Generic Mission Architectures

benefiting from these instruments

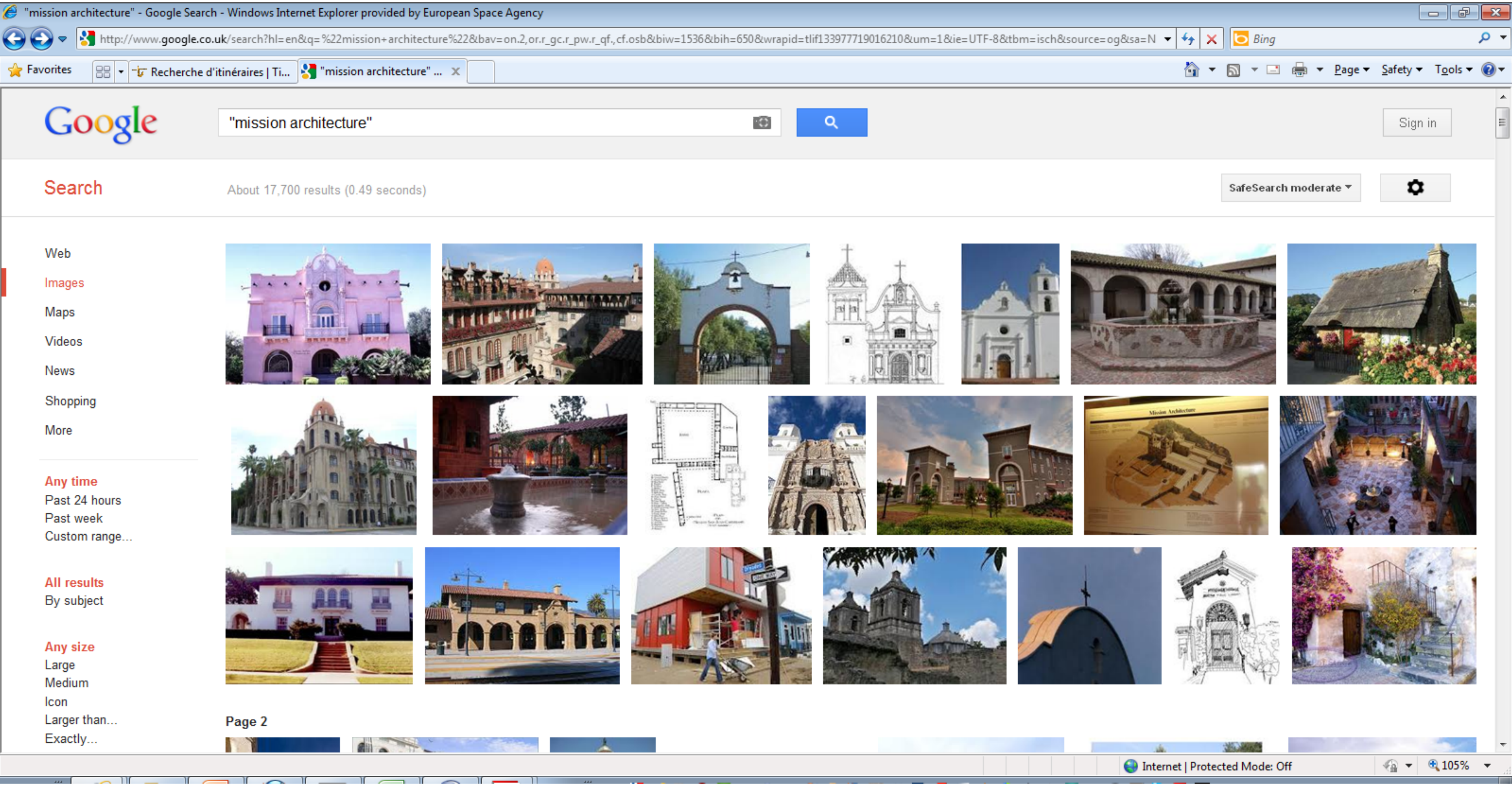
Andrew Ball

IPPW9 Short Course on Probe Science Instrumentation Technologies, Toulouse, 16-17 June 2012

Overview

- Definition & examples

Mission Architecture?



What is a (Probe) Mission Architecture? (1)

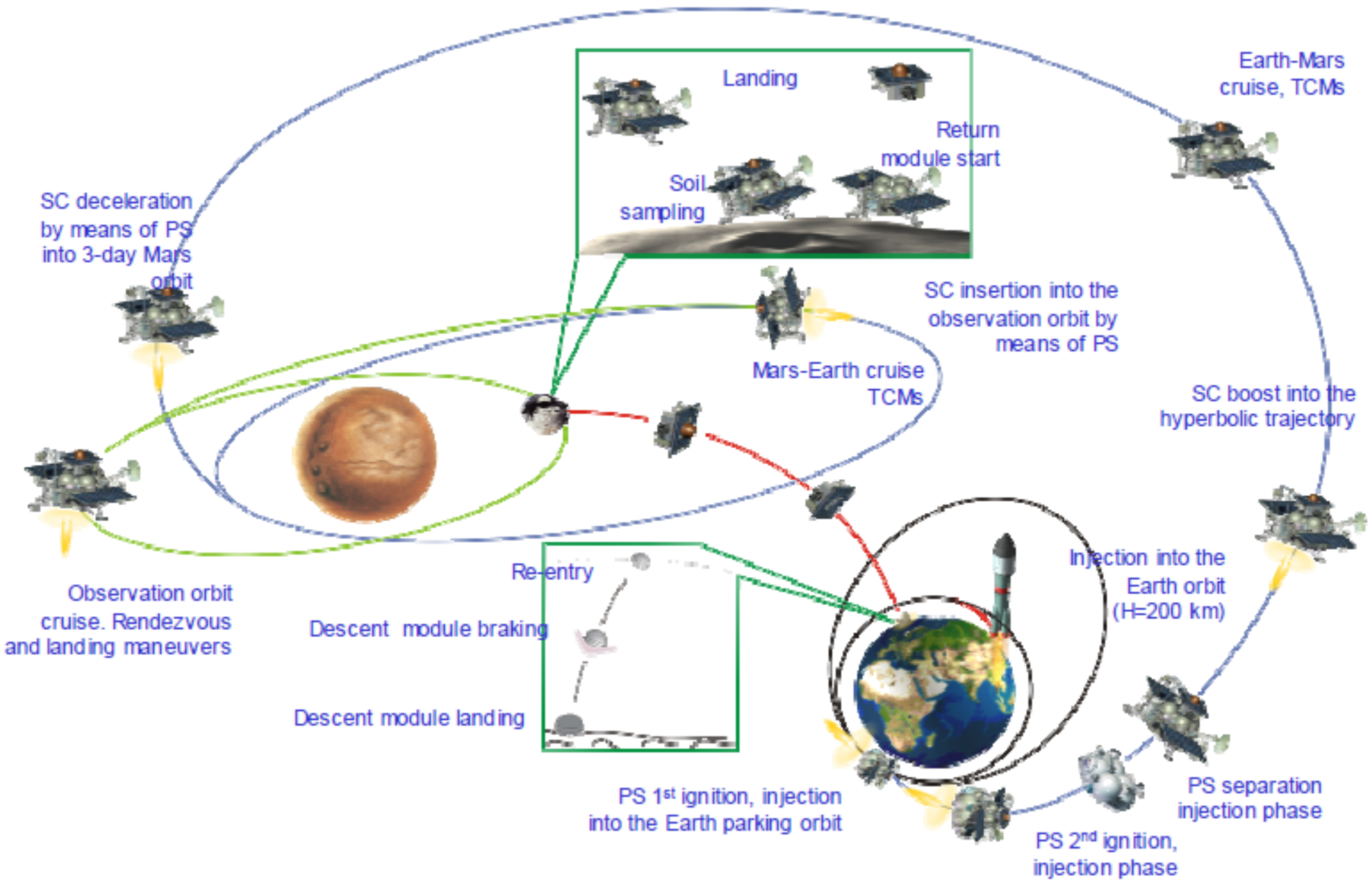
- A top-level* description of the spacecraft elements and their relation to each other, the mission target and Earth during mission operations
  - *May be part of a higher-level programme architecture
  - Devised as a means to address a set of mission objectives…
  - …or alternatively to show how a set of heritage elements may be used.
  - Can be described as part of the mission profile

