ExoMars Atmospheric Mars Entry and Landing Investigations and Analysis (AMELIA)

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and

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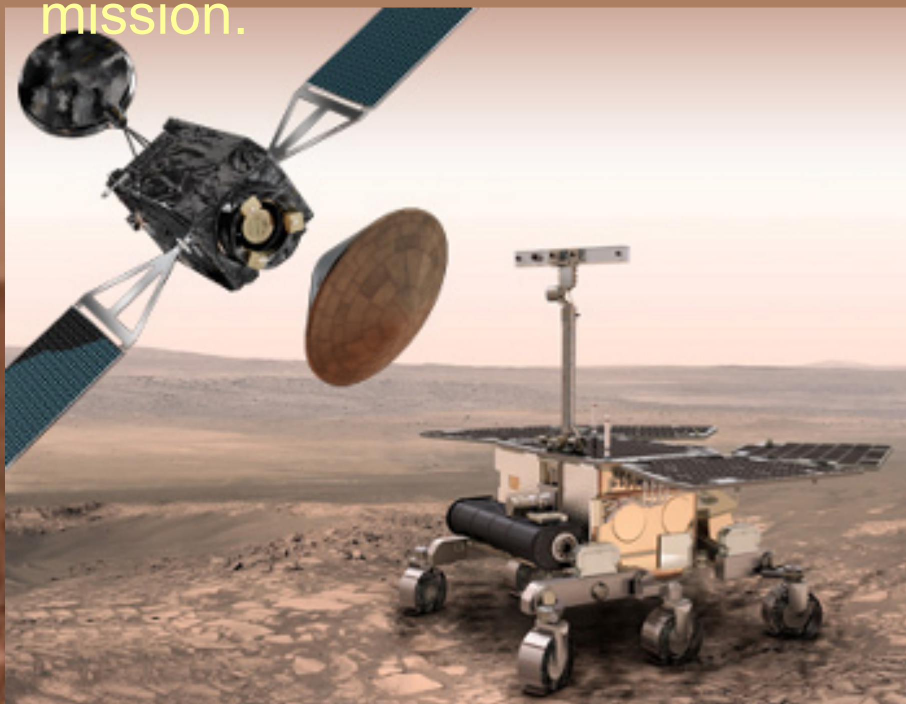
ESA ExoMars programme 2016-2018

The ExoMars programme is aimed at demonstrate a number of flight and in-situ enabling technologies necessary for future exploration missions, such as an international Mars Sample Return mission.



<u>Technological objectives</u>:

- **Entry, descent and landing (EDL) of a payload on the surface of Mars;**
- **Surface mobility with a Rover;**
- **Access to the subsurface to acquire samples; and**
- **Sample acquisition, preparation, distribution and analysis.**

<u>Scientific investigations</u>:

- **Search for signs of past and present life on Mars;**
- **Investigate how the water and geochemical environment varies**
- **Investigate Martian atmospheric trace gases and their sources.**

<u>ESA ExoMars 2016 mission</u>: Mars Orbiter and an Entry, Descent and Landing Demonstrator Module (EDM).

<u>ESA ExoMars 2018 mission</u>: the PASTEUR rover carrying a drill and a suite of instruments dedicated to exobiology and geochemistry research

EDLS measurements

- **Entry, Descent, Landing System** (EDLS) of an atmospheric probe or lander requires mesurements in order to trigger and control autonomously the events of the descent sequence; to guarantee a safe landing.
- These measurements could provide
  - the engineering assessment of the EDLS and
  - essential data for an accurate trajectory and attitude reconstruction
  - and atmospheric scientific investigations
- EDLS phases are critical wrt mission achievement and imply development and validation of technologies linked to the environmental and aerodynamical conditions the vehicle will face.

