CL03-2520
FINAL

# Surface & Atmosphere Geochemical Explorer (SAGE)

Final Version

## Baseline Design
## from March 2003 Team X Studies

Presented by Ross M. Jones
NASA Jet Propulsion Laboratory
California Institute of Technology
ross.m.jones@jpl.nasa.gov
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# Agenda

- Overview of Baseline Design
  - Science objectives
  - Landing site requirements
  - Mission design
  - Strawman payload
  - In-situ science phase scenario
  - Lander design summary by subsystem
  - Telecom as a design driver
  - Carrier design summary
  - Mass summary
- Trades
  - Key findings from past trades
  - Current mission design trades
  - Other possible trade studies
- Known Risks
- Open Issues

# SAGE Science Objectives

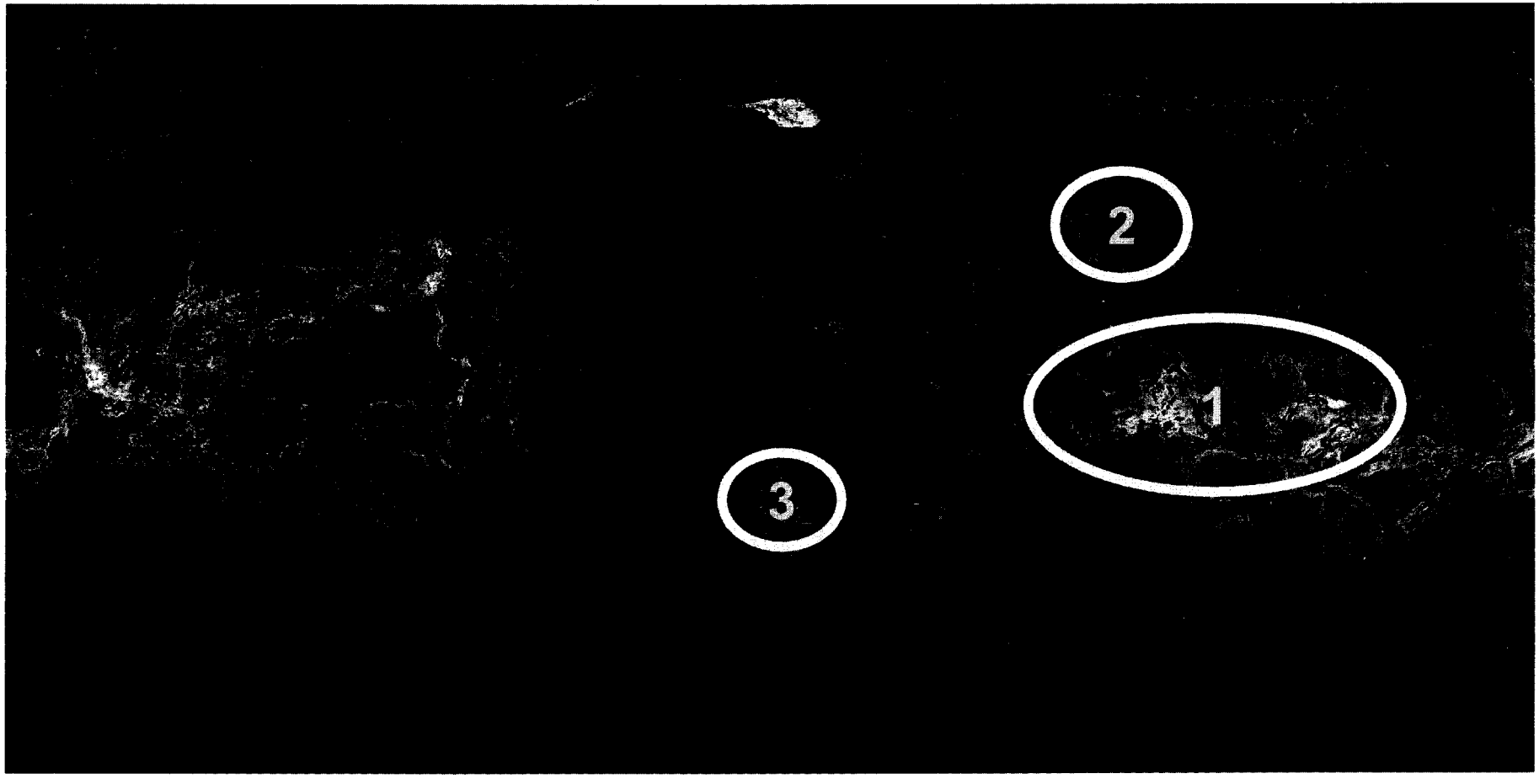
- High level science questions:
  - Bulk composition and origin of the atmosphere
  - Surface-atmosphere interactions
  - History of water and other volatiles
  - Geochemical cycles affecting climate
  - History of crust-mantle interactions

- Measurement Objectives
  - Composition of the surface
    - Mineralogy
    - Major elements
    - Minor elements
    - Trace elements
  - Descent and landed VIS-NIR images
  - Atmospheric composition, noble gases and isotopes
  - At least two landing sites: tessera and lowlands (plains)

- Source:
  - From the Decadal Survey Report
  - Selected by the SAGE science team as most important and feasible within the New Frontiers cost cap

# Landing Sites Requirements

- 1 Lander in a tessera region. Priorities are: (1) Aphrodite, (2) Tellus, or (3) Alpha; or (4) any of the high north latitude sites
- 1 Lander in a plains region (~blue)
- Some flexibility in landing site capability is desirable to accommodate community inputs
- Landings must made during daylight

