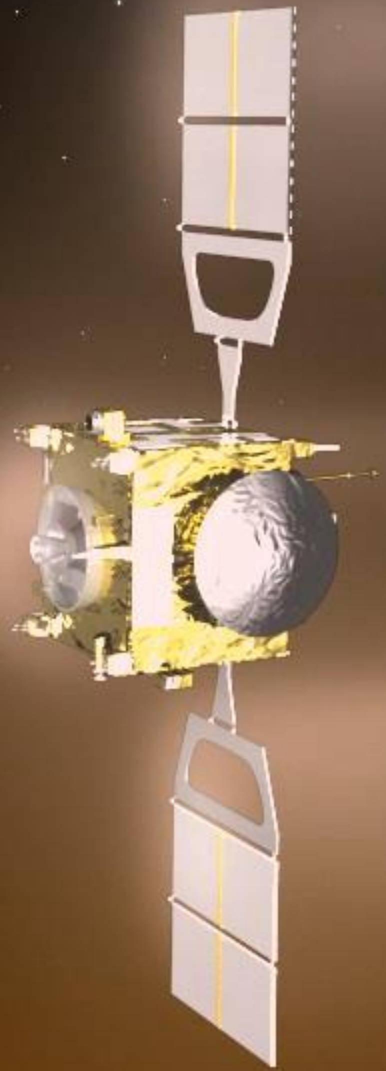
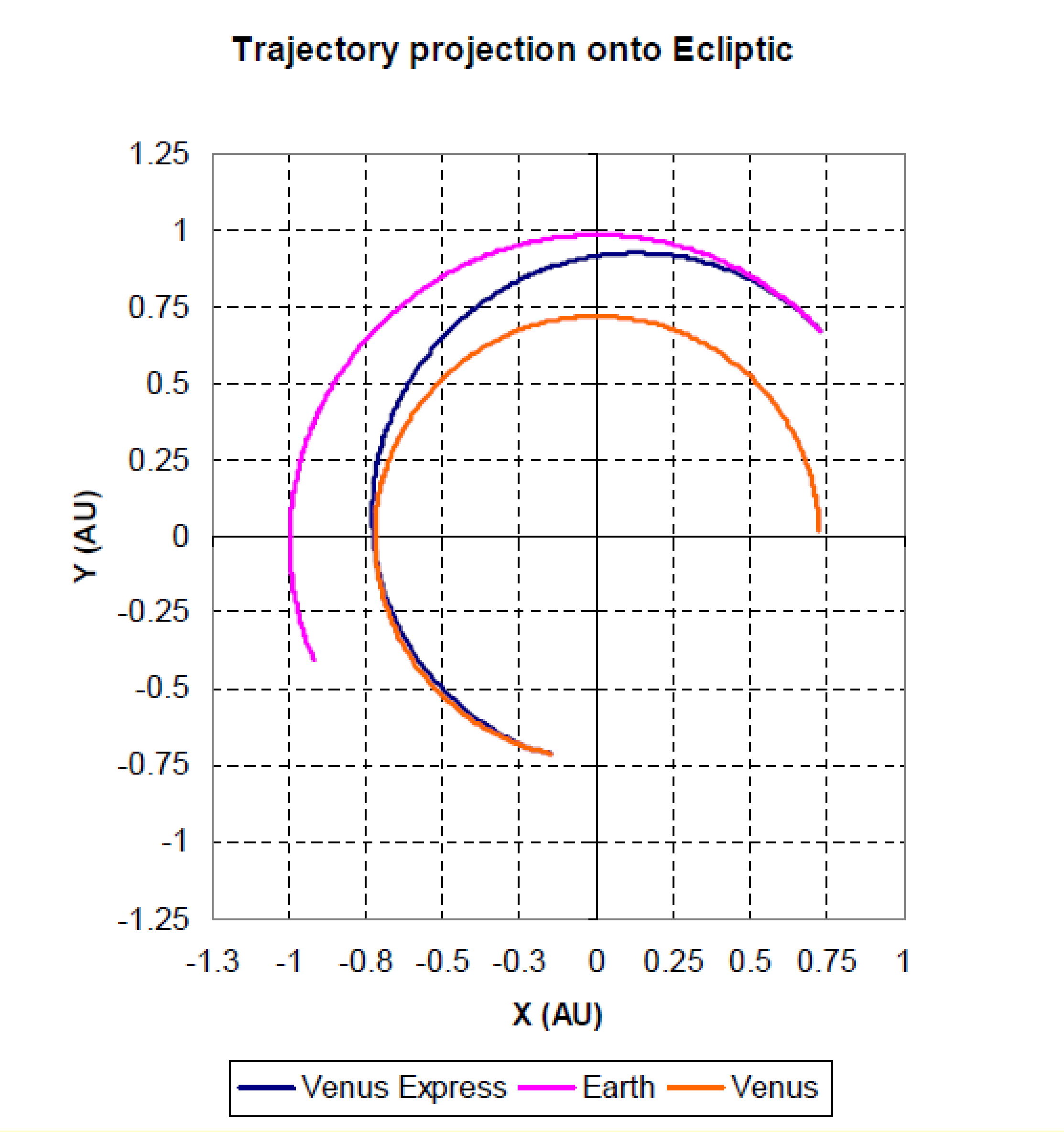