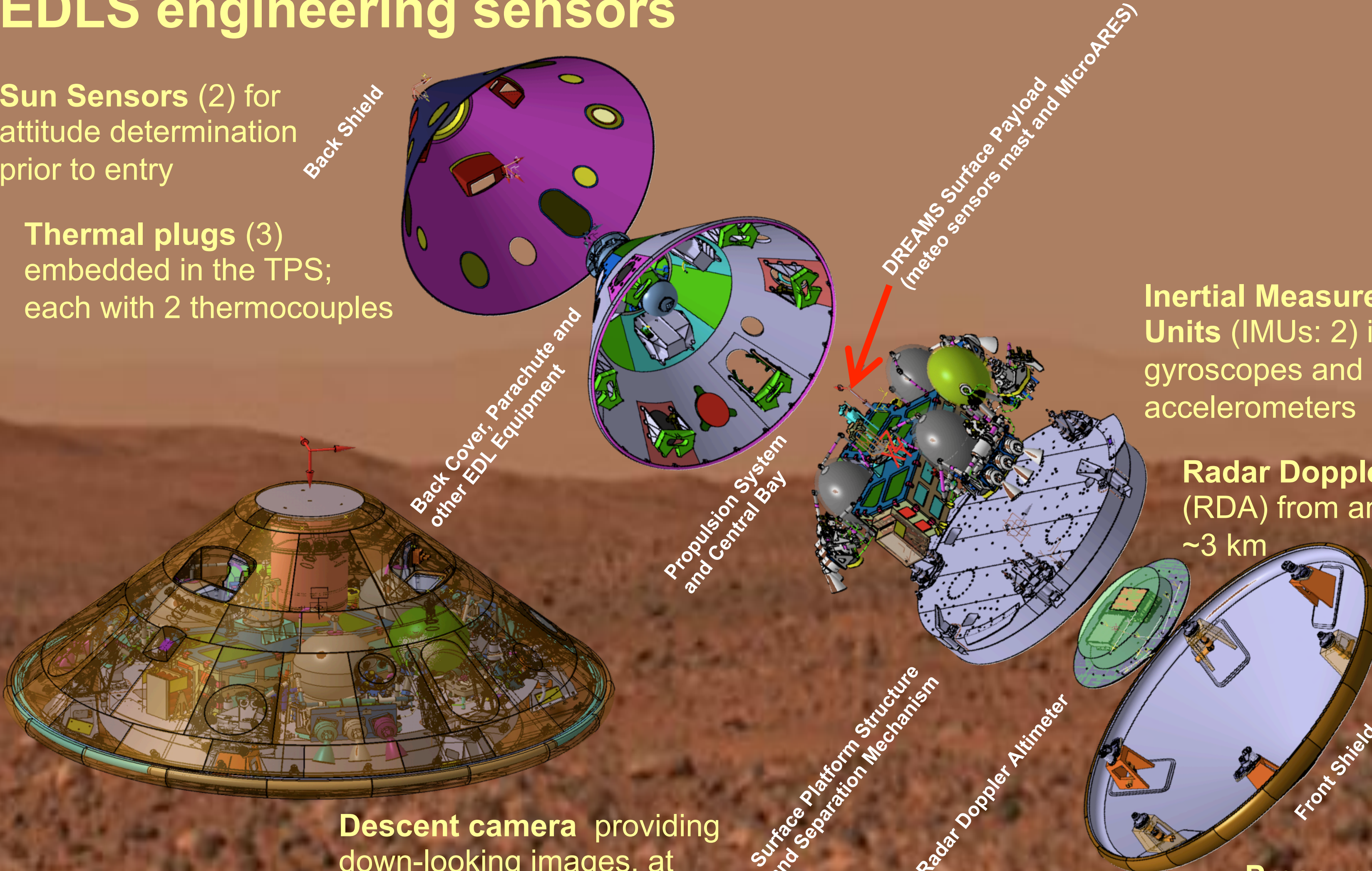
Main objective: to exploit the EDLS measurements for scientific investigations of Mars' atmosphere and surface

ExoMars 2016 Entry and Descent Module (EDM)

EDLS engineering sensors

Sun Sensors (2) for attitude determination prior to entry

Thermal plugs (3) embedded in the TPS; each with 2 thermocouples



Inertial Measurement Units (IMUs: 2) including gyroscopes and accelerometers

Radar Doppler Altimeter (RDA) from an altitude of ~3 km

Descent camera providing down-looking images, at intervals between Front Shield separation and touchdown

