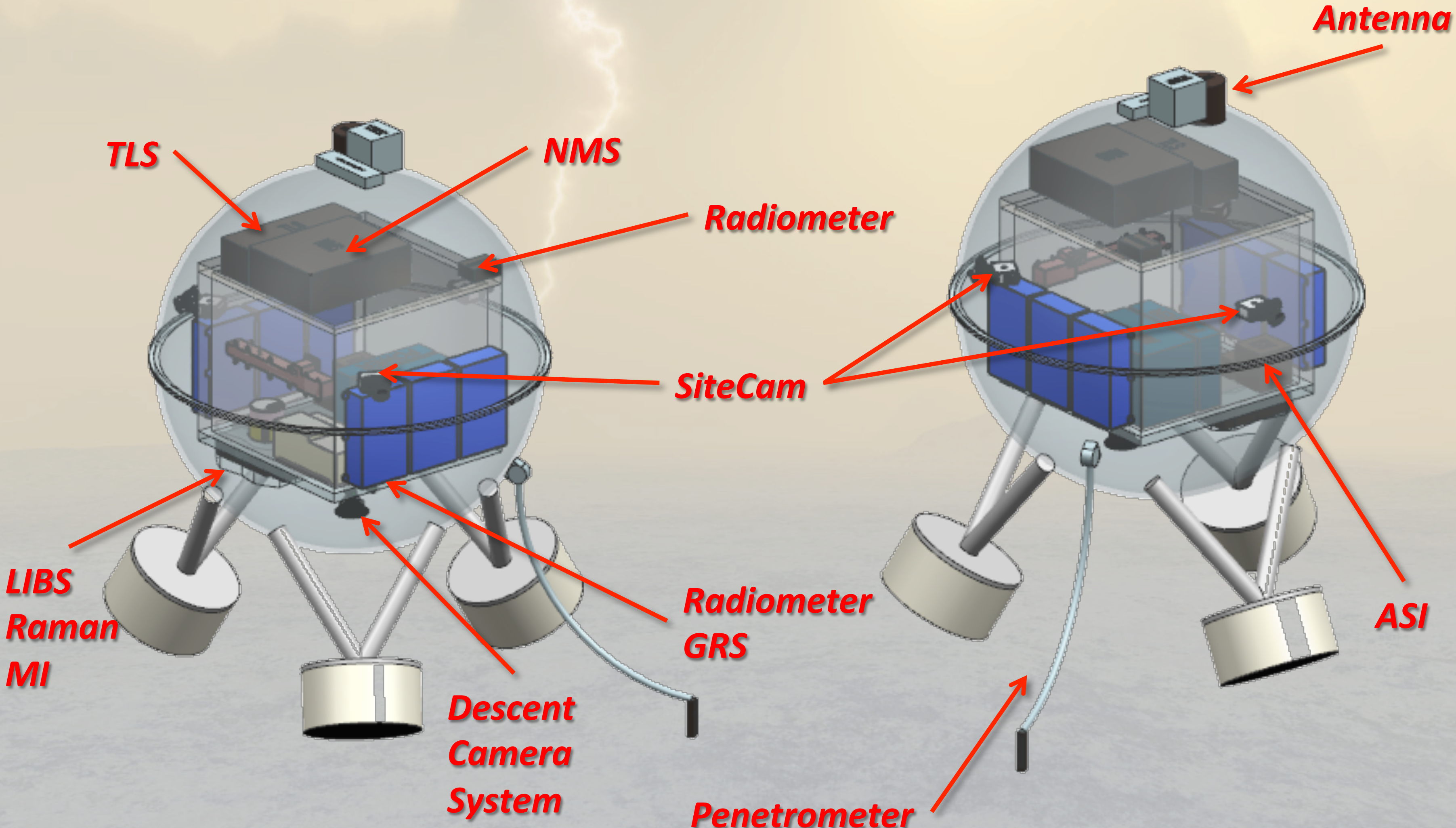
Science Objectives

Understand the:

- Composition of Atmosphere (NMS, TLS)
- Atmospheric Dynamics (ASI)
- Radiative processes (Radiometer)
- Weathering and Crustal Chemistry (Imaging Suite, LIBS/Raman, GRS)
- Hydrological Cycle (LIBS/Raman, NMS, TLS,)

Initial Instrument Placement

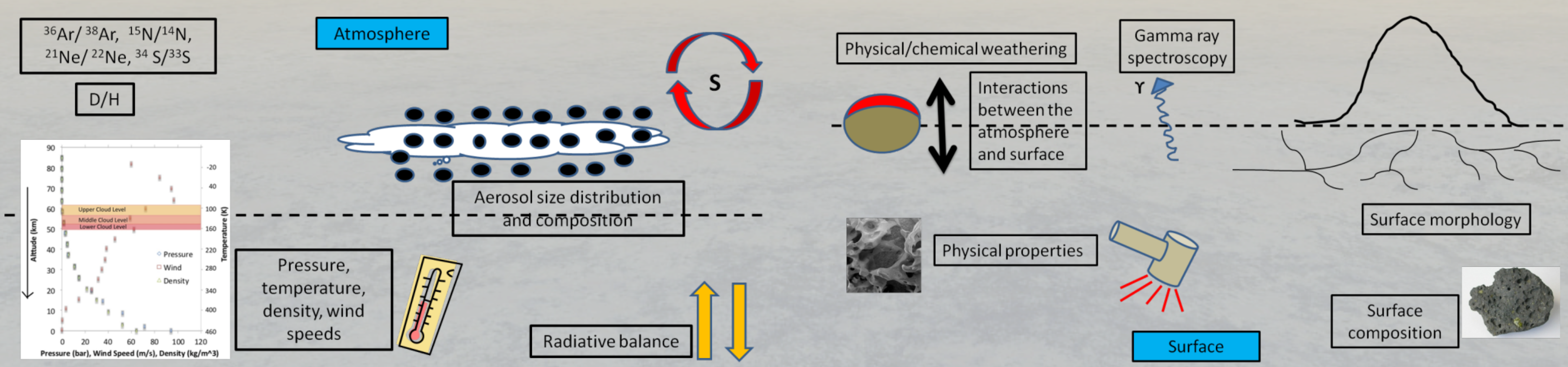
Hanley



Summary

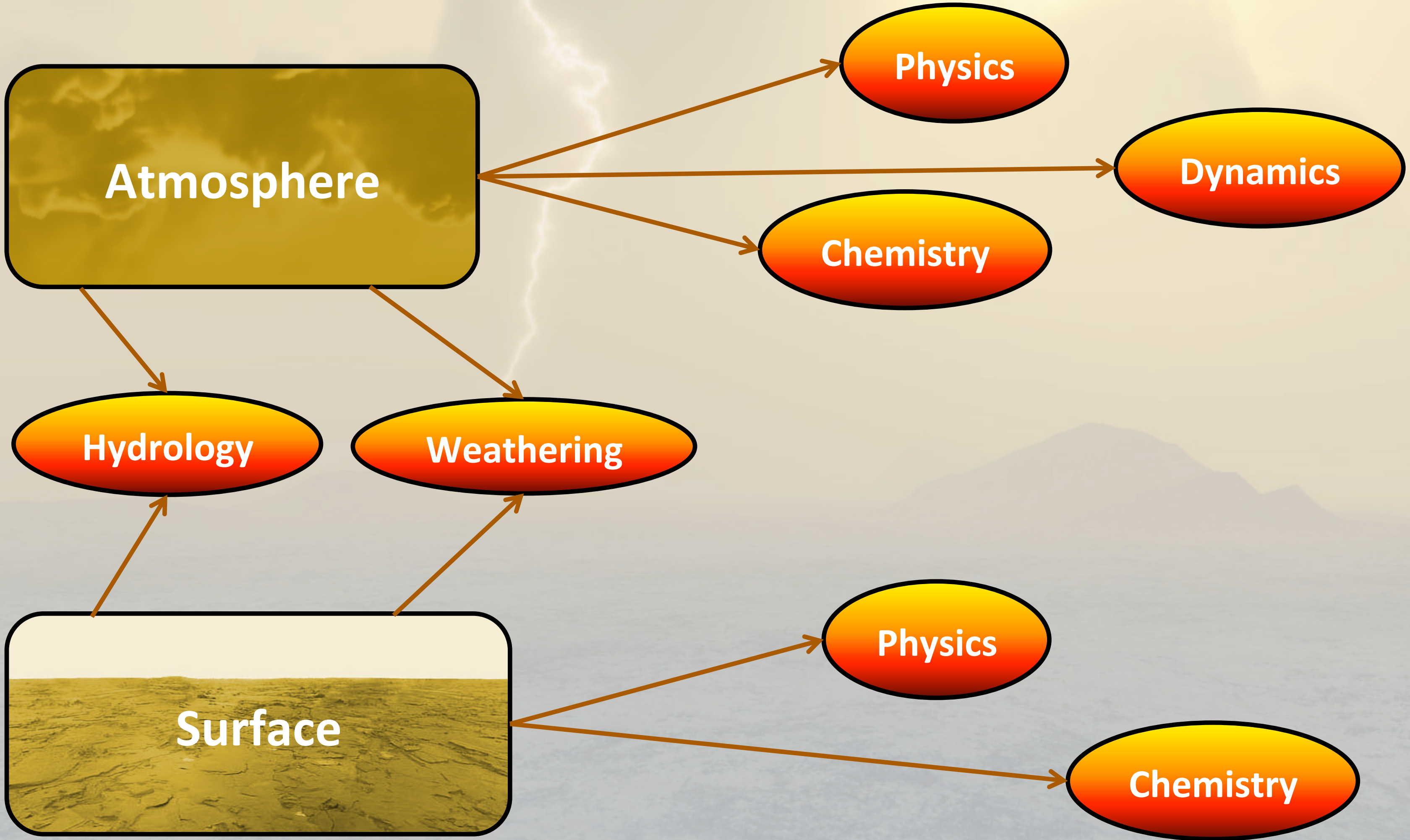
Ozhogin

- **Answer** the majority of outstanding questions of Venus' present state and its past
- **Understand** our strikingly different sister planet
- **Achieve** our science goals within the budgets
- **Produce** data with the unprecedented accuracy and resolution
- **Advance** our understanding of the atmosphere, surface, and interactions between them



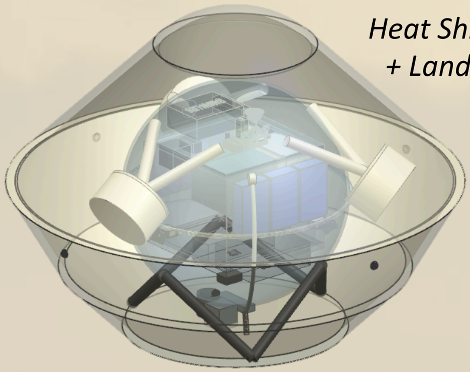
Science Objectives of the Mission

Ozhogin

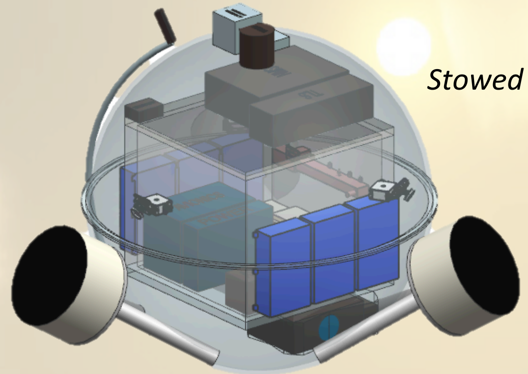


Structure

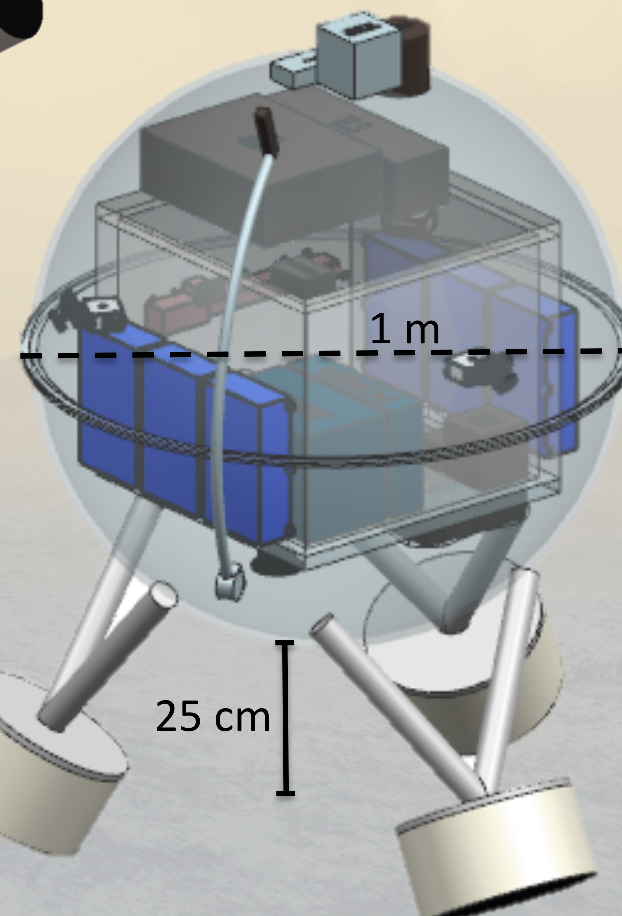
Bennett



Heat Shield + Lander



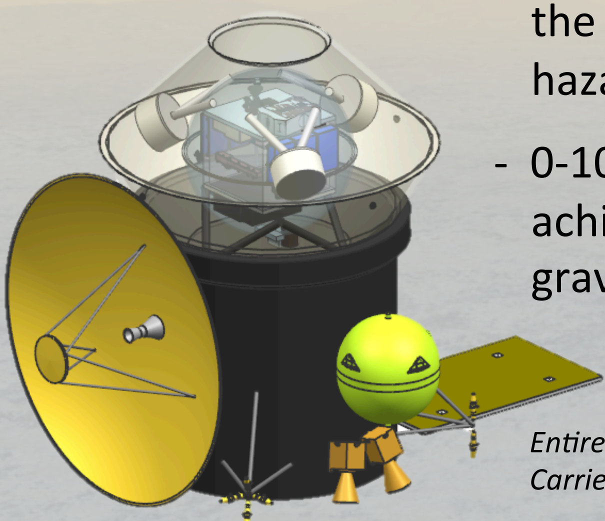
Stowed Lander



Deployed Lander

Landing System:

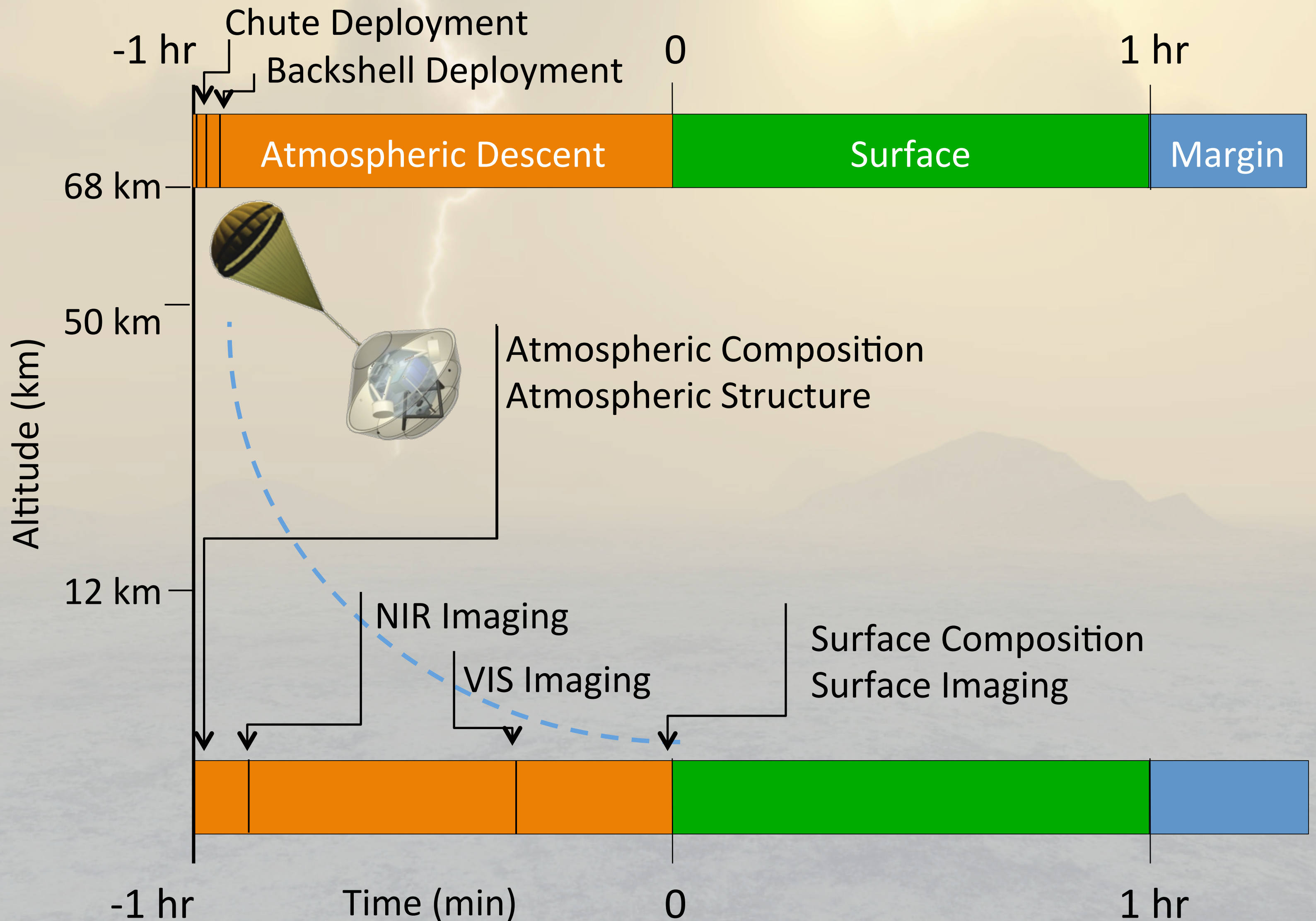
- 3 legs, pad of crushable material at the end of each leg reduces landing shock to meet the G requirement
- Bottom of the shell is 25 cm above the surface to meet 25 cm rock hazard avoidance requirement
- 0-10° slope landing requirement is achieved because the low center of gravity stabilizes the lander



Entire Spacecraft
Carrier + Heat Shield + Lander

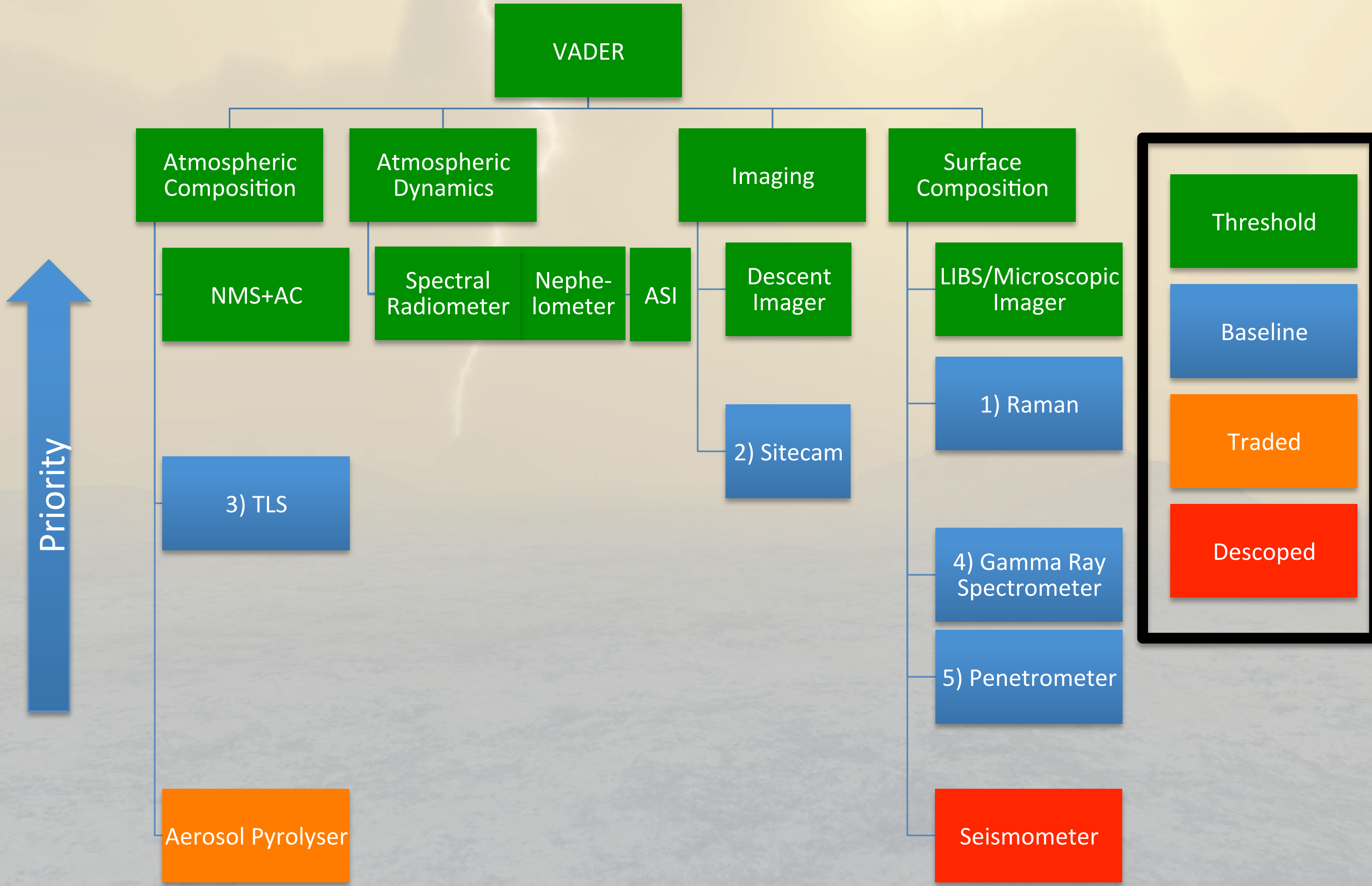
Mission Lifetime

Hanley



Traded, Descoped Instruments

Broiles



Thermal

Schwartz

Cruise Phase:

0 °C 5 days 0 °C

MLI and Two Phase-Change Materials:
H_2O and $LiNO_3 \bullet 3H_2O$.

0 °C ~1 hr 0 °C

0 °C 30 °C

Descent & surface science phase:

~15 min

10.8 kg of H_2O
37 kg of $LiNO_3 \bullet 3H_2O$

30 °C 30 °C

>1 hr

Systems Engineering Assessment

Larson

Constraint	Driving requirement	Fulfillment
Extreme temperature	Short surface duration, instruments inside shell	Cooling, remote sensing through windows
Extreme pressure	High pressure probe	Remote sensing through windows
Landing site	Constrained to narrow region due to orbital dynamics, <10° slopes and <25 cm-sized rocks	Compromise between science goals and risks
Short mission lifetime	High data volume	100 W transmitting antenna

- Landing site latitude: 8° S, 289° E (150x75 km)
- Lander dimension: 1 m diameter
- Operating temperature: 30° C
- Surface Lifetime: 1.25 hrs
- Data: 1.7 Gbit volume, 2.5 Gbit transmit capacity

Risk & Mitigation

Frank

Mission Risk:

Likelihood					
>25%					
10 - 25%				A	B
5 - 10%		E	D		
1 - 5%				C	
0 - 1%					
	<10%	10 - 24%	25 - 49%	50 - 99%	100%
	Minimal impact to mission	Small reduction in mission return	Moderate reduction in mission return	Significant reduction in mission return	Mission failure

Impact

Mitigation Plan

A. Thermal
- → Thorough modeling and testing
- → Use of water as phase-change material

B. G-load
- → Thorough modeling and testing

C. Image smearing during descent
- → Stable structure design
- → Maximizing number of pictures taken

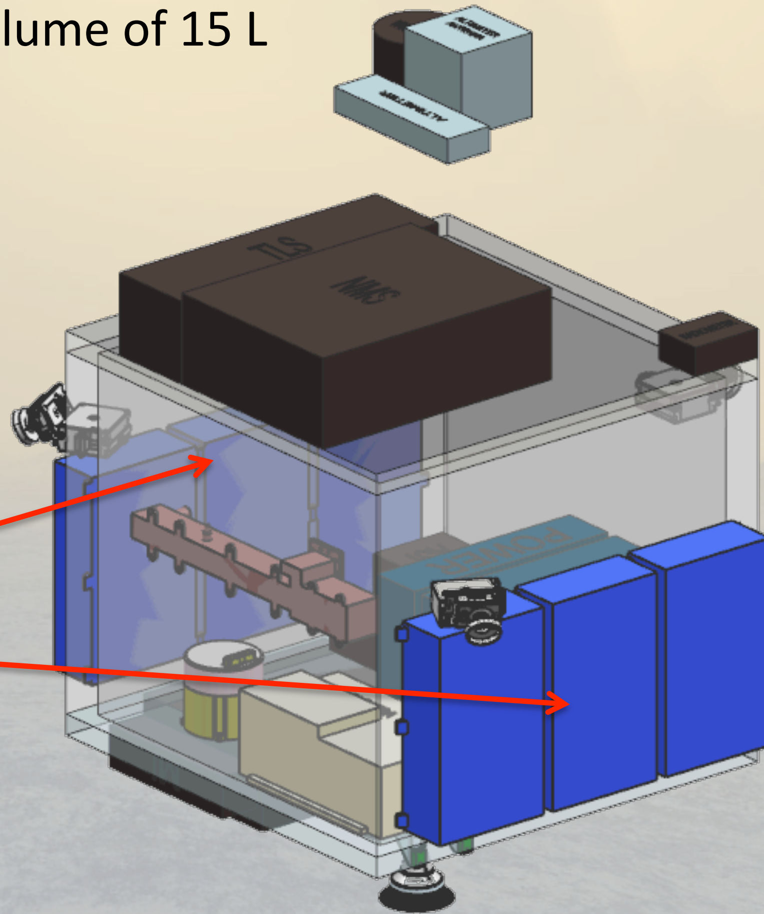
D. Landing site
- → Landing on shallow slope
- → Leg design for 25-cm clearance