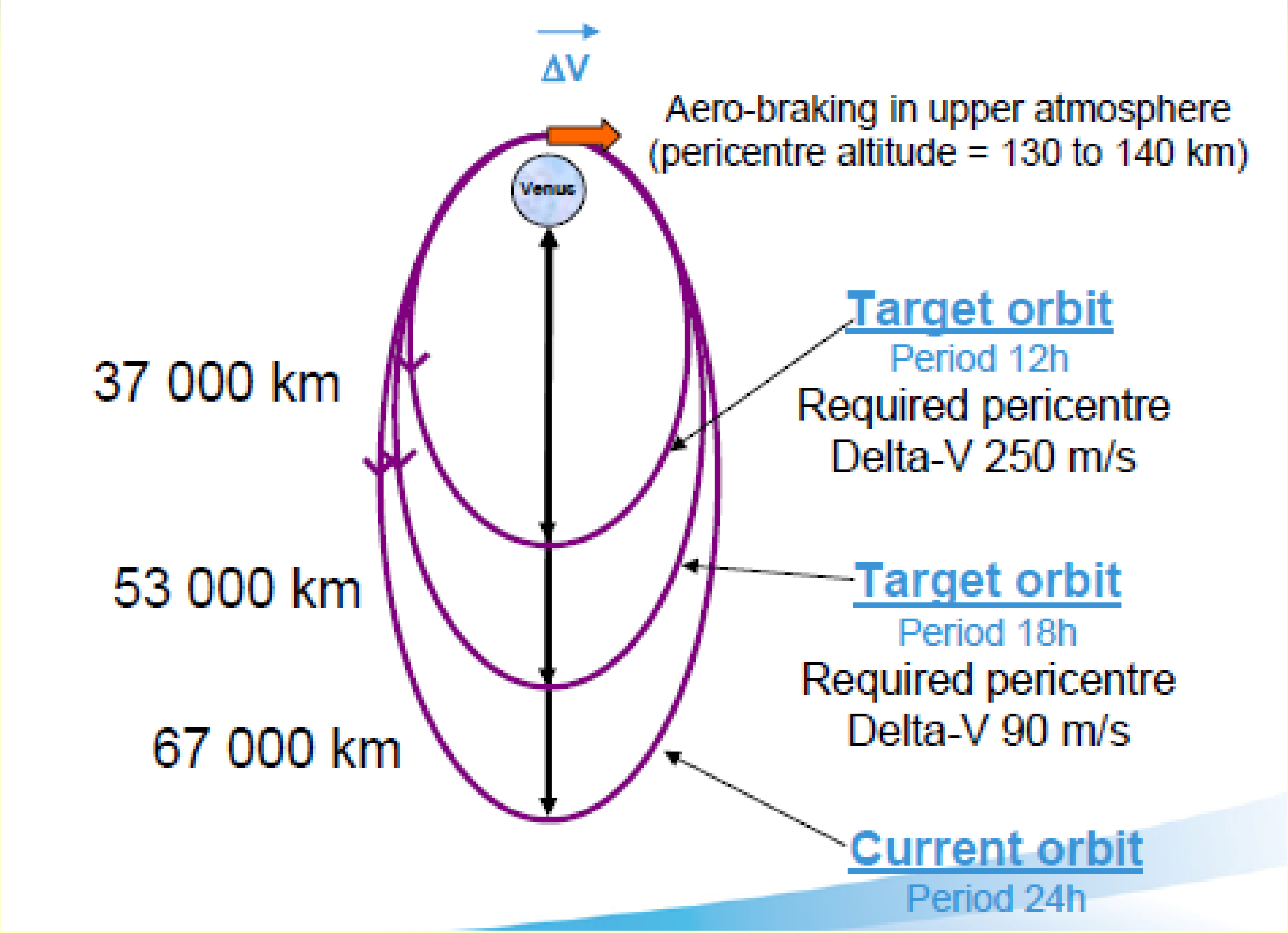
Aerobraking – A mission enabling and fuel saving technique for orbit changes - Venus Express and ExoMars TGO

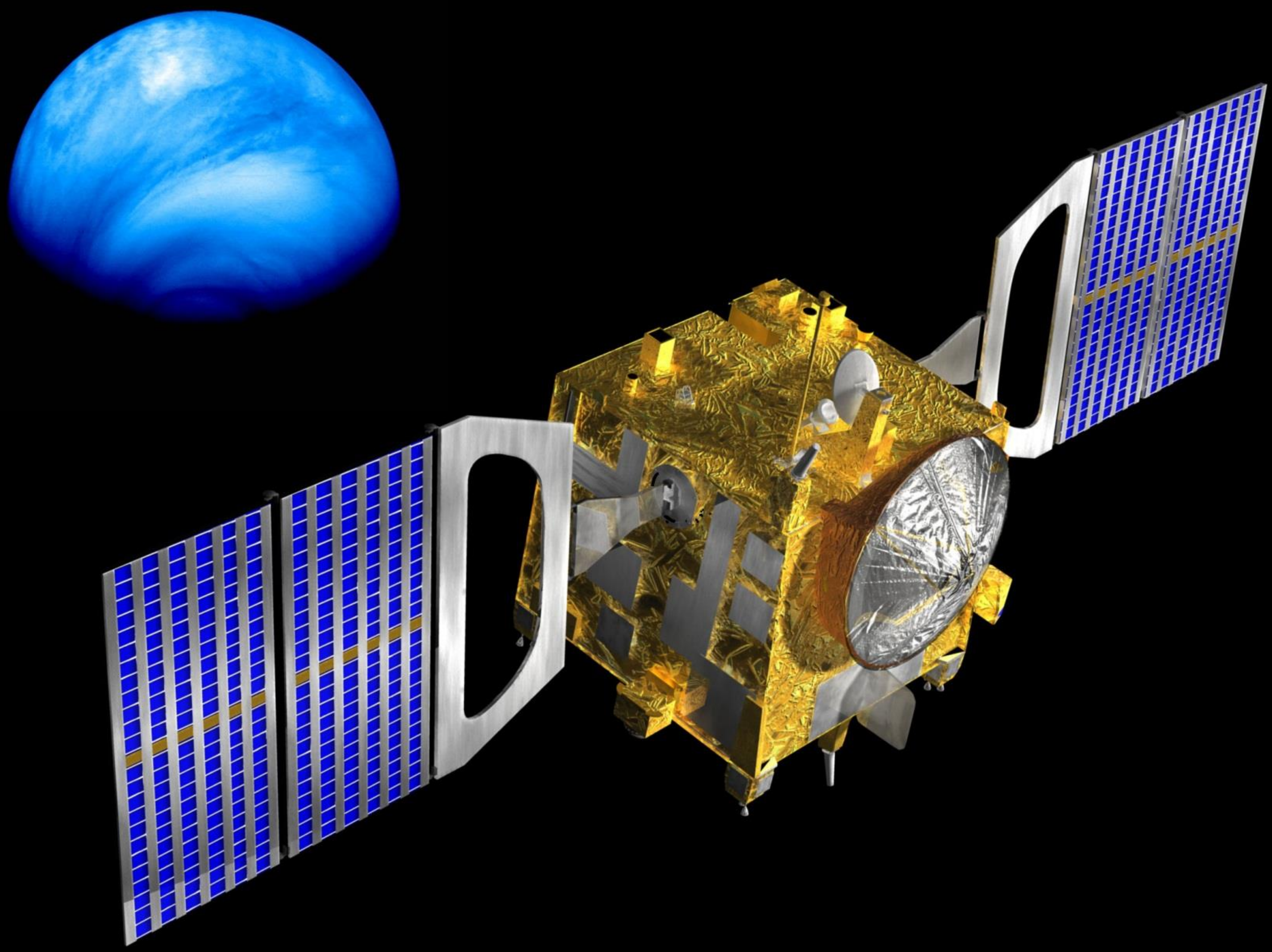
Håkan Svedhem
ESA/ESTEC

Earth – Venus Trajectory



Reducing Apocentre altitude





Venus Express

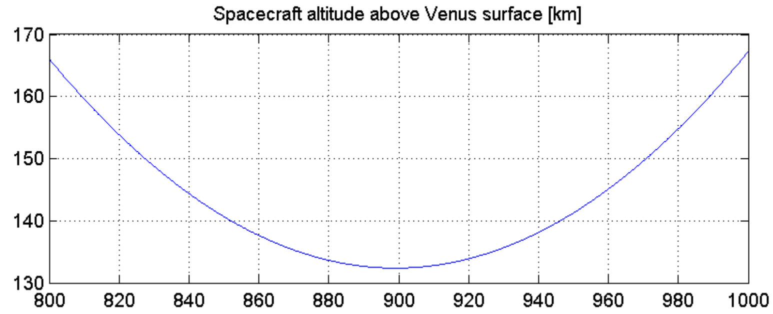
Specific points to be considered for the test case of Venuis Express