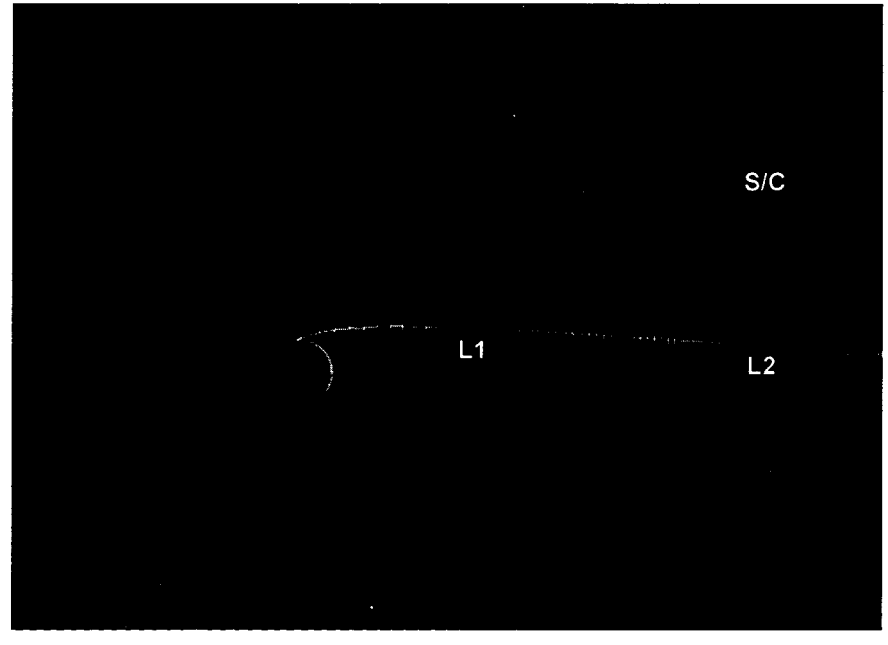


# Baseline Mission Design

*Satisfies the Priority 1 Tessera Landing Site Requirement*

- Launch on Jan 23, 2009 to a C3 of 14.7 $km^2/s^2$ (Type II)
- Arrival on July 25, 2009 after a 6-month cruise, with $V_{infty}$ = 6.5 km/s
- Lander 1 deployed 14 days before entry and targeted to the plains South of Aphrodite
- 60 m/s carrier maneuver to delay Lander 2 by 3 hr
- 2 m/s carrier maneuver to offset Lander 2 landing site
- Lander 2 deployed 5 days before entry and targeted to the Aphrodite tessera region
- 100 m/s carrier maneuver to flyby Venus at an altitude of 41,000 km
- 15 m/s carrier maneuver to delay arrival by 15 min in order to optimize relay telecom
- Lander 1 enters the atmosphere and performs in-situ science and telecom relay for a total of 3 hours
- Lander 2 then enters and performs the same sequence
- The Carrier is constantly in view of the Earth; the Landers are not in view of the Earth for their EDL and surface phases.

| Lander | 1 (plains) | 2 (tessera) |
|---|---|---|
| Released | Entry – 14 days | Entry – 5 days |
| Landing site | 18.2 S, 81.8 E | 8.8 S, 79.5 E |
| Entry angle | - 18 deg | - 18 deg |
| Max deceleration | 180 g | 180 g |
| Landing ellipse | 315 x 60 km (3σ) | 280 x 70 km (3σ) |



# Baseline Arrival Geometry

Venus landing, 18 deg entry, Late Type II, open (C3 14.7)

