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Post-Flight Analysis of the Radio Doppler Shifts of the ExoMars Schiaparelli Lander

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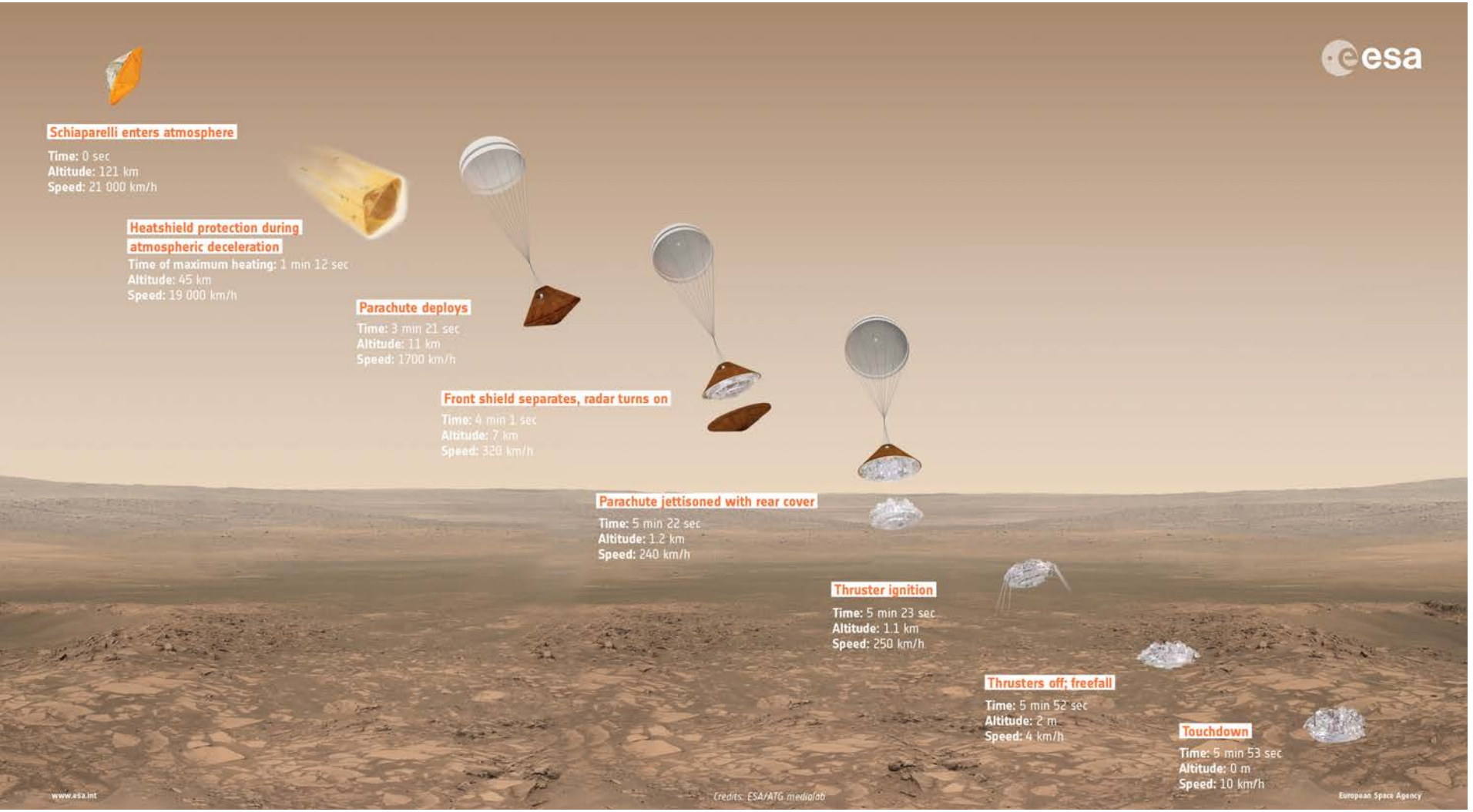
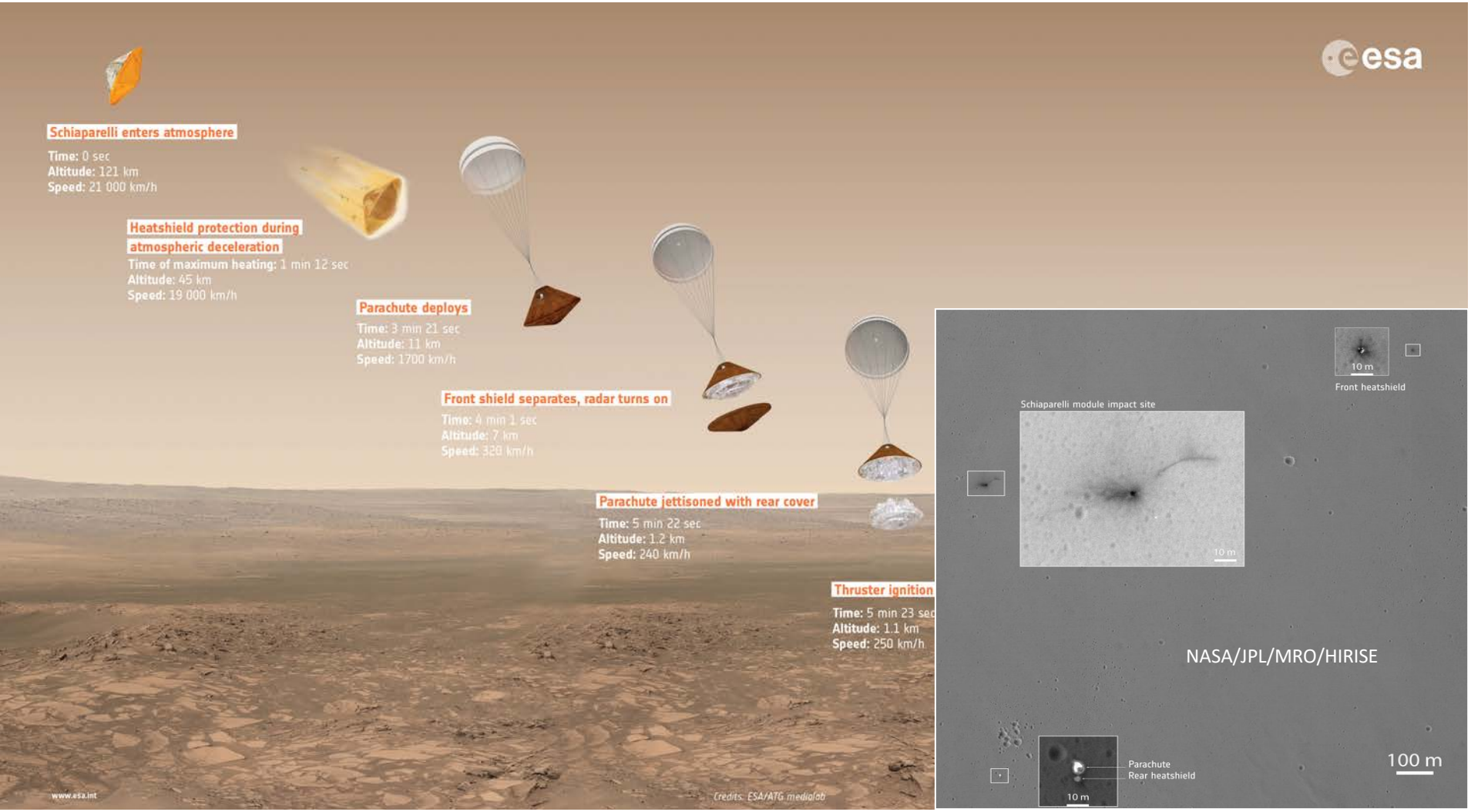
AMELIA: Atmospheric Mars Entry and Landing Investigations & Analysis

