AMELIA
(Atmospheric Mars Entry and Landing Investigations & Analysis)
the ExoMars Entry, Descent & Landing Science

F. Ferri¹, O. Karatekin², A. Aboudan¹, B. Van Hove², G. Colombatti¹, C. Bettanini¹, S. Debei¹, S. Lewis³, F. Forget⁴, S. Asmar⁵

¹Università degli Studi di Padova, Centro di Ateneo di Studi e Attività Spaziali “Giuseppe Colombo” (CISAS)
(francesca.ferri@unipd.it)

²Royal Observatory of Belgium (ROB), Brussels, Belgium

³School of Physical Sciences, The Open University, Walton Hall, Milton Keynes MK7 6AA, UK.

⁴Laboratoire de Météorologie Dynamique, UPMC BP 99, 4 place Jussieu, 75005, Paris, France

⁵Jet Propulsion Laboratory, California Institute of Technology - NASA, Pasadena, CA, USA

EuroPlanet Workshop: ExoMars Atmospheric Science and Missions Workshop
Saariselkä, Finland 26-30 March 2017
**In situ measurements**

- First *in situ* measurements of the Mars atmospheric structure by URSS Mars 6 before crashing [Kerzhanovich, 1977]
- To date only seven vertical profiles of density, pressure and temperature 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 Rovers (MER): Spirit and Opportunity** [Withers & Smith 2006] with much lower accuracy.
  - **Phoenix**: first profile from the martian polar regions [Withers & Catling 2010]
  - **MSL-Curiosity** [Holstein-Rathlou *et al.* 2016]
ExoMars AMELIA – EDL science

- Atmospheric Mars Entry and Landing Investigations & Analysis (AMELIA)
  to exploit the EDLS engineering measurements for scientific investigations of Mars’ atmosphere and surface.
Schiaparelli EDL scenario

Crash landing
Schiaparelli impact site

MRO HiRISe image on 28 Oct 2016

MRO CTX image on 20 Oct 2016
Schiaparelli flight data for AMELIA

- Doppler tracking (TGO/MEx/GMRT Pune)

- Essential data set:
  - GNC estimates (derived from IMU)
  - FADS heat shield pressures
  - Radar altimeter (very few samples)
UHF radio Signal from GMRT at PUNE, India
Doppler tracking by TGO

EDM-TGO Doppler shift

- Doppler shift samples
- 14:42:23 Start of Plasma Blackout
- 14:42:22 Start of EIP
- Doppler pre-steering
- 14:43:32 End of Plasma Blackout
- 14:45:23 Parachute opening
- Doppler rate as computed from simulation including TX frequency compensation
- 14:46:49 Backshell separation
- 14:47:27 LOS

Doppler measured at TGO  Doppler presteering at TGO[Hz]  Doppler predicted TASI (after SEP)  Carrier Lock: 0=Lock Dropped, 1=No Drop Locks
Schiaparelli flight data

load factor $= I_a \_ I\_ \text{aerol} \text{ and (in figure) multiplied by } x180$, FADS data were debiased using average from [-80 -30] sec

end of blackout: EIP+91 s

EDM acceleration load factor

heat shield pressure measurements
INPUT FOR AMELIA SIMULATION/RECONSTRUCTION

- **EDL Measurements**
  - GNC measurements: IMU, RDA, (SDS)
  - TPS sensors: FADs (pressure sensors)
  - Doppler tracking of the EDM UHF signal
- **Entry state vector**
- **Mars models (e.g. gravity, atmosphere)**
- **EDM dynamical models**
  - 3-6 DoF Entry model
  - 9 DoF Descent model
  - + Extended Kalman filtering

EDM TRAJECTORY & ATTITUDE

ATMOSPHERIC PROFILE

- CO₂ ice clouds
- Gravity waves
- Thermal tides
- General circulation
- Convection & boundary layer
- Winds
- Dust & dust storms
• **MIMU saturation**
  - detected checking the angle between GNC velocity and sensed acceleration
  - Oscillations at parachute opening produced using a physical model (too many degrees of freedom)
  - Angular rate computed from sensed accelerations
DESCENT RECONSTRUCTION

- Attitude 10s before RCS on
Schiaparelli landing groundtrack

Impact site:
Lon: -6.20° E
Lat: -2.05° N
ATMOSPHERIC RECONSTRUCTION

Density

Geocentric altitude [km]

Density [kg/m$^3$]

FE2E
EDM

Saariselka EPN WS 2017
AMELIA: ExoMars EDL science
F. Ferri & the AMELIA team
ATMOSPHERIC RECONSTRUCTION

Pressure

![Graph showing atmospheric pressure and geocentric altitude relationships.](image-url)
ATMOSPHERIC RECONSTRUCTION

Temperature

- Geocentric altitude [km]
- Temperature [K]

Blue line: FE2E
Red line: EDM
Tools to model the environment

Dust fronts, regional dust storms, local gusts, dust devils

Global Circulation Models

Mesoscale Models

Mars Climate Database: www-mars.lmd.jussieu.fr

Large-Eddy Simulations
Data available for Schiaparelli

- **MRO: HIRISE, and MCS**
  - CTX and HIRISE observations of the impact site
  - MCS (inverted profile of T + dust + cloud + estimated dust column optical depth)
  - **Mars Express / PFS**: Temperatures; dust opacities
    - up to 3 nighttime/3daytime measurements

- **Opportunity dust opacity measurements**
  - At least 1 measurement / day

Lemmon [http://www.lpl.arizona.edu/~lemmon/mars-tau-b.html](http://www.lpl.arizona.edu/~lemmon/mars-tau-b.html)
ATMOSPHERIC RECONSTRUCTION
Schiaparelli vs models / data assimilation

Mars Climate Database
(MCD 5.2) scenarios

- **Schiaparelli**
  Meridiani Planum
  2.05° S -6.2 E
  Ls 244.4°
  LMST 13:00
ATMOSPHERIC RECONSTRUCTION
Schiaparelli vs models / data assimilation

OU GMC with data assimilation; MRO-MCS obs

- **Schiaparelli**
  Meridiani Planum
  $2.05^\circ$ S, $-6.2^\circ$ E
  $L_s 244.4^\circ$, MY33
  LMST 13:00
EDM profile vs models/data assimilation

- Mars Climate Database (MCD 5.2) scenarios;
- OU GMC with data assimilation;
- MRO-MCS obs

- **Schiaparelli**
  Meridiani Planum
  2.05° S -6.2 E
  Ls 244.4° MY33
  LMST 13:00
EDM profile vs models/data assimilation

- **Schiaparelli**
  Meridiani Planum
  $2.05^\circ$ S - $6.2^\circ$ E
  $L_s$ $244.4^\circ$
  LMST 13:00

- **MPF**
  $19.09^\circ$ N,
  $326.74^\circ$ E
  $L_s$ $142.7^\circ$
  02:58 LT nighttime
MEx-PFS observations over Schiaparelli landing site

8 spot-pointing observations over Schiaparelli landing site: 2 before (Oct 16, 18) and 6 after landing (Oct 20, 21, 22, 23, 25, 27)
Conclusions

- Atmospheric reconstruction from dynamic pressures is consistent with the one retrieved from GNC/inertial sensors.
- Need to validate flight data and verify the trajectory reconstruction, before assessing a consolidated atmospheric profile.

- Putting the experience and the lessons learned into perspectives for ExoMars 2020 EDL.
- *Schiaparelli Investigation Anomaly / Inquiry Review Board still to be completed.*