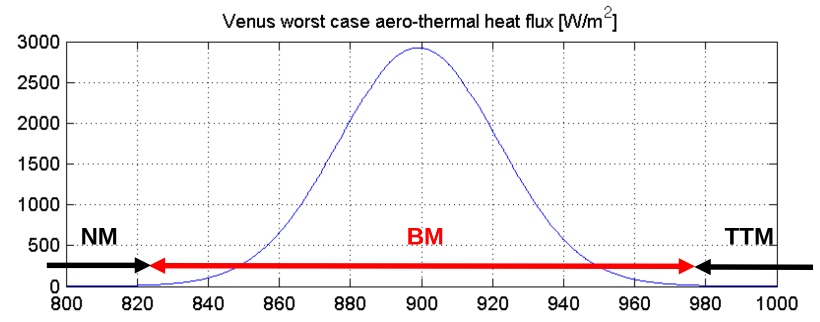
1. Venus Express has a body/solar array layout that results in a dynamically stable attitude.
2. A software mode to operate the spacecraft is during aerobraking is a part of the on board software. Aerobraking was initially foreseen as a backup in case the Venus orbit insertion would fail, however it was never intended to be used as a part of the nominal mission. Only limited testing of this has been performed.
3. Additional high temperature tests have been done on the solar panels, but unidentified hotspots may exist.
4. The most limiting factor on Venus Express is likely to be the aerothermal heat input on the Multi Layer Insulation on the –Z platform.
5. The uncertainty and variable character of the Atmosphere needs to be considered.

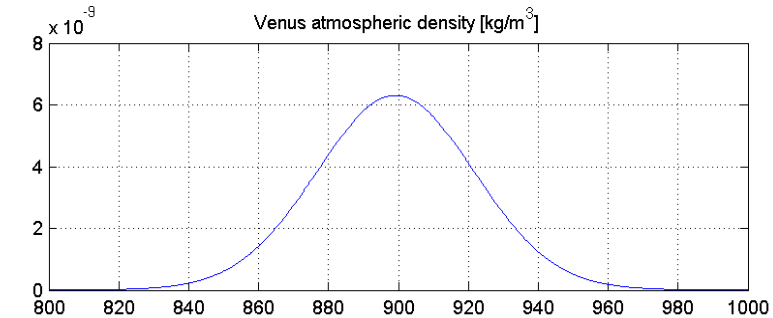
The aerodrag equation

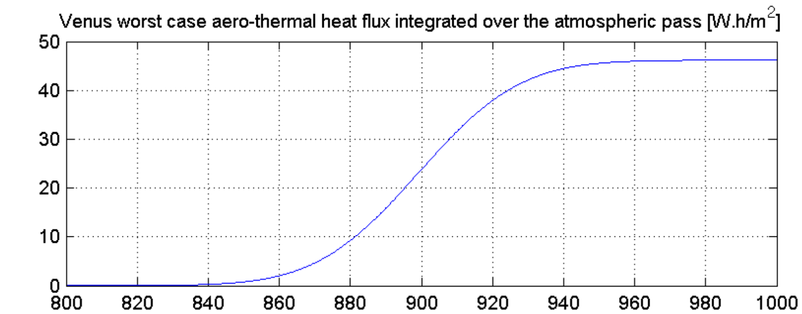
$$m\,a = \tfrac{1}{2}\,\rho\,C_d\,A\,v^2$$