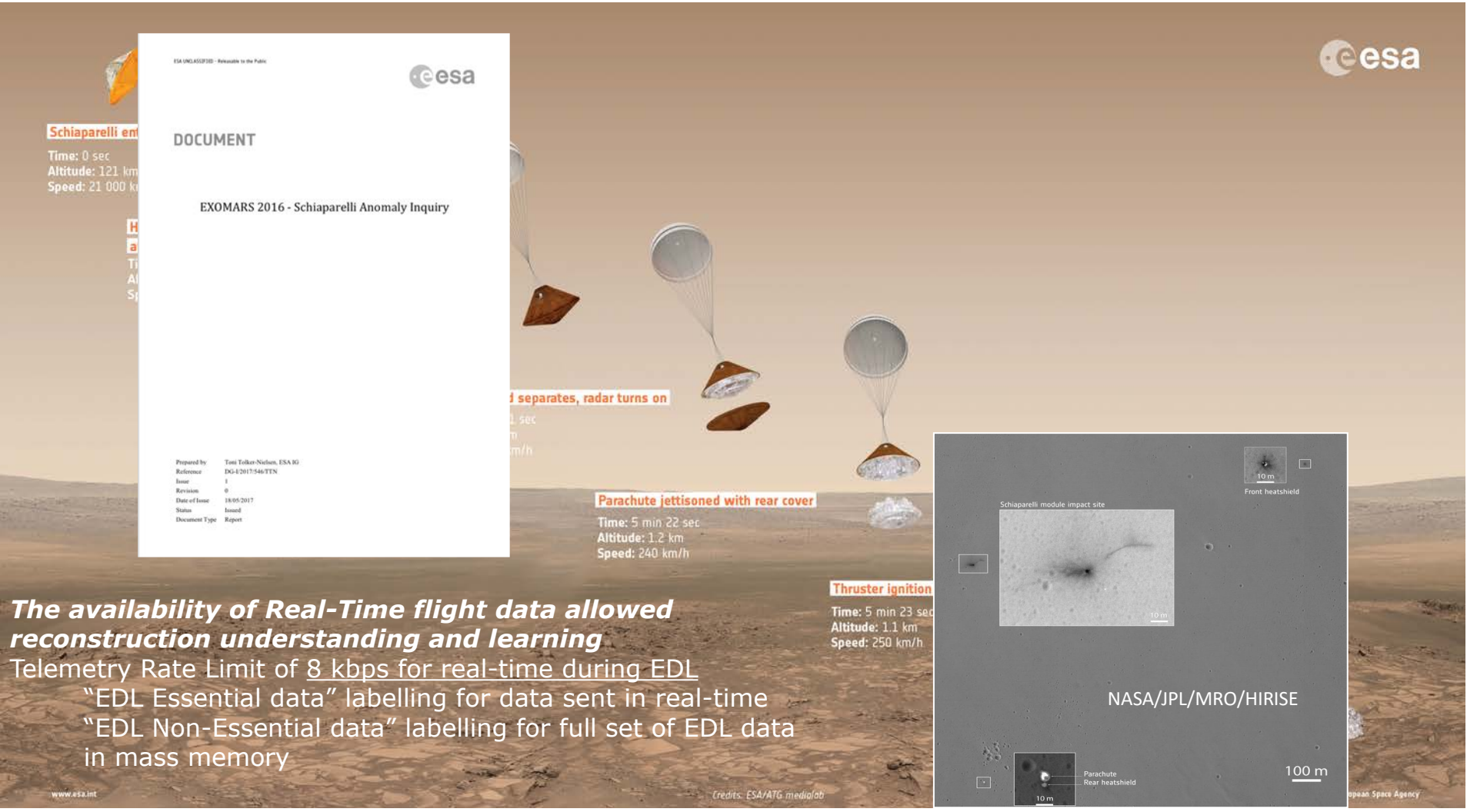
EXOMARS 2016 EDM EDL



EXOMARS 2016 EDM EDL



EXOMARS 2016 EDM EDL



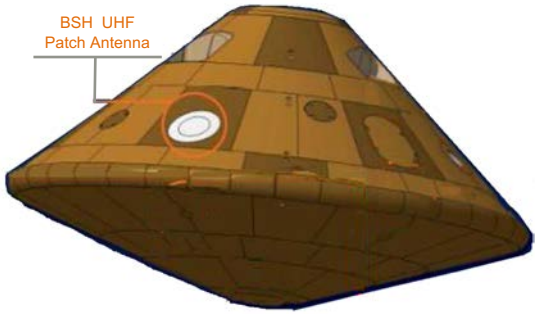
The availability of Real-Time flight data allowed reconstruction understanding and learning

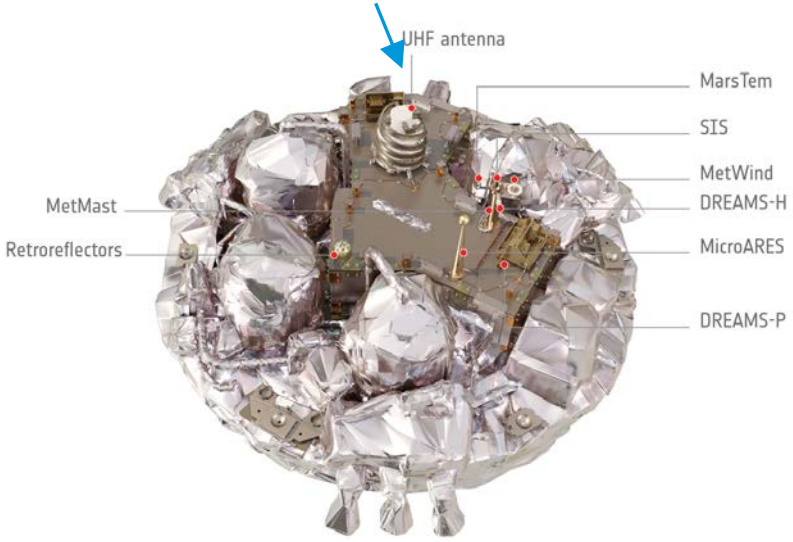
Telemetry Rate Limit of 8 kbps for real-time during EDL

- "EDL Essential data" labelling for data sent in real-time
- "EDL Non-Essential data" labelling for full set of EDL data in mass memory

EDM Radio Communication System

EDM's Telemetry, Tracking and Command (TT&C) subsystem was composed of a UHF (ultra-high frequency) Transceiver Unit transmitting at at ~401.58 MHz and two UHF low gain antennas.





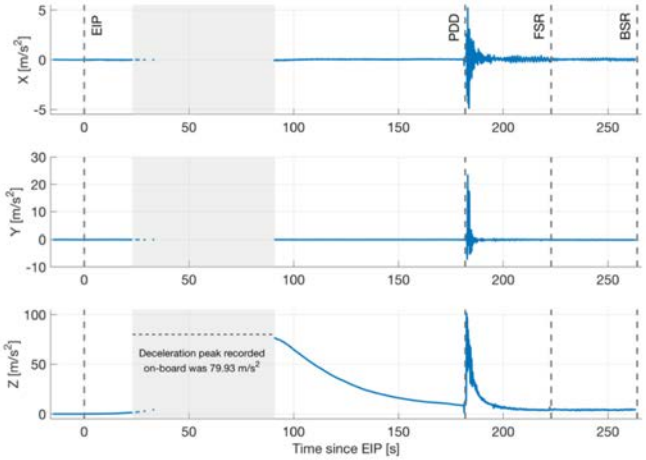
The patch antenna, mounted on the base of back shell, is used during first part of EDL phase.

The helix antenna mainly designed for Mars ground operations was used during the EDL phase after Back Cover separation.