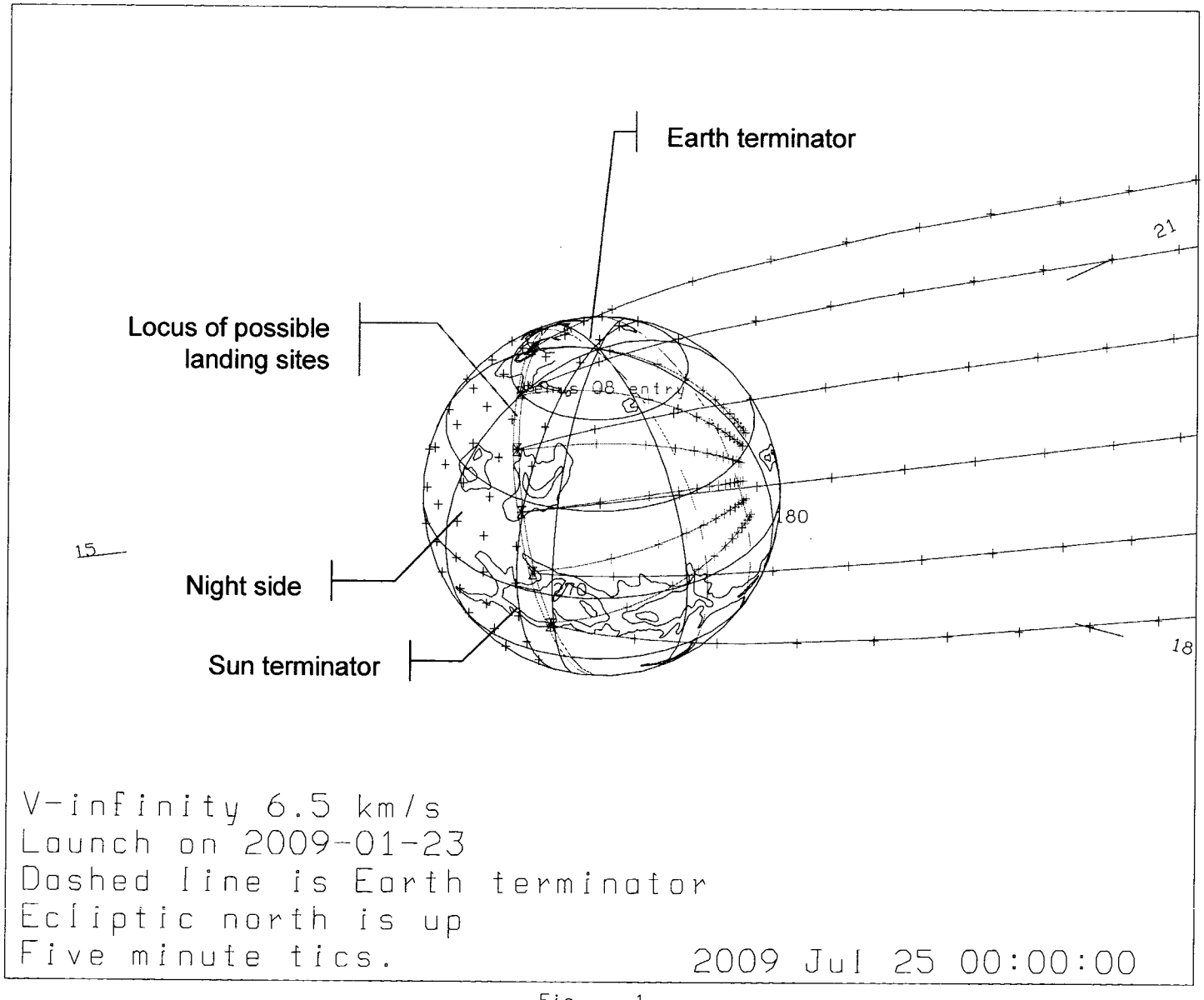



Fig 1

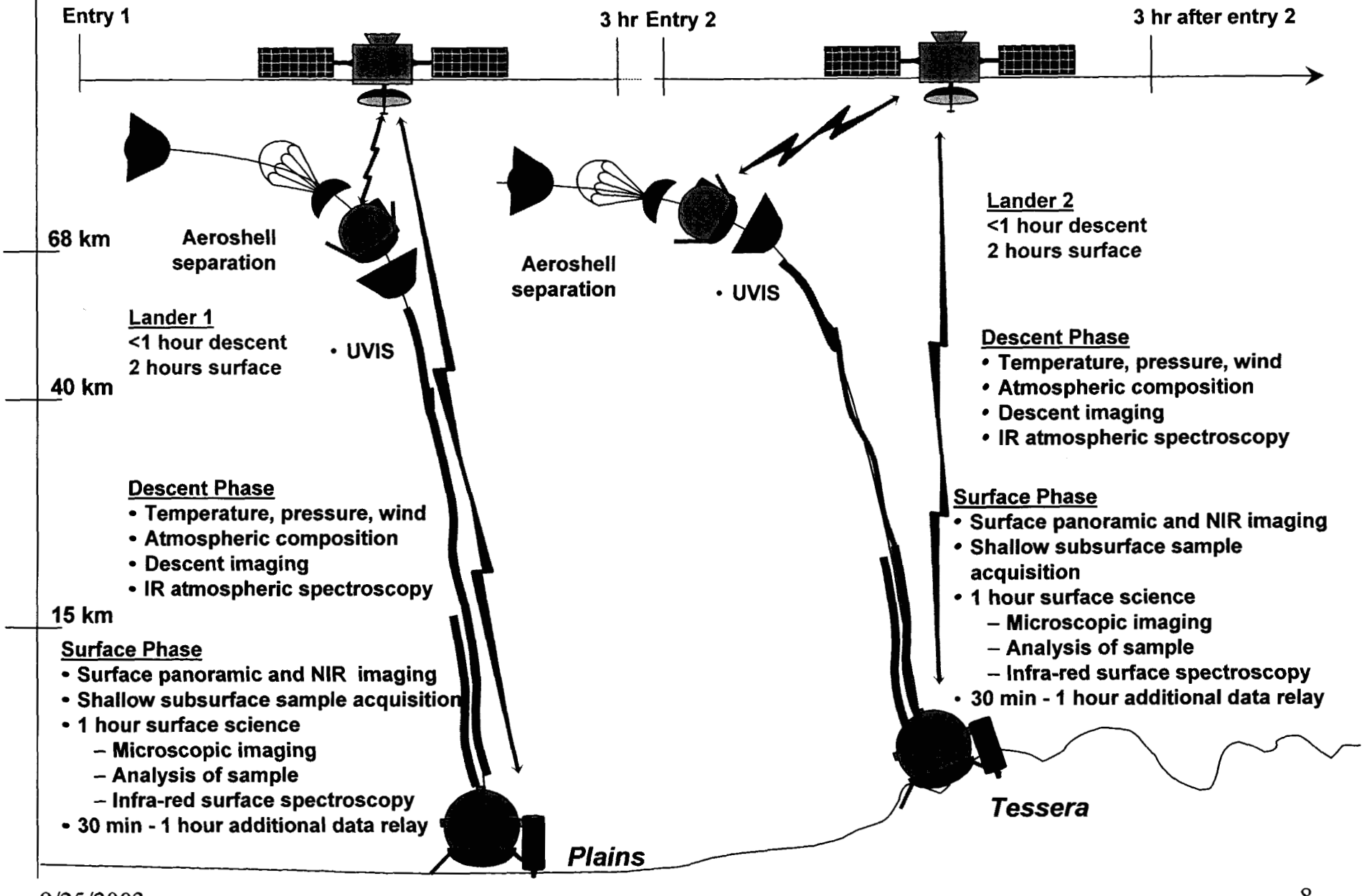
# Strawman Payload Summary

*As used in this design*

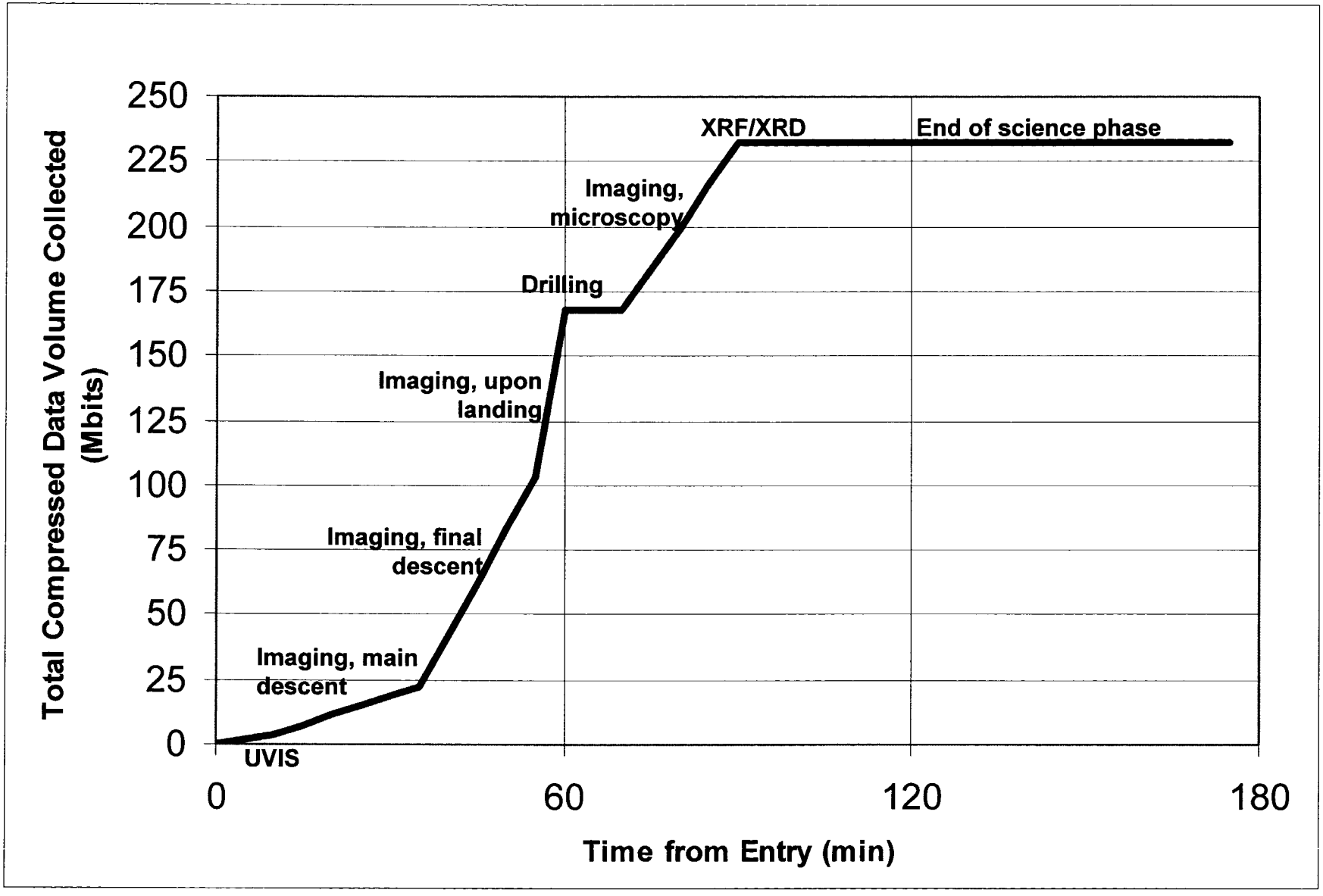
| Flight System Element | Instrument | Location Requirements | Used during | Mass (kg) | Peak Power (W) | Average Power (W) | Data Production | Dimensions ($cm^3$) |
|---|---|---|---|---|---|---|---|---|
| LANDER | | | | | | | | |
| Inside Pressure Vessel | **Atmospheric Structure Investigation (ASI)** | Sensors outside boundary layer | Descent to touchdown | 3 | 15 | 9 | 128 bps | 18 x 12 x 12 |
| | **Descent Imager and Spectral Radiometer (DISR/NIR)** | Up and down viewing | Descent to touchdown, >1 landed image; NIR surface | 12 | 12 | 12 | 100 Mbits total | 13 x 21 x 9 electronics +20 x 10 x 10 sensors |
| | **Panoramic Camera (Pancam)** | Periscopic mirror poking out from pressure vessel top. | Upon landing | 6 | 5 | 5 | 64 Mbits total | TBD |
| | **X-Ray Fluorescence and Diffraction (XRF/XRD)** | Analysis of surface sample inside vessel | Surface science phase | 1 | 5 | 5 | 256 kbits total | 15 x 13 x 8 |
