

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.

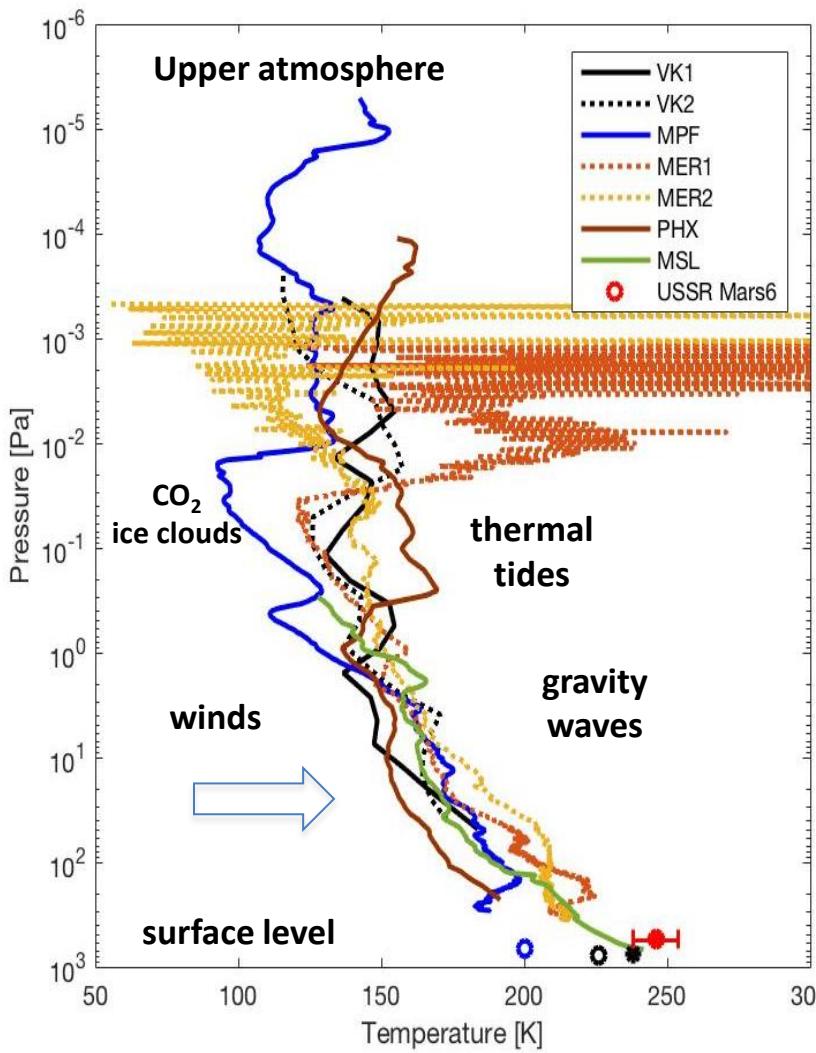
⁴Laboratoire de Météorologie Dynamique, UPMC BP 99, 4 place Jussieu, 75005, Paris, France

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.