TRAJECTORY AND ATMOSPHERIC PROFILES FROM REAL TIME TELEMETRY

AMELIA

GNC DATA SET



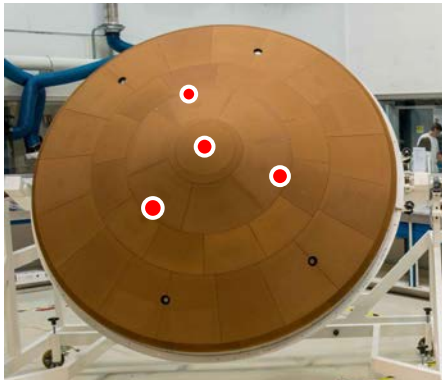
Space Science Reviews manuscript No.
(will be inserted by the editor)

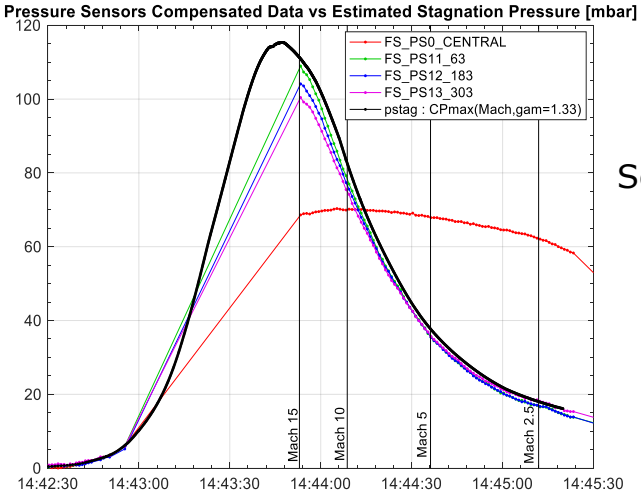
Schiaparelli Module Trajectory and Atmospheric Profiles Reconstruction

Analysis of the on-board inertial and radar measurements

A. Aboudan · G. Colombatti · C. Bettanini · F. Ferri · S. Lewis · B. Van Hove · O. Karatekin · S. Debei.

FRONT SHIELD PRESSURE



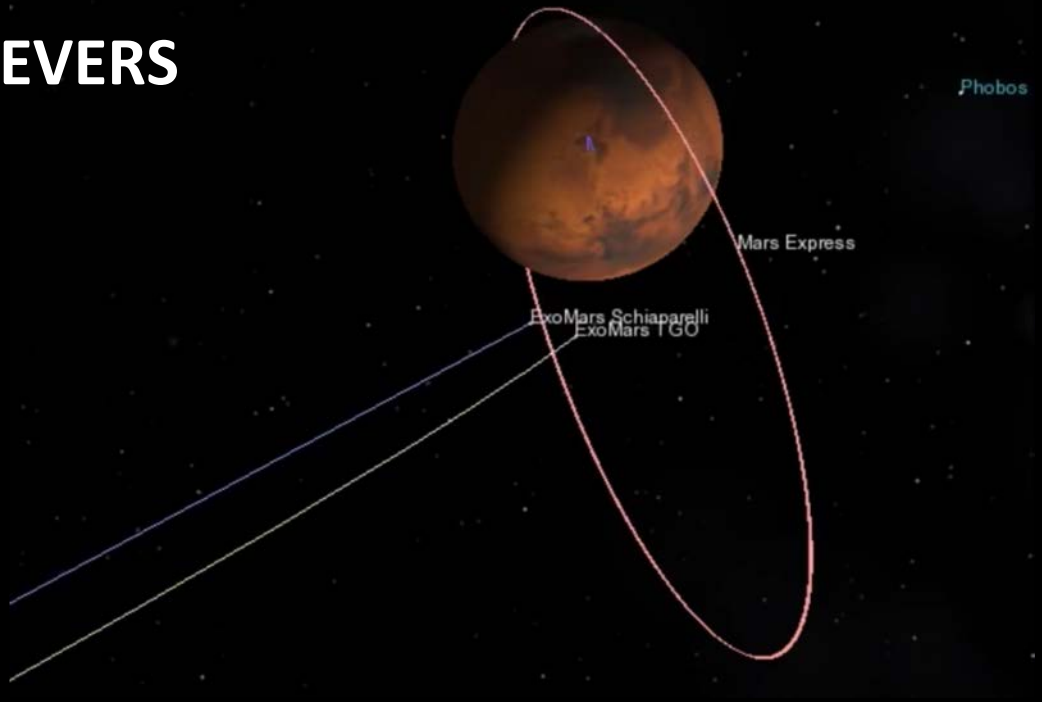


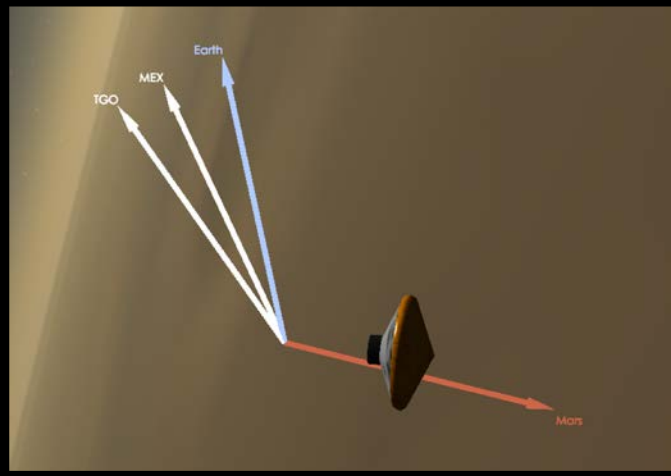
See the talk by van Hove

RADIO LINK

Present talk!

RECIEVERS





Trace Gas Orbiter (TGO)'s twin Electra UHF transceivers were able to record and relay the essential telemetry at 8 kps .

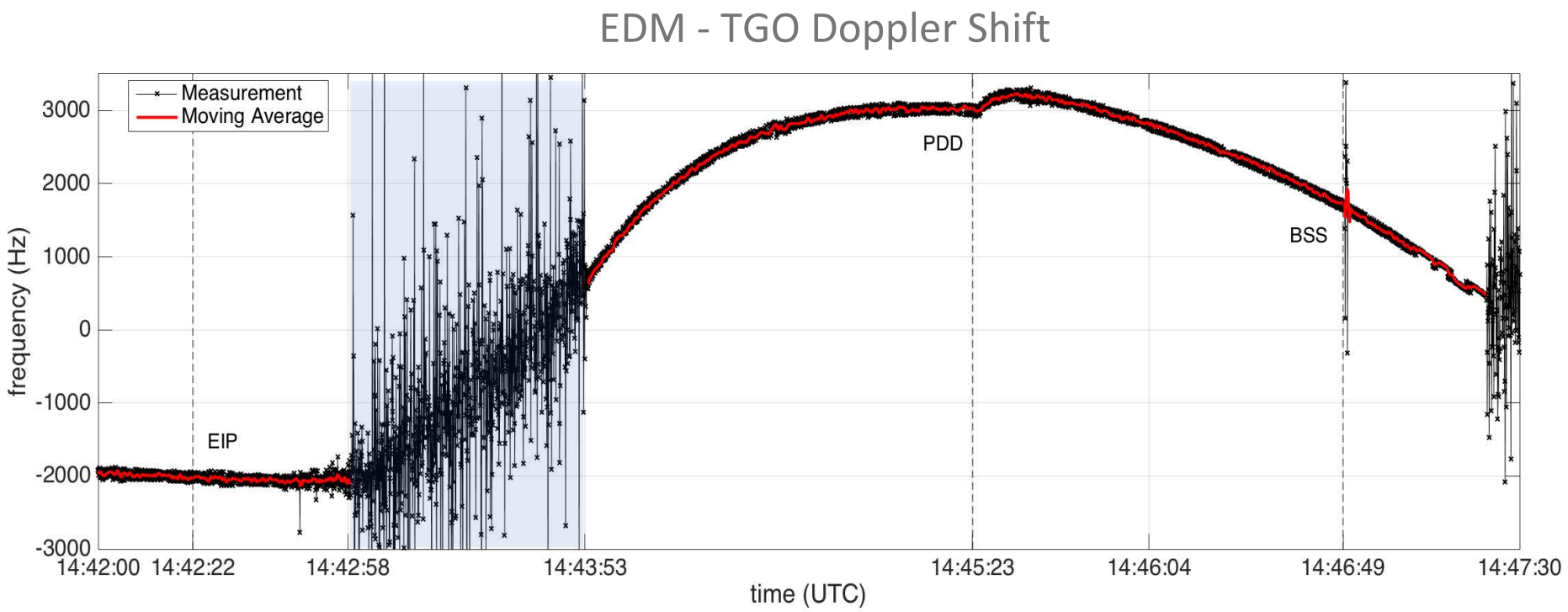
The Mars Express ' MELACOM transceiver recorded and relayed the EDM carrier signal.

GMRT was able to detect and track EDM carrier signal

EDM-TGO Radio Link

- The Doppler shift and rate profiles are **lines-of-sight observations** of the relative velocity and accelerations between EDM and the radio receiver. They contain a unique "signature" of the entry trajectory.