Thermal plugs (7) embedded in the TPS; each with 3 thermocouples

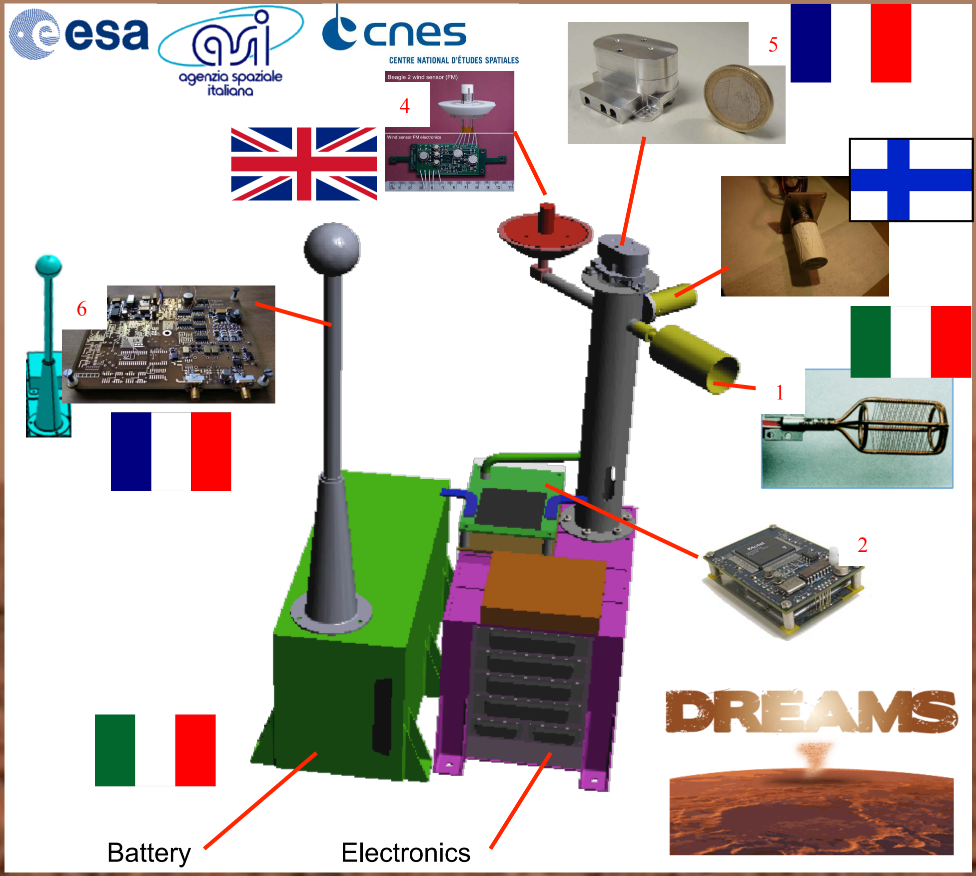
Pressure sensors (4) 1 at stagnation point , 1 at each of 3 radial locations

Credit: ESA / TAS-I

EDM DREAMS Surface Package

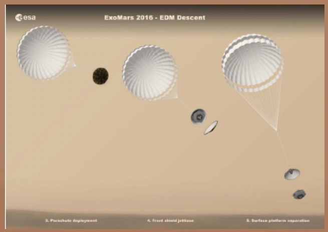
The DREAMS Surface Payload is a complete meteorological station comprising six sensors, a battery and electronics.

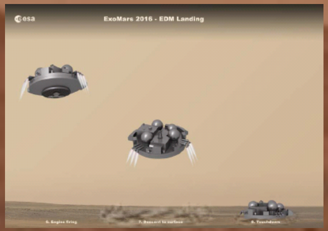
- **MarsTEM**– atmospheric temperature sensor (I)
- **MetBaro** – atmospheric pressure sensor (Fin)
- **MetHumi** – atmospheric humidity sensor (Fin)
- **MetWind** – wind sensor (UK)
- **ODS** – optical depth sensor (F)
- **MicroARES** – atmospheric electricity sensor (F)



DREAMS can demonstrate high technology readiness, based on existing European heritage from Huygens, Beagle 2, Humboldt and Phoenix

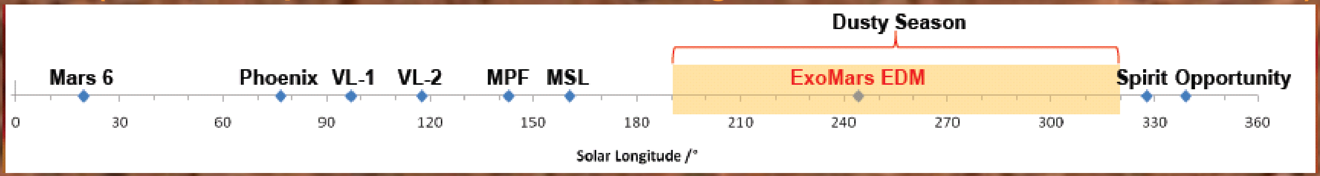
ExoMars EDLS science





- To retrieve a new **atmospheric vertical profiles** (r, p & T) along the entry & descent trajectory from an accurate trajectory and attitude reconstruction.
- To extend data set of previous entry probes at **higher altitude range** (from 160 km down to the ground) and **higher resolution**
- Reaching altitude range not covered by orbiter and providing a **ground truth** for remote sensing observations
- To provide important **constraints** for updates and validations of the Mars **General Circulation models.**