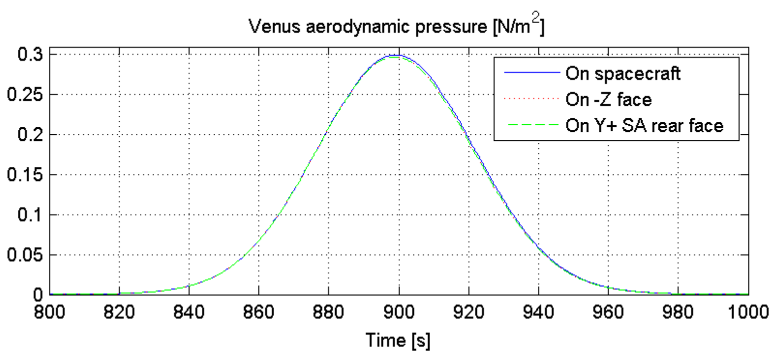
Parameters to consider

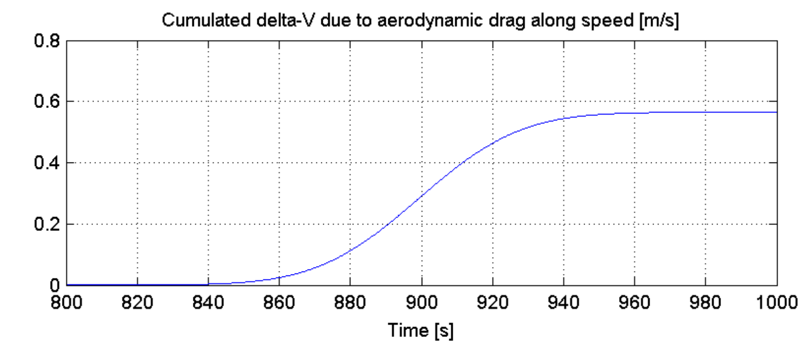




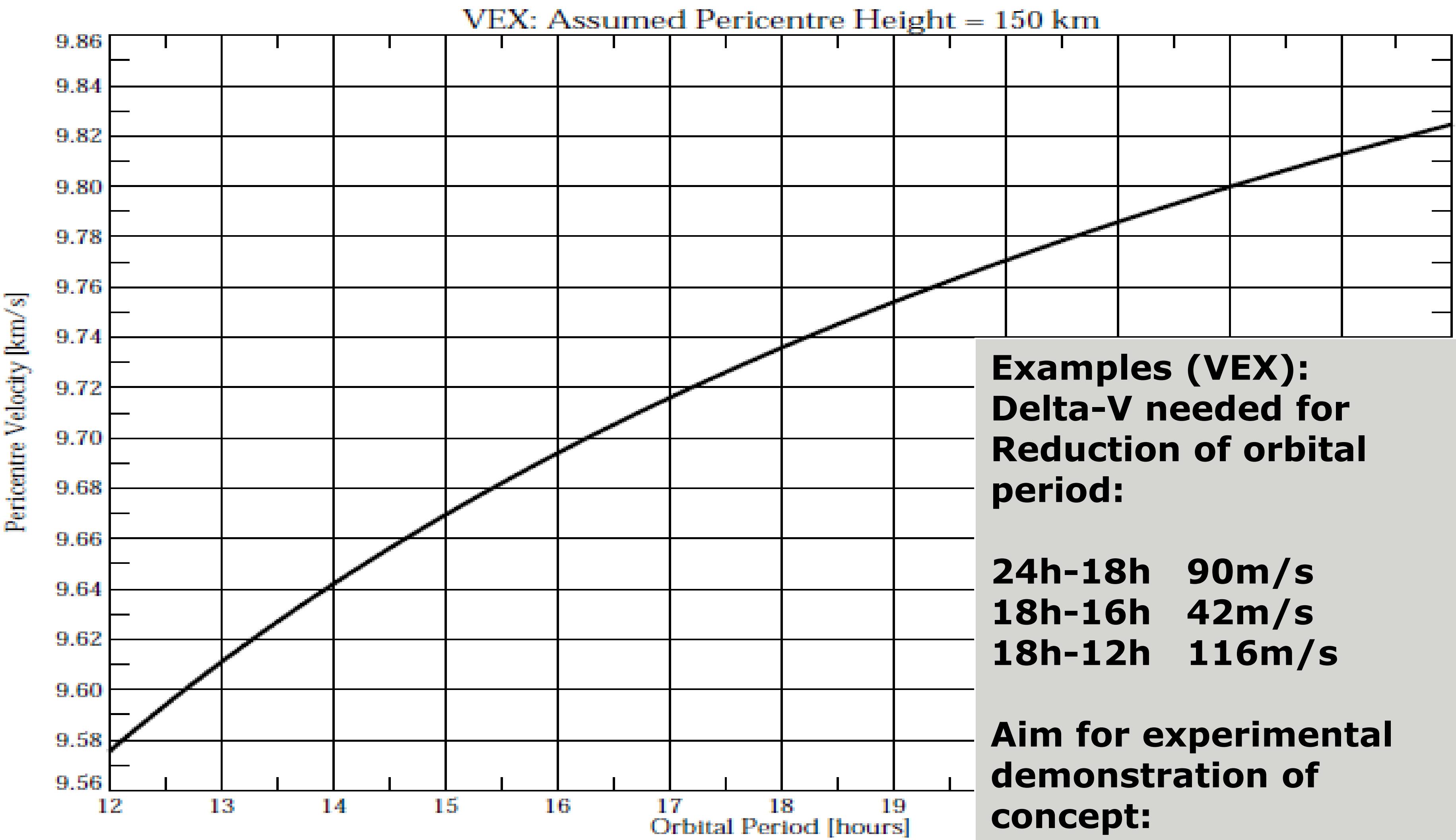








Pericentre velocity vs Orbital Period

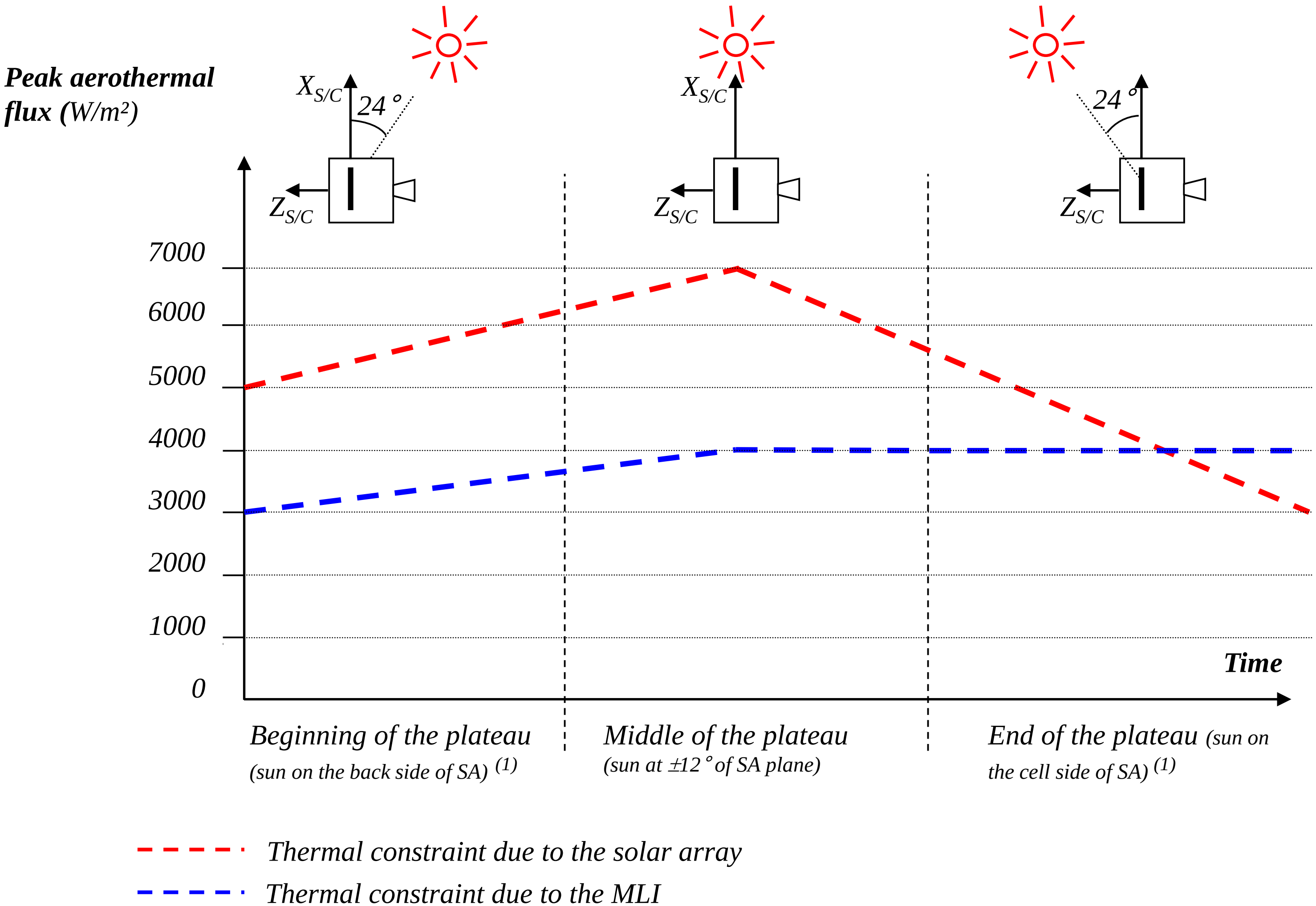


Examples (VEX):
Delta-V needed for Reduction of orbital period:

24h-18h 90m/s
18h-16h 42m/s
18h-12h 116m/s

Aim for experimental demonstration of concept:
24h-23h 12 m/s

Aerothermal flux limitations



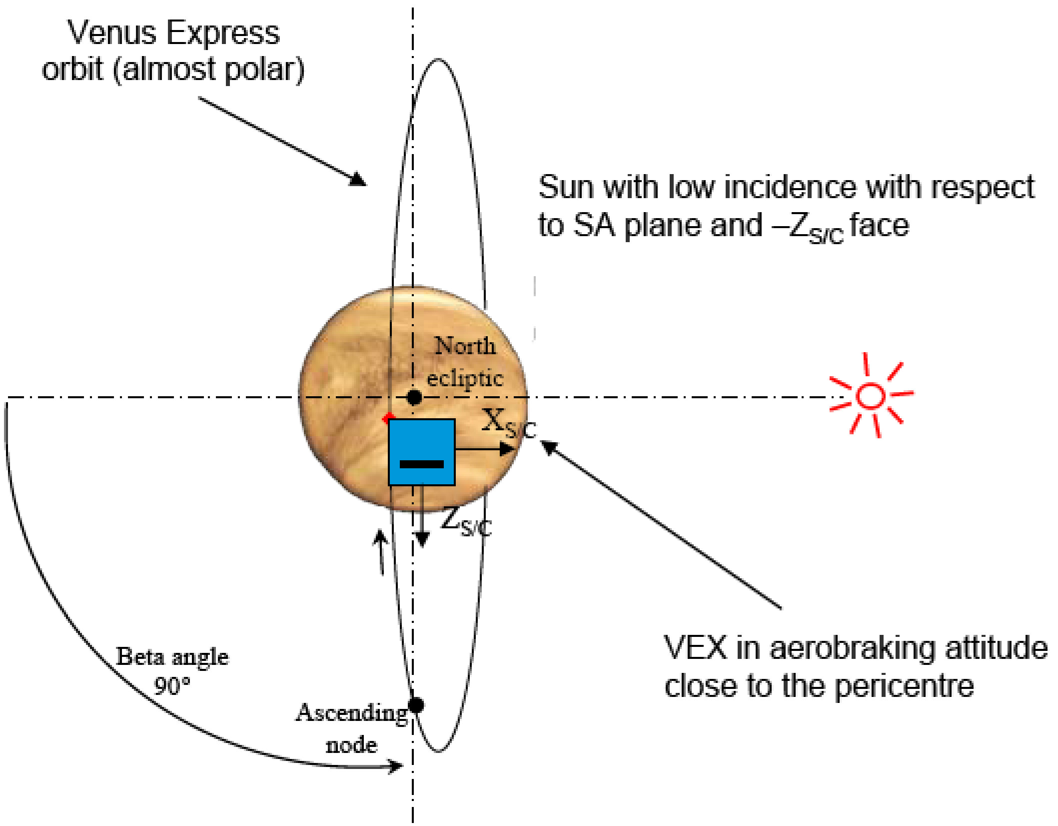
***Note (1)** : Depending on the plateau the sun will be illuminating the back side of the SA either at the beginning or at the end of the plateau*

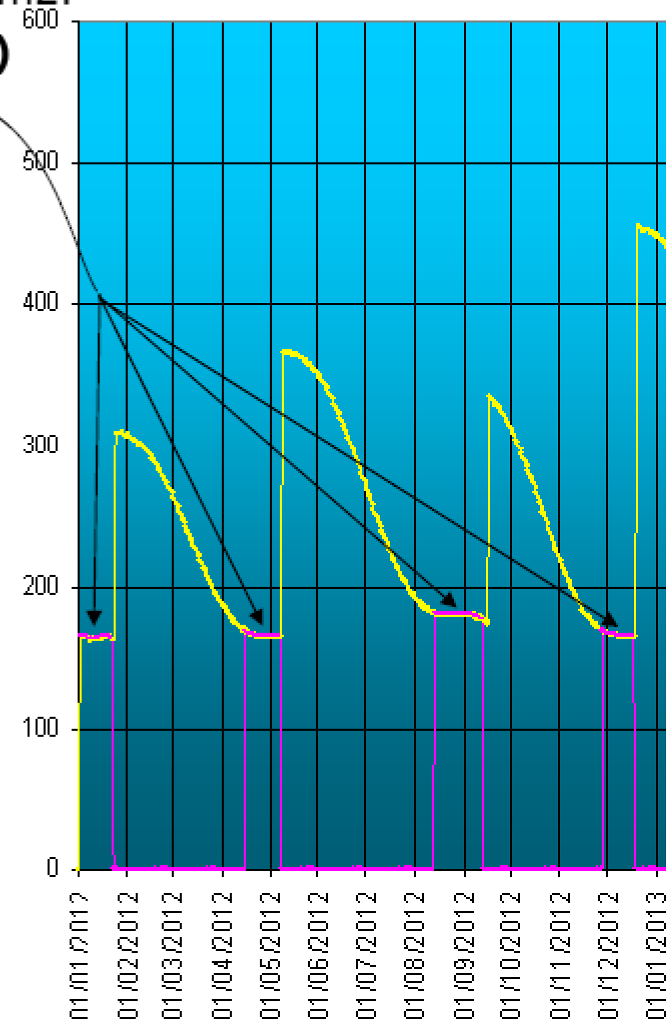
Optimum conditions for aerobraking at Venus

Reference case = most favourable conditions for Sun Aspect Angle allowing a Heat Flux of about 3000 W/m2 <> Dynamic Pressure of 0.3 N/m2.