| | **Gas Chromatograph/ Mass Spectrometer (GCMS)** | Inlet at stagnation point | Descent to touchdown | 8 | 40 | 20 | 960 bps | 30 x 20 x 20 |
| | **Camera Hand Lens Microscope (CHAMP)** | Views surface through window | Surface science phase | 2.5 | 5 | 5 | 64 Mbits | 10 x 13 x 8 |
| Outside Pressure Vessel | **Sample acquisition system** | Fixed on lander side, inserts sample into XRF/XRD chamber | Upon landing | 26 | 90 | 90 (over 10 min) | 0 | Small |
| | **Ultraviolet Imaging Spectrograph (UVIS)** | On shelf outside pressure vessel | Descent above 50 km | 5 | 10 | 10 | 256 bps | 20 x 50 x 15 |
| ORBITER (if any) | | | | | | | | |
| Orbiter | **Orbiter Camera** | Nadir viewing | Orbital science phase | 1 | 4 | 3 | 60 kbps | 10 x 10 x 10 |
| | **Orbiter Spectrometer** | Nadir viewing | Orbital science phase | 12 | 12 | 12 | 15 kbps | 20 x 20 x 15 |

- Instrument list is *representative*, not definitive
- Instrument specifications are *envelopes* only; they represent *conservative* estimates of the state-of-the-art, not any actual instruments flown or in development
- Some instrument providers have been identified to help update and refine the instrument accommodation requirements.