What is a (Probe) Mission Architecture? (2)

- The mission architecture indicates:
  - the main events of a mission timeline
    - E.g. launch, orbit insertion, separation, landing,…
  - configuration of the spacecraft
    - E.g. launch configuration, orbiter or carrier, number of probes, …
  - configuration of key systems
    - E.g. power source, EDL architecture
  - often also the communications scenario
    - Data relay vs. Direct To Earth (DTE), ground segment
  - May or may not show the orbital geometry…

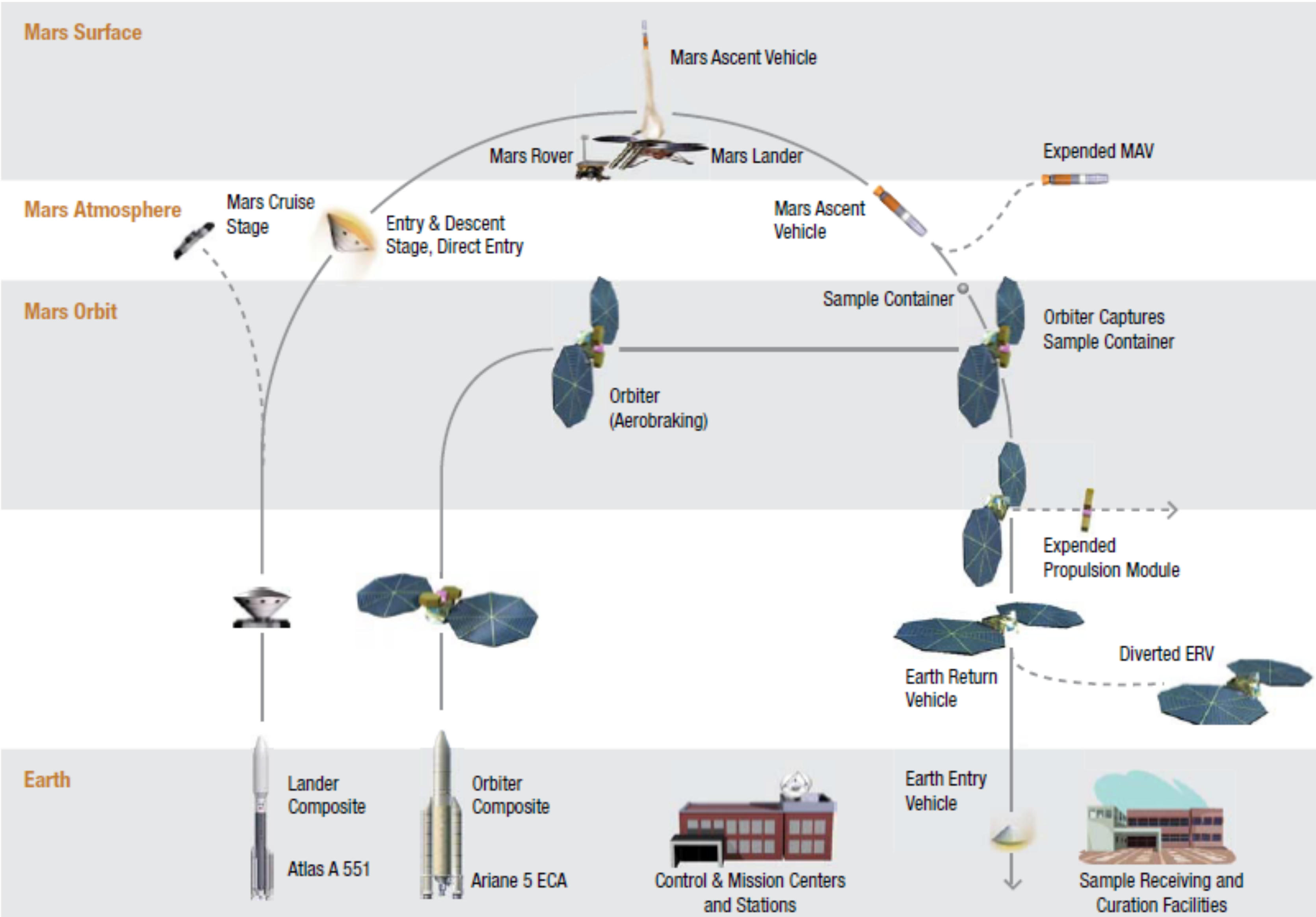
- (There's probably no such thing as a generic mission architecture!)