E. Single-string systems
- → Short mission design

Power

Kay

- System powered by primary battery ($LiSOCl_2$)
- High temperature range (-40°C to 140°C)
- 6 (24 A-hr) batteries each with a combined volume of 15 L
- The system is capable of producing 4.1 kW with a margin of 50%
- 2,030 W for Mission Design
- Cost ~$10 Million
- System weight 35 kg with contingency



C&DH/Software

Pendleton

Command & Data Systems

Components	Type	Mass (kg)	Mass with Contingency (kg)	Power (W)
Processor	RAD750	0.55	0.58	11.1
Memory	NVMCAM	0.71	0.75	4.0
Telecom IF	MTIF	0.73	0.77	4.0
General IF	MSIA	1.42	1.49	11.6
Custom	CRC	0.66	0.77	6.0
Power	CEPCU	1.15	1.27	3.9
Back Plane	CPCI	0.60	0.78	0.0
Chassis	CDH	2.85	3.71	0.0
Analog IF	MREU	0.82	0.87	3.8

Software

Heritage Cost Drivers	Code Reuse*
Command & Data Handling	>75%
Ground Navigation & Control	25-75%
Engineering Applications	<25%
Payload Accommodation	<25%
Systems Services	25-75%

**Algorithm inheritance from MER and MSL*

- Software developed by a highly experienced team, in-house
- Our team is familiar with developing similar projects

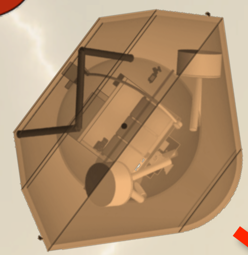
Cost Summary

Cost Goal: **$1.069B**
Proposed Mission Cost: **$1.042B**
Cost estimation: Team-X Model (JPL Institutional Cost Models).
Mission reserve of 50% as recommended by the Decadal Survey

COST SUMMARY (FY2015 $M)	Team X Estimate		
	CBE	Res.	PBE
Project Cost	$696.4 M	50%	$1042.3 M
Launch Vehicle	$0.0 M		$0.0 M
Project Cost (w/o LV)	$696.4 M	50%	$1042.3 M
Development Cost	$672.8 M	50%	$1008.0 M
Phase A	$6.7 M	50%	$10.1 M
Phase B	$60.6 M	50%	$90.7 M
Phase C/D	$605.5 M	50%	$907.2 M
Operations Cost	$23.6 M	45%	$34.3 M

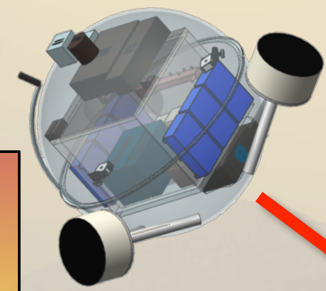
Attitude Control Subsystem

Chojnacki

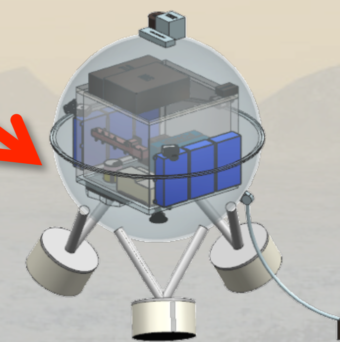


Spin-up after carrier separation (~5 rpm) providing 1-axis of orientation

Sun Sensors acquire remaining 2-axes during 5-day cruise



Inertial measurement unit (IMU) power and axes acquisition prior to atmospheric entry



IMU and altimeter provide orientation and altitude for EDL decent instruments

IMU continues to operate after landing for surface instruments

Education & Public Outreach

Frank

Message: "Why is Earth's sister planet not its twin?"

audience
- educators
- students
- kids

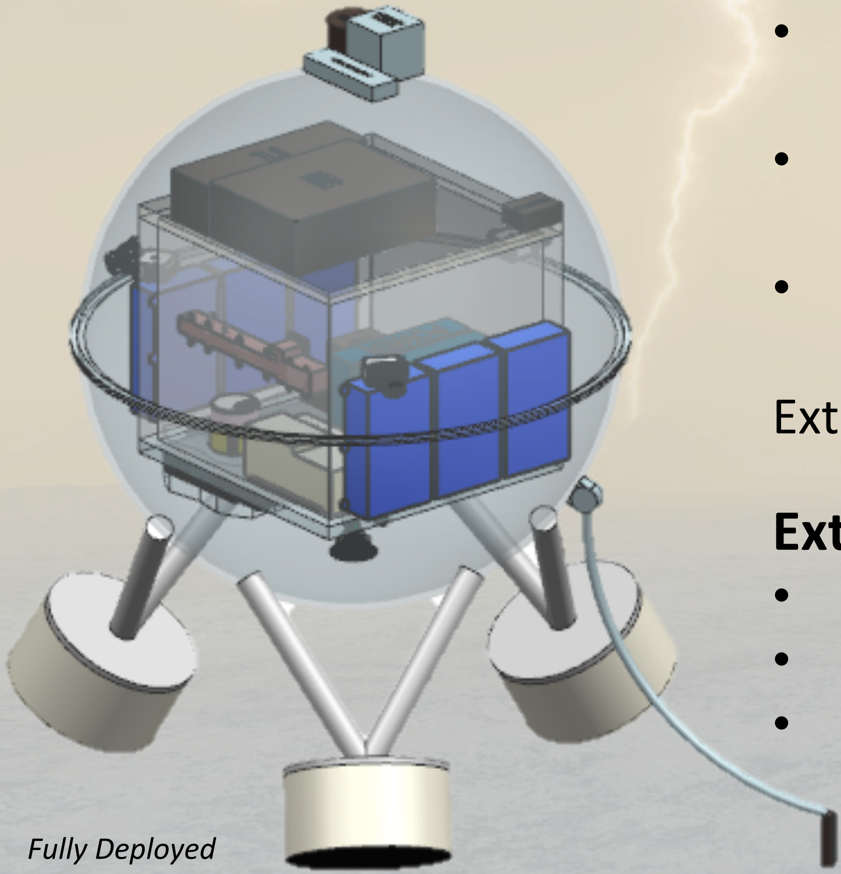
participation
- workshops, lesson plans
- science activity competitions
- activities on NASA website

"WHY GO?"

- Venus is most similar terrestrial planet to Earth, but least understood
- First mission to do areal imaging below cloud deck
- Implications for greenhouse effects and climate change

Structure

Bennett



Fully Deployed Configuration

Inside the lander

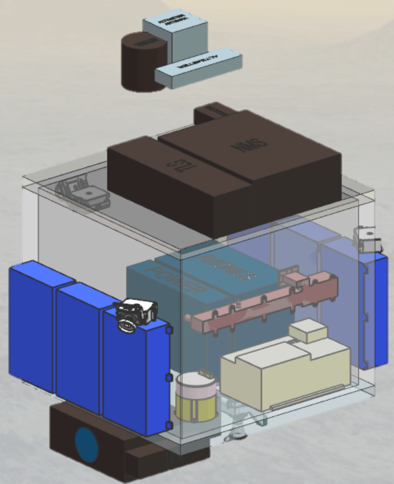
Mounting Box

- Instruments and other hardware are physically mounted
- Connected to shell by 4 struts (low heat transfer from the outside)
- Phase change material in walls

Extra phase change material fills all voids

Exterior interaction

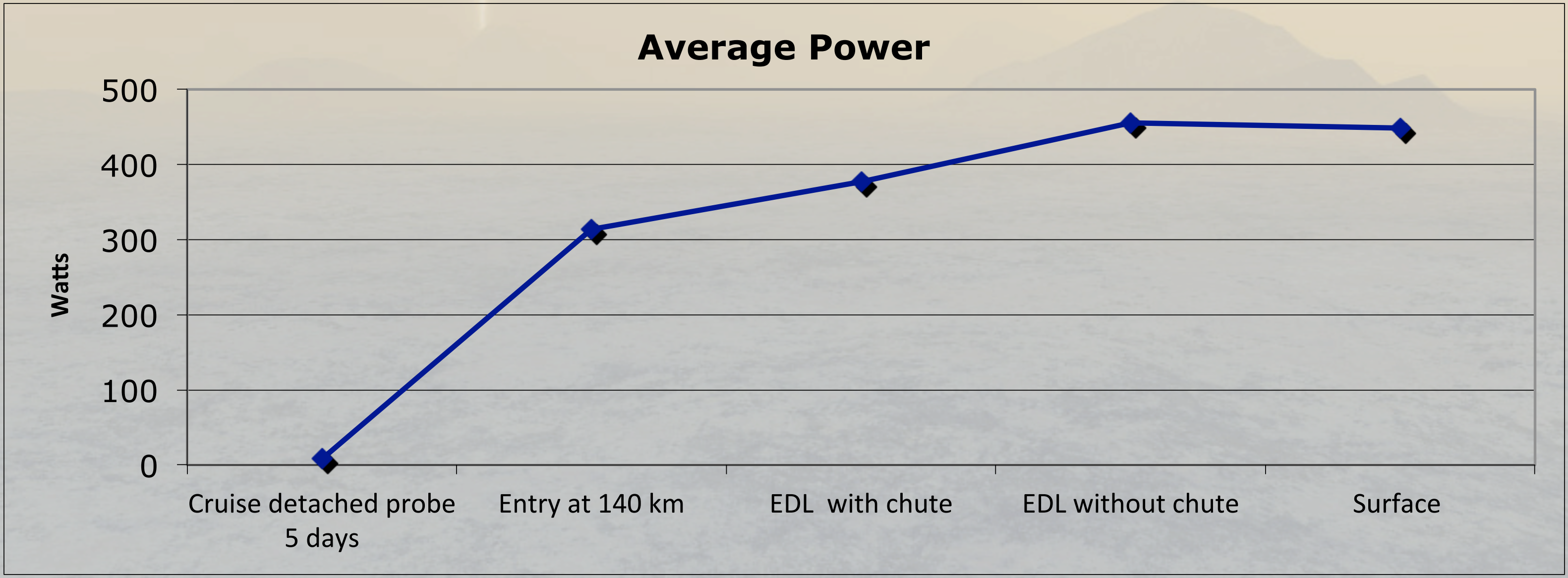
- Antenna UHF Helix
- 9 windows
- 1 inlet for NMS and TLS