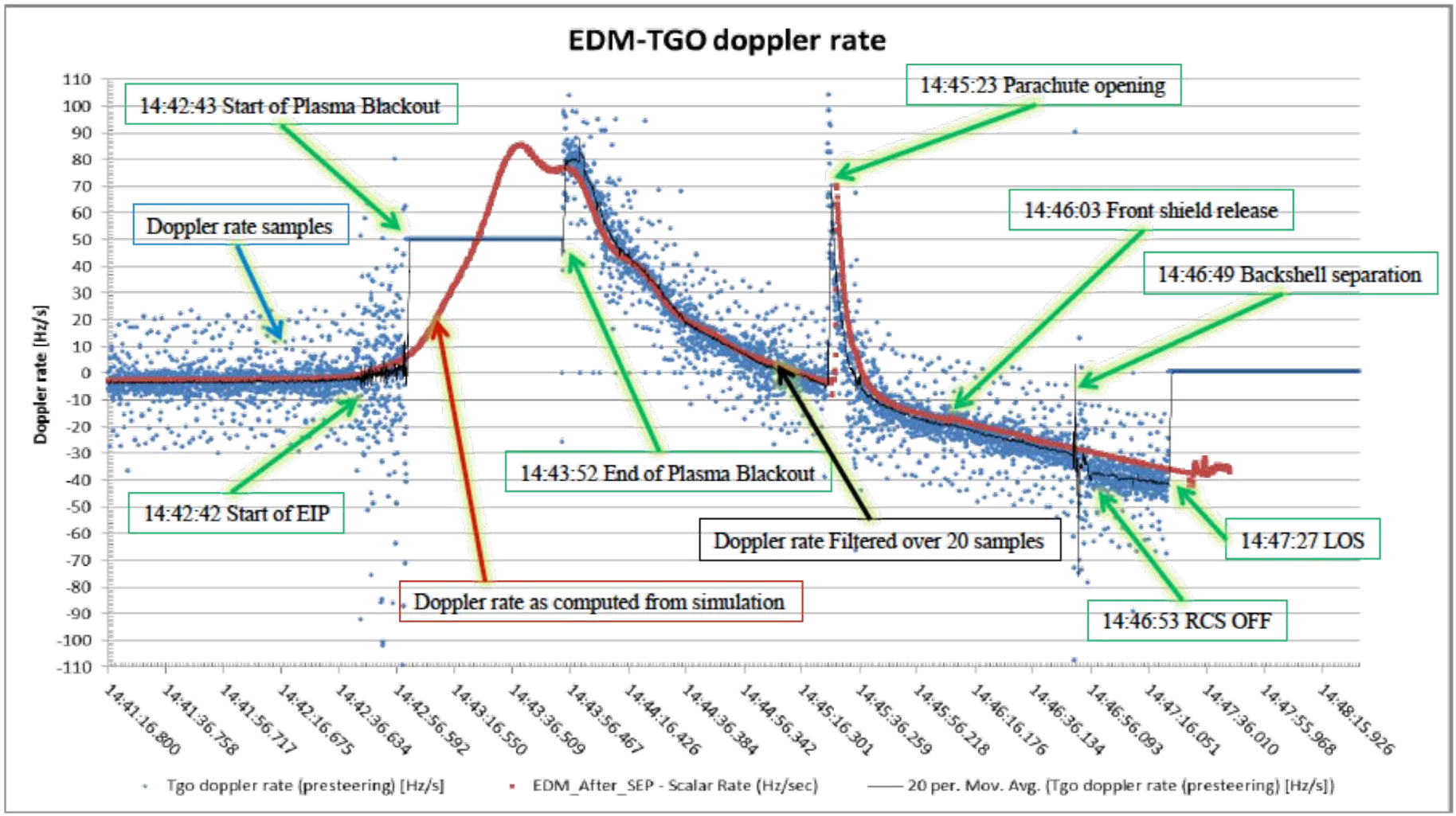
- Doppler data analysis and receive power analysis is a **major outcome of Post-Flight confirming observations**
- The three Doppler shifts between EDM and TGO/MEX/GMRT have been measured along their respective lines-of-sight.



EDM-TGO Radio Link

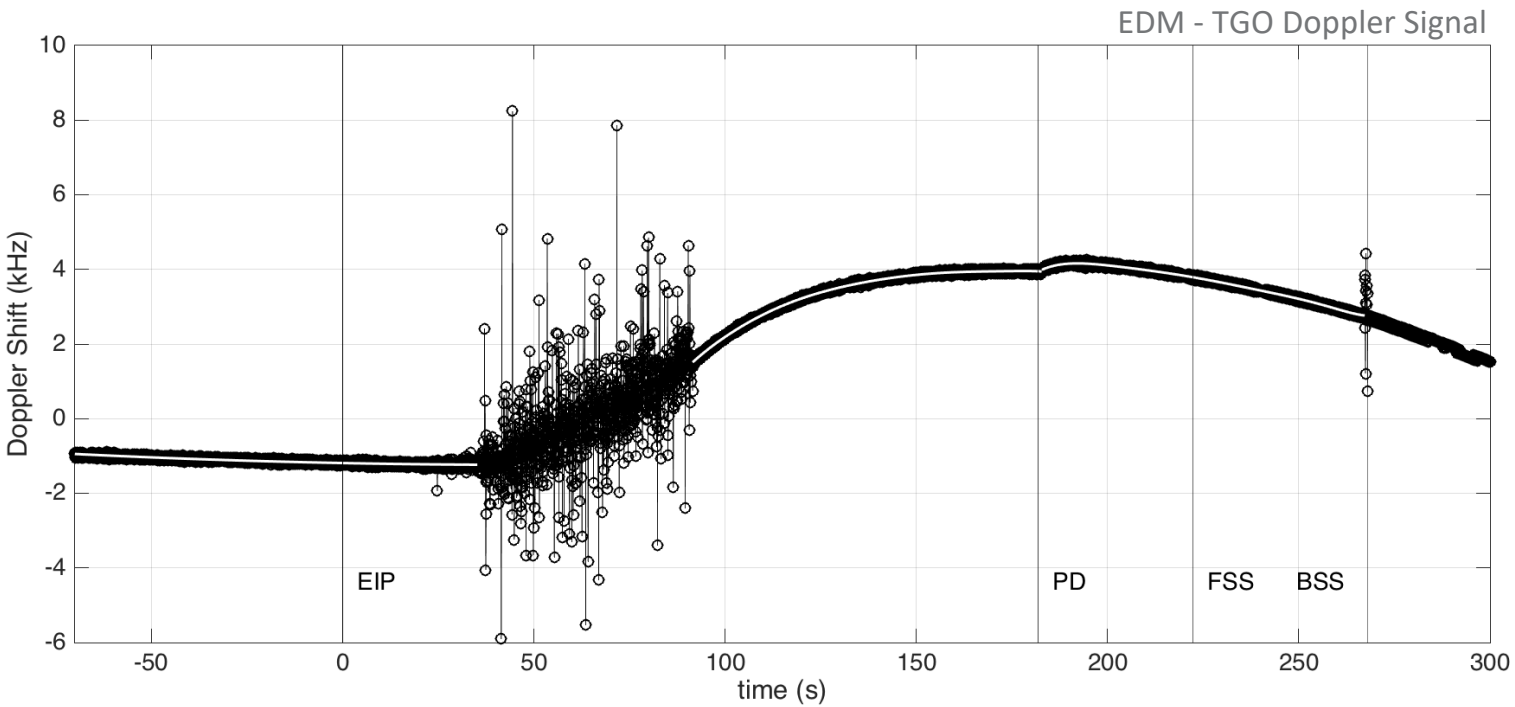
AMELIA

1. Blue dots: telemetry Black Line: Filtered Telemetry Brown Line : Simulation (Pre-EDL Trajectory)



Portigliotti et al. 2017

DENOISING DOPPLER DATA

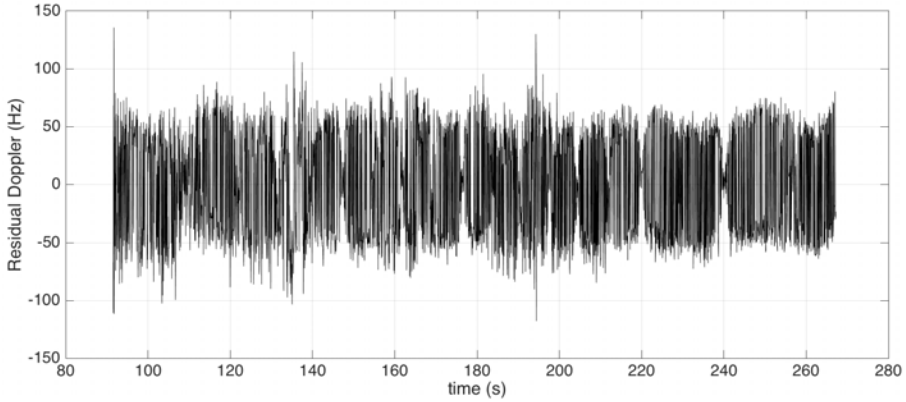


- Data is denoised by applying a polynomial fits over 3 separate ranges:

1- Start - black out

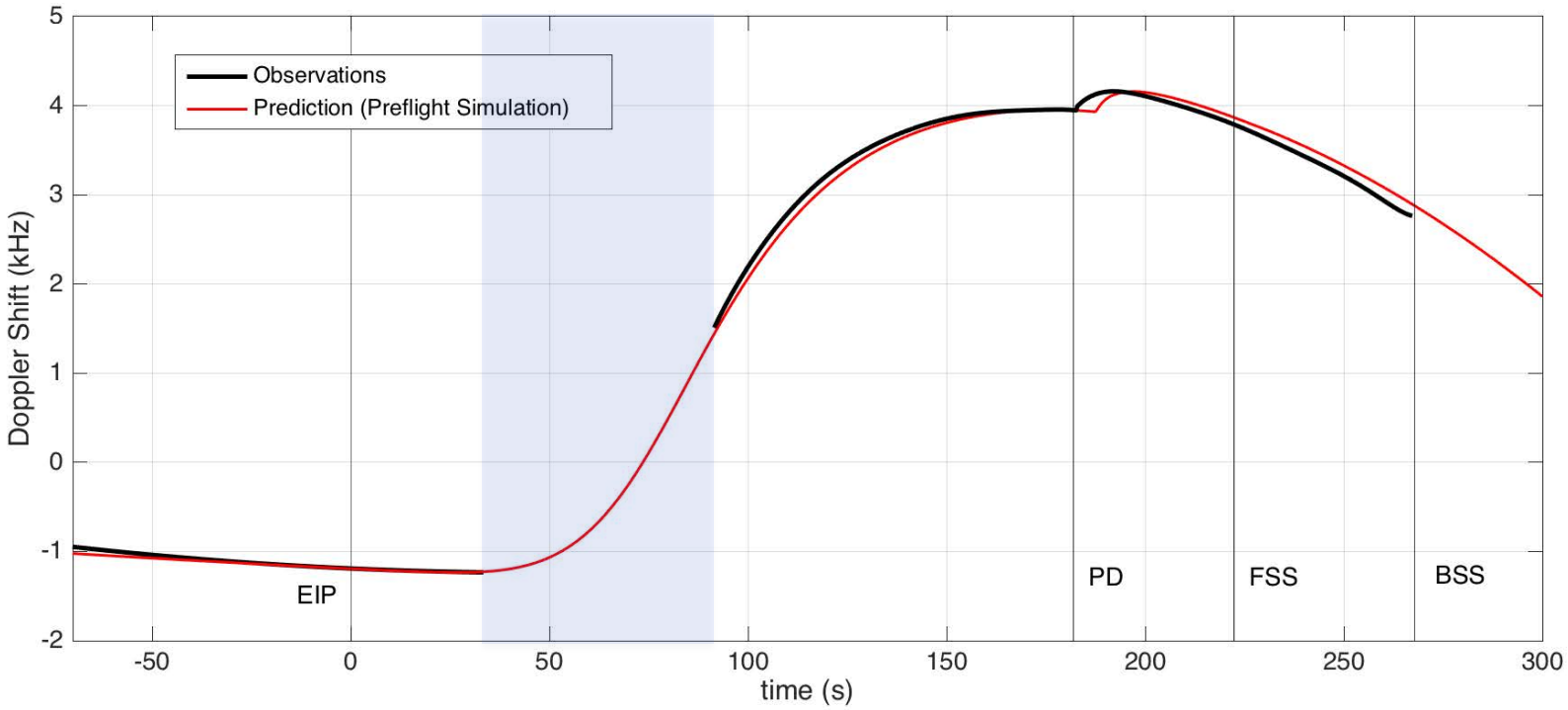
2- Out of black out – Parachute Deployment (PD)

3- Parachute Deployment (PD) – Back Shell Separation



Predicted Doppler (Preflight)

EDM - TGO Doppler Signal

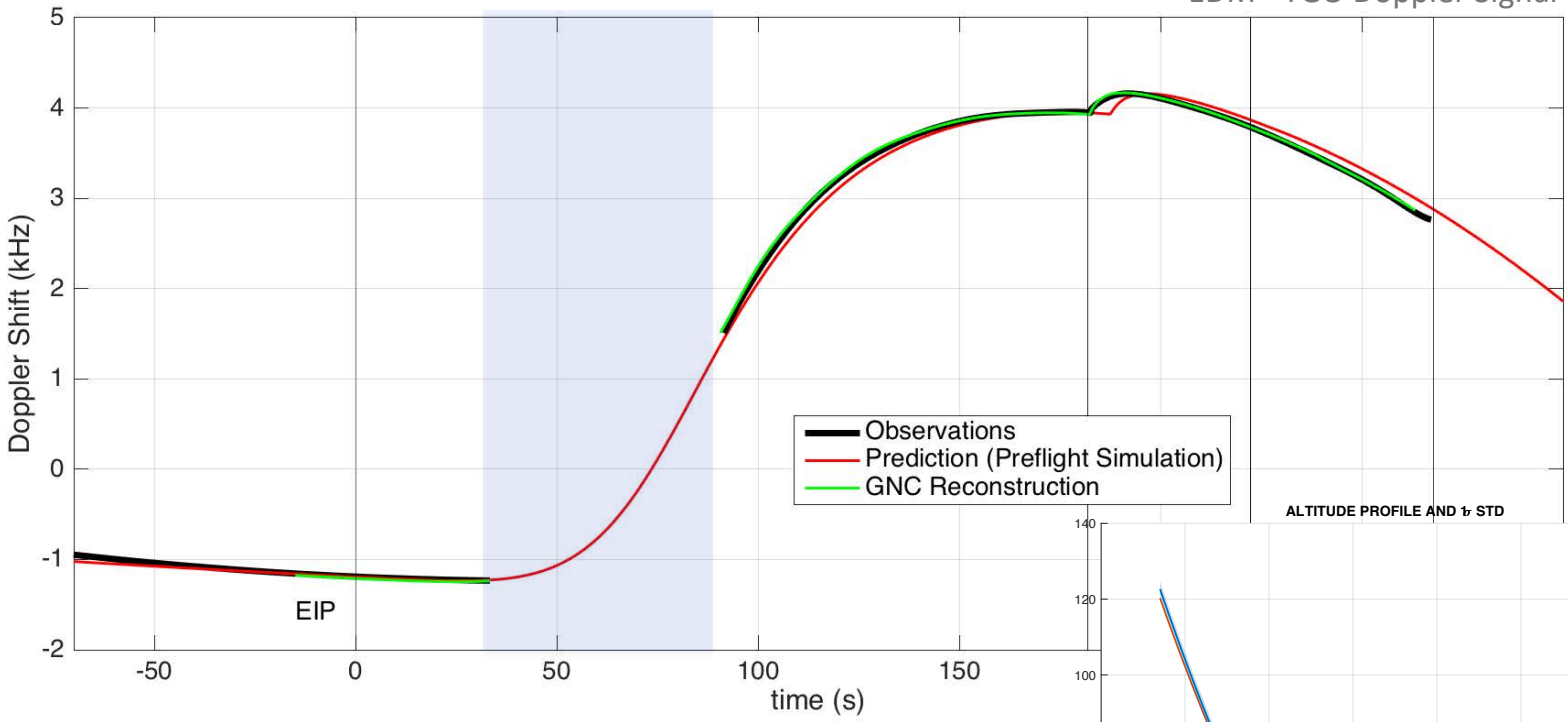


- A bias (~850 Hz) is applied to the data set to take into account the clock-drift
- Data over the black out period is neglected