PHOBOS SAMPLE RETURN
MISSION PROFILE



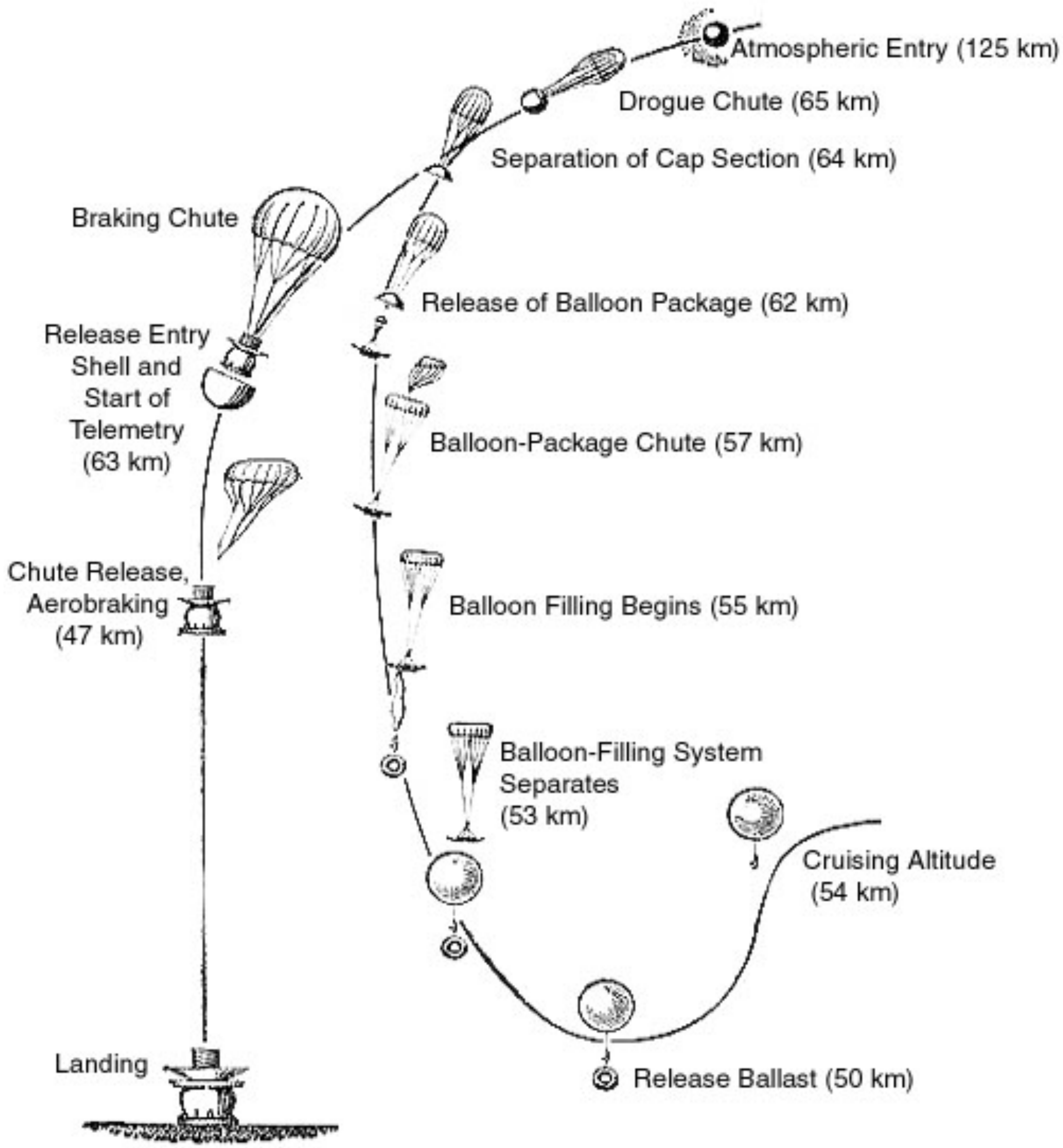
Zakharov et al.