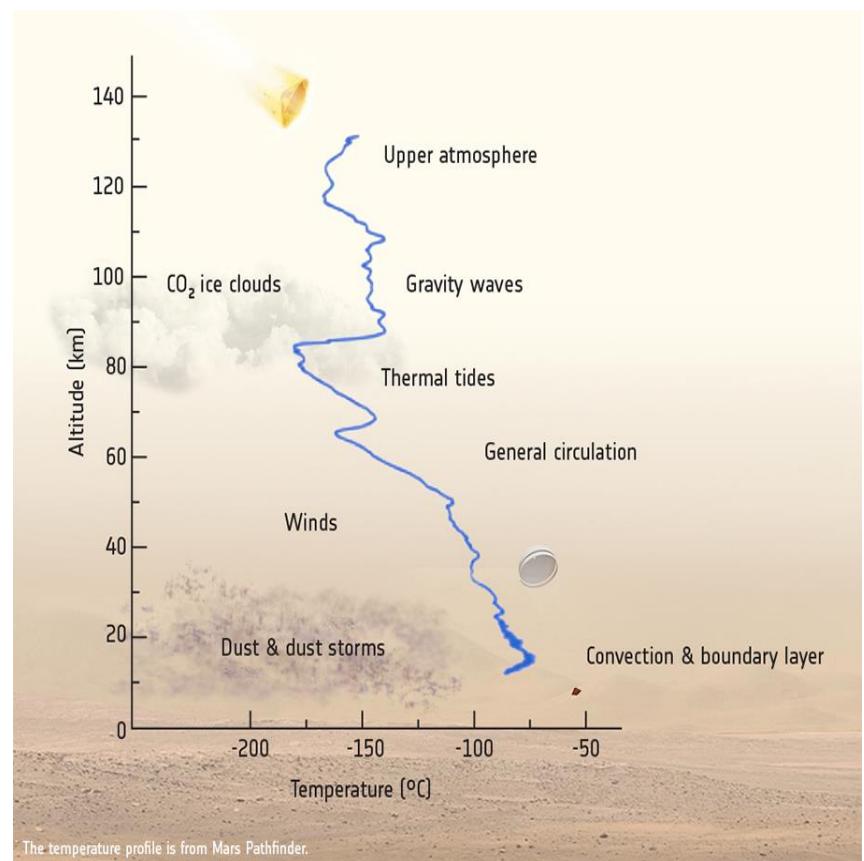
Entry



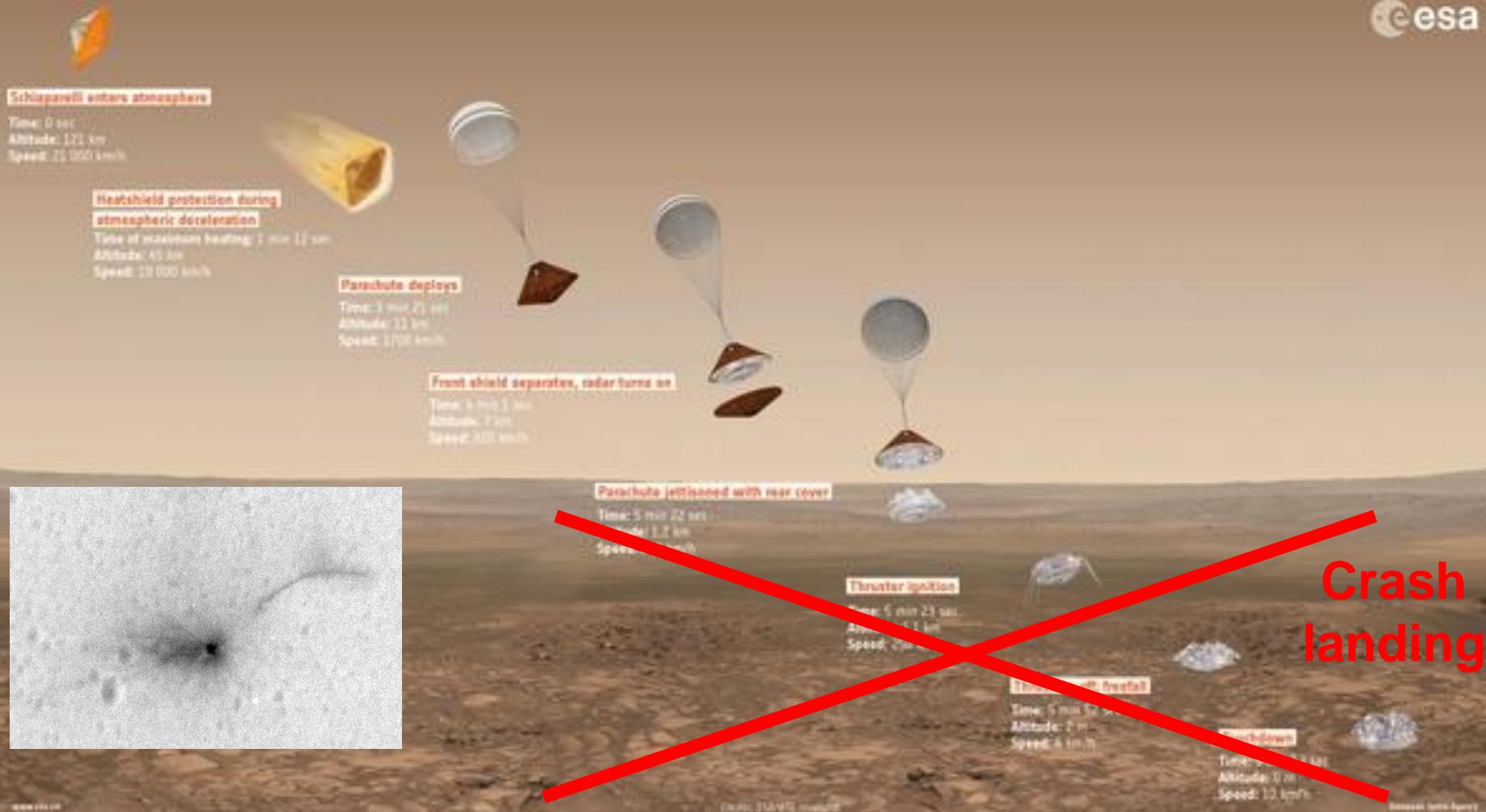
Descent



Landing



Schiaparelli EDL scenario

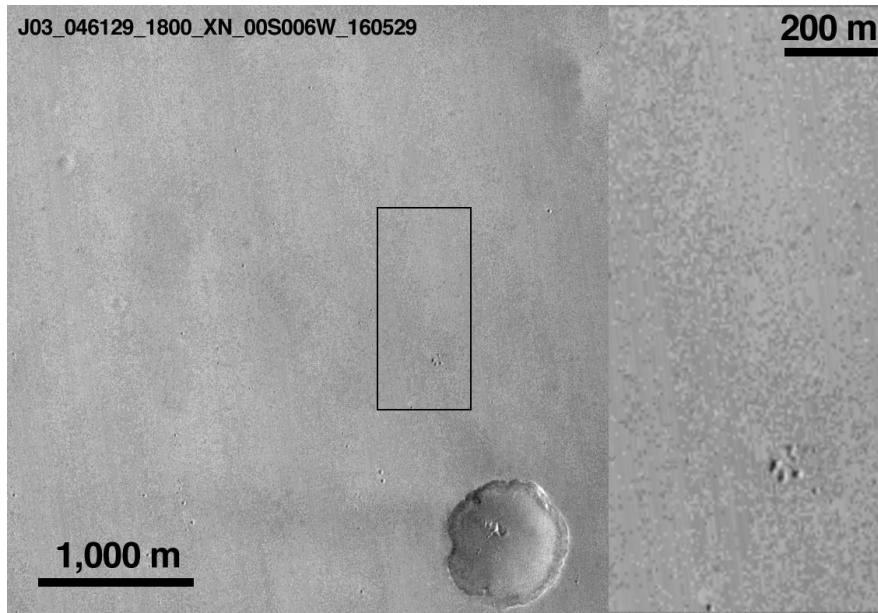


Schiaparelli impact site

MRO HiRise image on 28 Oct 2016

J03_046129_1800_XN_00S006W_160529

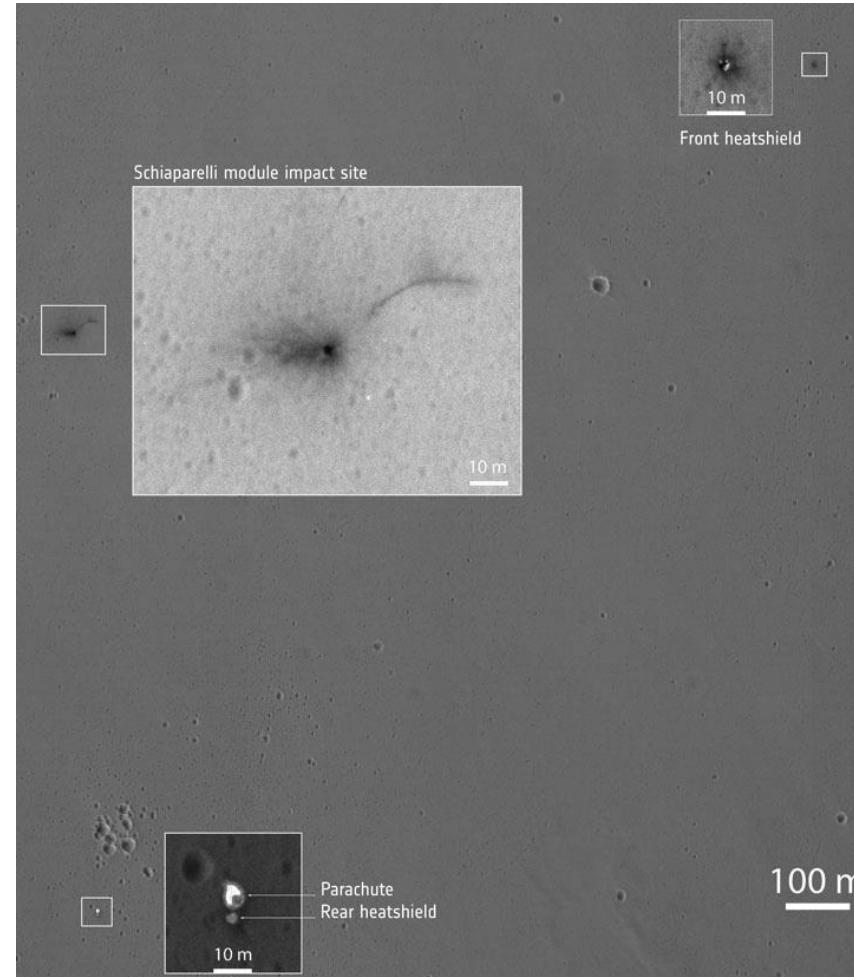
200 m



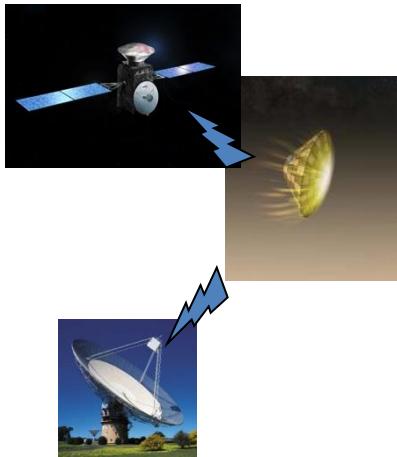
MRO CTX image on 20 Oct 2016

Schiaparelli module impact site

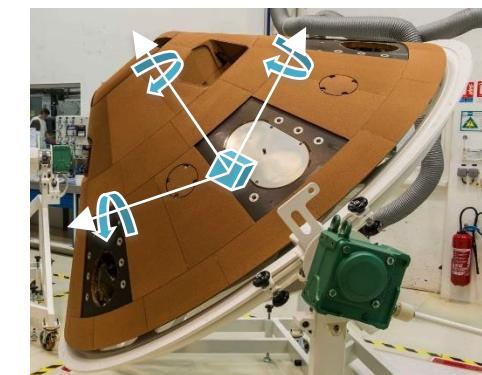
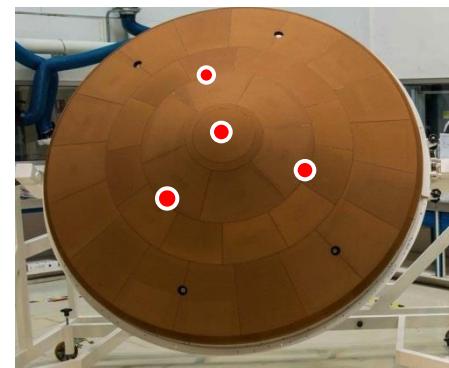
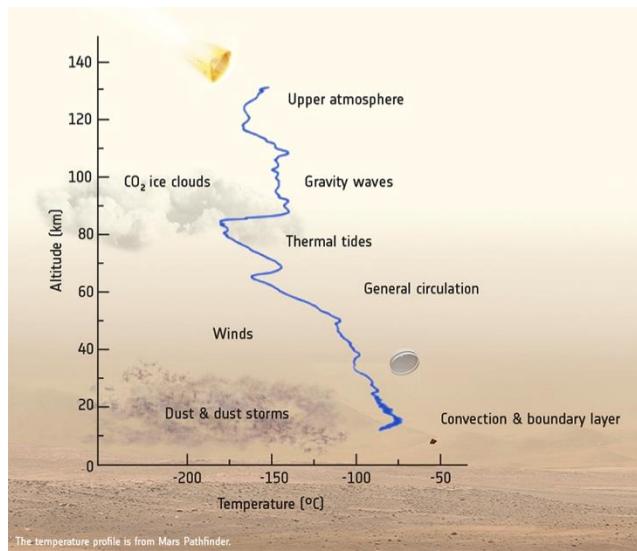
10 m

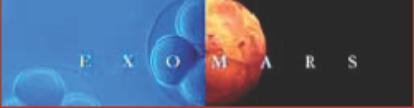


Schiaparelli flight data for AMELIA

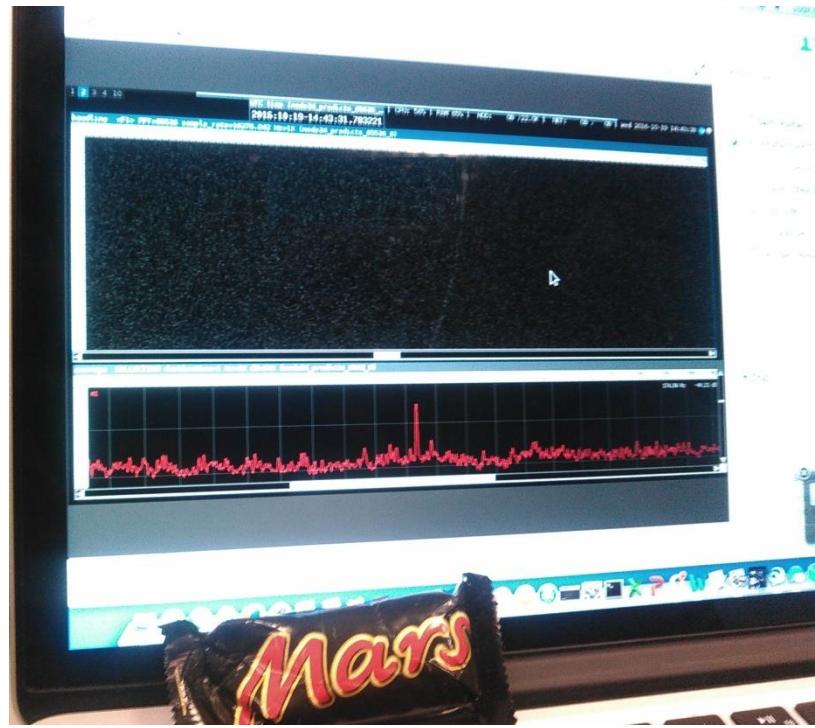


- Doppler tracking (TGO/MEx/GMRT Pune)
- Essential data set:
 - GNC estimates (derived from IMU)
 - FADS heat shield pressures
 - Radar altimeter (very few samples)