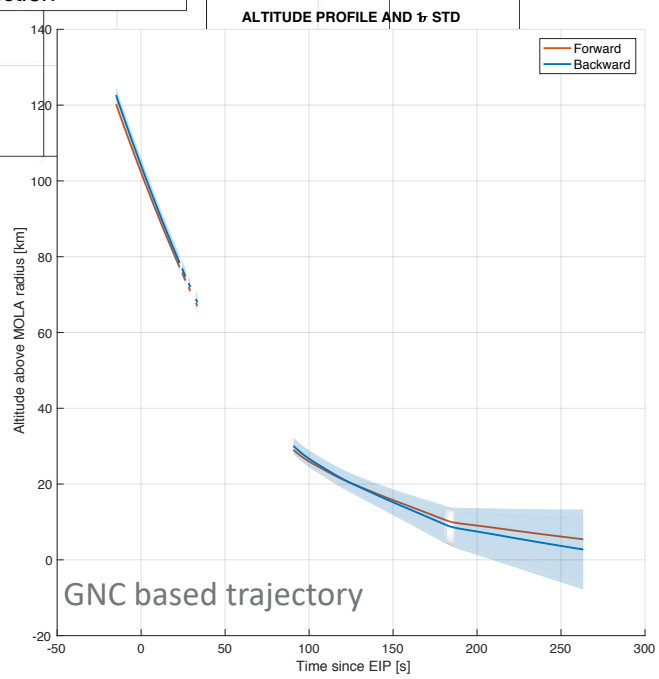
- -Predicted data is based on post-separation simulations few days before the Entry
- Radio Data after the black out is slightly different and Parachute opening happened earlier then precited

Reconstructed Doppler Signal

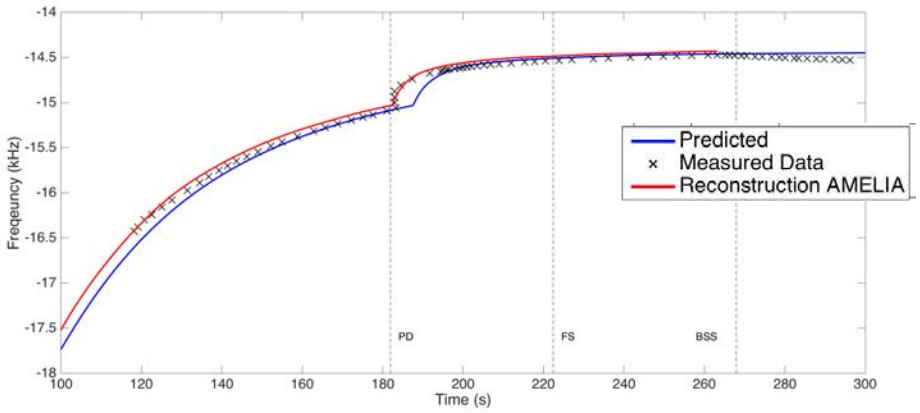
EDM - TGO Doppler Signal



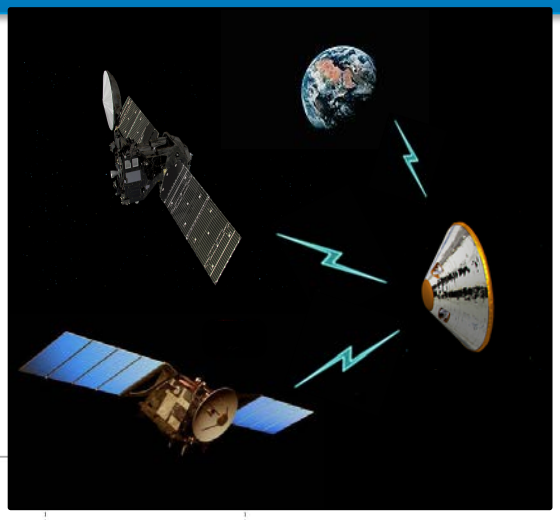
Comparison with Doppler based on GNC reconstruction (Aboudan et. al, 2018)

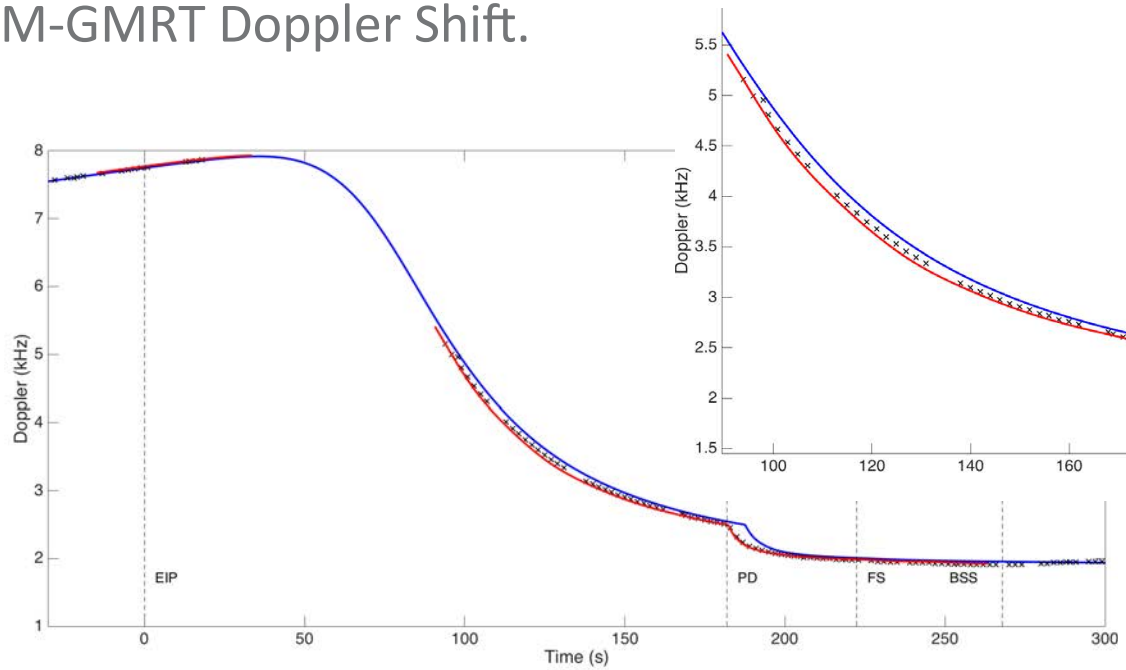


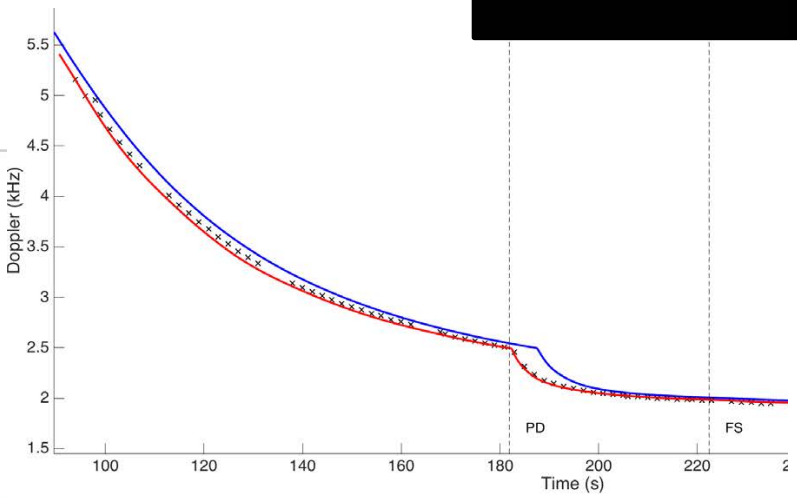
Comparison with Doppler based on GNC



EDM-GMRT Doppler Shift.