Sample Return Architecture



iMARS Final Report: http://mepag.nasa.gov/reports/iMARS_FinalReport.pdf

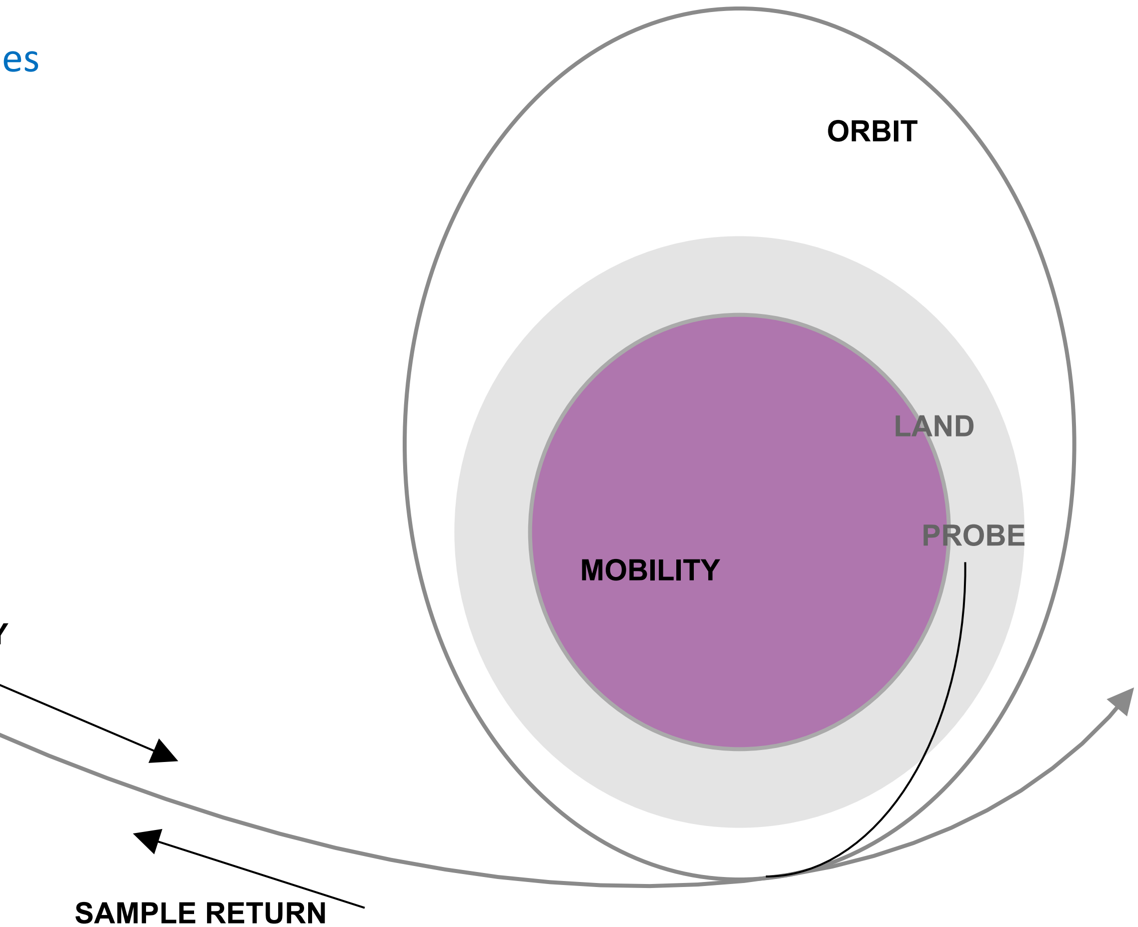
EDL & EDI architecture

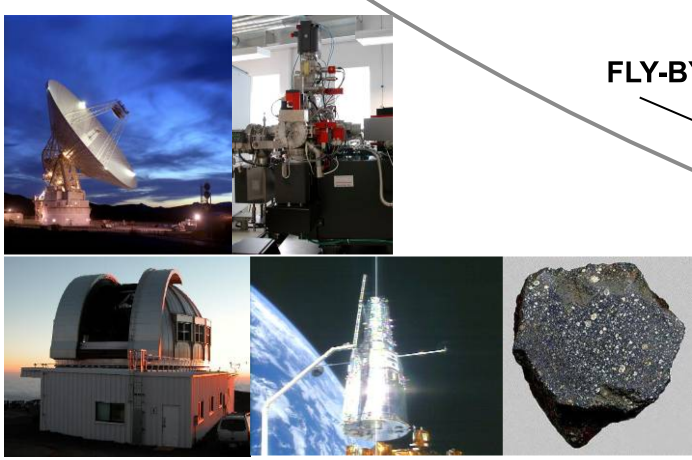


VeGa

Mission Architecture vs. Complexity

- Ground-based
  - telescopes, radio science, laboratory, analogues, meteorite & sample analyses
- Flyby
- Destructive impact / entry probes
- Orbit
- Atmospheric entry probe
- Lander
- Mobility (rover, balloon, etc.)
- Sample return
- (Human exploration)





Some Benefits of *In Situ* Investigation

- Measurements that are impossible remotely
  - Many environmental parameters, physical properties
  - Detailed composition (trace el'ts, isotopic,…), petrology
  - Measurements hindered by the atmosphere
- Validation of measurements or inferences from remote investigations, modelling, lab simulation, etc.
- Scales much finer than achievable remotely
- Interaction with the environment (active techniques)
- Sampling of material for *in situ* analysis
- Access to sub-surface (sampling, thermal meas., etc.)
- Mechanical coupling for seismology & rotation meas.
- Sampling for return to terrestrial labs

Single or Multiple probes?

- Network measurements
  - Meteorology
  - Seismology
  - Geodesy
- Can be used for redundancy (though rarely since mid-80s)
- Multiple probes on a single craft – likely to mean ballistic entry and large landing ellipse, which luckily is OK for network experiments
- Multiple probes demanding on data relay architecture
  - covering 4 probes at the same time as orbit insertion practically impossible!

Probe Delivery

- Atmospheric probes to: Venus, (Earth), Mars, Jupiter, Saturn, Titan, Uranus, Neptune
- Generally from a carrier spacecraft of some sort
  - Earth's Moon (and Earth) are the only possible exceptions
- Delivery from hyperbolic, highly elliptical or near-circular orbit
  - Together with the target's escape speed and rotation speed, the geometry of this choice determines the entry speed relative to the atmosphere
  - And together with the Flight Path Angle (FPA) and other parameters helps determine what ballistic coefficient, aeroshell design, Thermal Protection System (TPS) to select
- The probe may have the correct velocity already after separation
  - If not, probe needs its own deorbit propulsion.
- Probe may be on course for entry
  - Avoidance manoeuvre if carrier needs to survive for orbital mission and / or data relay
- Importance of atmospheric models (profiles of density, wind, variability,…)
- And of surface datasets (elevation, slopes, thermal inertia,…)
- Landing ellipse – combined effect of the various dispersions

Spin

- Spin may be needed for stability and thermal reasons during coasting phase
- May be imparted by parent spacecraft or separation mechanism
- May be too fast
  - yo-yo despin
- May be too slow
  - Spin-up thrusters
  - Spin vanes
  - Oscillation dampers
- If guided entry then needs to be zero
- Useful for stability (and heat distribution) during ballistic entry

Entry

- Pre-entry environment
  - Fields, radiation
- Entry state
  - Navigation problem
- Probe dynamics – IMU
- Engineering instrumentation
  - Studies response of system to the environment but also needs to know what the environment is
  - Gas properties, heat fluxes, TPS response
- Science instrumentation
  - Aims to derive properties of the target environment independent of probe
  - Probes in the flow, upper atmospheric composition

Descent

- Mars descent very short (~2min) and mission-critical so difficult to add experiment objectives
- Venus, Earth, Titan, Giant planets – medium to long descent
- For giant planets and (most of) Huygens, the descent *is* the mission

- Many more measurement opportunities than entry:
  - Probe dynamics (more complex than entry, however)
  - Radio science
  - Local
  - Integrated (up or down)
  - Surface – imaging, radar
  - Analytical measurements
  - Sampling and analysis
- Measurements have to be compatible with the descent dynamics and environment
- Some may require sophisticated IF to the environment – needs to be compatible with the platform

Phased Descent Measurements

- Hostility of Venus lower atmosphere may mean some in situ measurements are only possible higher up (>30km) and one accepts loss of part of the payload
- i.e. tailor payloads to different altitude ranges or surface

DTE vs. Relay

- DTE used nowadays usually for EDL monitoring only
- DTE may however be attractive for some missions where the objectives can be achieved with the data rate / volume available and establishing a data relay is too costly for the envelope
- Mission architecture has to achieve geometry for relay
- Deep probes – watch out for absorption

Power Architecture

- Primary battery
  – Suited to short / limited duration missions
- RTG + secondary battery
  – Suited to cold targets, e.g. Mars and Titan
- Solar array + secondary battery
  – Suited to longer missions in inner solar system: Mars surface, maybe Venus balloons?