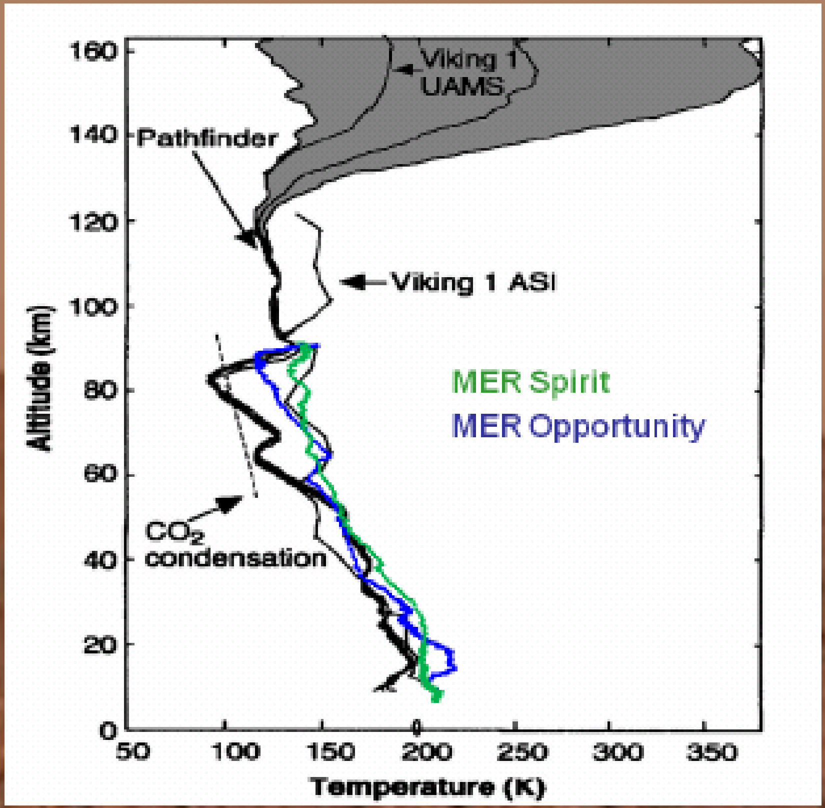
☺ **New direct measurements** from different site, season and time period (the unique recorded during the **dust storm season**)



to investigate the Mars atmospheric structure, dynamics and variability and to study the effect of the dust on Mars climate and meteorology

Scientific case: in situ measurements

Mars' atmosphere is highly variable in time and space



- To date only six vertical profiles of density, pressure and temperature of martian atmosphere have been derived from *in situ* measurements:
- *Viking 1 & 2* in day time [Seiff & Kirk, 1977]
- *MarsPathfinder* at night time [Schofield *et al.* 1997; Magalhães *et al.* 1999]
- Two more profiles from *Mars Exploration Rover* (*MER*) [Withers & Smith 2006] with much lower accuracy.
- Mars Phoenix: first profile from the martian polar regions [Withers & Catling 2010]

Around 80-90 km altitude *Opportunity* as *Pathfinder* observed a strong thermal inversion and very low temperature

😐 only **three *in situ* high vertical resolution** and **high accuracy profiles**.