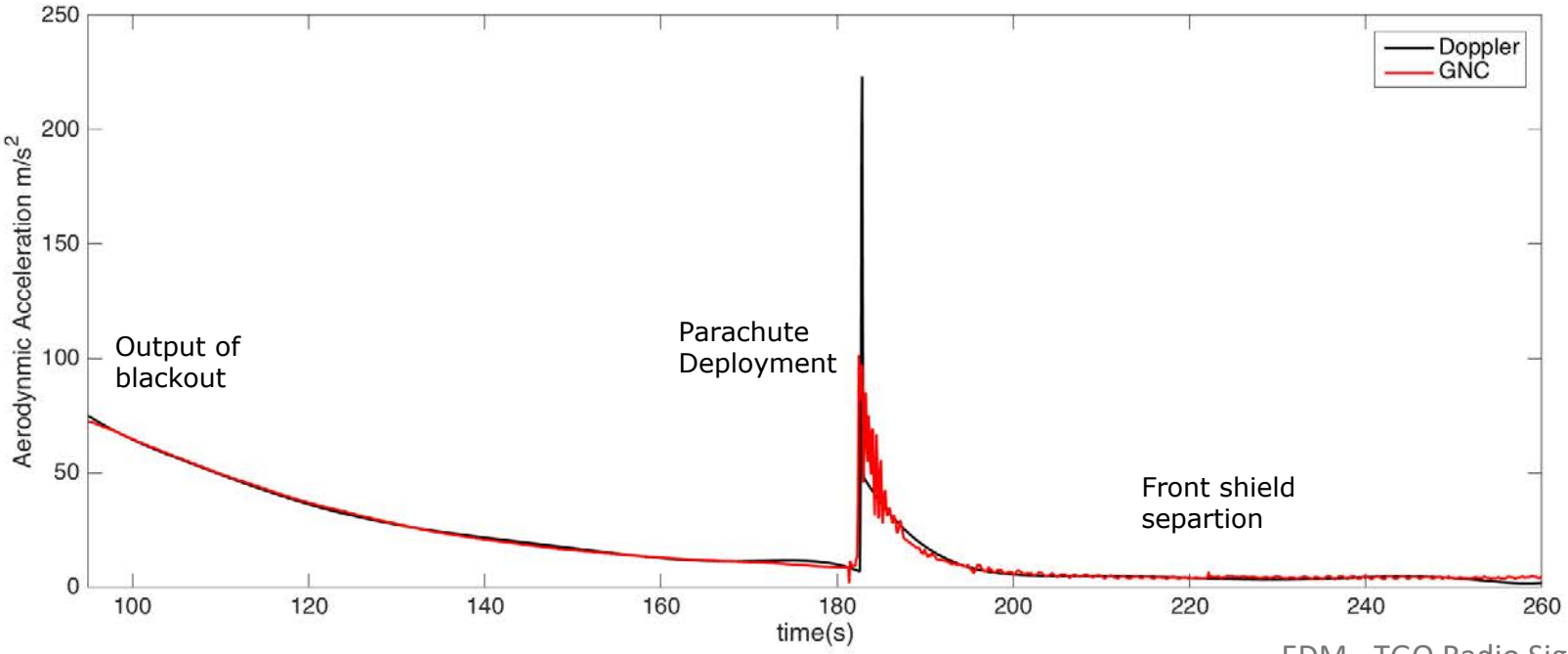




EDM-MEX Doppler Shift.

RECONSTRUCTED TRAJECTORY

- From radio link, the trajectory reconstruction can be done using one or more receivers . Applied successfully previous landers such as Opportunity and Phoenix which transmitted radio signal in X band 8.4 Ghz (Withers 2010, Gerbal et al. 2015).
- Reconstruction using only one Receiver assumes purely ballistic trajectory
- Acceleration is derived using the time derivative of the observed line of sight velocity (Withers 2010).

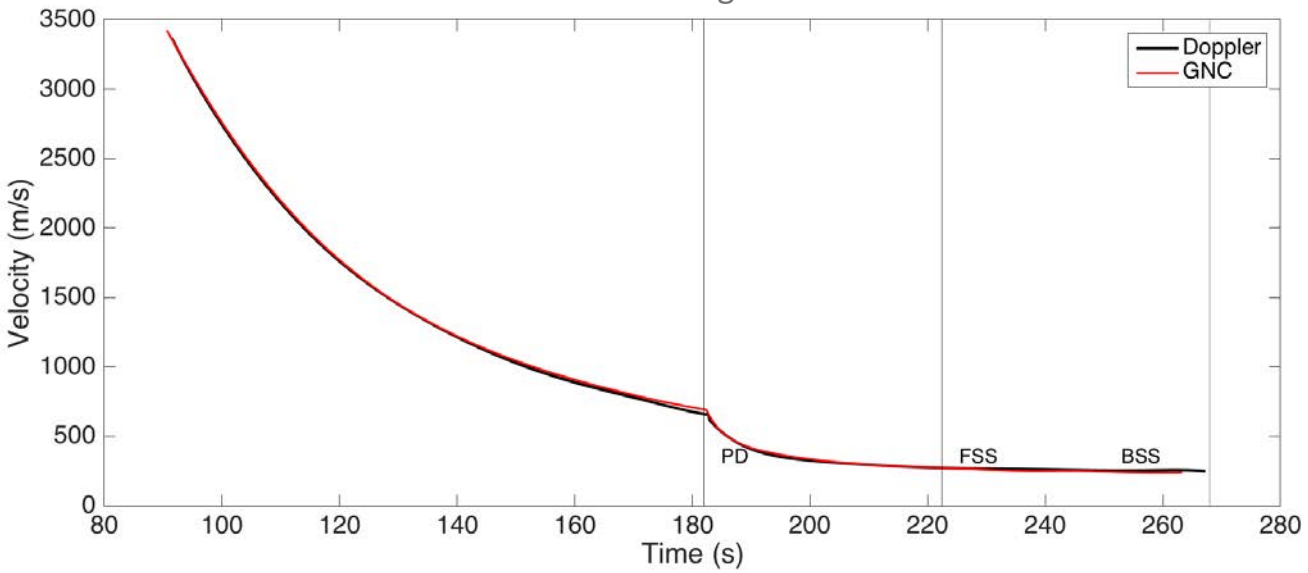


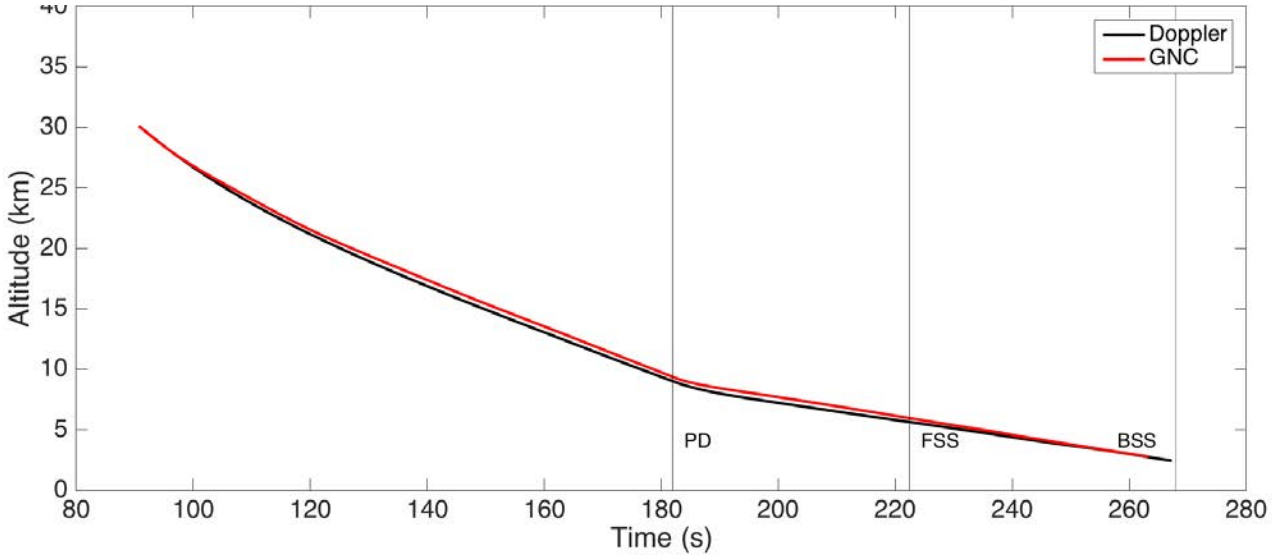
EDM - TGO Radio Signal

- Initial trajectory state in taken from GNC data)