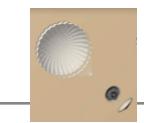


UHF radio Signal from GMRT at PUNE, India

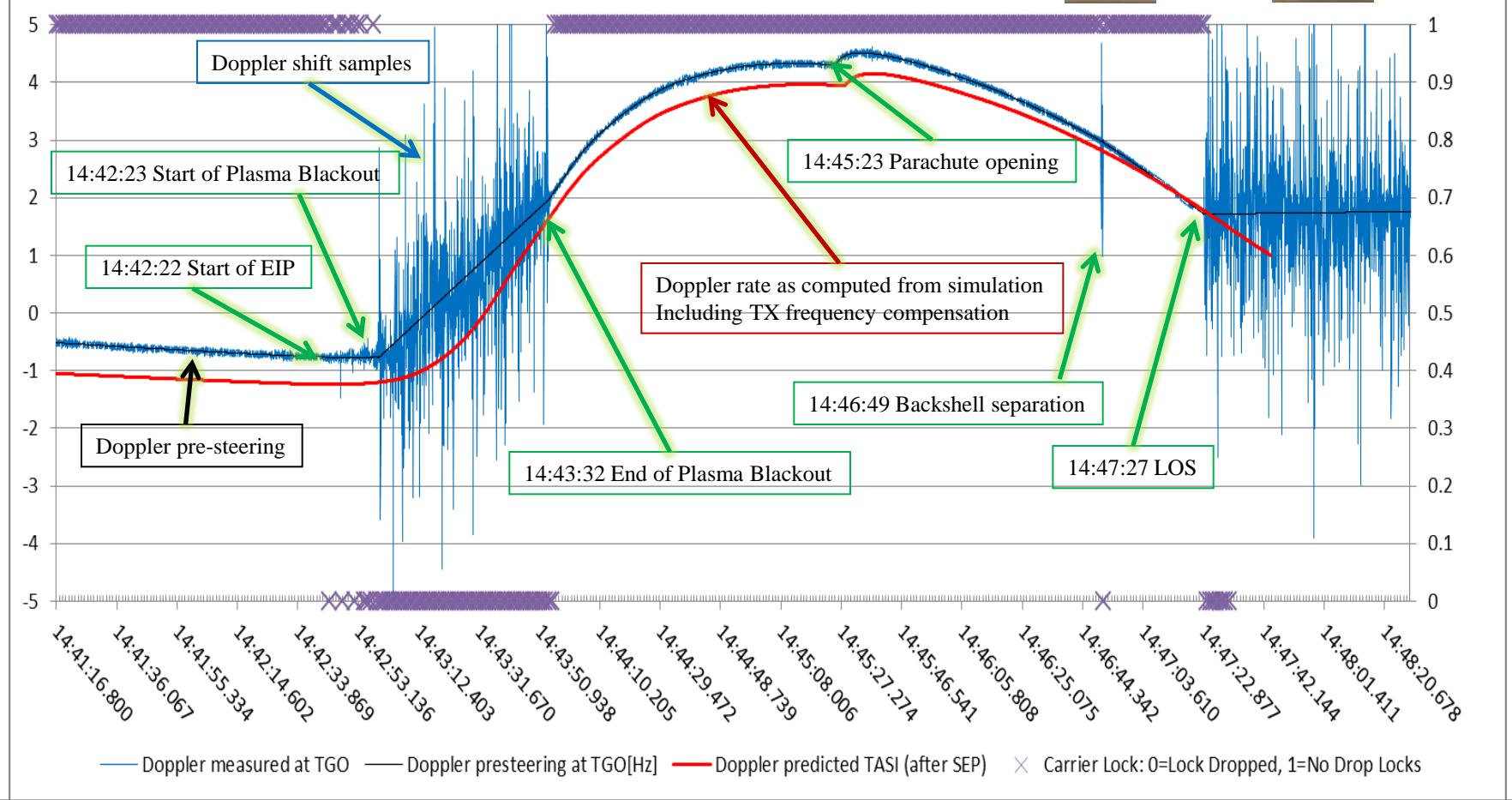


ESOC main control center

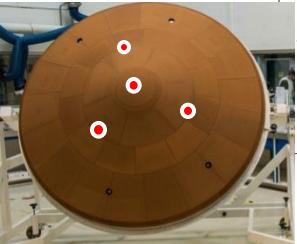
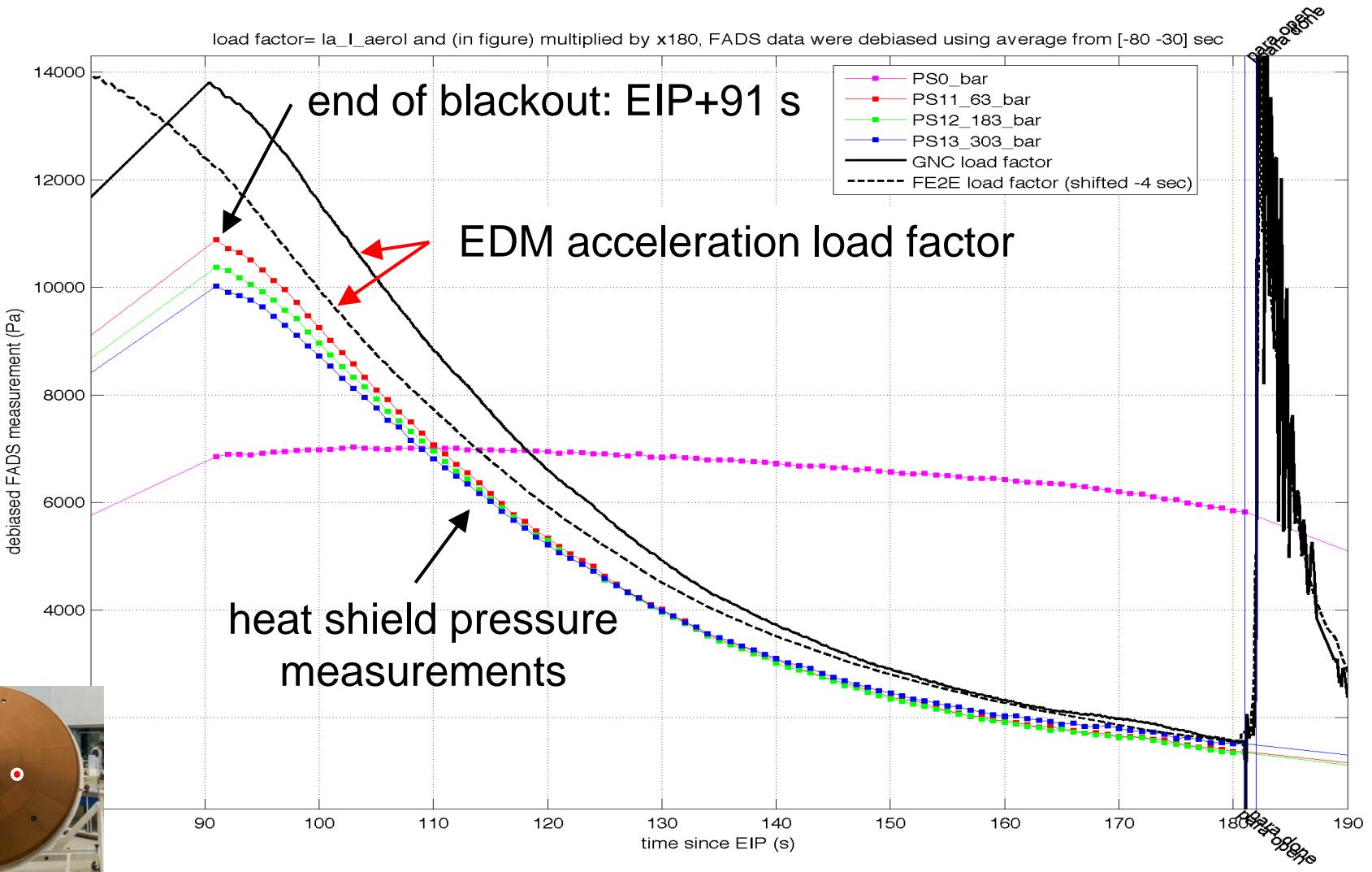
Doppler tracking by TGO



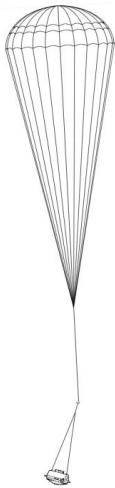
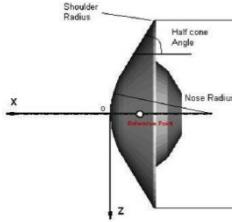
EDM-TGO Doppler shift