# In-Situ Science Phase Scenario



# Payload Data Collection

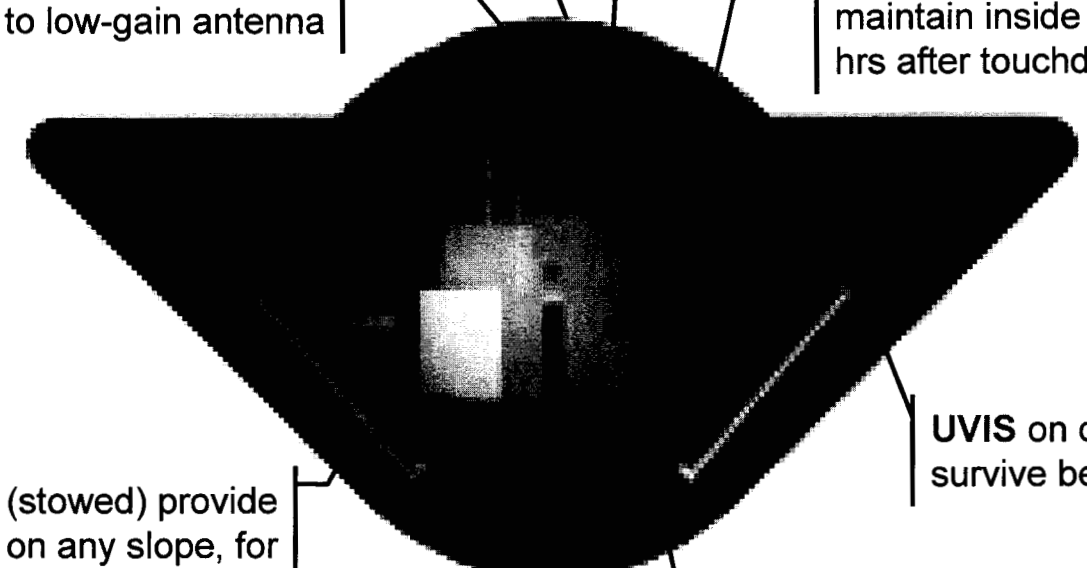


# Lander Design Summary

| Subsystem | Requirements | Design |
|---|---|---|
| **ADCS** | No attitude control (low RPM spin)<br>Initialize timers on entry<br>Descent trajectory and attitude reconstruction | 3 accelerometers to detect peak deceleration<br>1 IMU for reconstruction information to complement Doppler |
| **C&DH** | Interface and command for <270 kbps data collection, <64 kbps relay; >240 Mbits memory | Based on 16-bit microcontroller (DS2, Athena)<br>750 Mbits data storage (>100% contingency) |
| **Telecom** | Return 240 Mbits of compressed science data to the relay S/C in <3 hr, varying range & elevation<br>Provide coherent signal for Doppler | Electra radio modified to operate at S-band<br>2 LGAs, SSPA with 100 W output power<br>8, 16, 32 and 64 kbps capability |
| **Power** | Intermittent RF tone during cruise, telecom warm-up, 2 hr science, 3 hr telecom<br>Peak 500W, total 1800 W-hr | $LiSOCl_2$ Primary battery (-> 120 °C), 90 A-hr; made out of D-cells to be arranged in convenient shape<br>Dumb solid state switches and COTS power converters |
| **Thermal** | Maintain inside vessel < 50 deg C for 1 hr descent and 2 hr surface in an outside environment of 470 C, 92 bar, with >100-200 W inside power dissipation<br>Limit leaks through 8 penetrations | 10 cm thick Aerogel insulation on the inside wall<br>Phase-change material melting at room T (paraffin)<br>Conduction isolation to minimize thermal conduction through penetrations |
| **Structures** | Accommodate and house instruments and subsystems with 30% volume contingency<br>Provide structural support during launch, entry, landing events | 80 cm Ti pressure vessel with inside shelves (PV heritage)<br>Drag skirt for descent stability<br>Crushable landing ring<br>Sample acquisition system deployment mechanism |
| **Entry and descent system** | Accommodate 180 g entry loads, 11 km/s entry, 18° flight path entry angle<br>Free fall after aeroshell separation | Based on Pioneer Venus heritage (minus parachutes) with improvements in materials<br>35% of total entry mass based on discussions with ARC |

- Lander 1 and Lander 2 are identical

# Strawman Entry System Configuration



**Aeroshell and TPS** for entry and early descent

**Telecom** cable from 100-W S-band amplifier to low-gain antenna

**Pressure Vessel** (60-cm usable I.D.) houses all instruments (except UVIS) and electronics and maintains low inside pressure

Pressure vessel **Insulation** (10-cm thickness) and phase-change materials maintain inside room-temperature for 2 hrs after touchdown

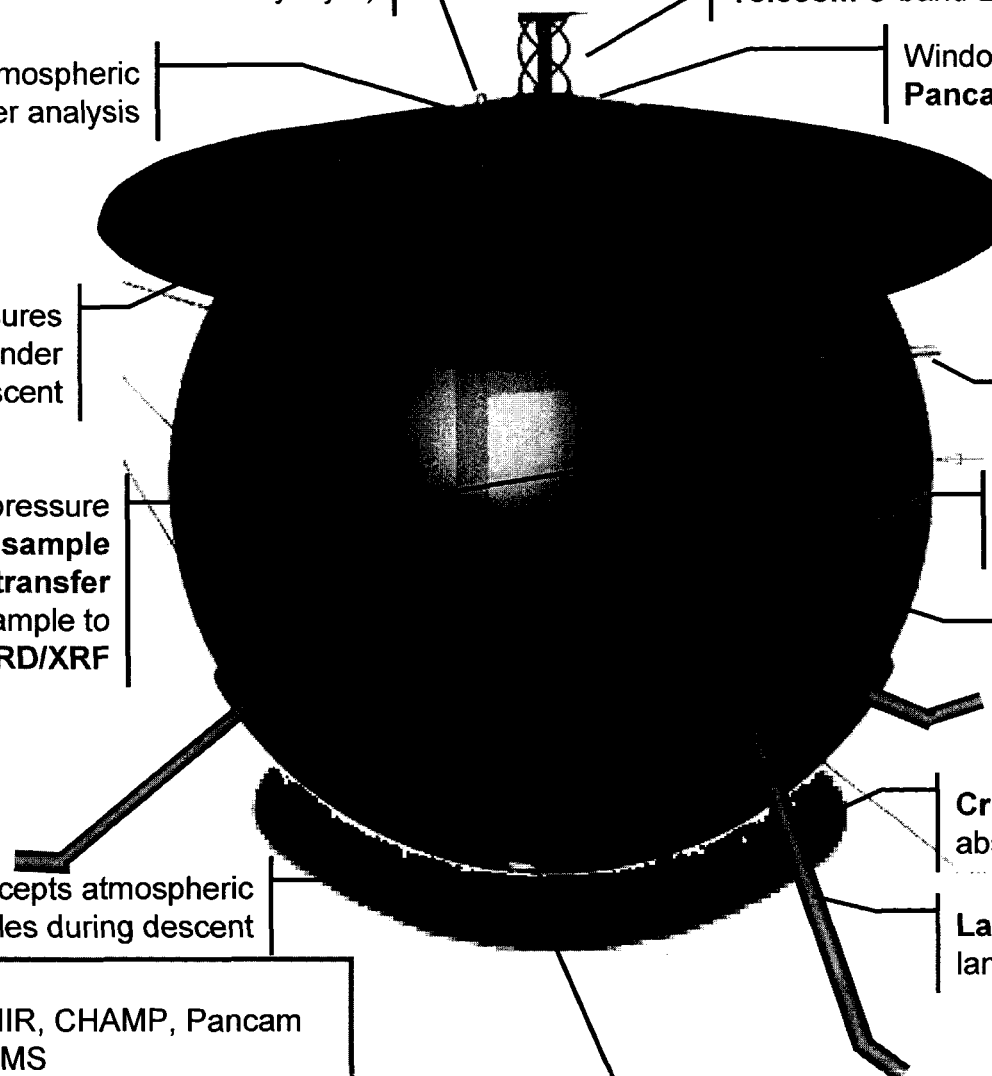
**UVIS** on drag disk, doesn't survive below ~50 km altitude

**Outriggers** (stowed) provide landing stability on any slope, for access to all terrain types

**Crushable landing pad (or torus)** provides the required protection for the final free-fall

**Batteries** power the Lander for the entire descent and surface phases

# Strawman Landed Configuration



**ASI** sensor (outside the boundary layer)

**Telecom** S-band LGA

**GCMS** outlet lets atmospheric samples out after analysis

Window and outside mirror for **Pancam** (not shown)

**Pressure Vessel** (60-cm usable I.D.) houses all instruments except UVIS and drill

**Drag Ring** ensures stability of the lander during descent

Power/data bus to/from **UVIS** (not shown)

**Drill** (outside pressure vessel) with **sample acquisition and transfer system** brings sample to internally located **XRD/XRF**