Spacecraft Modes

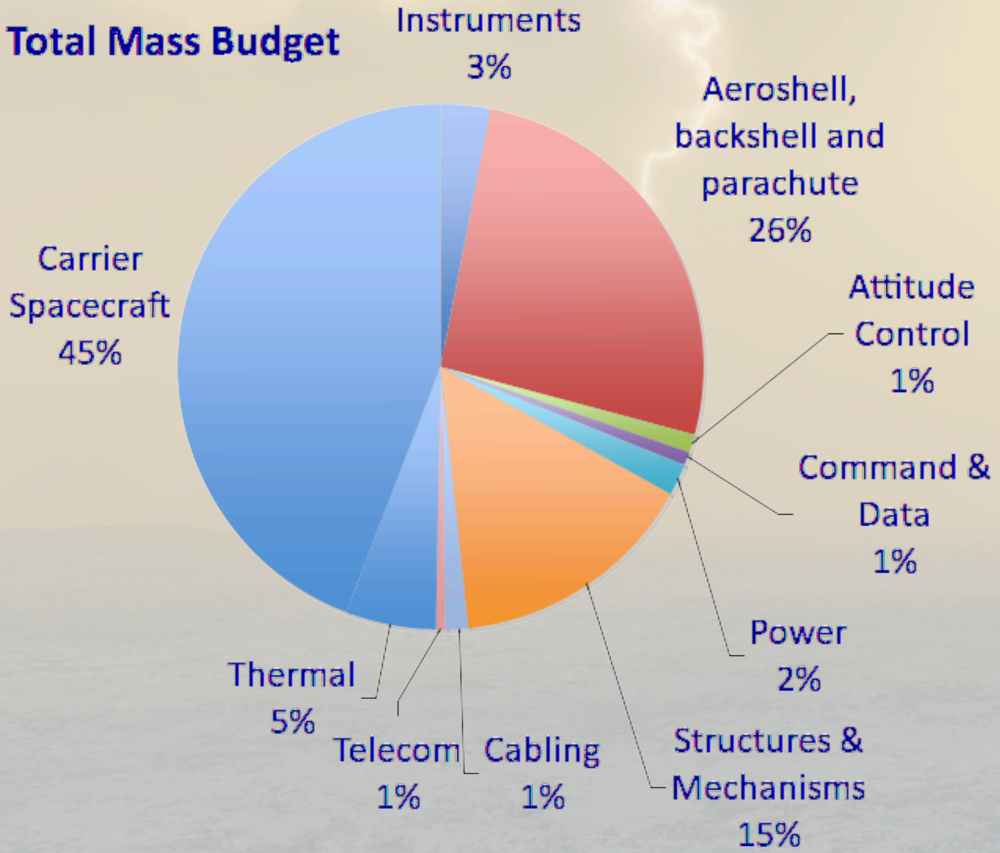
Larson

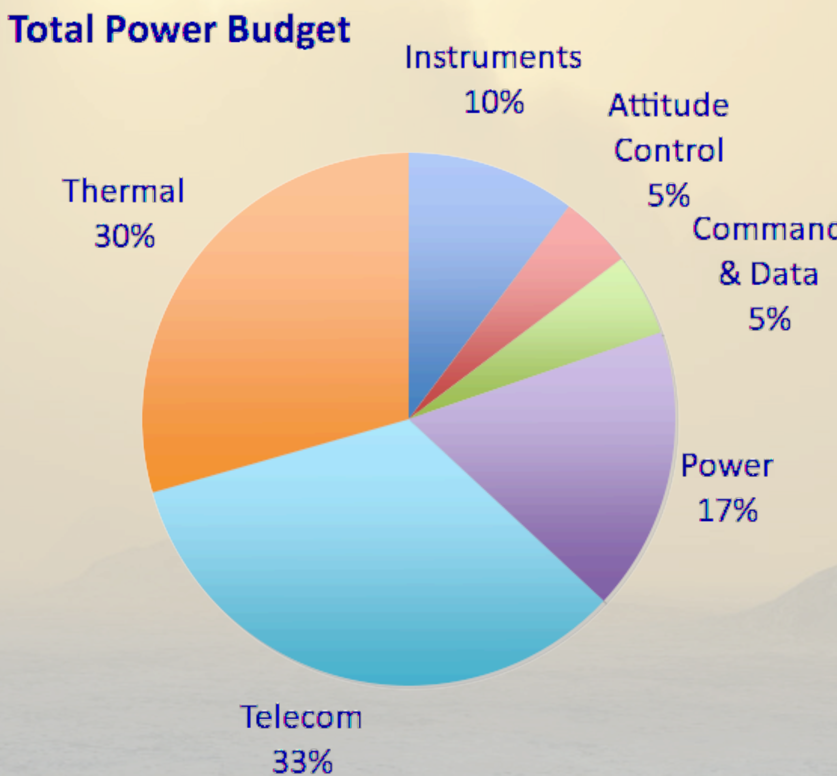
Mode 1 Power (W) Launch	Mode 2 Power (W) Checkout	Mode 3 Power (W) Cruise: detached probe	Mode 4 Power (W) Entry	Mode 5 Power (W) Entry with chute	Mode 6 Power (W) EDL after chute	Mode 7 Power (W) Surface
3 (hrs)	3	120	0.033	0.1	0.87	1.25



Attributes/Capabilities

Frank, Larson



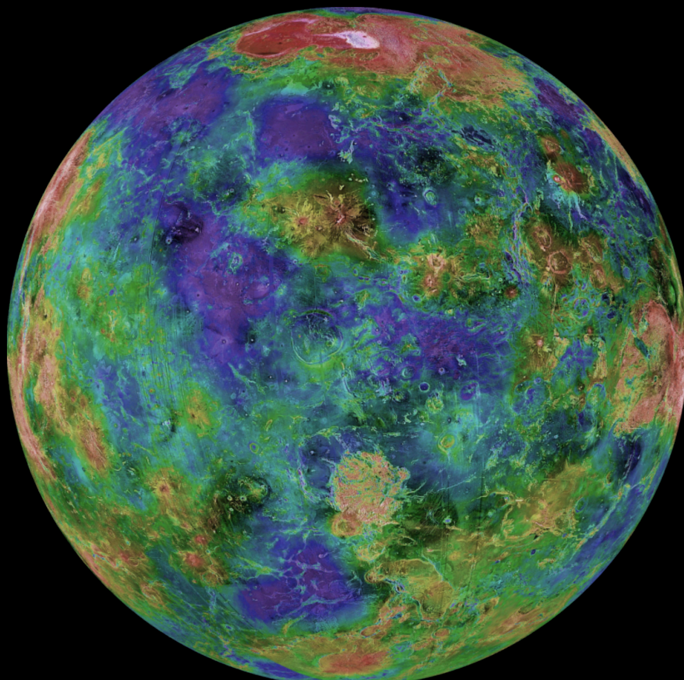


Launch capacity: 2,590 kg
Launch mass: 1,354 kg (48% margin)

Power requirements: 2 kWh
Battery power: 4.1 kWh (50% contingency)

Unlock Venus, Understand Earth

Vixie, Frank, Byrne



- ***Unprecedented Venus science***
- ***Ground-truth global Magellan data***
- ***Understanding planetary climate change***

Venus Missions

Chojnacki

Flybys/Orbiters

- Mariner series
- Venera series
- Pioneer Venus series
- Vega series
- Magellan
- Venus Express

Probes/Landers

- Venera series
- Vega series
- Pioneer Venus probes

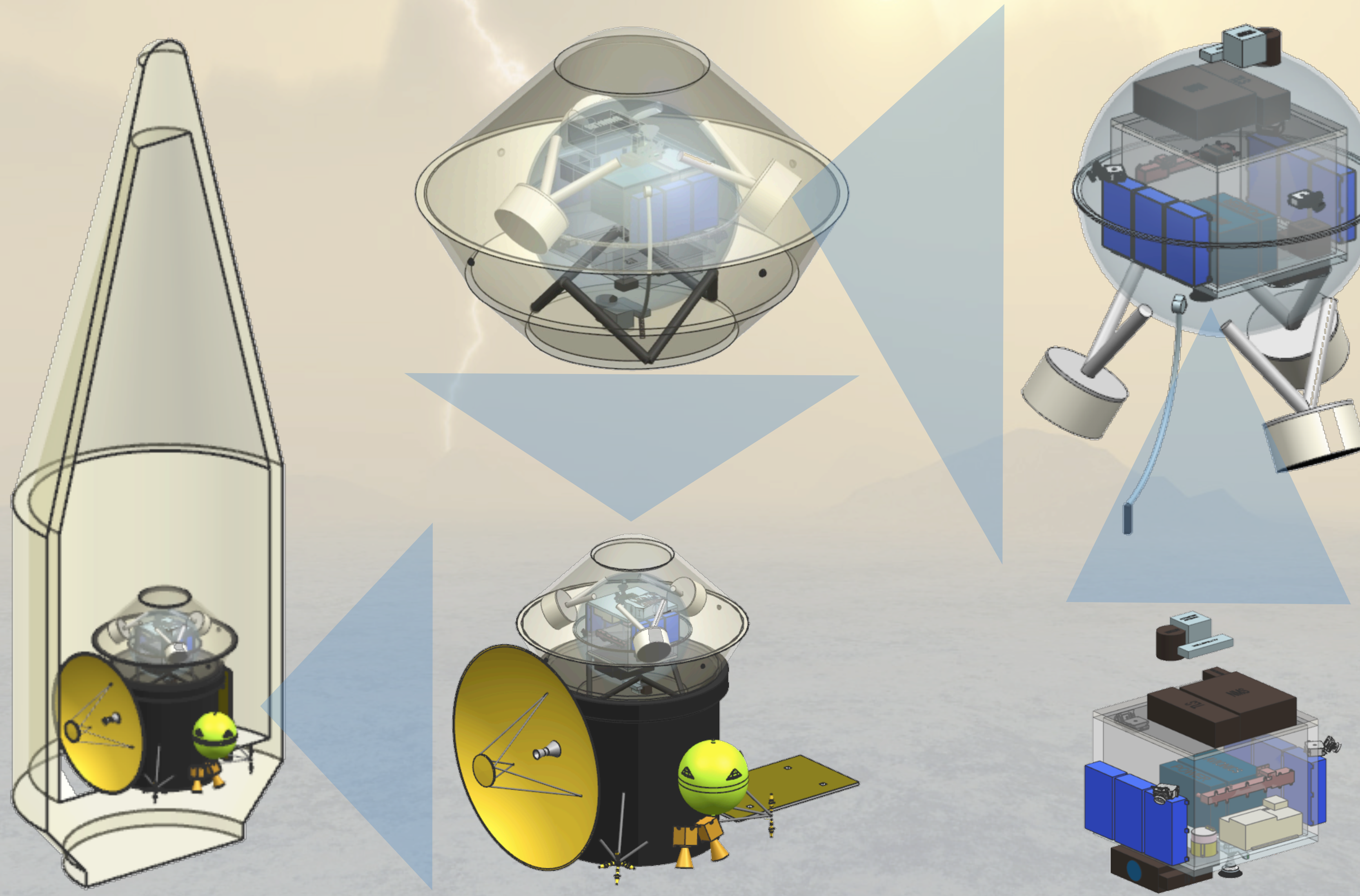
Venus Missions

Chojnacki

- Many missions have flown to Venus, but most were **20+ years ago**
    - New technology/sensors are needed to answer science goals
- VADER would address fundamental science questions about Venus