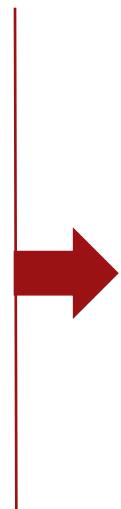
Schiaparelli flight data



INPUT FOR AMELIA SIMULATION/RECONSTRUCTION

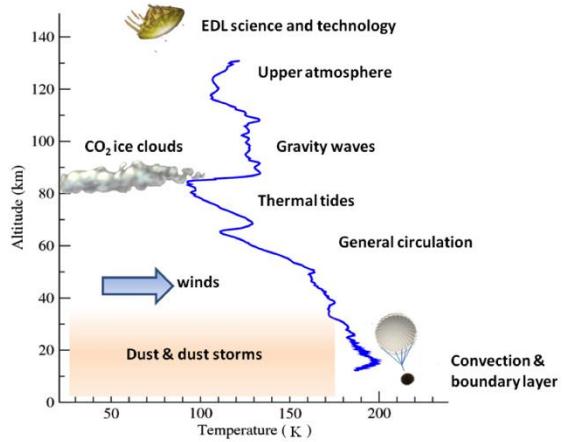


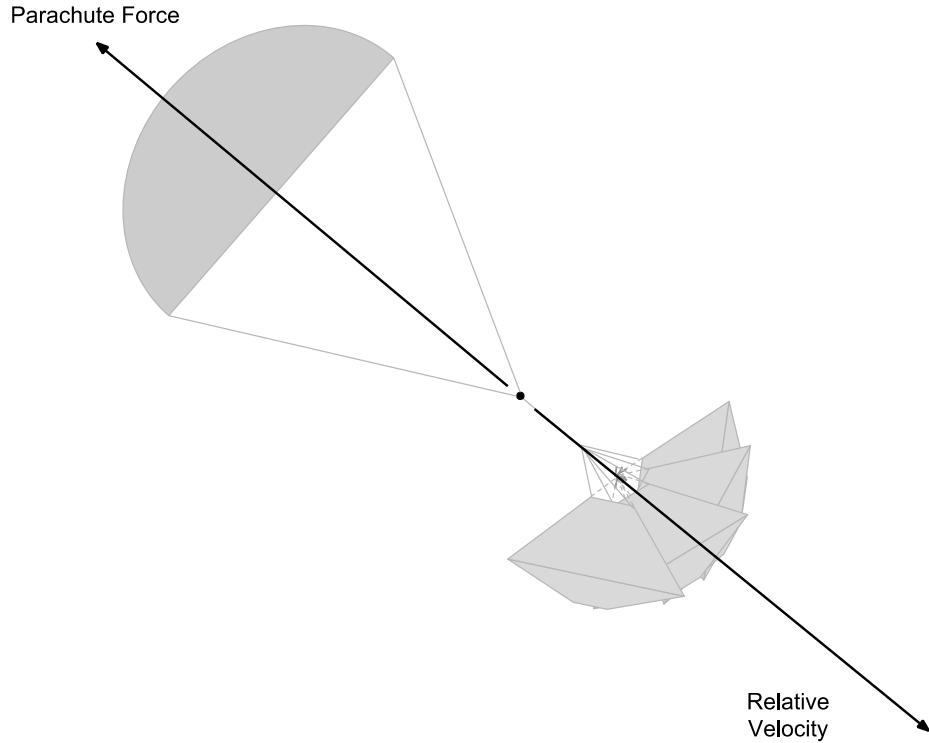
- **EDL Measurements**
 - GNC measurements: IMU, RDA, (SDS)
 - TPS sensors: FADs (pressure sensors)
 - Doppler tracking of the EDM UHF signal
- **Entry state vector**
- **Mars models (e.g. gravity, atmosphere)**
- **EDM dynamical models**
 - 3-6 DoF Entry model
 - 9 DoF Descent model
- **+ Extended Kalman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



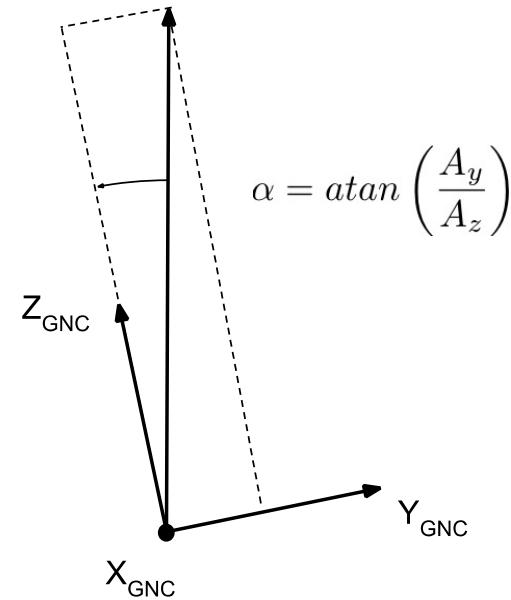
**EDM
TRAJECTORY &
ATTITUDE**

ATMOSPHERIC PROFILE





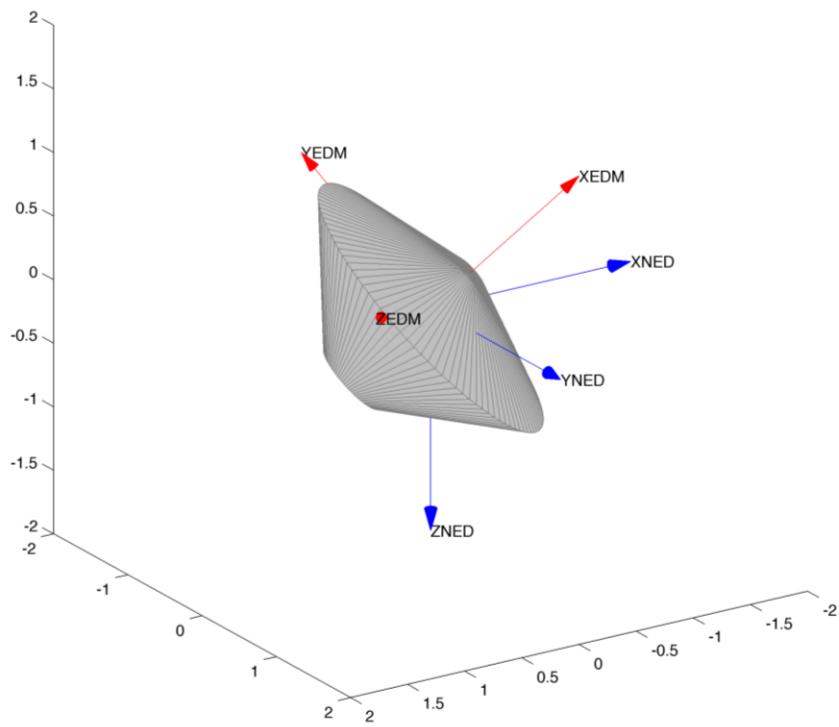
Aerodynamic Acceleration



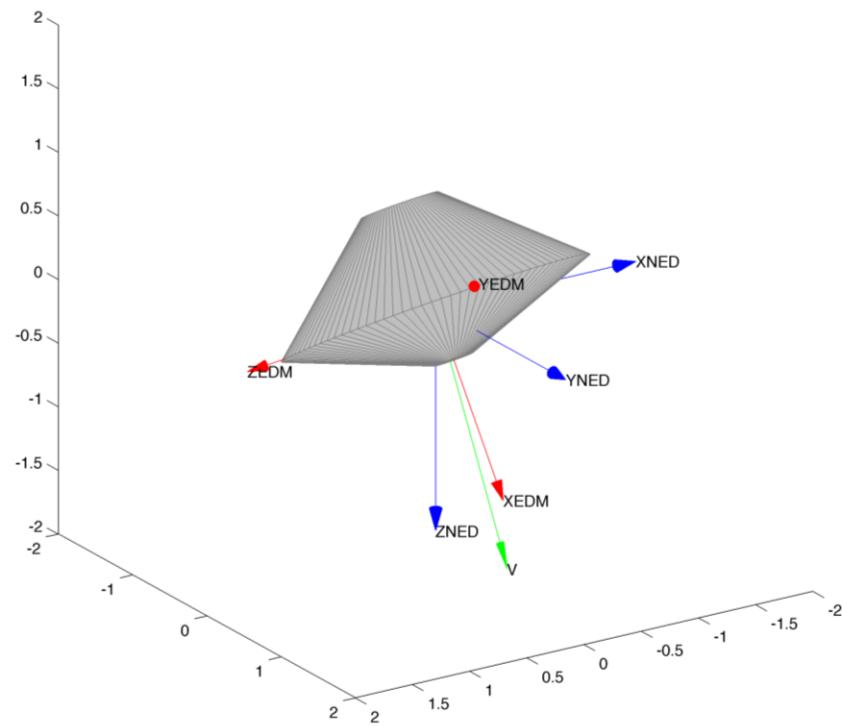
- MIMU saturation
 - detected checking the angle between GNC velocity and sensed acceleration
 - Oscillations at parachute opening produced using a physical model (too many degrees of freedom)
 - Angular rate computed from sensed accelerations