→ Sun at 90° from the VEX orbit plane **(Beta Angle)**

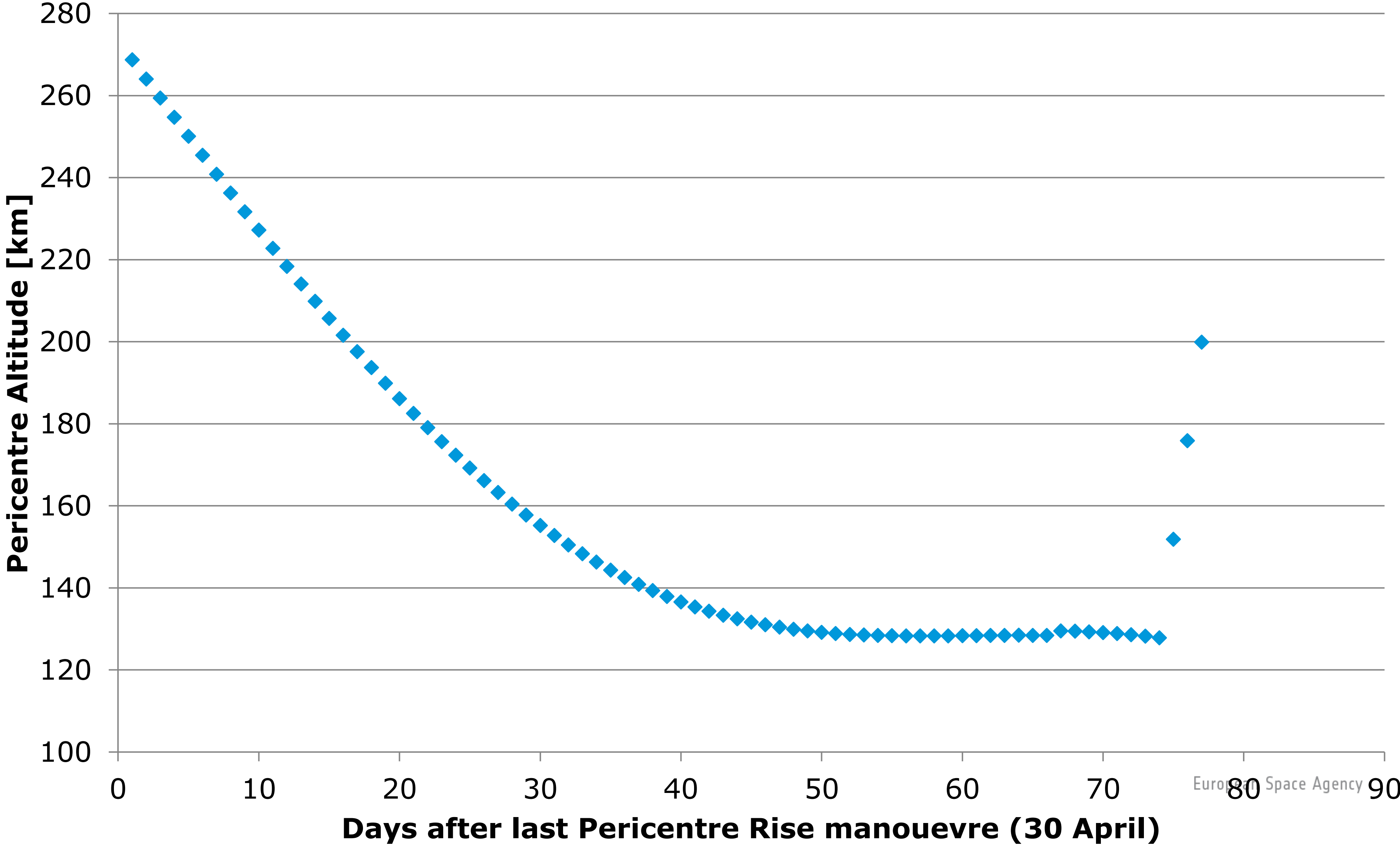
→ ß= 90° <> Middle of Plateaus



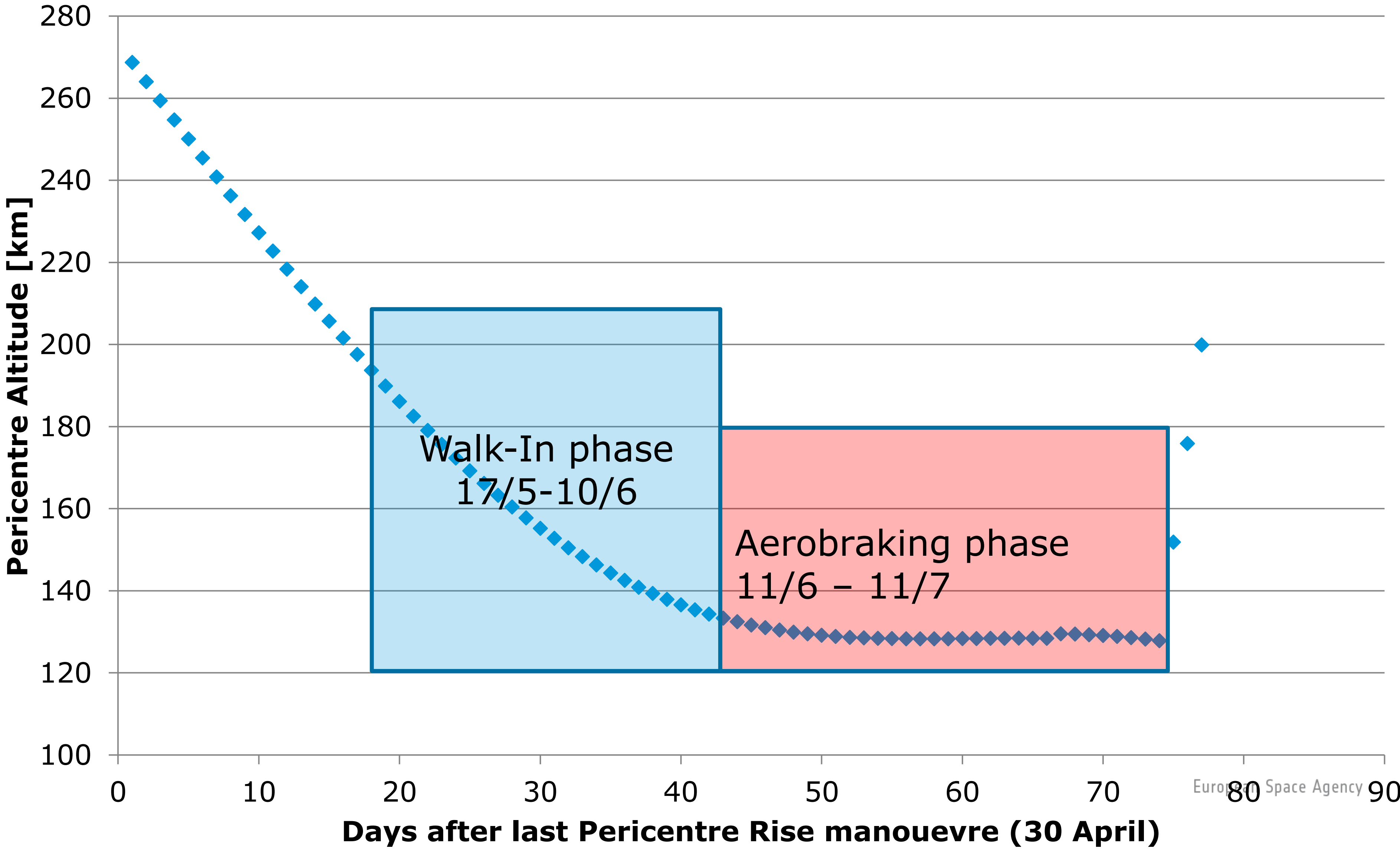


View from above Venus orbit plane