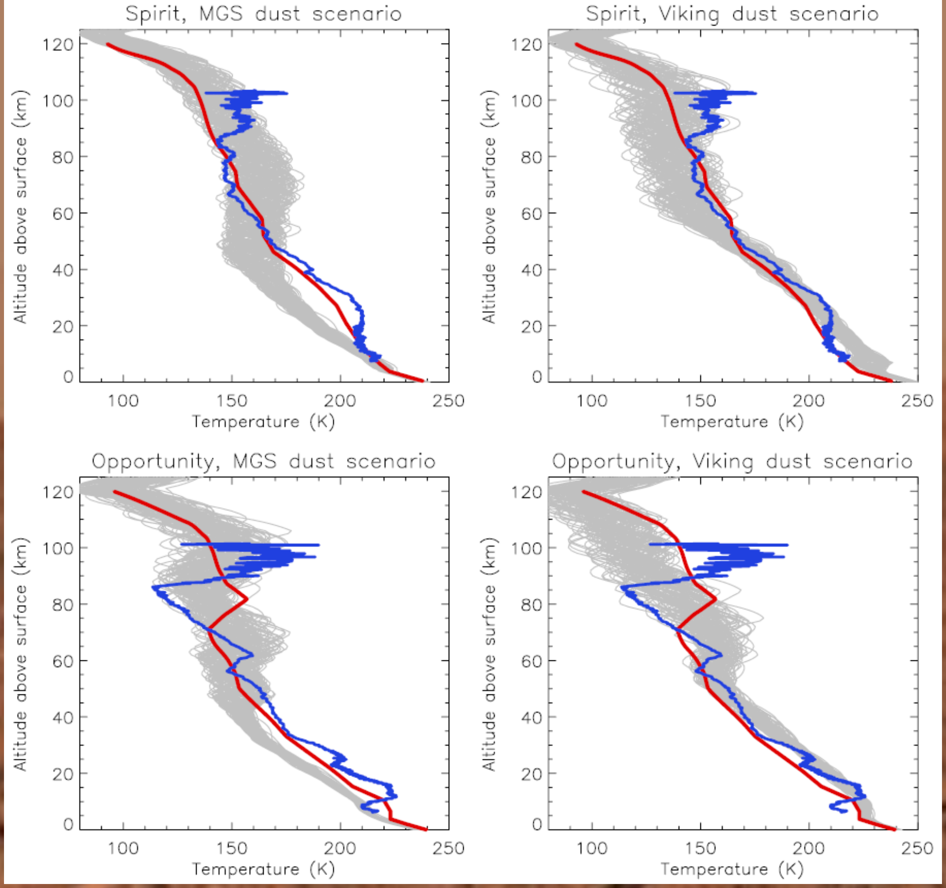
☹ **Pathfinder, MER, Phoenix, MSL: no direct atmospheric temperature measurements**

EDL science
Modelling and Data assimilation

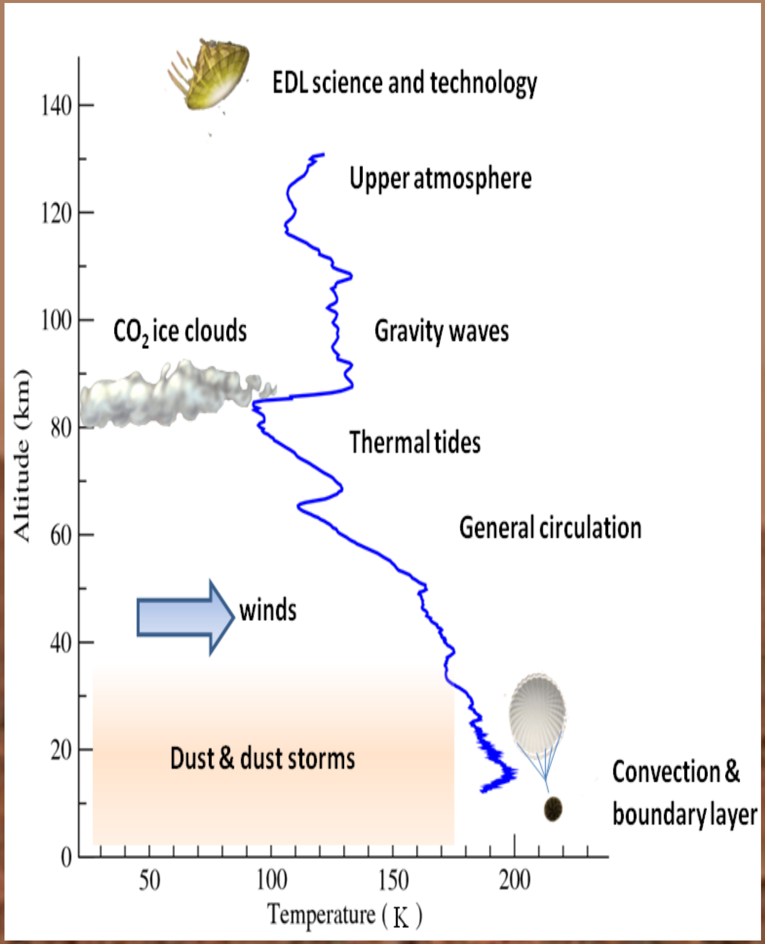
Comparison of **MER entry profiles** with both general circulation model results [Lewis *et al*. 1999] and the assimilation of MGS TES data [Lewis *et al*. 2007]