- Attitude 10s before RCS on

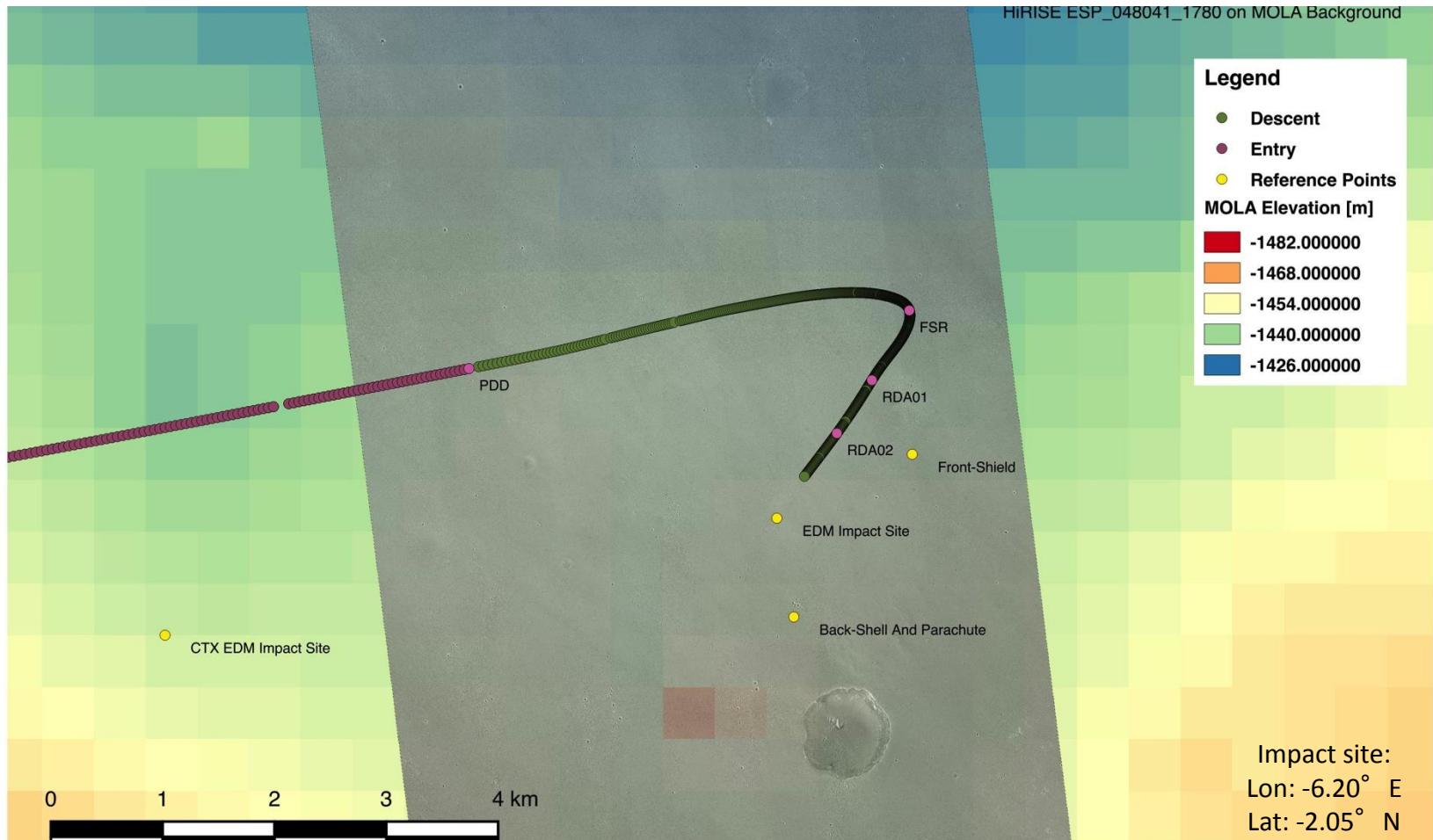
GNC

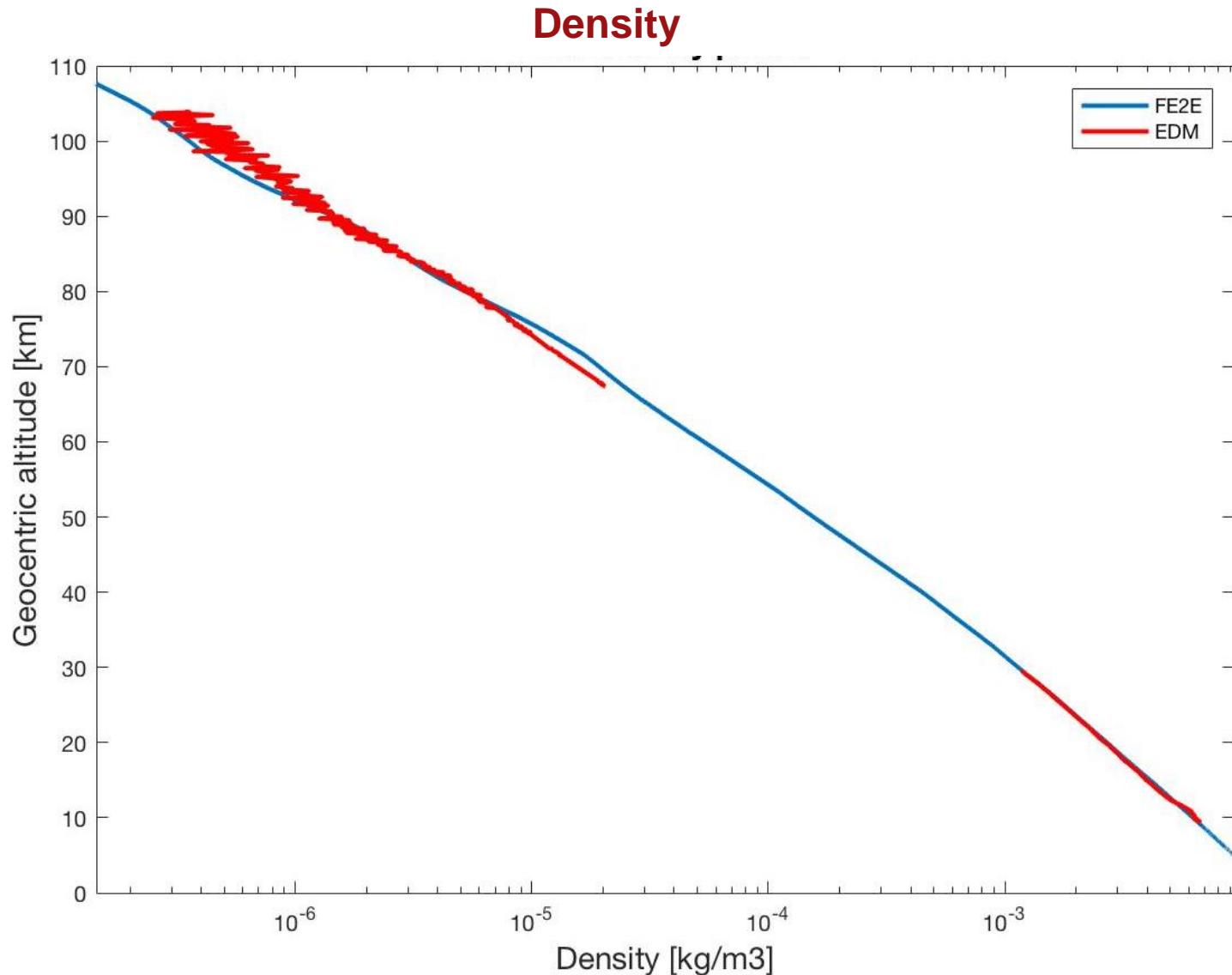


Integrated

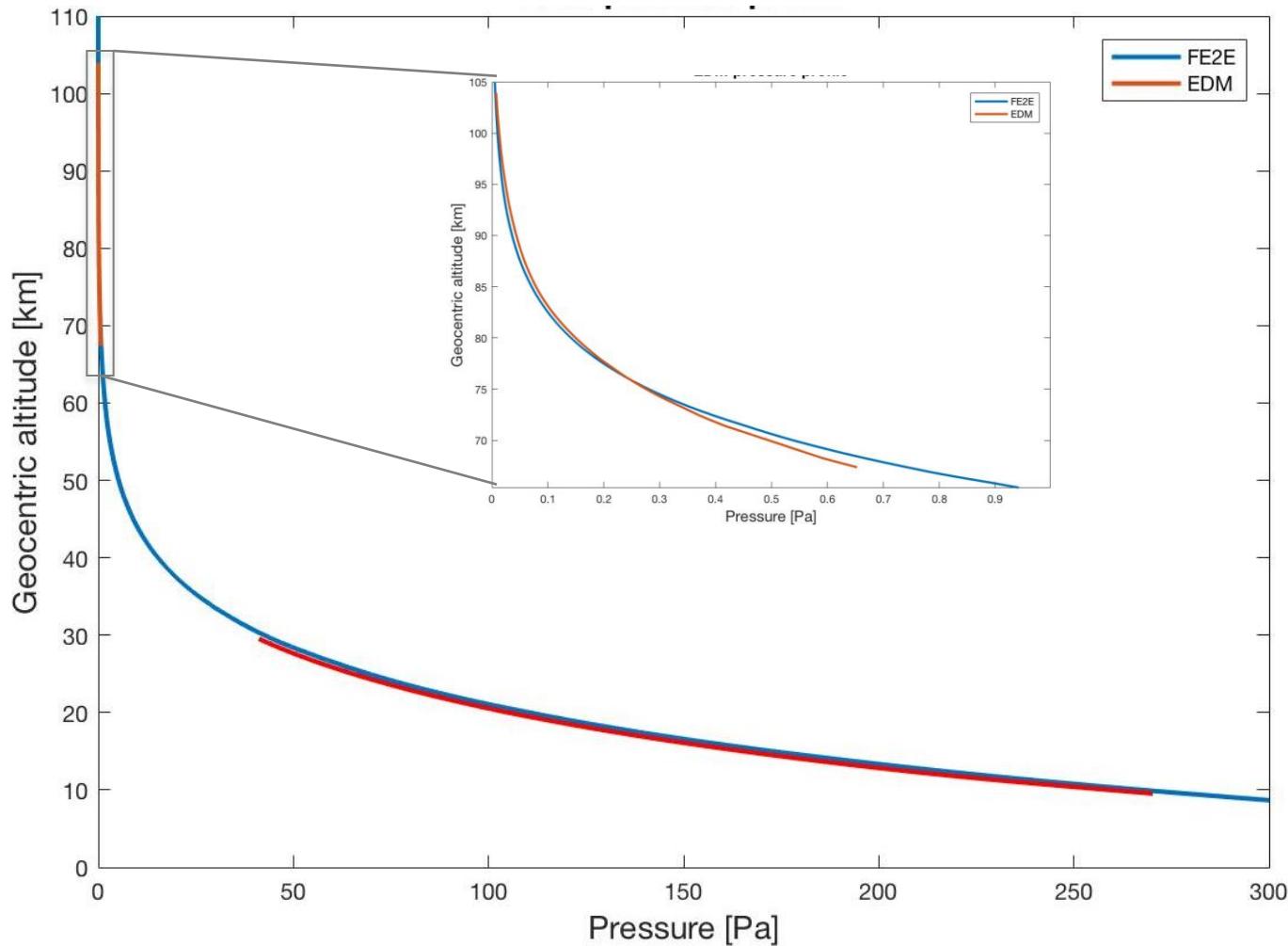