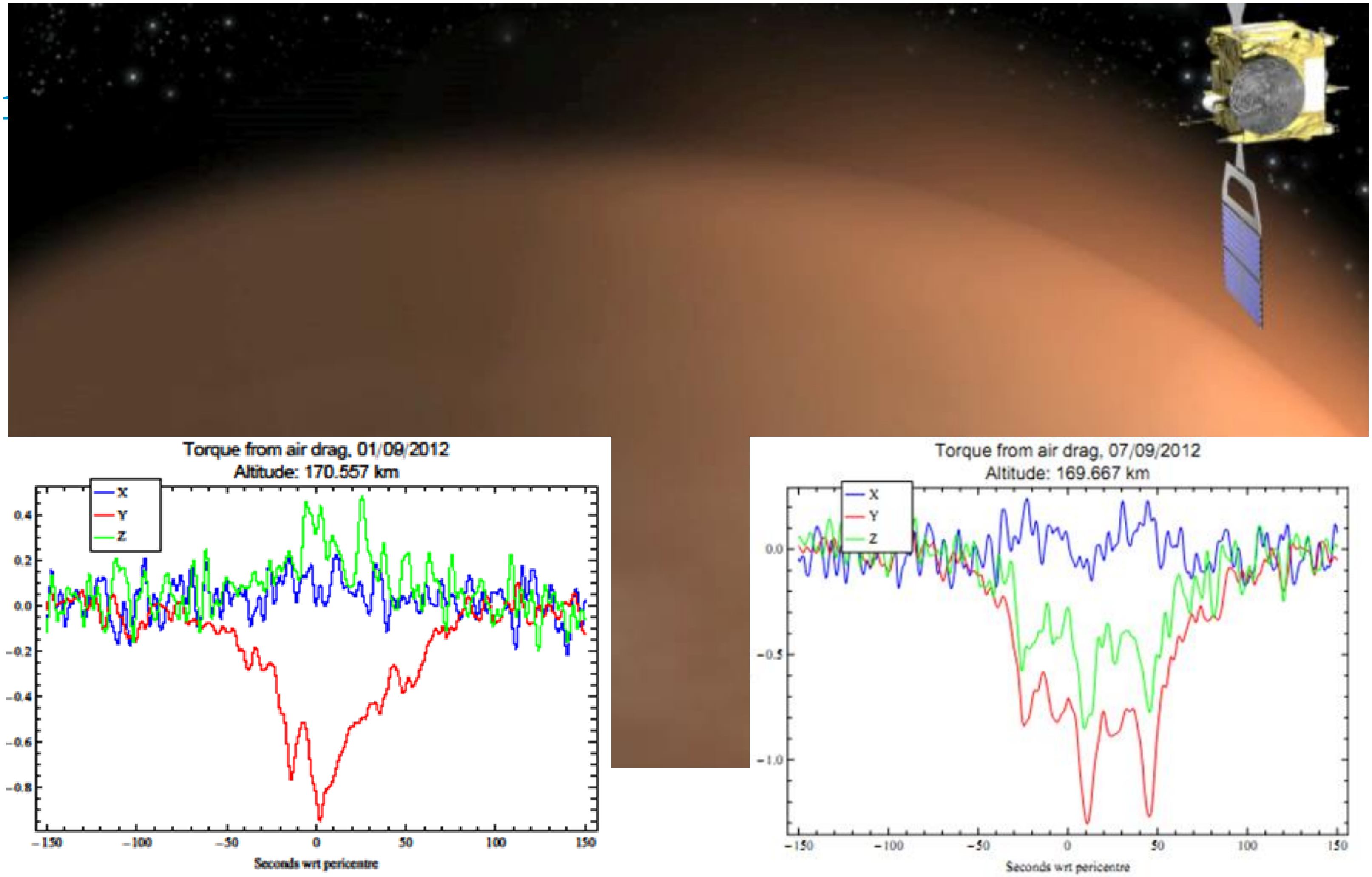
Pericentre Altitude [km]



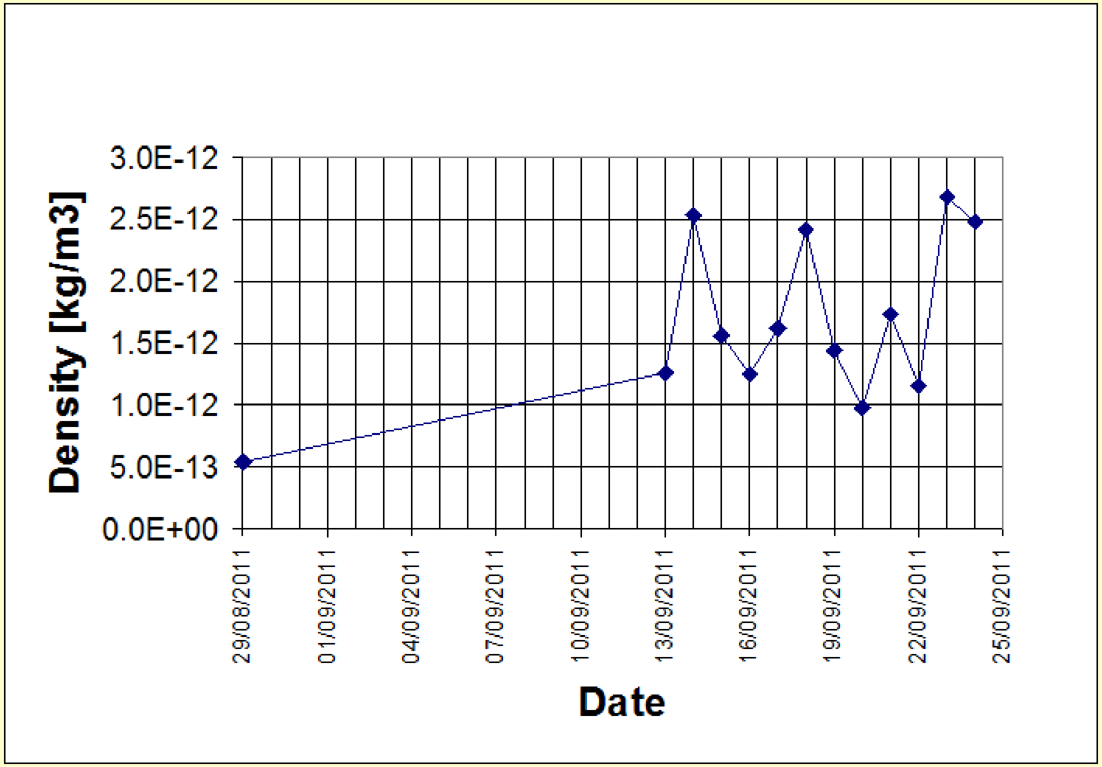
Pericentre Altitude [km]



Preparation for aerobraking: Torque technique for measuring atmospheric density at low altitudes