Between 20-40 km temperatures are warmer than expected from GCM (similar for *Viking*), but in disagreement with radio occultation and TES observations

High resolution and wide altitude range *in situ* measurements could provide constrains and validation of remote sensing observations and models



AMELIA key science objectives



Atmospheric investigations:

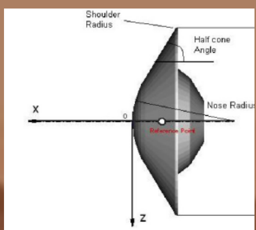
- Charaterize the **atmospheric structure** along the entry probe trajectory.
- Investigate **atmospheric dynamics** and **horizontal structures** from temperature profile and wind determination.
- Determine the vertical propagation of atmospheric **gravity waves** and **tides** and hence vertical coupling of the atmosphere
- Characterize **aerosols** aboundances (**dust** and condensate).

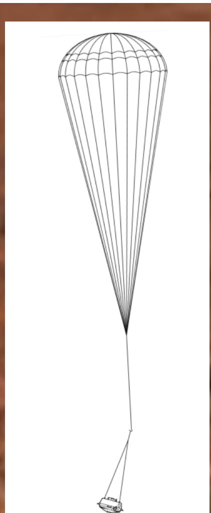
EDL engineering assessment:

- **Trajectory** and **attitude reconstruction**
- **Landing site** characterization and assessment – **Surface Science**

Mars' atmosphere structure, dynamics and variability will be studied by comparison with previous *in situ* measurements, data assimilation and General Circulation Models

EDL science
Trajectory and attitude reconstruction





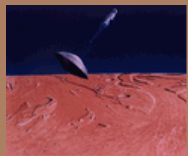
- **Entry** reconstruction from pressure sensors embedded in the frontshield (TPS sensors).
- **3DoF** reconstruction using **Direct integration** of the acceleration data (in axial and normal directions of probe body frame); iterative procedure to fix the entry state vector.
- **Entry phase 6DoF EKF:** 6DoF dynamical model + Extended Kalman filter.
- **Descent phase 6DoF EKF:** similar approach, with EKF incorporating IMU data, radar altimeter and/or descent images.
- Near-real time reconstruction using **EDL radio communication link.**

*Algorithms for simulation and reconstruction have been developed and validated with **Huygens** mission data and from balloon experiments, and tools for reconstruction of **MERs** and **Phoenix**.; also expertise from **MSL MEDLI***

Different approaches and methods will be applied within the AMELIA team for cross-check validation and to retrieve the most accurate atmospheric profile.

Lessons learned and requirements

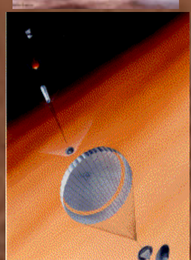
Viking



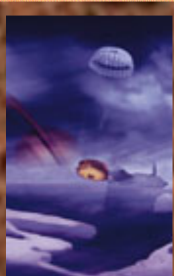
Pioneer Venus

Galileo

Mars Path-finder



Huygens



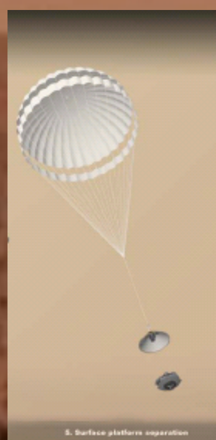
Experience *and* ***lessons*** *learned with* ***Huygens*** *in perspectives for future in situ exploration:* ***ExoMars***

- Accurate knowledge of the entry state (initial position, velocity) by flight dynamics, probe imaging, radio tracking …
- Instrumented heat shield for engineering assessment of entry phase and support of trajectory (and atmospheric profile) reconstruction.
- For EDLS dynamics reconstruction 3-axial ACC and/or gyros are necessary for a accurate attitude (AoA) determination
- Redundant devices to ensure safety (e.g. G-switch)

Genesis

EDL science
Atmospheric profile reconstruction

- **Density** (directly from deceleration measurements), **pressure** (assuming hydrostatic equilibrium law) and **temperature** (by mean of the ideal gas law) profiles retrieved from acceleration data