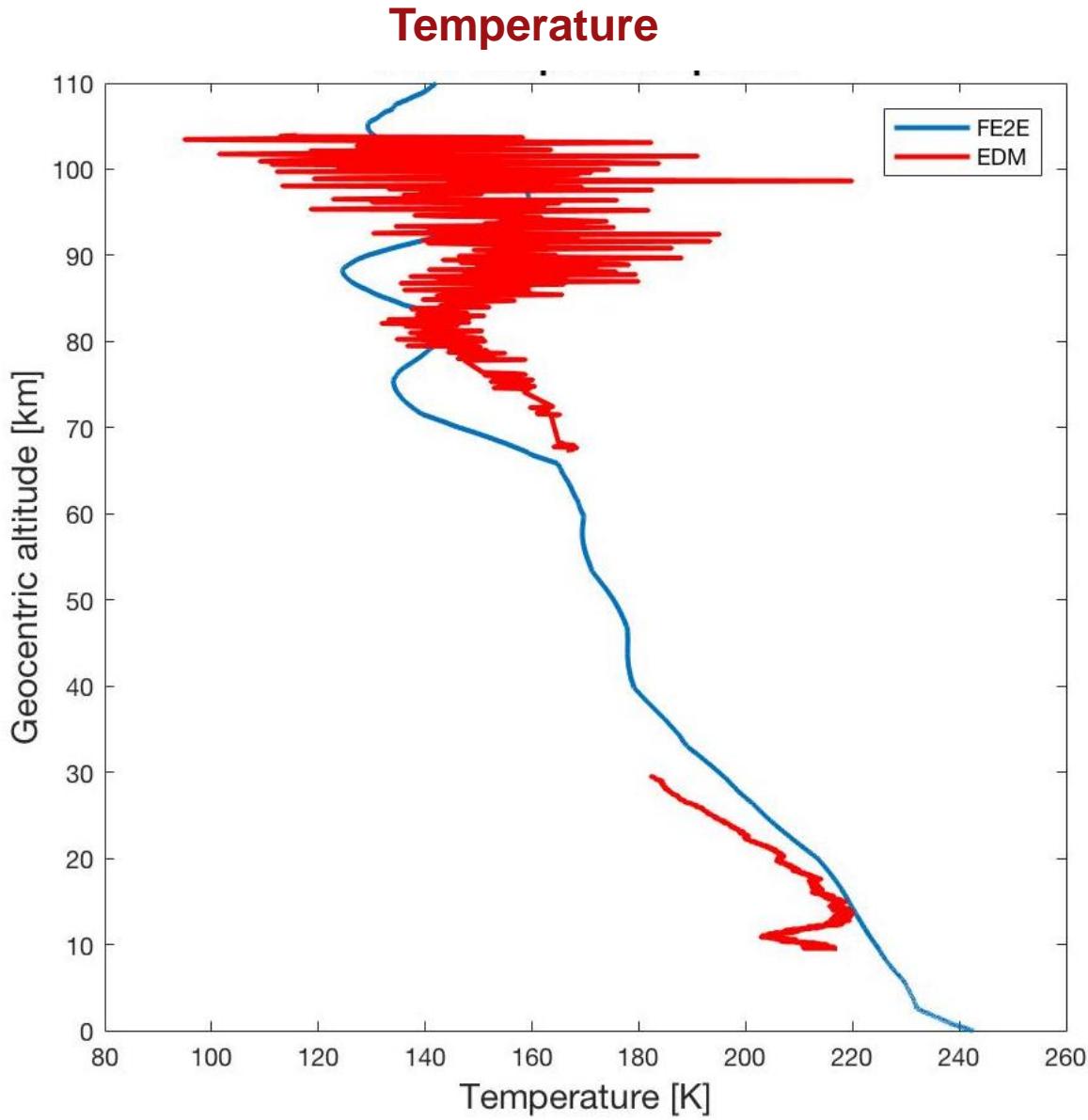
Schiaparelli landing groundtrack



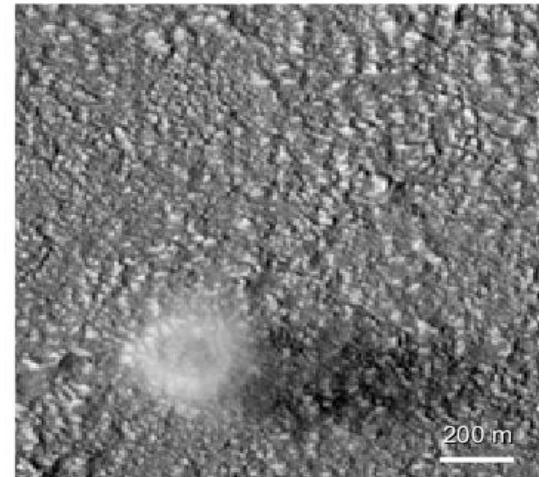
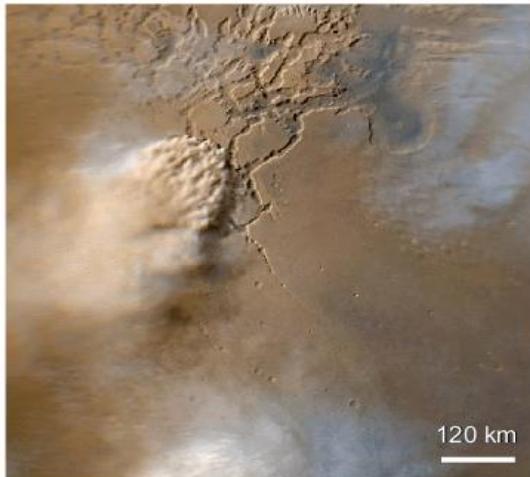
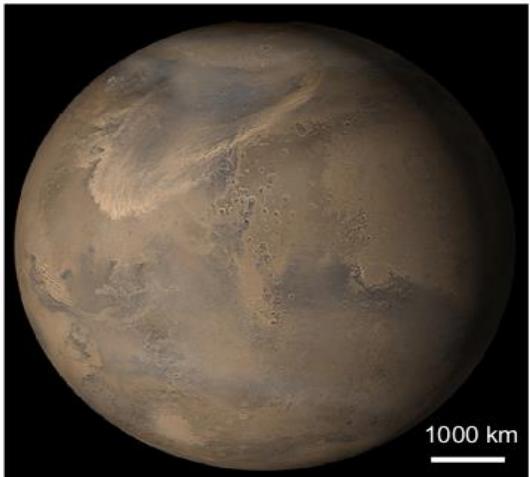