Window for **DISR/NIR** provides down and up-looking abilities

10-cm Aerogel **Insulation** layer covers the **Ti pressure vessel**

**Crushable landing pad (or torus)** absorbs landing shock (<10m/s)

**GCMS** inlet accepts atmospheric samples during descent

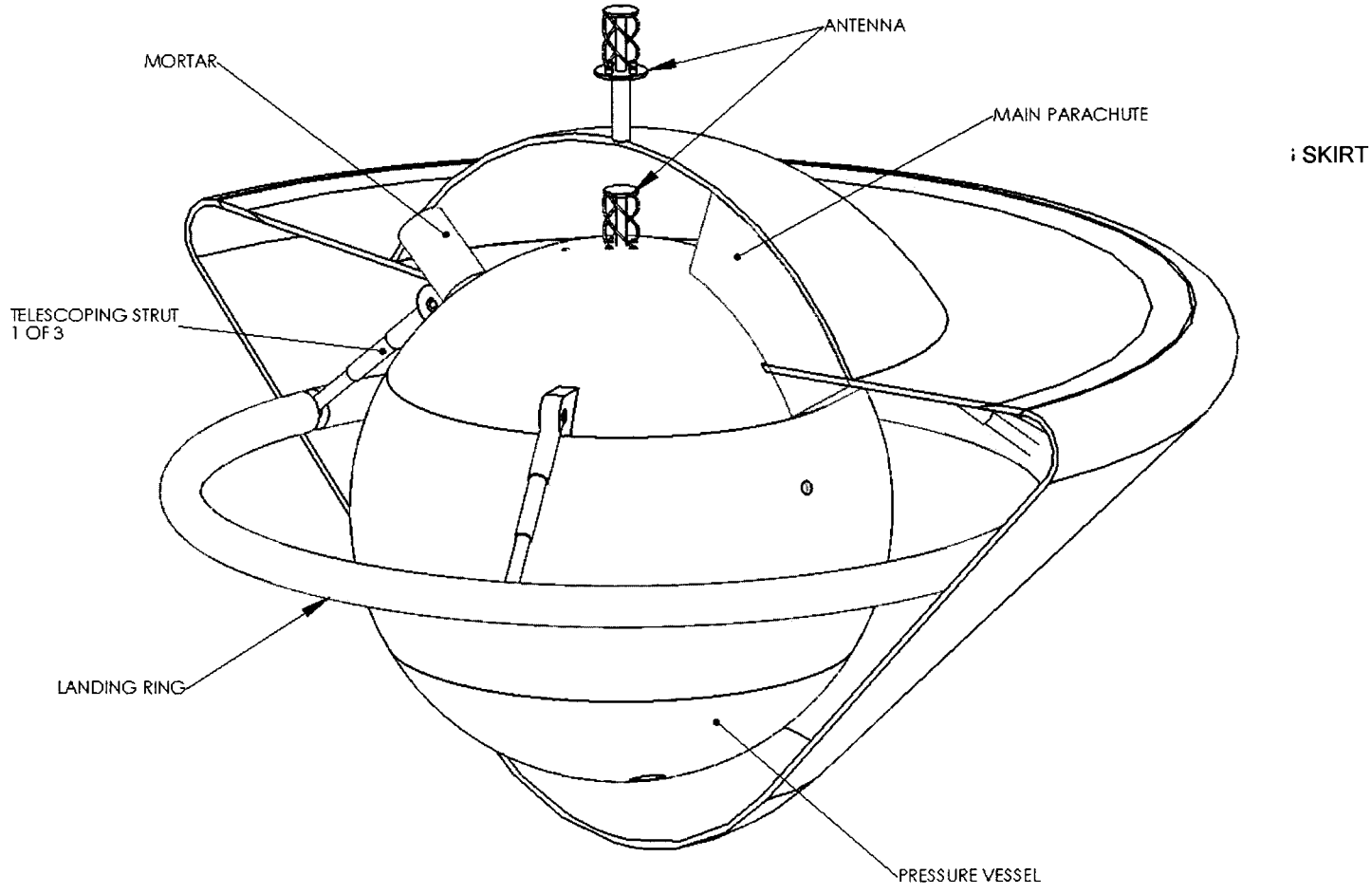
**Landing outriggers** (deployed) ensure landing attitude over a range of slopes

**Through-holes:**
- 3 windows: DISR/NIR, CHAMP, Pancam
- 2 inlets/outlets: GCMS
- 3 electrical: telecom, UVIS, ASI
- 1 sample acquisition air lock: from drill