From acceleration measurements

density profile from the top of the atmosphere (1570 km) to parachute deployment at ~ 160 km

$$\mathbf{r(z)}=-2(m/C_DA)(a/V_r^2)$$

$\mathbf{V_r}$ and **z** from measured acceleration & initial conditions

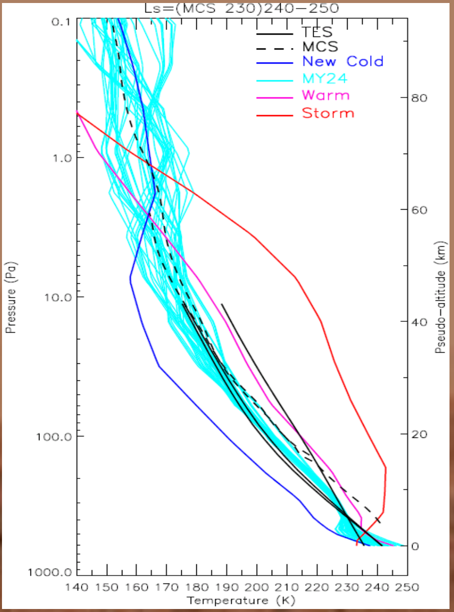
Indirect **temperature** and **pressure** measurements

Hydrostatic equilibrium $dp=-grdz$ **p(z)**

Equation of state of gas $r= mp/RT$ **T(z)** , $T=mp/rR$

EDL science
Modelling and Data assimilation

Prediction at ExoMars landing site

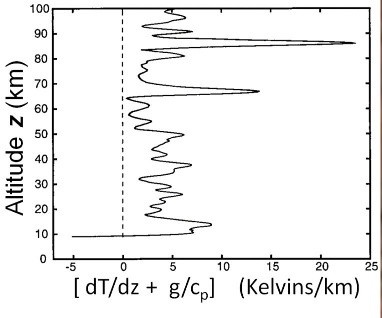


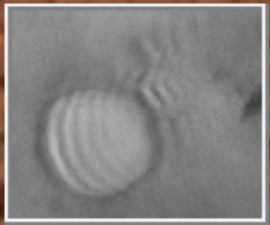
Dynamics and **static stability**

- General atmospheric structure
- Impact of atmospheric dust on the general circulation.
- Measure winds in the free atmosphere

Gravity waves and **tides**

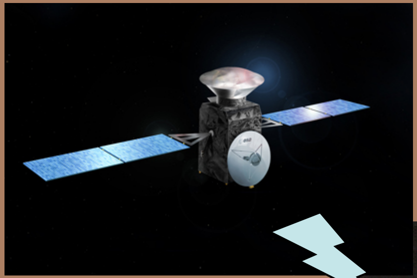
- Observe gravity waves (and constrain their parametrization)
- Characterize thermal tides and their sensitivity to dust.



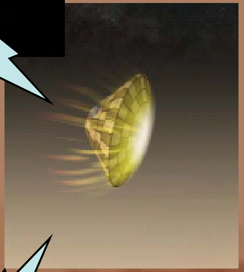


Pathfinder [*Magalhaes et al.,1999*]

EDL science
Modelling and Data assimilation



- **Wind** profile along entry probe path from EDM radio tracking both from TGO and Earth [e.g. Huygens DWE, Bird et al. 2005] and from trajectory and attitude variations;



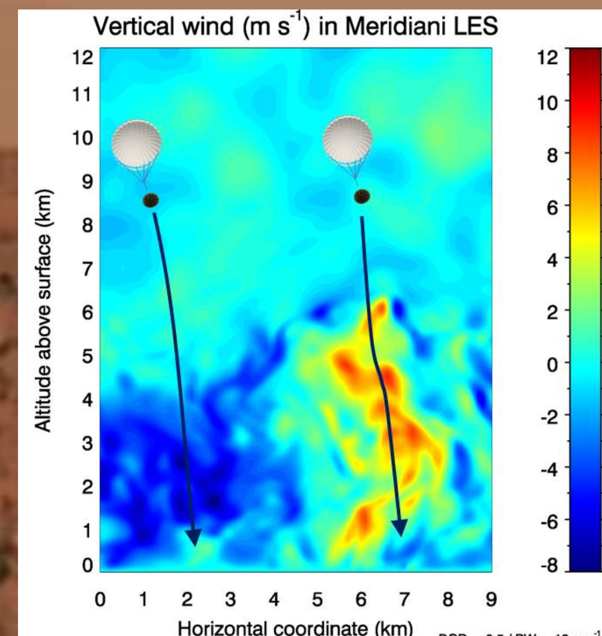
- During parachute descent phase, **wind** motions could be inferred from horizontal motion of the pendulum system of parachute chain + EDM [e.g. Seiff 1993, 1997]