Pressure





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

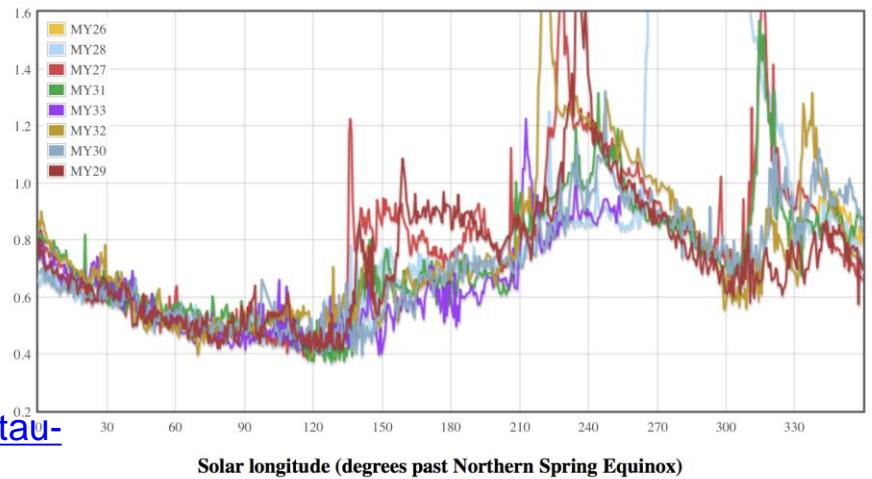
Large-Eddy Simulations



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

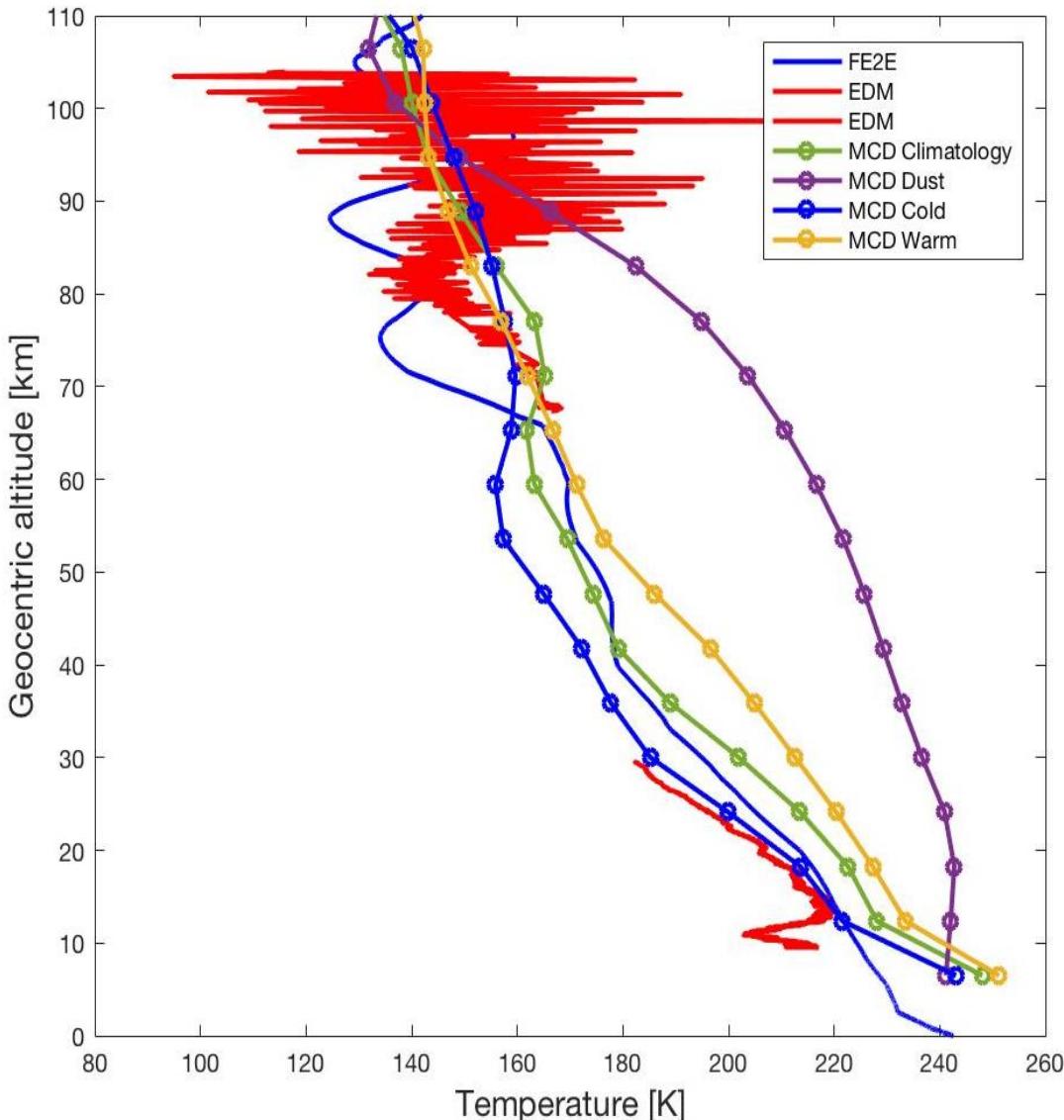
MER-B seasonal optical depth for all Mars Years (MY)