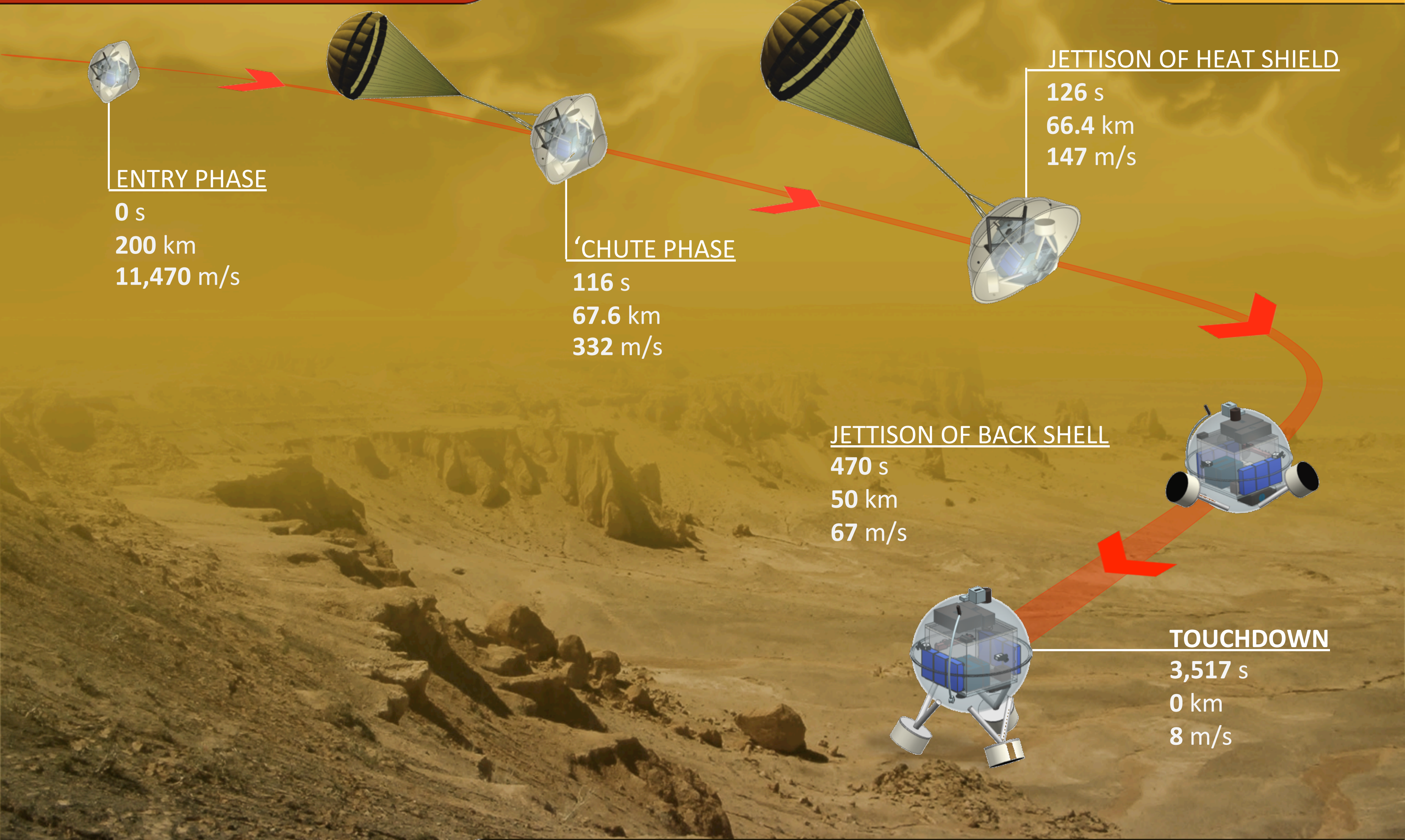
Baseline Design

Systems



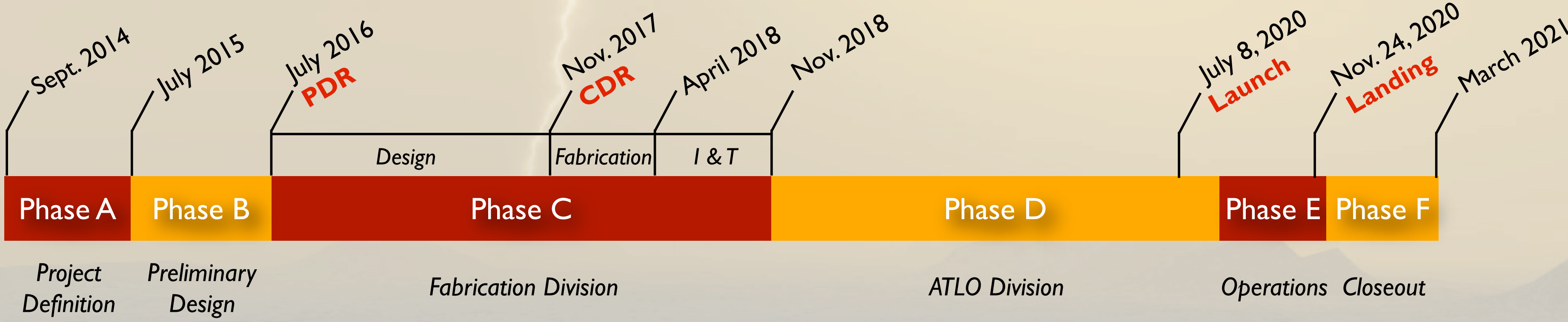
Entry, Descent, and Landing

Byrne



Schedule

Frank



PDR = Preliminary Design Review

I & T = Integration and Testing

CDR = Critical Design Review

ATLO = Assembly, Technology, Launch, and Operations

Development Cost

Vixie

	NRE	RE	1st Unit
Development Cost (Phases A - D)	**$784.8 M**	**$223.2 M**	**$1008.0 M**
01.0 Project Management	$18.4 M		$18.4 M
02.0 Project Systems Engineering	$21.5 M	$0.3 M	$21.8 M
03.0 Mission Assurance	$20.9 M	$3.9 M	$24.8 M
04.0 Science	$22.6 M		$22.6 M
07.0 Mission Operations Preparation	$22.0 M		$22.0 M
09.0 Ground Data Systems	$25.6 M		$25.6 M
10.0 ATLO	$15.5 M	$14.5 M	$30.0 M
11.0 Education and Public Outreach	$2.0 M	$0.6 M	$2.6 M
12.0 Mission and Navigation Design	$9.3 M		$9.3 M
Development Reserves	$260.8 M	$74.4 M	$335.2 M

Spacecraft Cost

Vixie

	NRE	RE	1st Unit
06.0 Flight System	**$276.5 M**	**$92.9 M**	**$369.4 M**
6.01 Flight System Management	$4.6 M		$4.6 M
6.02 Flight System Systems Engineering	$46.9 M		$46.9 M
Lander	$107.9 M	$41.2 M	$149.1 M
6.04 Power	$4.8 M	$4.9 M	$9.7 M
6.05 C&DH	$16.1 M	$12.2 M	$28.3 M
6.06 Telecom	$17.0 M	$4.7 M	$21.7 M
6.07 Structures (includes Mech. I&T)	$41.8 M	$9.5 M	$51.3 M
6.08 Thermal	$4.6 M	$4.8 M	$9.4 M
6.09 Propulsion	$0.0 M	$0.0 M	$0.0 M
6.10 ACS	$3.6 M	$2.3 M	$5.9 M
6.11 Harness	$2.6 M	$1.8 M	$4.4 M
6.12 S/C Software	$17.0 M	$0.9 M	$17.8 M
6.13 Materials and Processes	$0.5 M	$0.1 M	$0.5 M
Carrier	$64.5 M	$49.8 M	$114.3 M
6.04 Power	$5.3 M	$5.6 M	$10.9 M
6.05 C&DH	$0.8 M	$5.2 M	$6.0 M
6.06 Telecom	$18.0 M	$15.5 M	$33.5 M
6.07 Structures (includes Mech. I&T)	$19.7 M	$7.5 M	$27.2 M
6.08 Thermal	$2.1 M	$4.4 M	$6.5 M
6.09 Propulsion	$3.9 M	$5.1 M	$8.9 M
6.10 ACS	$5.3 M	$4.7 M	$10.0 M
6.11 Harness	$3.1 M	$1.4 M	$4.5 M
6.12 S/C Software	$5.3 M	$0.3 M	$5.6 M
6.13 Materials and Processes	$1.1 M	$0.0 M	$1.1 M
Entry System	$47.0 M	$0.0 M	$47.0 M
6.14 Spacecraft Testbeds	$5.6 M	$1.9 M	$7.5 M

Instruments Cost

Vixie

	NRE	RE	1st Unit
05.0 Payload System	**$89.6 M**	**$36.7 M**	**$126.3 M**
5.01 Payload Management	$12.3 M		$12.3 M
5.02 Payload Engineering	$8.1 M		$8.1 M
Lander	$69.2 M	$36.7 M	$106.0 M
NMS	$3.1 M	$2.2 M	$5.3 M
ASI	$1.9 M	$1.4 M	$3.3 M
Raman/LIBS/micro imager	$31.3 M	$22.7 M	$54.0 M
Descent imager	$2.3 M	$1.7 M	$4.0 M
Nephelometer	$0.4 M	$0.3 M	$0.7 M
Sitecam	$1.0 M	$0.7 M	$1.7 M
TLS	$7.2 M	$5.2 M	$12.4 M
Spectral Radiometer	$2.1 M	$1.5 M	$3.6 M
Gamma ray spec.	$1.0 M	$0.7 M	$1.8 M
Penetrometer	$0.3 M	$0.2 M	$0.5 M
Instrument Spares	$18.5 M	$0.0 M	$18.5 M

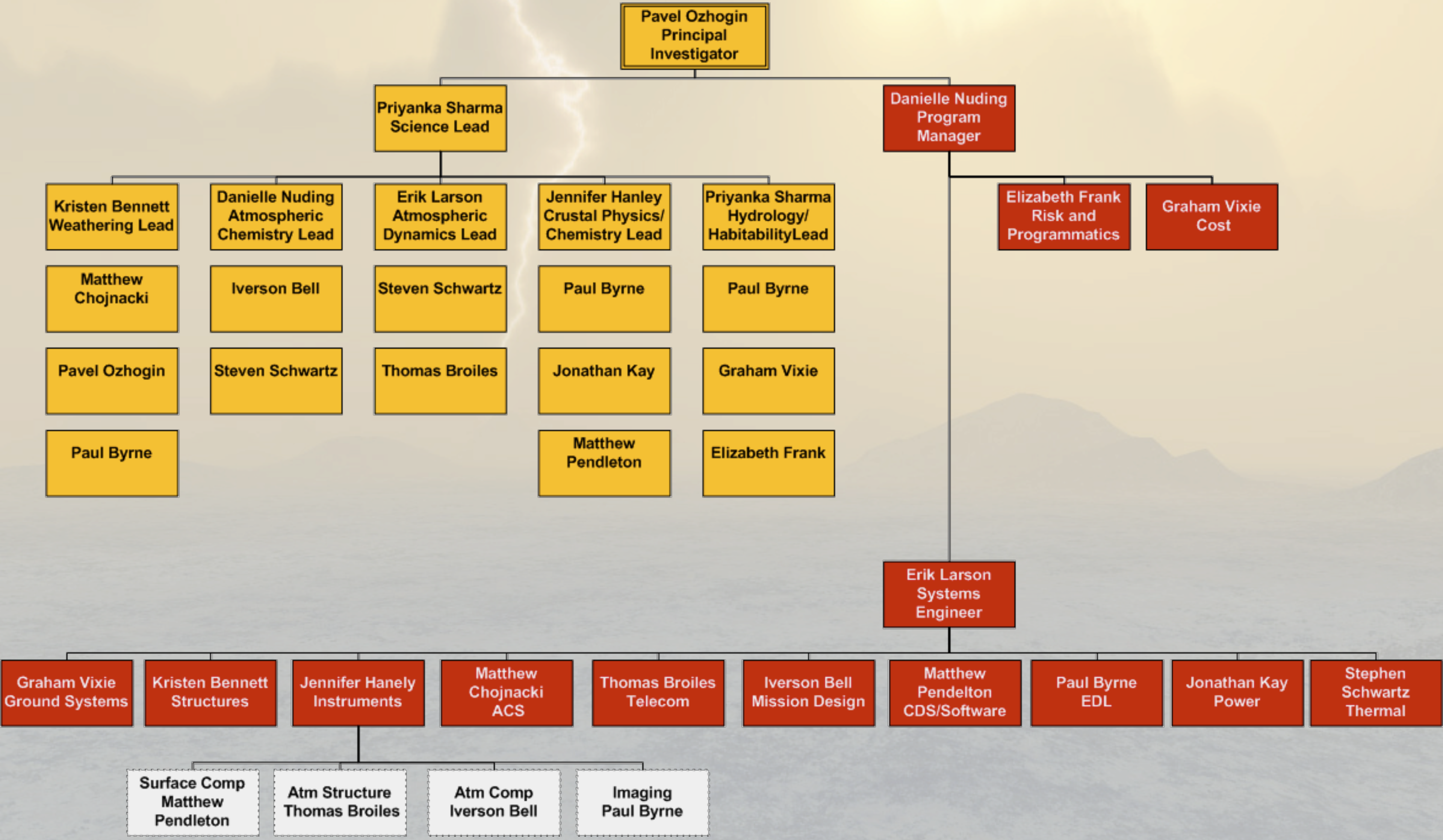
Operations Cost

Vixie

	NRE	RE	1st Unit
Operations Cost (Phases E - F)	**$31.7 M**	**$2.6 M**	**$34.3 M**
01.0 Project Management	**$0.6 M**		**$0.6 M**
02.0 Project Systems Engineering	**$0.0 M**	**$0.0 M**	**$0.0 M**
03.0 Mission Assurance	**$0.1 M**	**$0.0 M**	**$0.1 M**
04.0 Science	**$9.1 M**		**$9.1 M**
07.0 Mission Operations	**$5.4 M**		**$5.4 M**
09.0 Ground Data Systems	**$0.7 M**		**$0.7 M**
11.0 Education and Public Outreach	**$6.1 M**	**$1.7 M**	**$7.7 M**
12.0 Mission and Navigation Design	**$0.0 M**		**$0.0 M**
Operations Reserves	**$9.9 M**	**$0.9 M**	**$10.7 M**

VADER Organizational Chart

Nuding



Microscopic Imager

Bennett

- Remote visible images with spatial resolution of ~0.1 mm at a distance of ~4-5 m
- Provides geologic context for LIBS/Raman observations in the form of grain sizes/shapes and small scale texture/morphology
- Mass: ~2 kg
- Power: 12 W
- Data Volume: 654311.4 kb
  - (2:1 compression)
- Cost: included with LIBS/Raman
- Measurements before LIBS laser ablations
  - 26 total images
- Heritage: Raman/LIBS Context Imager (Venus Intrepid Tessera Lander)

Attitude Control Subsystem

Chojnacki

Attitude Determination and Control, including system pointing requirements and Capabilities:

- Minimal ACS requirements for science mission
- Altimeter (Cassini/Huygens heritage has been identified), would provide elevation context for descent measurements
- Inertial measurement unit (IMU) would provide craft's velocity (engineering), orientation (engineering), and gravitational forces (science)
- IMU orientations would be verified with thermal- and visible-wavelength descent images
- IMU continues to operate at the surface for surface instruments

Attitude Control Subsystem

Chojnacki

Attitude Determination and Control, including system pointing requirements and Capabilities:

Total Cost: $6,066K

TOTAL # IN SIMULTANEOUS DEVELOPMENT	1

All Units Cost	Total ($K)
06.10 GN&C Subsystem	**6,066**
06.10.01 GN&C Subsystem Management	-
06.10.02 GN&C Subsystem Engineering	-
06.10.02.01 Subsystem Engineering	-
06.10.02.03 Controls Design & Analysis	-
06.10.03 GN&C Sensors AND	**5,747**
06.10.04 GN&C Actuators AND	
06.10.05 GN&C I/F Electronics	
Labor	**1,248**
CTM	1,248
Procurements ($k)	**4,499**
Procurements - Altimeter ($k)	**3,545**
Enginering Models	1,013
Flight Models	1,266
Flight Spares	1,266
Procurements - Sun Sensors ($k)	**103**
Flight Models	51
Flight Spares	51
Procurements - IMUs ($k)	**529**
Flight Models	265
Flight Spares	265
Procurements - Gimbal Drive Electronics ($k)	**322**
Enginering Models	92
Flight Models	115
Flight Spares	115
06.10.06 GN&C GSE (delivered to FS Testbed)	**320**
Labor	320

Attitude Control Subsystem

Chojnacki

Chojnacki

Cost: $6,066K

(i) Spin-up after carrier separation (~5 rpm) providing 1-axis of orientation

(ii) Sun Sensors acquire remaining 2-axis during 5-day cruise

(iii) IMU power and axes acquisition prior to atmospheric entry

(iv) IMU and altimeter provide orientation and altitude for EDL decent instruments

(v) IMU continues to operate at the surface for surface instruments

Development Costs

Vixie

Development Cost (Phases A - D)	$784.8 M	$223.2 M	$1008.0 M
01.0 Project Management	**$18.4 M**		**$18.4 M**
1.01 Project Management	$7.4 M		$7.4 M
1.02 Business Management	$9.6 M		$9.6 M
1.04 Project Reviews	$1.3 M		$1.3 M
1.06 Launch Approval	$0.1 M		$0.1 M
02.0 Project Systems Engineering	**$21.5 M**	**$0.3 M**	**$21.8 M**
2.01 Project Systems Engineering	$8.4 M		$8.4 M
2.02 Project SW Systems Engineering	$4.3 M		$4.3 M
2.03 EEIS	$1.3 M		$1.3 M
2.04 Information System Management	$1.6 M		$1.6 M
2.05 Configuration Management	$1.5 M		$1.5 M
2.06 Planetary Protection	$0.0 M	$0.0 M	$0.0 M
2.07 Contamination Control	$1.1 M	$0.3 M	$1.3 M
2.09 Launch System Engineering	$1.0 M		$1.0 M
2.10 Project V&V	$2.0 M		$2.0 M
2.11 Risk Management	$0.4 M		$0.4 M
03.0 Mission Assurance	**$20.9 M**	**$3.9 M**	**$24.8 M**
04.0 Science	**$22.6 M**		**$22.6 M**
04.01, 04.02, & 04.03 Science Teams	$22.6 M		$22.6 M
07.0 Mission Operations Preparation	**$22.0 M**		**$22.0 M**
7.0 MOS Teams	$18.2 M		$18.2 M
7.03 DSN Tracking (Launch Ops.)	$2.4 M		$2.4 M
7.06 Navigation Operations Team	$1.4 M		$1.4 M
7.08 Mission Planning Team	$0.0 M		$0.0 M
09.0 Ground Data Systems	**$25.6 M**		**$25.6 M**
9.0 Ground Data System	$25.2 M		$25.2 M
9.06 Navigation H/W & S/W Development	$0.5 M		$0.5 M
10.0 ATLO	**$15.5 M**	**$14.5 M**	**$30.0 M**
Lander	$15.5 M	$7.0 M	$22.5 M
Carrier	$0.0 M	$7.4 M	$7.4 M
11.0 Education and Public Outreach	**$2.0 M**	**$0.6 M**	**$2.6 M**
12.0 Mission and Navigation Design	**$9.3 M**		**$9.3 M**
12.01 Mission Design	$1.6 M		$1.6 M
12.02 Mission Analysis	$2.9 M		$2.9 M
12.03 Mission Engineering	$1.7 M		$1.7 M
12.04 Navigation Design	$3.3 M		$3.3 M
Development Reserves	**$260.8 M**	**$74.4 M**	**$335.2 M**

Operations Costs

Vixie

Operations Cost (Phases E - F)	$31.7 M	$2.6 M	$34.3 M
01.0 Project Management	$0.6 M		$0.6 M
1.01 Project Management	$0.4 M		$0.4 M
1.02 Business Management	$0.2 M		$0.2 M
1.04 Project Reviews	$0.0 M		$0.0 M
1.06 Launch Approval	$0.0 M		$0.0 M
02.0 Project Systems Engineering	$0.0 M	$0.0 M	$0.0 M
2.06 Planetary Protection	$0.0 M	$0.0 M	$0.0 M
03.0 Mission Assurance	$0.1 M	$0.0 M	$0.1 M
04.0 Science	$9.1 M		$9.1 M
4.02 Science Team	$9.1 M		$9.1 M
07.0 Mission Operations	$5.4 M		$5.4 M
7.0 MOS Teams	$2.2 M		$2.2 M
7.03 DSN Tracking	$2.1 M		$2.1 M
7.06 Navigation Operations Team	$0.9 M		$0.9 M
7.08 Mission Planning Team	$0.1 M		$0.1 M
09.0 Ground Data Systems	$0.7 M		$0.7 M
9.0 GDS Teams	$0.7 M		$0.7 M
9.06 Navigation HW and SW Dev	$0.0 M		$0.0 M
11.0 Education and Public Outreach	$6.1 M	$1.7 M	$7.7 M
12.0 Mission and Navigation Design	$0.0 M		$0.0 M
Service Center	$0.0 M		$0.0 M
Operations Reserves	$9.9 M	$0.9 M	$10.7 M
8.0 Launch Vehicle	$0.0 M		$0.0 M
Launch Vehicle and Processing	$0.0 M		$0.0 M
Nuclear Payload Support	$0.0 M		$0.0 M

Timeline Backup - Descent

Hanley

Time (min)	-58	-57	-52	-45	-40	-35	-30	-25	-20	-15	-10	-5	0
Altitude (km)	68	66	50	45	40	35	30	25	20	15	10	5	0

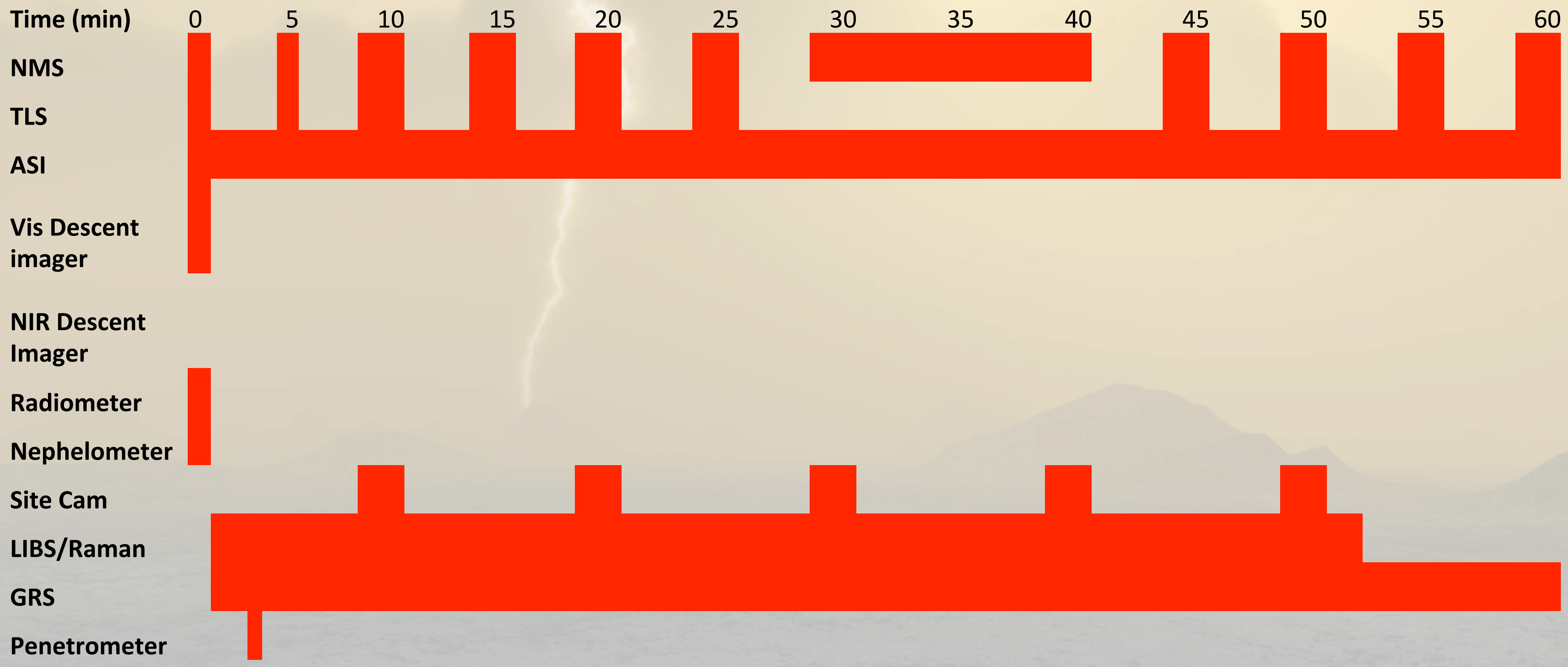
NMS
TLS
ASI

Vis Descent imager

NIR Descent Imager
Radiometer
Nephelometer
Site Cam
LIBS/ Raman
GRS
Penetrometer

Timeline Backup - Descent

Hanley



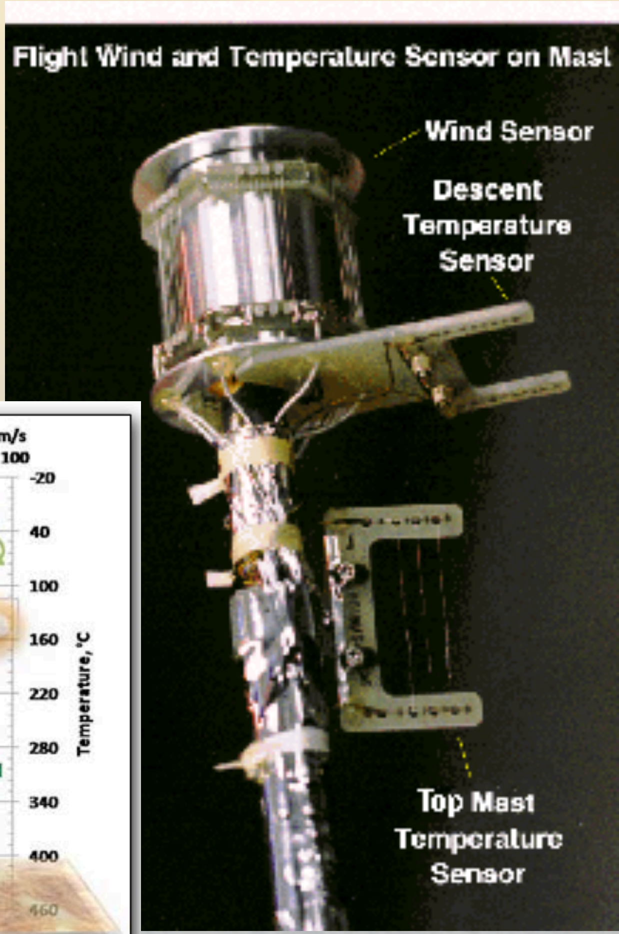
Atmospheric Structure Instrument

Ozhogin

Previously flown on Cassini-Huygens, Venera, and Venus Lander

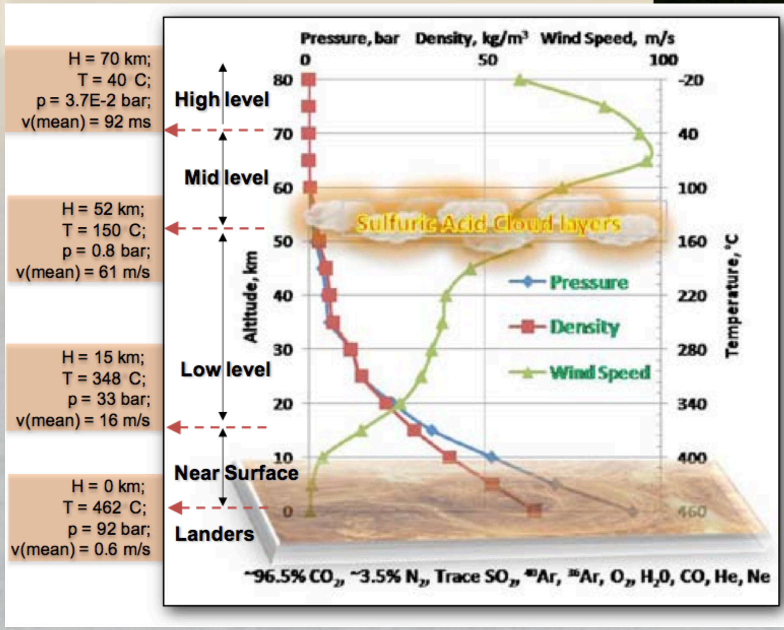
Instrument suite contains:

- Thermocouple (temperature)
- Barometer (pressure)
- Accelerometer (acceleration)



Key Instrument Parameters

- Mass: 2.1 kg
- Power: 3.2 W
- Cost: $4M
- Data rate: 2.5/0.25 kb s^{-1}
- Data volume: 17700 kb
- Volume: 6x8x12 cm



Dyson and Bruder 2010

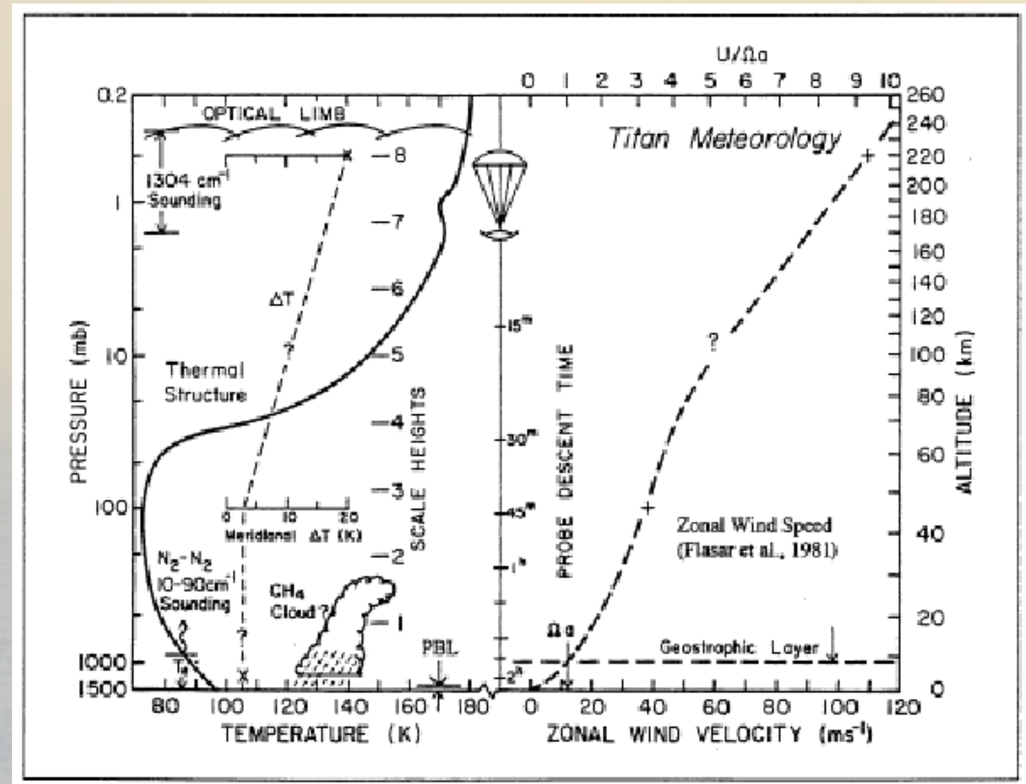
Doppler Shift Experiment

Ozhogin

Previously flown on the Cassini-Huygens probe

Key Instrument Parameters

- Mass: N/A
- Power: N/A
- Cost: $2M
- Data rate: N/A
- Data volume: N/A



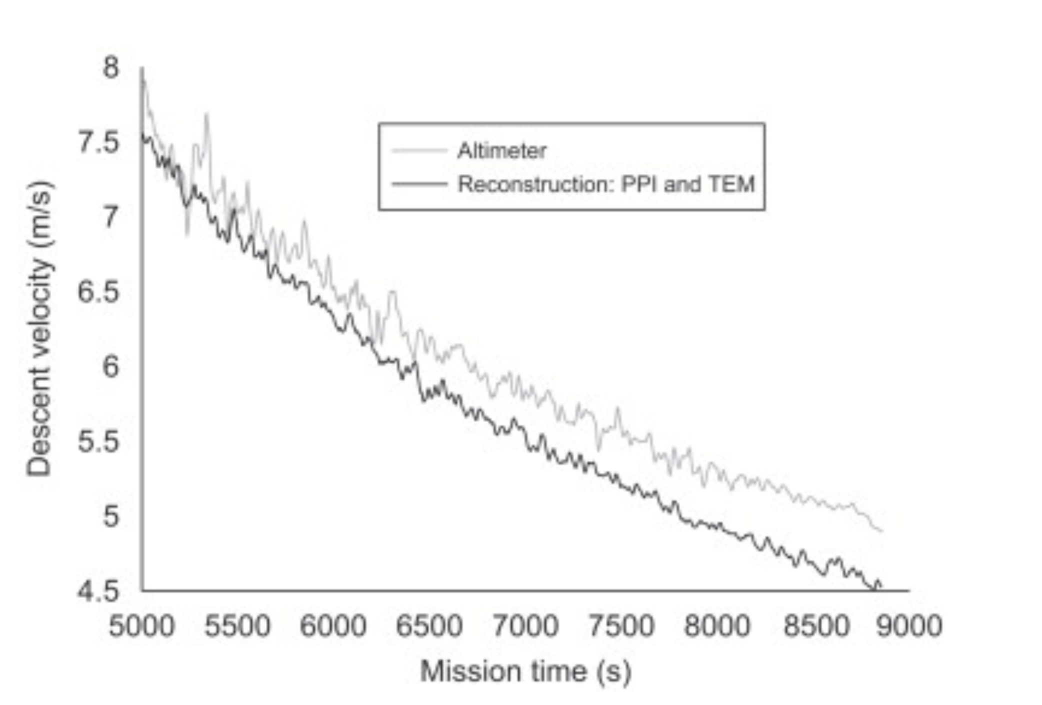
Bird et al. [1997]

Radar Altimeter

Ozhogin

Key Instrument Parameters

- Mass and Power embedded in ACS
- Mass: 10 kg
- Power: 70 W (84 W contingency)



Huygens altimeter data

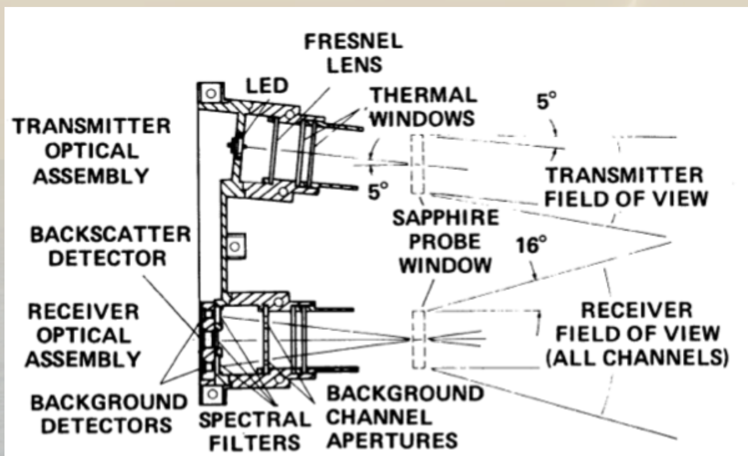
Nephelometer

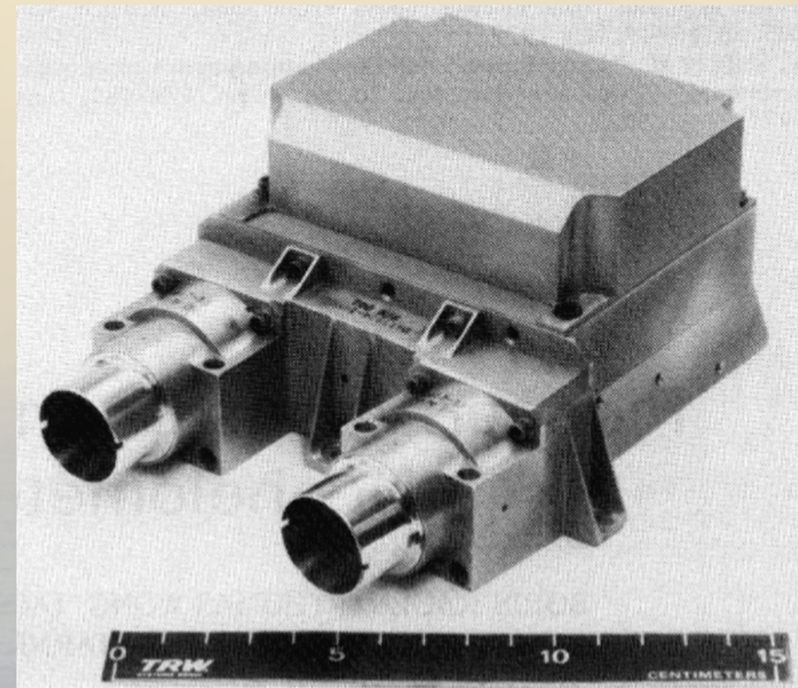
Ozhogin

Key Instrument Parameters

- Mass: 0.5 kg
- Power: 1.2 W
- Cost: $1.6 M
- Data rate: 0.16 kb/s
- Data volume: 576 kb

- Operate during descent only
- Measures aerosol backscattering at different wavelengths and backs out the size and number density of aerosols





Priority: 4-AC, 5-AP

Pioneer Venus Nephelometer

Neutral Mass Spectrometer

Ozhogin

Key Instrument Parameters

- Mass: 3 kg
- Power: 5 W
- Cost: $6 M
- Data rate: 0.15 kb/s
- Data volume: 435 kb

OVERVIEW:

- Has been employed on entry probes of Jupiter, Venus, Mars, and Titan.
- Provides a broad chemical survey of major and trace species.
- Only practical technique for measuring noble gas elemental and isotopic ratios important for understanding atmospheric evolution.
- Addresses scientific objectives from Atmospheric Chemistry, Hydrology, Weathering, and Crustal science groups.

Heritage: Rosetta
How often: 3/km, 500 sec on ground
Sampling Duration: 10 s x 150 samples + 5 samples per aerosol canister (10)

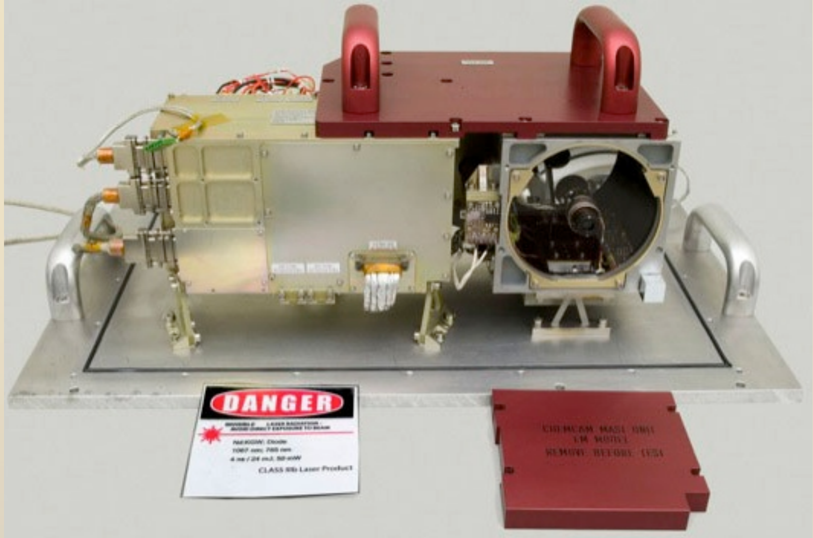
Gas Species	Mixing Ratio (PV)	NMS Accuracy	NMS Isotope Ratios	PV Value [atom/atom]	NMS Accuracy
N_2	0.035±0.8%	≤10%	$^{15}N/^{14}N$	0.00383±20	≤1%
^{4}He	0.6-12.0 ppm	≤5%	$^{3}He/^{4}He$		≤10%
^{20}Ne	9±3 ppm	≤10%	$^{22}Ne/^{20}Ne$	0.085±6%*	≤1%
			$^{21}Ne/^{20}Ne$	unmeasured	≤1%
^{36}Ar	30±15 ppm	≤10%	$^{38}Ar/^{36}Ar$	0.18±11%	≤1%
^{40}Ar	40±15 ppm	≤10%			
^{84}Kr	7-28 ppb	≤10%	$\delta^{78}Kr$, $\delta^{80}Kr$, $\delta^{82}Kr$, $\delta^{83}Kr$, $\delta^{86}Kr$	unmeasured	≤1%
^{132}Xe	0.5-2.5 ppb	≤25%	$\delta^{124}Xe$, $\delta^{126}Xe$	unmeasured	≤2%
			$\delta^{128}Xe$, $\delta^{129}Xe$, $\delta^{130}Xe$, $\delta^{131}Xe$, $\delta^{134}Xe$, $\delta^{136}Xe$	unmeasured	≤1%