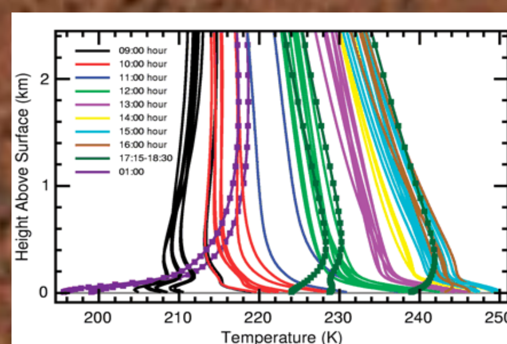
EDL science
Modelling and Data assimilation

Probing **Planetary Boundary Layer**:

- Estimating the altitude of the top of the PBL (comparison with Large Eddy simulation model)
- Measurements of wind speeds and turbulence inside the PBL
- Observing the turbulence scale and intensity

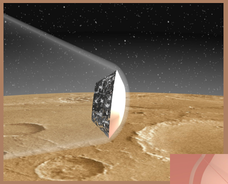
also in synergy with EDM DREAMS data (meteorological and enviroment measurements at surface)

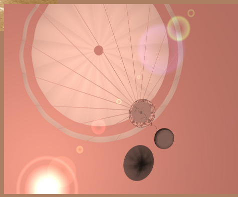




MER Spirit, Smith et al. (2004)

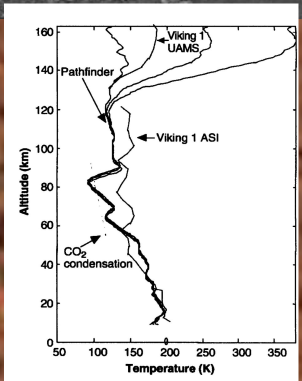
Scientific case: aerosols (dust, condensates)





- **Dust** and **aerosols** abundance by combination of measurements: atmospheric opacity (from solar flux measured by sun sensors on the back shield) + temperature profile; frontshield ablation.
- **Dust load** and detection of **condensates**: fog and clouds from temperature inversions and as sources of extra opacity

- ***Descent-truth*** measurements for atmospheric opacity as input for GCMs and **synergies** with TGO (EMCS & NOMAD) instruments

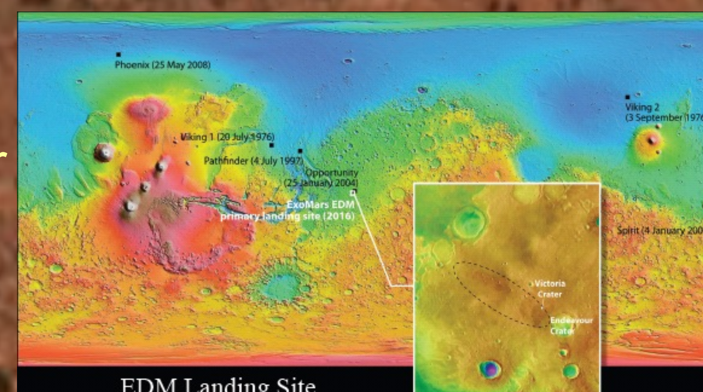


Surface Science

- **Impact detection**
  from impact trace recorded by IMU and accelerometer
  => dynamic response of the probe structure to impact and post-impact movements and attitude

- **Landing site characterization and assessment**
  remote sensing, descent and surface images for assessing landing site geomorphology & surface characteristics

  - **Orographic / elevation profile** over the ground track of the descent module:
    from radio tracking and radar Doppler altimeter from down 3 km
  - Digital Elevation Model (**DEM**)
    of the terrain surrounding the EDM
    from descent and surface images



Conclusions

- The entry, descent and landing of *ExoMars* offer a rare (once-per-mission) opportunity to perform *in situ* investigation of the martian environment over a wide altitude range.
- Assessment of the atmospheric science by using sensors of the Entry, Descent and Landing System (EDLS), over and above the expected engineering information.
- **The ExoMars 2016 EDM unique data will be analyzed combining together European expertise in Mars observations and modelling**.
- New data from different site, season and time period (the unique recorded during the dust storm season) ->
  to investigate the thermal balance of surface and atmosphere of Mars, diurnal variations in the depth of the planetary boundary layer and the effects of these processes and dust on the martian general circulation.
- A better understanding of the martian environment and meteorology also -> for refining and constraining landing techniques at Mars and to evaluate the possible hazardous to machines and humans in view of future Martian explorations.