Lemmon <http://www.lpl.arizona.edu/~lemmon/mars-tau-b.html>

ATMOSPHERIC RECONSTRUCTION

Schiaparelli vs models / data assimilation

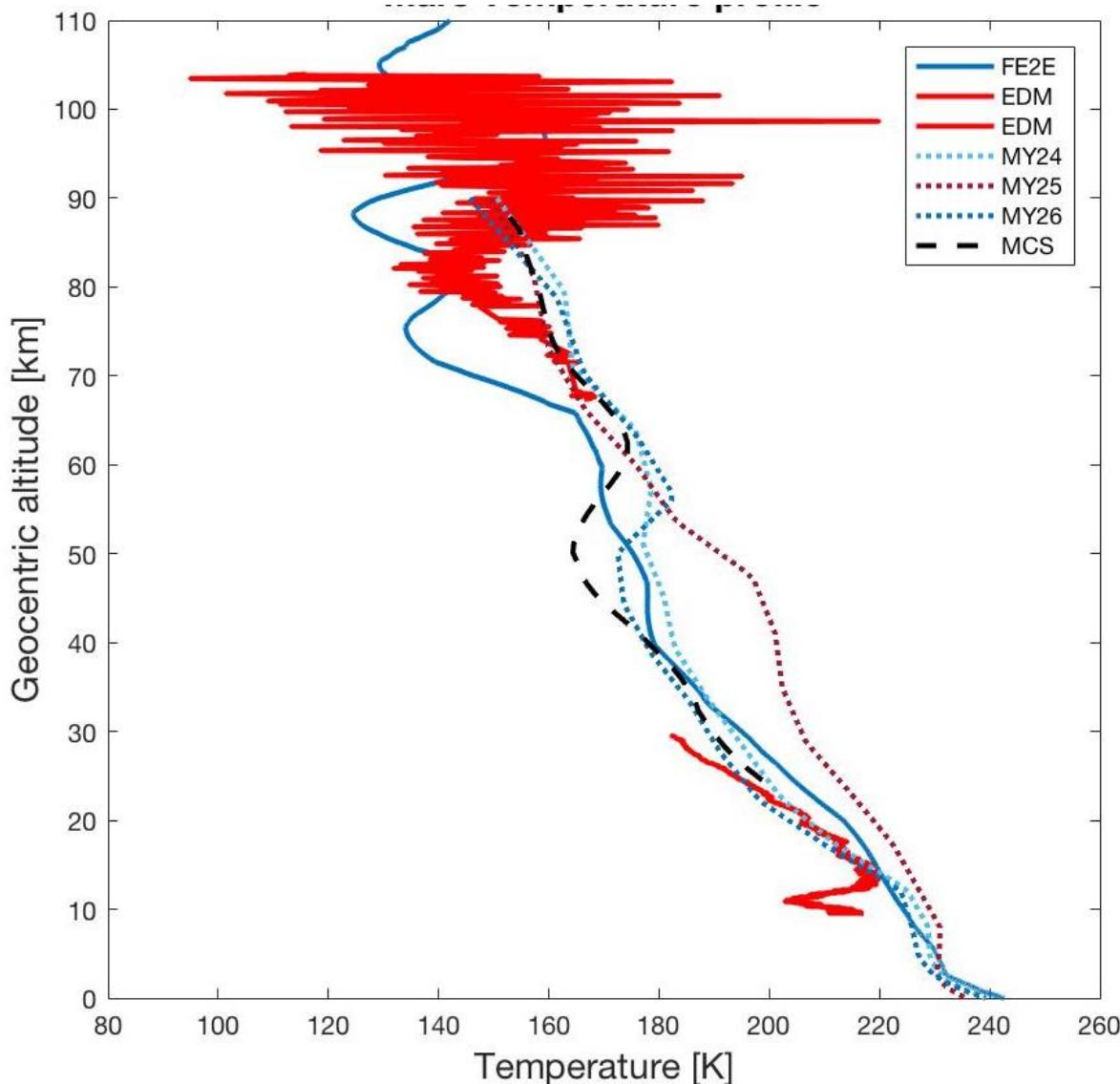


Mars Climate
Database
(MCD 5.2) scenarios

- **Schiaparelli**
Meridiani Planum
 2.05° S -6.2 E
 L_S 244.4°
LMST 13:00

ATMOSPHERIC RECONSTRUCTION

Schiaparelli vs models / data assimilation

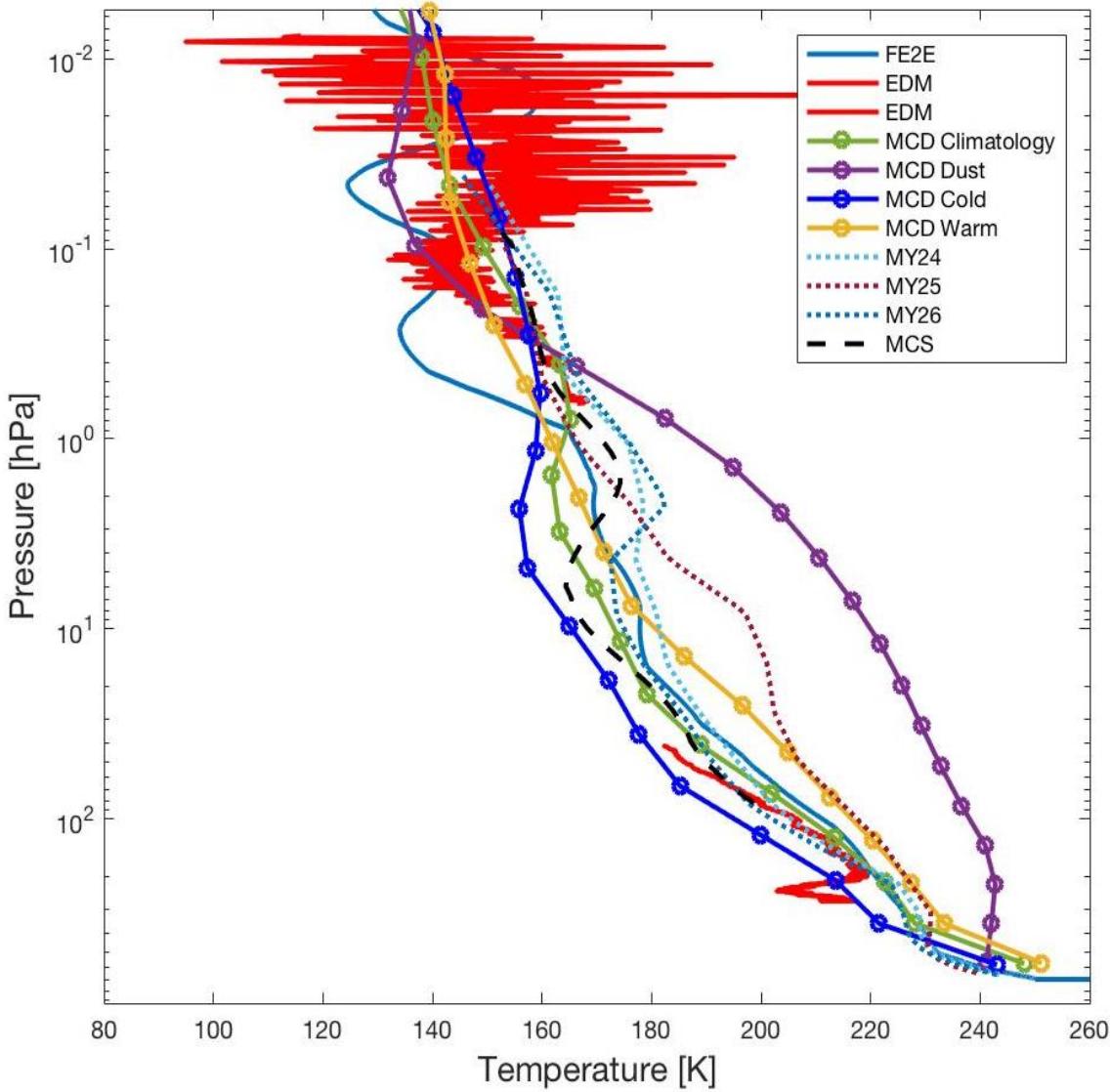


OU GMC with
data assimilation;
MRO-MCS obs

- **Schiaparelli**
Meridiani Planum
 2.05° S -6.2° E
 $L_S 244.4^\circ$ MY33
LMST 13:00

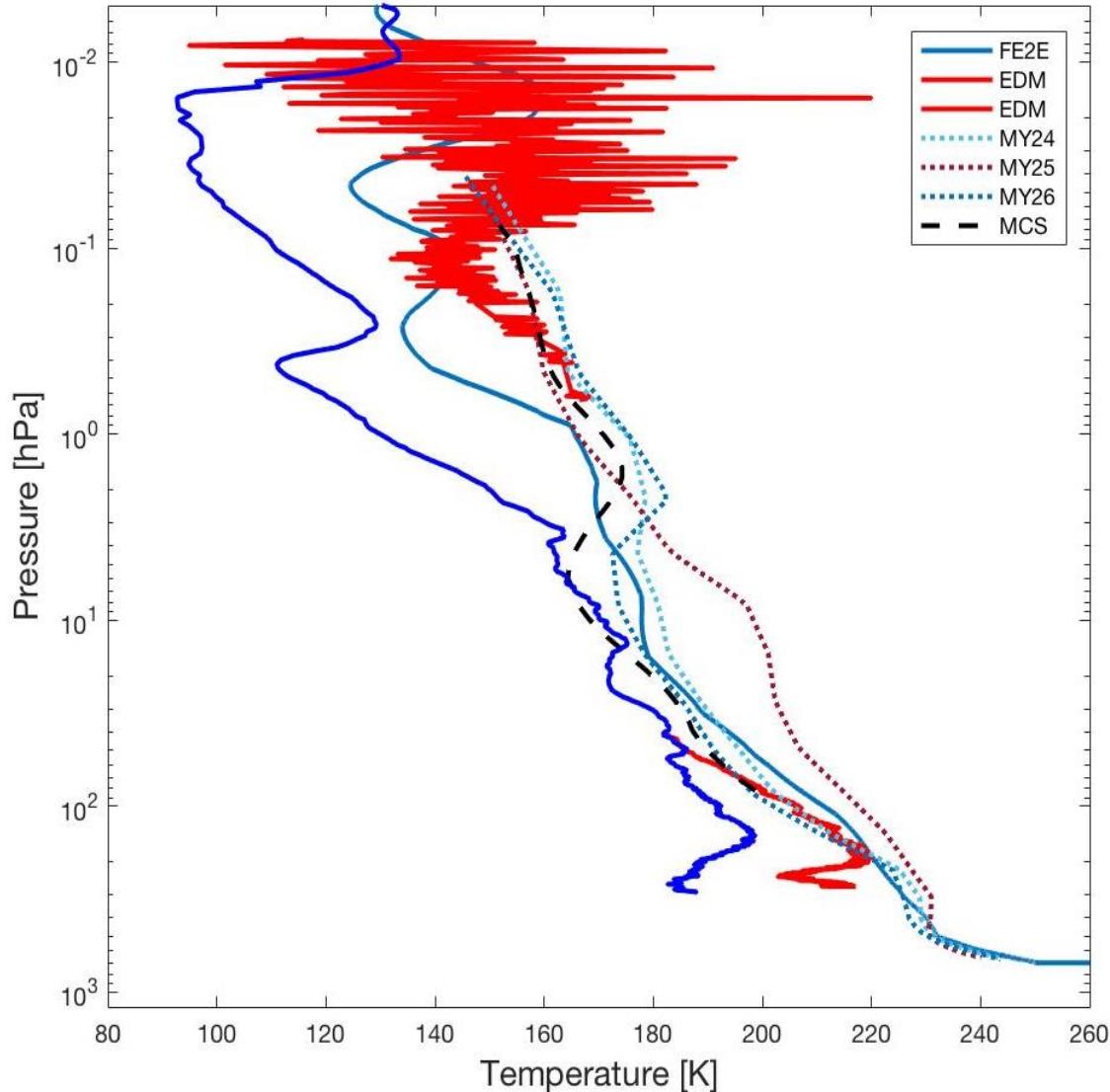
EDM profile vs

models/data assimilation

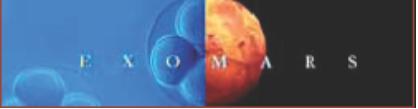


- Mars Climate Database (MCD 5.2) scenarios;
- OU GMC with data assimilation;
- MRO-MCS obs
- **Schiaparelli**
Meridiani Planum
 2.05° S - 6.2° E
 L_S 244.4° MY33
LMST 13:00

models/data assimilation

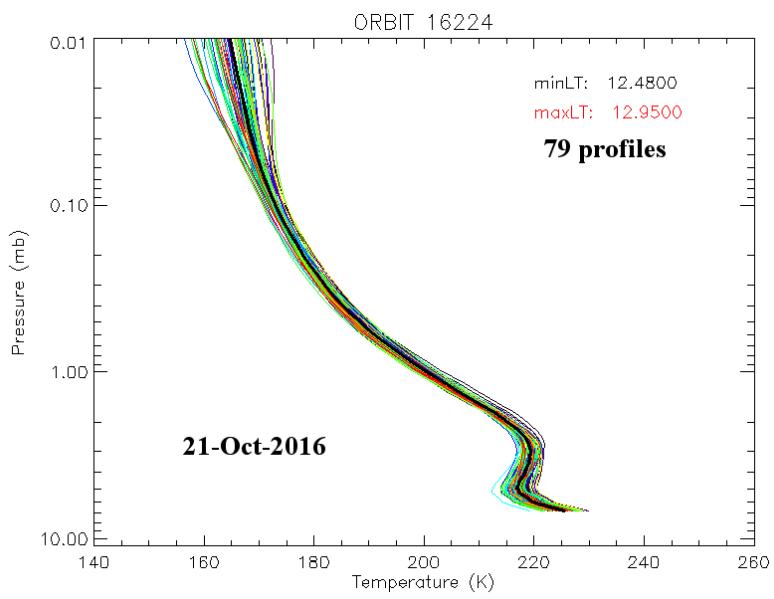
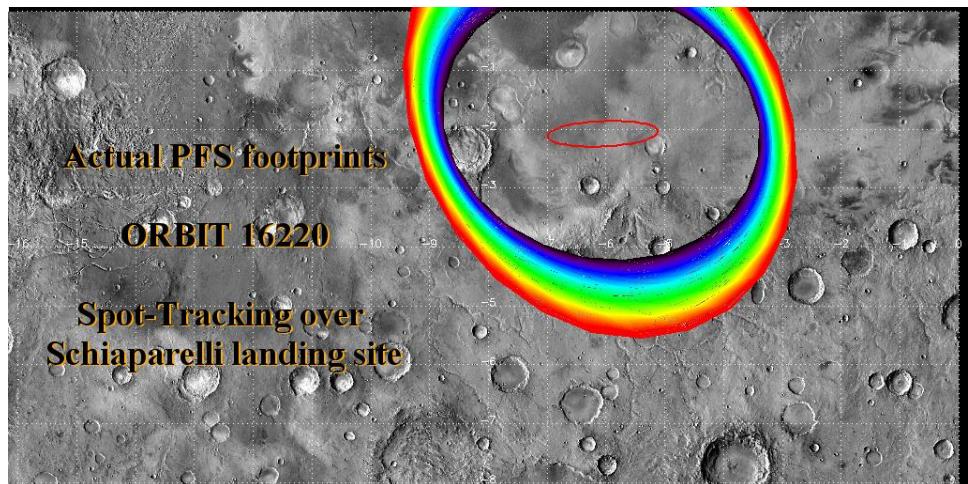


- **Schiaparelli**
Meridiani Planum
 2.05° S - 6.2° E
 L_s 244.4°
LMST 13:00
- **MPF**
 19.09° N,
 326.74° E
 L_s 142.7°
02:58 LT nighttime



MEx-PFS observations over Schiaparelli landing site

8 spot-pointing observations over Schiaparelli landing site: 2 before (Oct16, 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.*