Targeting

- The need to target a particular location (small area for landing ellipse) may drive the mission architecture
  - Guided entry instead of ballistic
  - Rover to reach the target from the landing site

Duration

- How long does it take to carry out the desired objectives of the mission in the atmosphere / on the surface?
- Major effect not just on any consumables but also power and thermal architecture, e.g. ‘keep alive’ heaters or cold electronics with a limited number of cycles?

Preprogrammed vs. commanded

- All probes preprogrammed to surface – the long descent destinations are too far away to make commanded operation attractive
- Long-lived balloons would be a possible exception
- Interaction almost always desirable once probe is on the ground

Programmatics & Mission Architecture

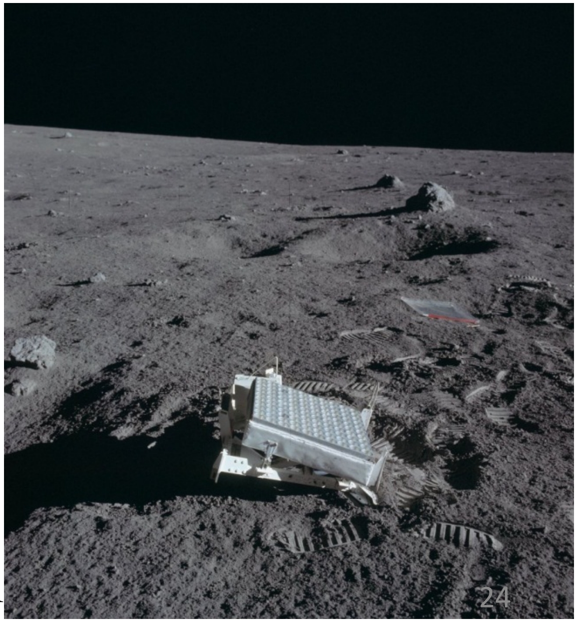
- What is to be classed as science payload?
  - Usually selected by AO
- What is provided by the 'system'?
  - E.g. system data, deployments, sampling,…
  - Can't count on science return but there often is one, even if not guaranteed
  - (Check auxiliary information, data rights, archiving)
- What needs to be in there at the top as a programmatic objective?
  - E.g. tech demo, data relay for other missions, compatibility with other sample return elements…

Measurement Categories

- Geodesy / tracking
- ‘Space physics’
- Atmospheric physics profiles
- Aerosol physics
- Fluid physics
- Sub-surface sounding
- Surface physical properties
- Imaging
- Photometry & spectrometry
- Microscopy
- Chemical composition
- Mineralogical & elemental composition
- Sample analysis
- Sample return

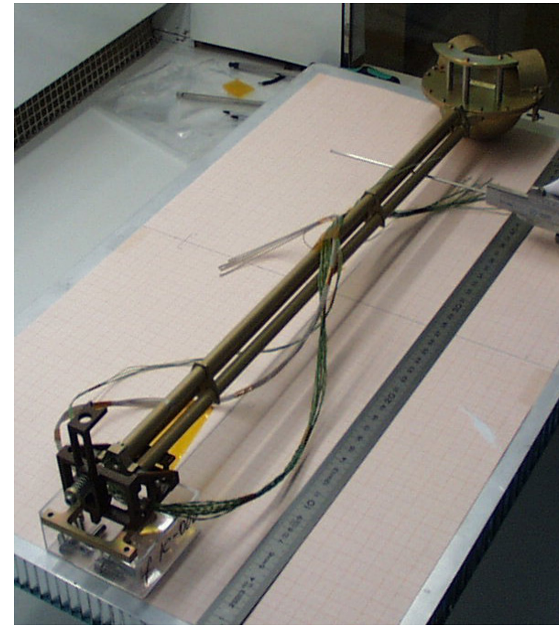
Geodesy / tracking

- Radio science (Doppler ranging, VLBI)
- Laser geodesy (retroreflectors)
- Radar/laser ranging/altimetry
- Gravimetry (link to seismometry)



Apollo LRRR

‘Space physics’