Window for **CHAMP** looks down for microscopic surface analysis near drill site

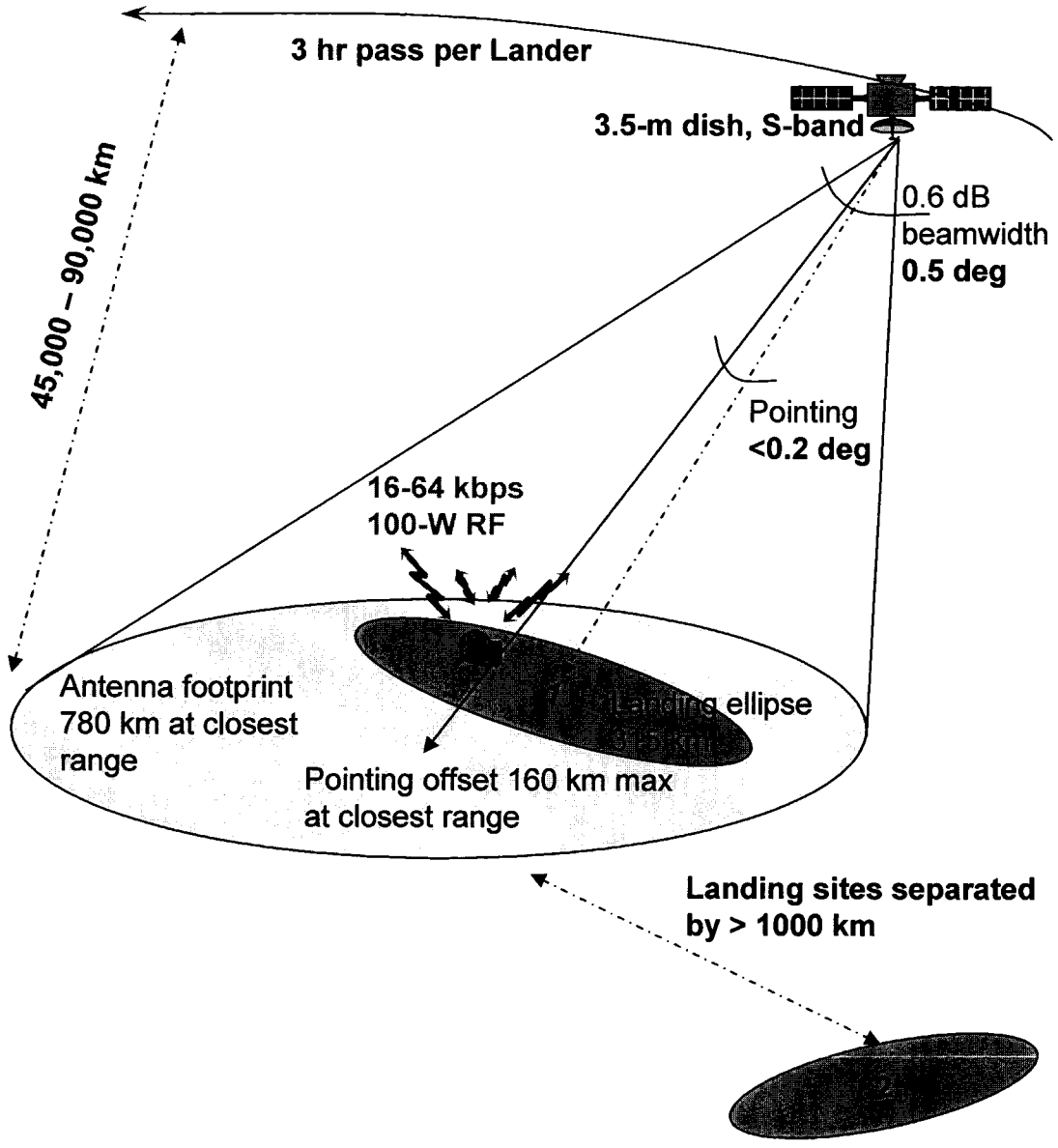
# Alternate Configuration

*Deployable Landing Ring*



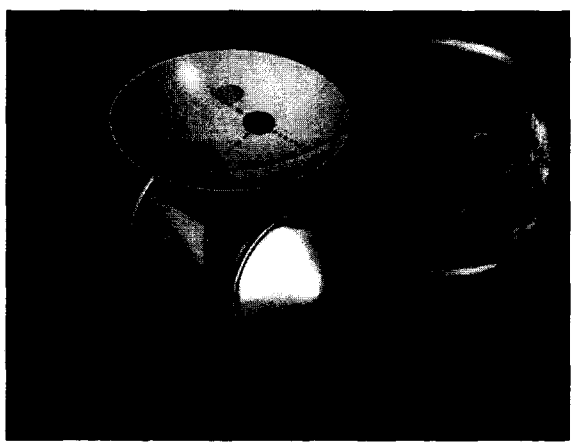
# Telecom as a Design Driver

- Requirement for two consecutive 3 hr passes leads to large variations in Lander-Carrier ranges
- Data return optimized by varying telecom data rates
- Body-fixed antenna points at center of predicted landing ellipse
- 100-W RF output transmitter required on the Lander to return 240 Mbits of compressed science data
- If allowed to be different, Lander 2 could return 480 Mbits
- This telecom design impacts the power, thermal and structures design:
  - 1800 W-hr total energy requirement
  - >200 W dissipated require phase change material for survival
  - Resulting volume requirements set the vessel inner diameter to 60 cm



# Strawman Carrier Design

- **The Carrier spacecraft:**
  - Keeps the Landers warm during cruise
  - Releases the Landers on the correct trajectories to their landing sites
  - Serves as a telecom relay between the Landers and the DSN
- **Design is driven by:**
  - Telecom pointing and data relay using a body-fixed HGA
  - Accurate Lander deployment



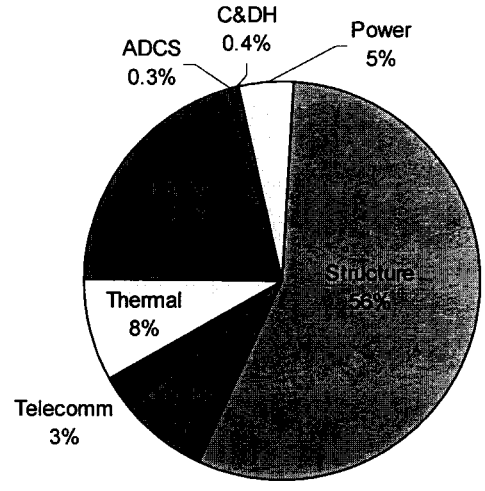
| Subsystem | Requirements | Design |
|---|---|---|
| **ADCS** | 3-axis stabilized<br>0.2 deg knowledge<br>0.1 deg accuracy | Ball CT-633 star trackers<br>Redundant Litton LN-200S IMU<br>Thrusters for control |
| **C&DH** | <64 kbps receive, 350 kbps relay; >3 Gbits memory | RAD750-based computer<br>Maximum use of MRO heritage |
| **Telecom** | 16-64 kbps receive from Landers at S-band<br>6 dB margin<br>Command to and 2-way Doppler | Body-fixed 3.5-m S-band antenna<br>Modified Electra radio<br>25-W transmit SSPA<br>Ultra-stable oscillator (USO) |
| | Return to 34-m DSN at 350 kbps X-band 0.5 AU<br>3 dB margin | Same high gain antenna plus two LGA<br>15-W SSPA |
| **Power** | 325 W (peak) from 1 to 0.7 AU | $1.1 m^2$ GaAs TJ arrays, single axis gimbal<br>55 A-hr $NiH_2$ secondary battery<br>Dual string, smart power electronics |
| **Thermal** | Temperature control for the Carrier and the Landers during cruise | Electric heaters/thermostats for sensitive elements<br>MLI, thermal surfaces, thermal conduction control and temperature sensors |
| **Propulsion** | 225 m/s delta-V plus RCS | Redundant monopropellant blowdown system, Ti tanks |