RECONSTRUCTED TRAJECTORY

EDM - TGO Radio Signal & EDM GNC Data



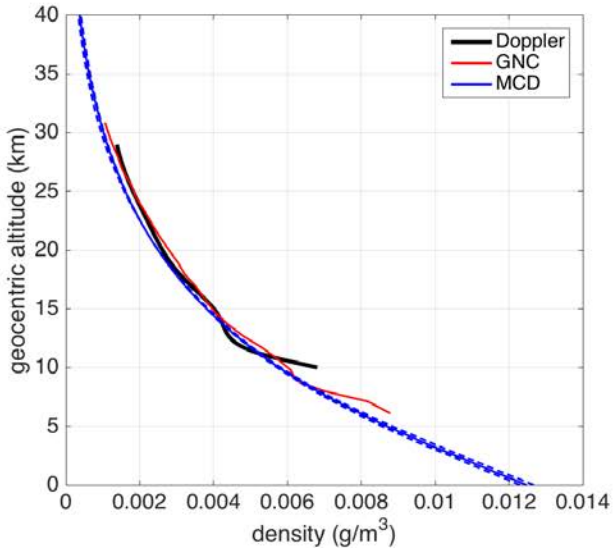


ATMOSPHERIC RECONSTRUCTION

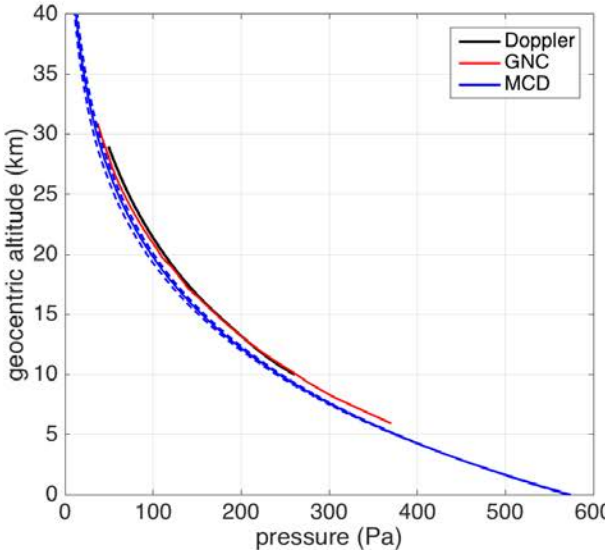
AMELIA

EDM - TGO Radio Signal, EDM GNC Data & Mars Climate Database (LMD) Scenarios: Climatology: "Best guess" scenario for a typical Mars year (solid blue line), Cold: very clear sky & Warm: dusty atmosphere (Dashed)

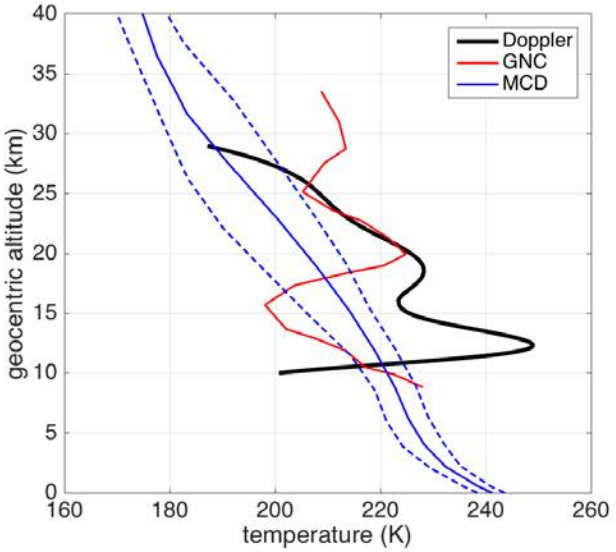
Temperature

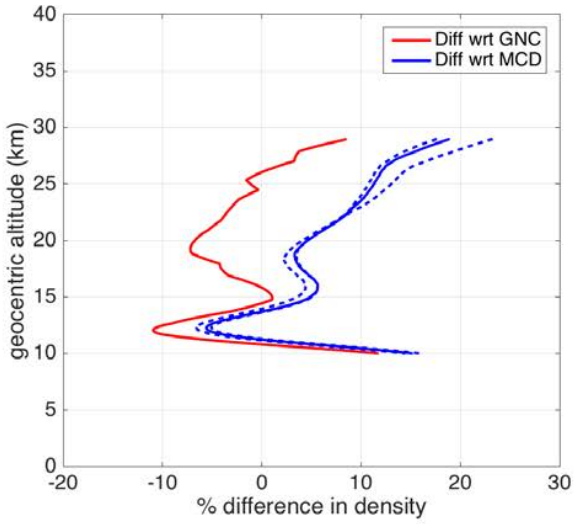


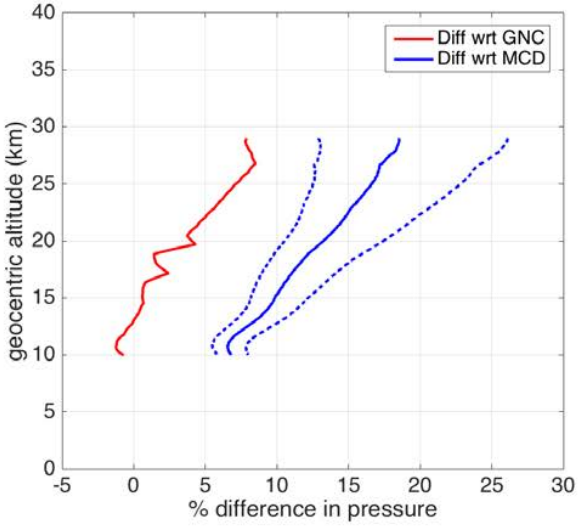
Pressure

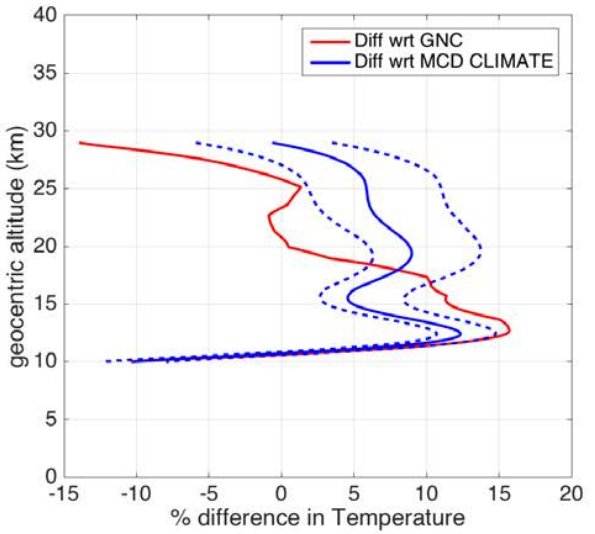


Temperature









CONCLUSIONS & SUMMARY

AMELIA

- ExoMars 2016 Schiaparelli radio communication provided **essential telemetry via orbiter relay**. This allowed reconstruction, understanding and learning in spite of telemetry rate limitation.

- Doppler shifted **radio carrier signals** contribute to constrain spacecraft state and trajectory and understanding Mars's atmosphere.

- Data acquired in **Direct-to-Earth** effort useful for reconstructing events, especially when combined with carrier signal received by TGO, Mars Express, and telemetry from on-board sensors.

- Atmospheric Mars Entry and Landing Investigations & Analysis **(AMELIA)** team working on the data analysis for reconstruction of Schiaparelli trajectory and attitude and **retrieval of atmospheric profiles using different data sets** (GNC, Surface Pressure, Radio).

- Putting the experience and the lessons learned into perspectives for **ExoMars 2020 EDL**.