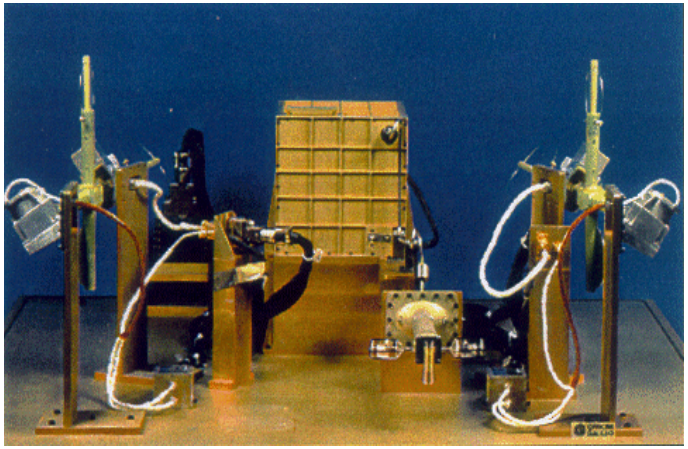


ROMAP

- Radiation
- Magnetometry
- Potentially also electric field, plasma sensors

Atmospheric physics profiles

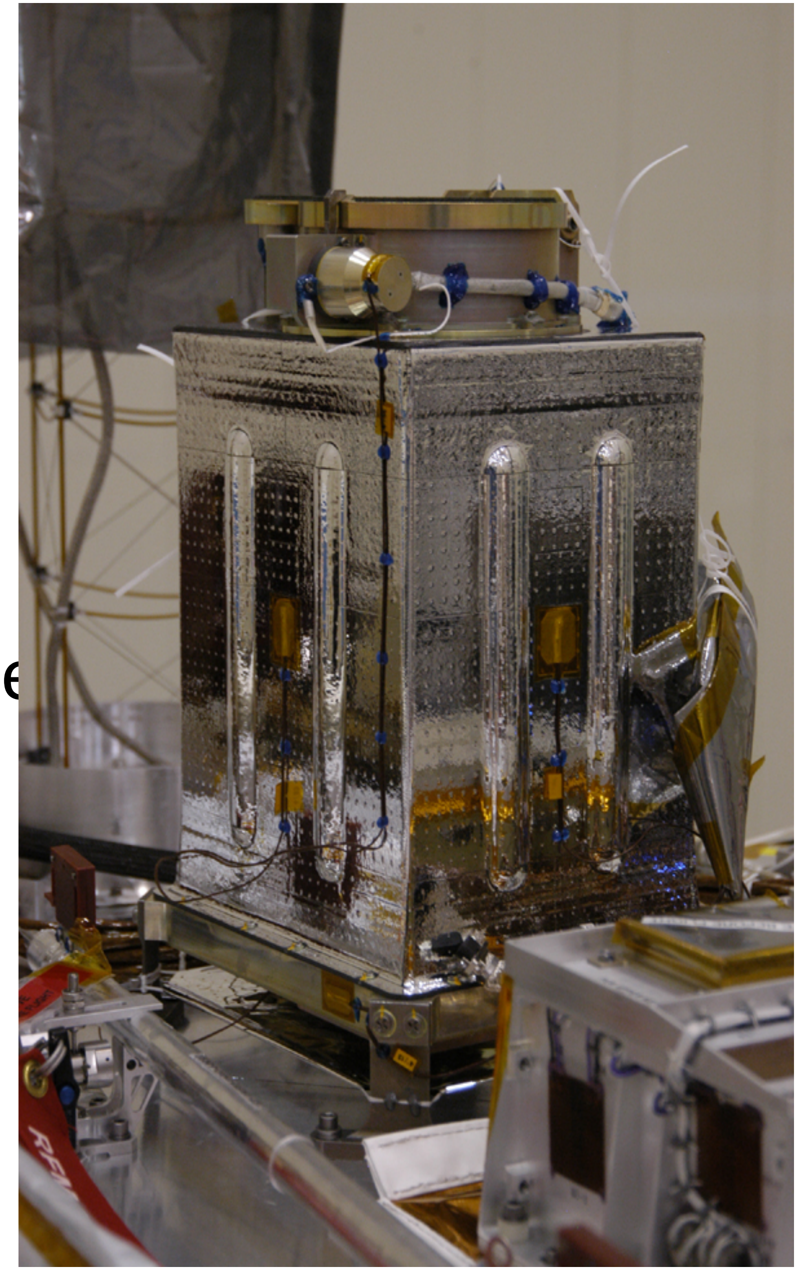
- Density (entry accelerometry)
- Temperature
- Pressure
- Humidity
- Wind / Turbulence
- Electrical field / conductivity / waves



HASI

Aerosol physics

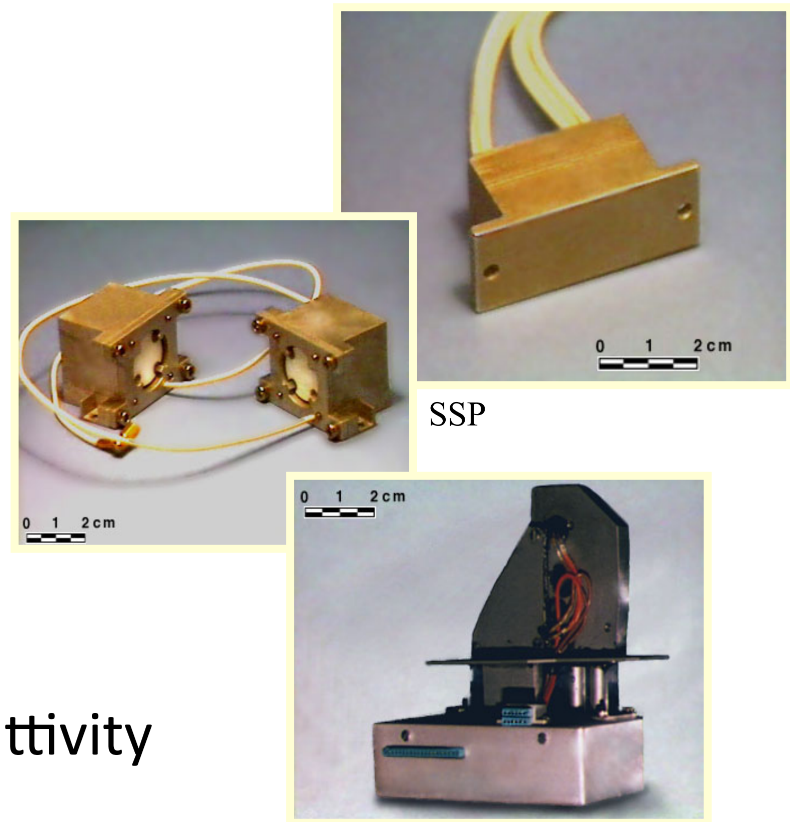
- Dust detector
- Nephelometry
- Cloud particle size spectrome
- LIDAR (for clouds)



Phoenix LIDAR

Fluid physics

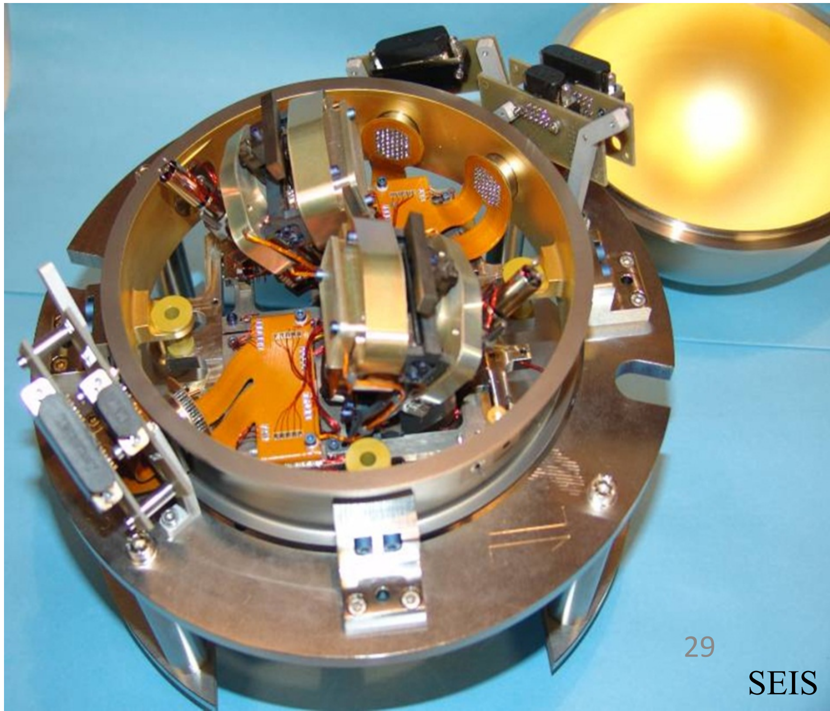
- Refractive index
- Density
- Motion (waves)
- Speed of sound
- Microphone
- Electrical conductivity / permittivity