Raman/LIBS/Microscopic Imager

Ozhogin

Key Instrument Parameters

- Mass: 15 kg
- Power: 62 W
- Cost: $55 M
- Data rate: 43 kb/s
- Data volume: 789511.4 kb



LIBS – Laser-Induced Breakdown Spectroscopy

- Measure surface by elemental abundances to10%
- Heritage on MSL ChemCam package
- Data Interval: 60s(Raman)/30s(LIBS)/30ms(MI): 1:2:2
- 10 SAMPLES (1 MI/1 Raman/2 LIBS) at one location. (Move FOV. 1 SAMPLE.) x6.
- Move FOV then 10 SAMPLES at one location. These measurements can be spaced out over lander life duration
- Volume: 26 cm x 21 cm x 10 cm (LIBS/Raman); 5 cm x 5 cm x 20 cm (MI - lenses only)

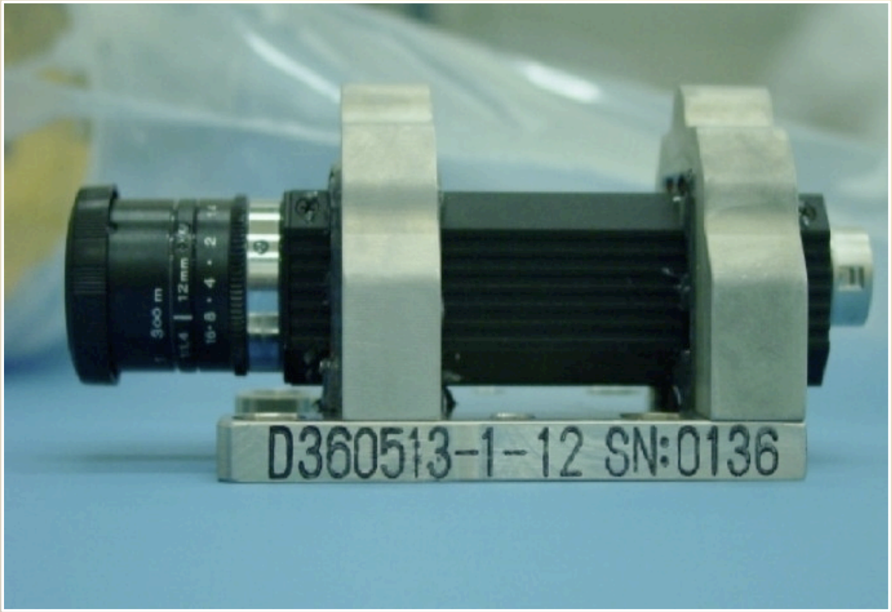
Descent Camera System

Ozhogin

Key Instrument Parameters

- Mass: 1 kg
- Power: 3 W
- Cost: $2 M
- Data rate: 1875 kb/s
- Data volume: 453750 kb

Would image surface of Venus to provide context for landing site, information about cloud structure, to assess spatial variations in color and inferred surface compositions, evaluate the morphology of the landing site at a variety of scales, and to evaluate morphological evidence for past hydrological cycles. Would provide the absorption and backscattering properties of the atmosphere at different wavelengths.



- Sampling starting at 12 km every 100 m down to 50 m
- MARDI 3 bands (0.55, 0.7, 0.8)
- Heritage: MSL MARDI (vis), LCROSS (IR), Galileo (rad.)
- Volume: 6x8x12 cm

SiteCam

Ozhogin

Key Instrument Parameters

- Mass: 0.735 kg (three at 0.245 kg each)
- Power: 6.45 W (three at 2.15 W)
- Cost: $2.5 M
- Data rate: 55 kb/s
- Data volume: 92160 kb

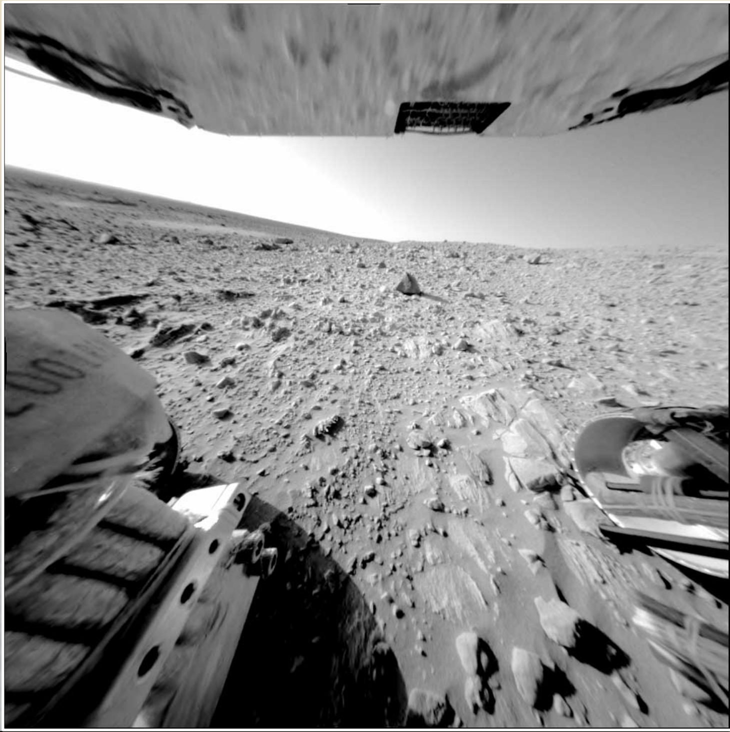
Three HazCam cameras mounted on the perimeter of the vehicle to image the immediate area surrounding the lander, providing information on the geology, morphology, and physical characteristics of the landing site.

Sampling Interval: Ground (T+10, every 10 min)

Volume: (6.7x6.9x3.4 cm)x3 electronics
(4.1x5.1x1.5 cm)x3 detector head

Heritage: MER Hazcam, 2 panoramas
3 bands (0.55, 0.7, 0.8)

Field of View: 124 x 124 degrees



Tunable Laser Spectrometer

Ozhogin

Key Instrument Parameters

Volume: 37 x 11 x 10 cm

- Mass: 4.5 kg
- Power: 25 W
- Cost: $10 M
- Data rate: 120 kb/s
- Data volume: 289 kb

The Tunable Laser Spectrometer (TLS) enables highly sensitive spectroscopy measurements utilizing small laser emitting and sensor diodes. Heritage example are S.A.M (MSL) & SAGE.

The TLS can *enhance* NMS accuracy of Sulfur (SO_2, OCS/COS, H_2S) inventory; Isotopic ratios of allotropic Sulfur, ^{34}S, ^{33}S

Sampling Interval: first 9 min: 6 samples/min ; after 9 min, starting at 50 km,3 samples/km during descent, 18 on ground (3 samples every 5 min for 30 min)

Isotope Ratio	Gas Species	Previous Measurements		Accuracy NMS [+TLS]
		Ratio	Method	
D/H	H_2O	0.016±0.002	PVLP-MS	5-10% [<1%]
		0.019±0.006	V11-12/MS	
$^{12}C/^{13}C$	CO_2	88.3±1.6	V11-12/MS	1-2% [<1%]
		86±12	IR Spec CO_2	
$^{16}O/^{18}O$	CO_2	500±25	PVLP-MS	1-2% [<0.1%]
		500±80	IR Spec CO_2	
$^{14}N/^{15}N$	N_2	273±56	PVLP-MS	1-2%
$^{35}Cl/^{37}Cl$	Cl_2	2.9±0.3	IR Spec HCl	TBD
$^{32}S/^{34}S$	SO_2, OCS, S_n	None (expect ~0.0443)		<2% [<0.2%]

Gas Species	Previous Measurements			Accuracy NMS [+TLS]
	Concentration	Altitude	Method	
H_2O	30±15 ppm	0-45 km	PV, VenSP, GalR, EBIR	<25% [<5%]
	30-70 ppm	0-5 km		
SO_2	150±30 ppm	22-42 km	PV, VenGC, VegUV, EBIR	<10%
	25-150 ppm	12-22 km		
OCS	4.4±1 ppm	33 km	EBIR	<25% [<2%]
H_2S	±2 ppm (?)	< 20 km	PV	<25%

Courtesy Tarsitano and Webster (2006)

Penetrometer

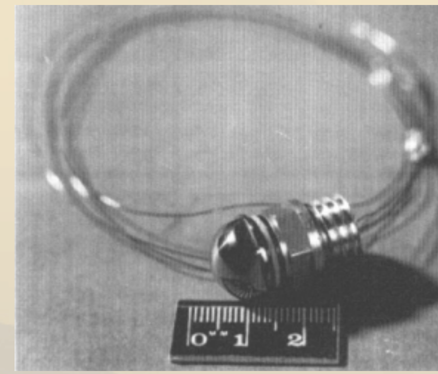
Ozhogin

Key Instrument Parameters

- Mass: 0.2 kg
- Power: 1 W
- Cost: $2.5 M
- Data rate: 1 kb/s
- Data volume: 8 kb

Sampling Time : T=0 (Landing); 10kHz sampling rate – 1 mm depth resolution
Heritage: piezoelectric ACC-E (Huygens probe), Venera 13-14
Volume: 2x2x10 cm

Resolve the physical and mechanical properties of the Venusian soil: determine the bearing strength of the soil material as a function of depth



Gamma Ray Spectroscopy

Ozhogin

Key Instrument Parameters

- Mass: 1.6 kg
- Power:3 W
- Cost: $2.5 M
- Data rate: NA
- Data volume: 289 kb

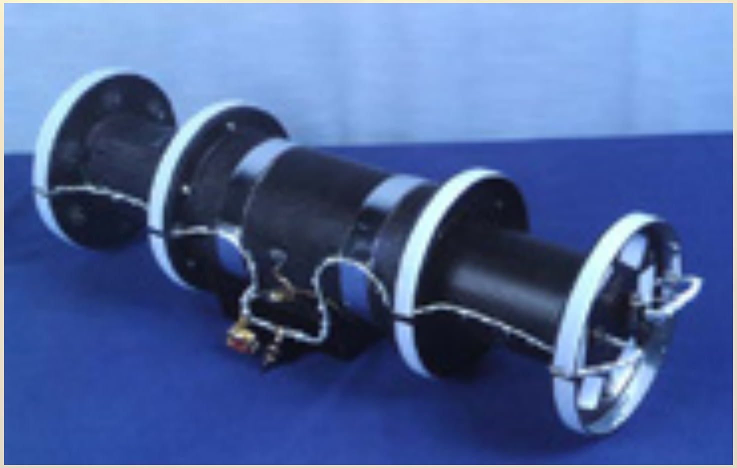


Image Credit: www.msl-chemcam.com

Volume: 4x4x5 cm

Heritage: Venera

- In-situ measurement
- Measurement taken on surface after landing
- Measures heavy elements (K, U, Th)
- Neutron activated measures additional elements, but no heritage exists

Spectral Radiometer

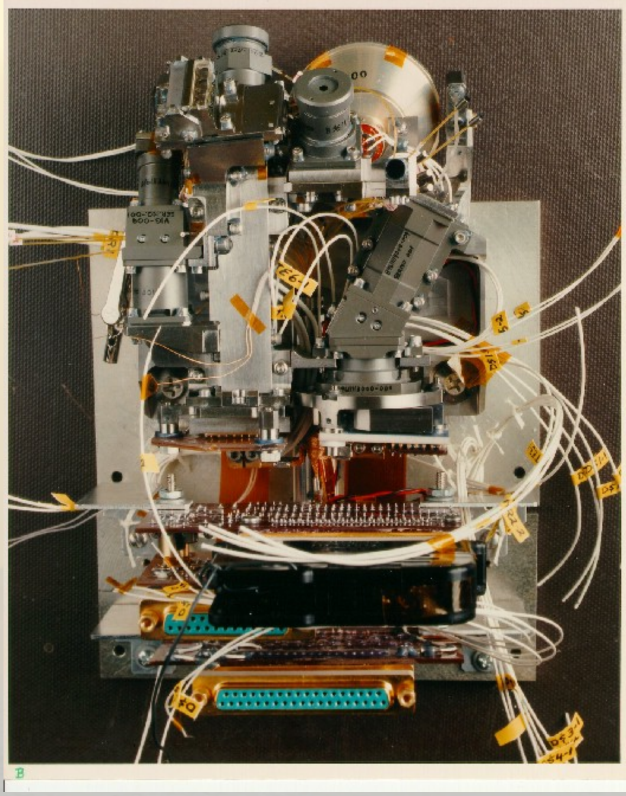
Ozhogin

Key Instrument Parameters

- Mass: 0.4 kg
- Power: 2.5 W
- Cost: $2.0 M
- Data rate: 0.16 kb/s
- Data volume: 576 kb

Volume: 2x (9x6.5x3.5) cm

Heritage: Similar to DISR, that flew on Cassini-Hyugens



- Sampling interval: every 1s during descent