# Strawman Mass Summary

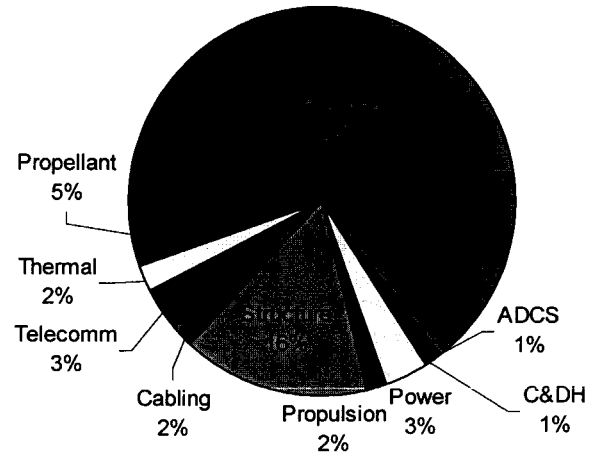
**Mass (kg) with 30% contingency**

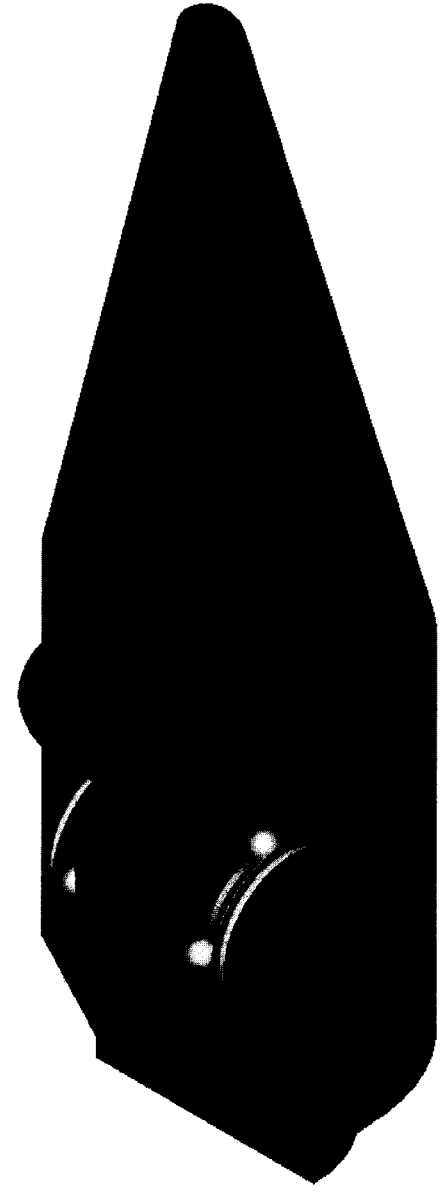
| System | Subsystem | Mass (kg) |
|---|---|---|
| Lander | Payload | 82.6 |
| | ADCS | 1.3 |
| | C&DH | 1.5 |
| | Power | 18.0 |
| | Structure | 220.8 |
| | Cabling | 27.1 |
| | Telecomm | 12.3 |
| | Thermal | 32.8 |
| | **Total Landed** | **396.4** |
| Entry System | EDL System | 213.4 |
| | **Total Entry** | **609.8** |
| Orbiter/ Carrier | Instruments | 0.0 |
| | Landers | 1219.5 |
| | **Payload** | **1219.5** |
| | ADCS | 11.3 |
| | C&DH | 13.8 |
| | Power | 65.3 |
| | Propulsion | 32.8 |
| | Structure | 296.6 |
| | Cabling | 36.7 |
| | Telecomm | 64.1 |
| | Thermal | 46.3 |
| | **Bus Total** | **566.8** |
| Flight System | **Total Dry** | **1786.3** |
| | Propellant | 101.0 |
| | **Total Launch** | **1887.3** |
| Launch Vehicle | | Atlas V 511 |
| C3 | | 14.7 |
| Launch Vehicle Capability | | 2823.4 |
| **Launch Margin** | | **33.2%** |

**Landed Mass Breakdown Baseline**




**Launch Mass Breakdown Baseline**



# Key Findings From Past Trades

## Venus Multi-Lander

- Key features:
  - 1-day science orbit
  - Landers released on approach
  - 3 landing sites (few constraints)
  - No contact with the surface
- Key findings:
  - Orbiter adds an extra ~$80M
  - Although is has some cost/risk attractiveness, "near remote sensing" is not sufficient to meet surface science objectives

## Deploy from Orbit

- Key features:
  - 3-day science orbit
  - Landers released from orbit
  - Dumb de-orbit propulsion stage on Landers
- Key findings:
  - Does not improve landing site accessibility as much as hoped
  - Data return per Lander can be increased x3 or the Landers made slightly smaller
  - Option adds an extra >$100M
  - Orbit insertion, de-orbit propulsion stages, and requirement for active tracking increase mission risk

## Aerolander (ARC)

- Key features:
  - Use aerodynamics to speed up descent at high altitudes and slow down for low altitude imaging
  - End-to-end flight system impacts not considered
- Key findings:
  - Feasible with reasonable cost impacts at the Lander level
  - Instrument accommodation issues not considered (very difficult)
  - Extremely high perceived risk makes makes option not viable

# Current Mission Design Trades

- Considered lower C3 options for the late 2008-early 2009 opportunity
  - Low C3 possible if going to Alpha tessera and tolerating a steeper entry angle
- Considered a 2-flyby option as a way to learn from the first landing
  - Significantly limits the landing site accessibility and time in view for the first Lander
  - No viable option identified so far
- Considering launch in 2010
  - The most favorable launch opportunity occurs in July 2010, beyond the current latest acceptable data per the AO
  - Launch before March 2010 requires a higher C3 or a parking orbit
    - A higher C3 is very feasible with a larger Atlas according to the current mass estimates
    - Launching into a parking orbit would require a large propulsion stage, with the corresponding added cost and risk
  - A 2-flyby option might also be possible with a launch in February 2010?
- Due to the slow rotation of Venus, landing site requirements are very strong design drivers. Landing site selection cannot be as flexible to community input as it can be for Mars.

# Other Possible Trade Studies

- Use of "smart landers" to optimize science return based on actual subsystem performance
- Use of autonomous rock recognition imagery and S/W combined with articulated drill placement to maximize science return
- Alternate designs for maximizing capability for successful landing on rough terrain
- Use of high-temperature electronics, solder, etc.
- Use of possible advanced, passive cooling systems
- Addition of a third lander, to go to a hot spot

# Known Risks

- Sample acquisition and transfer system development for Venus
- Most instruments require development for Venus
- Tight timing sequence: all science data collected and transmitted in six hours, with little time for re-orientation of the Carrier between the two EDL periods
- Schedule and cost risk for challenging packaging and pressure vessel manufacturing
- Re-qualification of TPS material
- Re-build of test facilities
- Organizational complexity (multiple Centers, multiple industrial partners)

# Open Issues

- Draft AO selection schedule and last allowable launch date are not consistent with Venus launch windows, requiring unworkable Phase B/C/D durations
- Finalize instrument suite definition and accommodation requirements
- Sample acquisition and transfer system design
- Science data volume growth
- Develop higher fidelity design based on updated payload; in particular
  - Detailed analysis and design of the entry, descent, and landing to ensure the quality of the descent science and an adequate landing attitude
  - Configuration that ensures proper instrument access while minimizing through-holes
  - Detailed environmental conditions inside the pressure vessel
  - Detailed timing of data generation and relay to ensure proper telecom and C&DH margins
  - Higher fidelity designs of all subsystems
- Fitting within the $650M cost cap