SSP

Sub-surface sounding

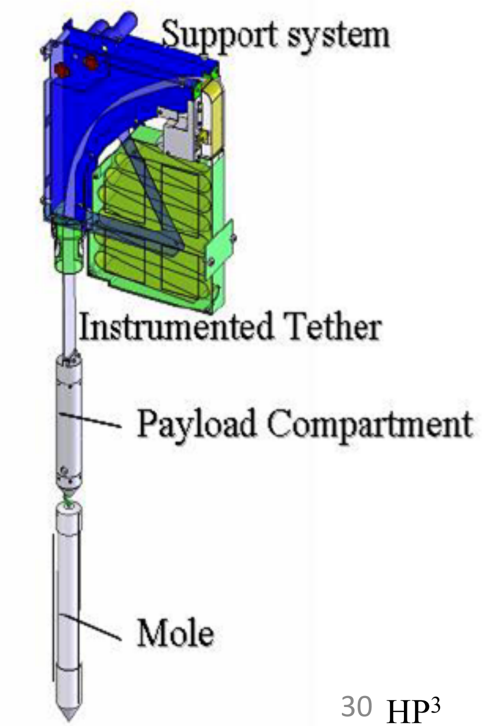
- GPR
- Radio Reflection Tomography
- Radio Transmission Tomography
- Sonar
- Seismometry (active & passive)



SEIS

Surface physical properties

- Temperature / profile / conductivity / diffusivity / heat flow (IR radiometry, T sensors)
- Magnetic permeability / susceptibility
- Electrical Permittivity / conductivity
- Abrasion
- Adherance
- Landing dynamics / attitude
- Geotechnical Properties
  - Penetration resistance
  - Drilling resistance
  - Trafficability
  - Bulk density



 HP3

Imaging

SCS

- Cameras
  - Descent
  - Panoramic (wide-angle)
  - Narrow-angle
  - Close-up
- Filters, polarisation, etc.
- Imaging of passive elements e.g. windsocks, sundial, colorimetric patches, magnets, etc.
- Imaging spectroscopy (Vis, near-IR to thermal IR)

Photometry & spectrometry

- Atmospheric profiling
  - Upward-looking
  - Downward-looking
- Atmospheric transmission to surface
- Temporal variation
- Spectral resolution (e.g. UV)
- Surface mineralogy
  - Point spectrometer
  - Raman

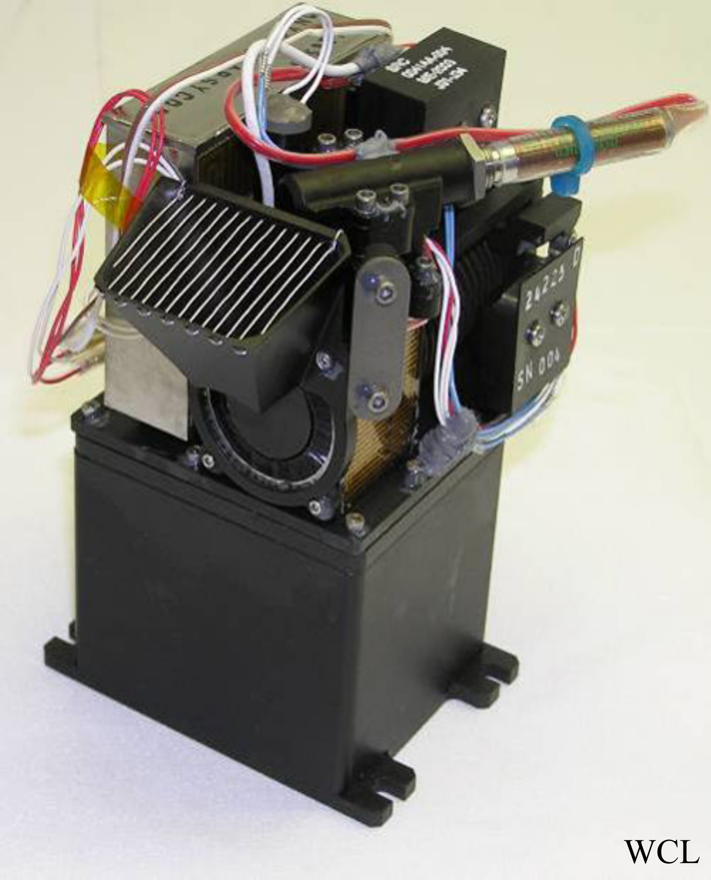
UVIS

Microscopy

ÇIVA-M

- (Imaging) IR Microscope
- Scanning Electron Microscope
- Atomic Force Microscope

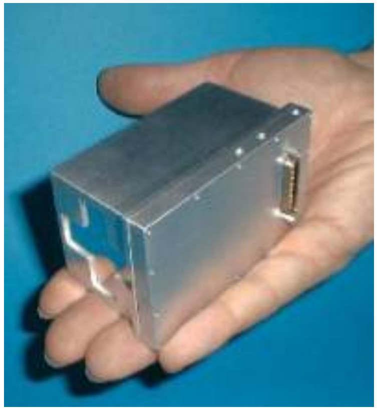
Chemical composition



- Chemical gas analyser
- Geochemical indicator
- Oxidation sensor
- Helium abundance detector
- Evolved water experiment (e.g. thermogravimetry)
- Wet chemistry lab
- Tuneable diode laser spectrometer
- Neutral Mass Spectrometer

Mineralogical & elemental composition

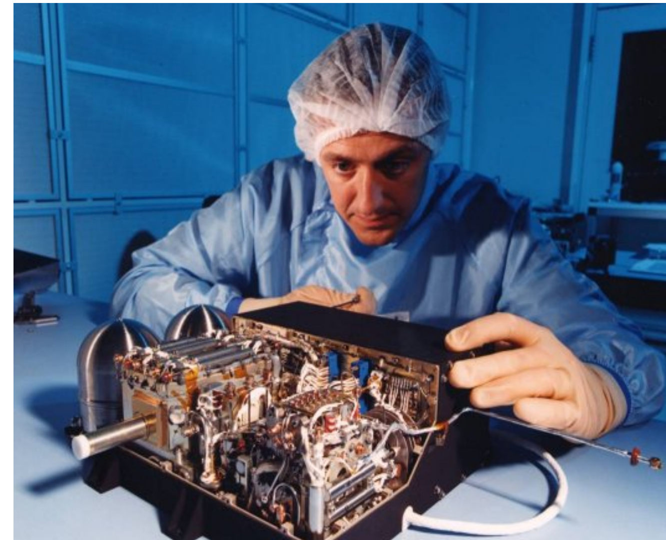
- X-ray diffractometer
- X-ray Fluorescence Spectrometer
- Alpha-(Proton-)X-Ray-Spectrometer
- Laser Ionisation Breakdown Spectrometer
- Mößbauer spectrometer
- Neutron spectrometer / pulsed neutron source
- Gamma ray spectrometer



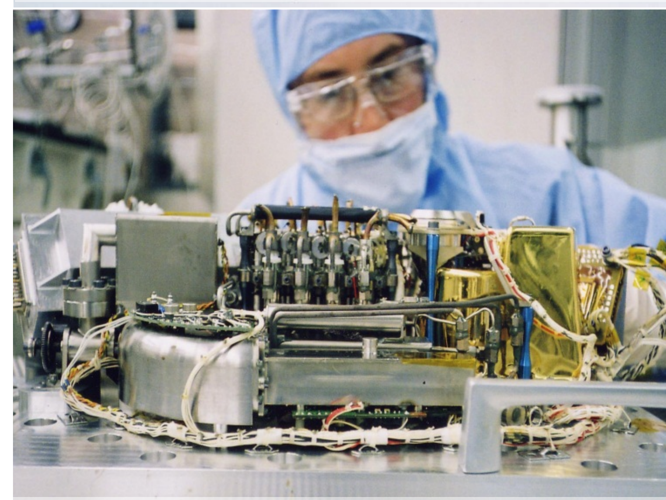
MIMOS II

Sample analysis

- GCMS
- Aerosol collection / pyrolysis
- Evolved gas analyser
- …



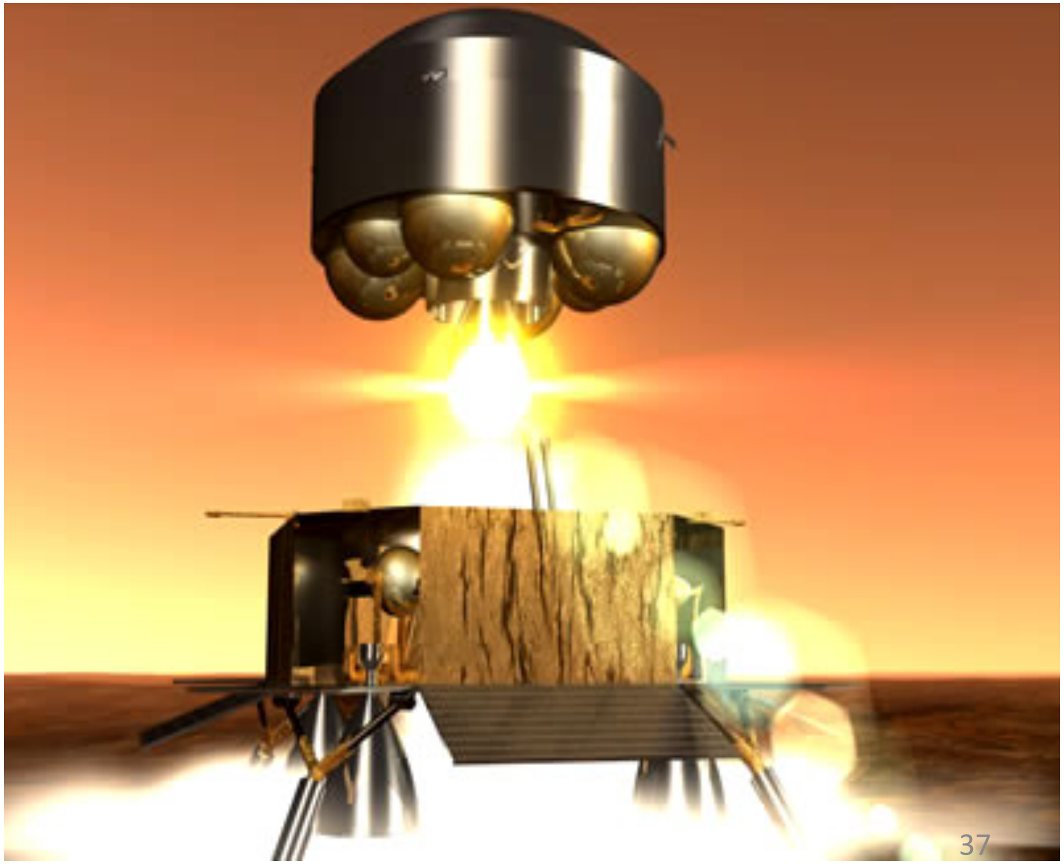
Rosetta - Ptolemy



Beagle 2 – Gas Analysis Package

Sample return

- Atmosphere
- Aerosols
- Dust
- Surface regolith
- Rock samples



ESA

Trends

- Network science (geophysics, meteorology)
- Astrobiology
- Mobility (across & below surface)
- Bulk properties [illegible] tracers
- Wider international participation / co-operation
- Lower frequency of missions
- Higher data rates / volumes
- More narrowly focused objectives

- Importance of landing site selection
- Sampling and sample return
- More exotic / extreme target environments
- Exoplanets / comparative planetology
- Money-limited
- Exploration context
- Establishment of programmes
- More precise measurements of the same targets / Focus on data quality
- Narrow objectives for smaller missions only

Payload Mass Fractions