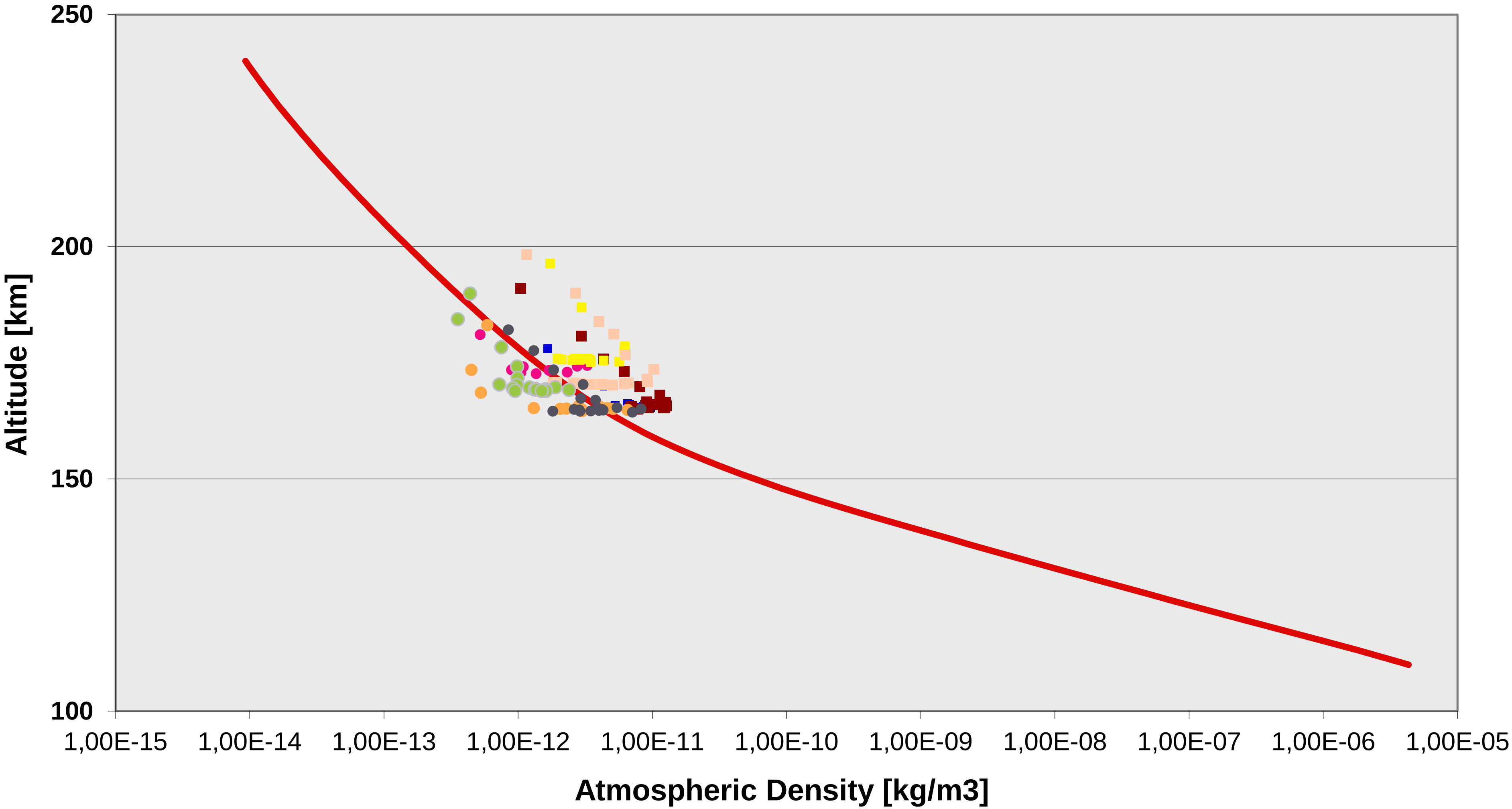
High day to Day variablity from Drag/Torque measurements at 165km

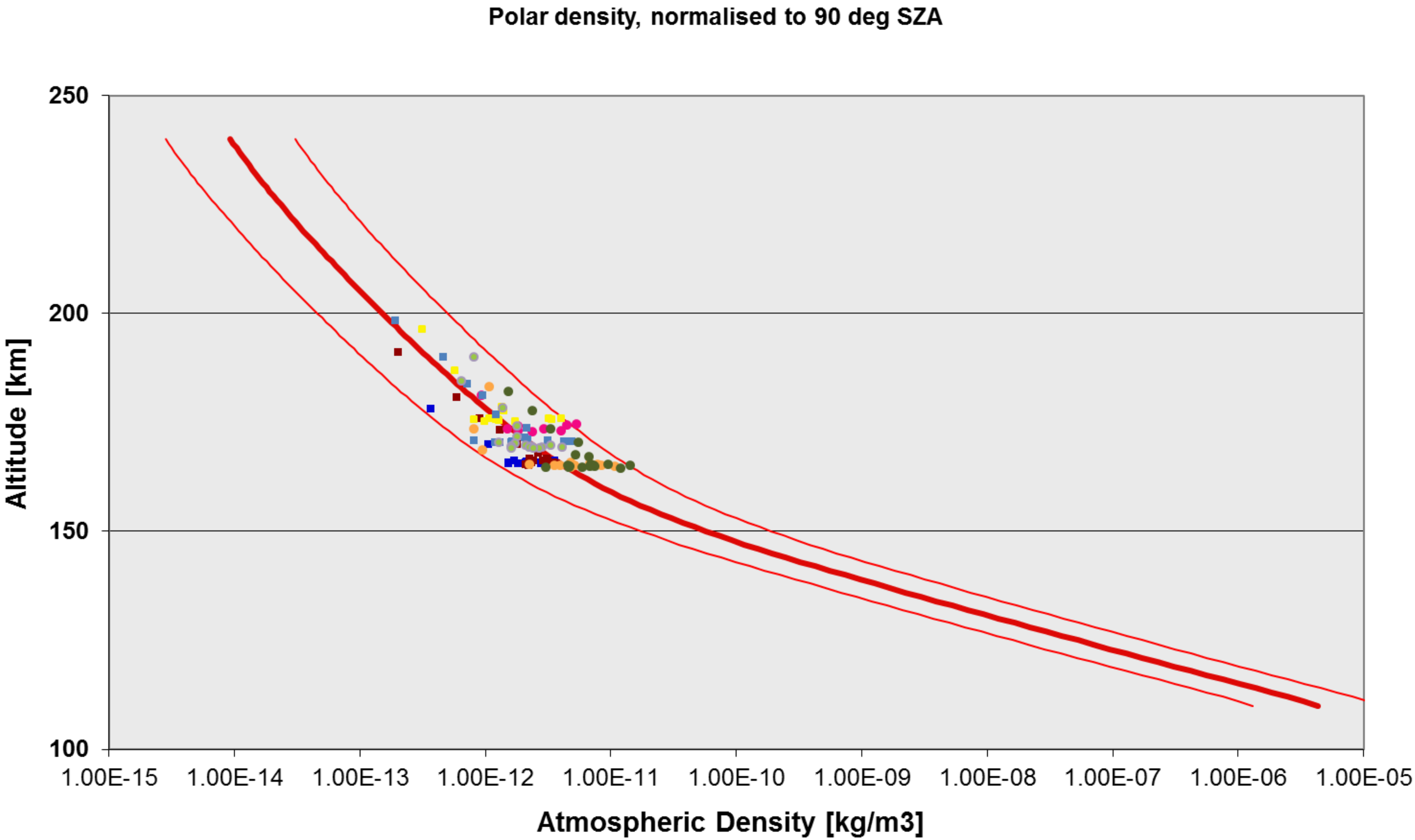


Models and measurements of density and temperature

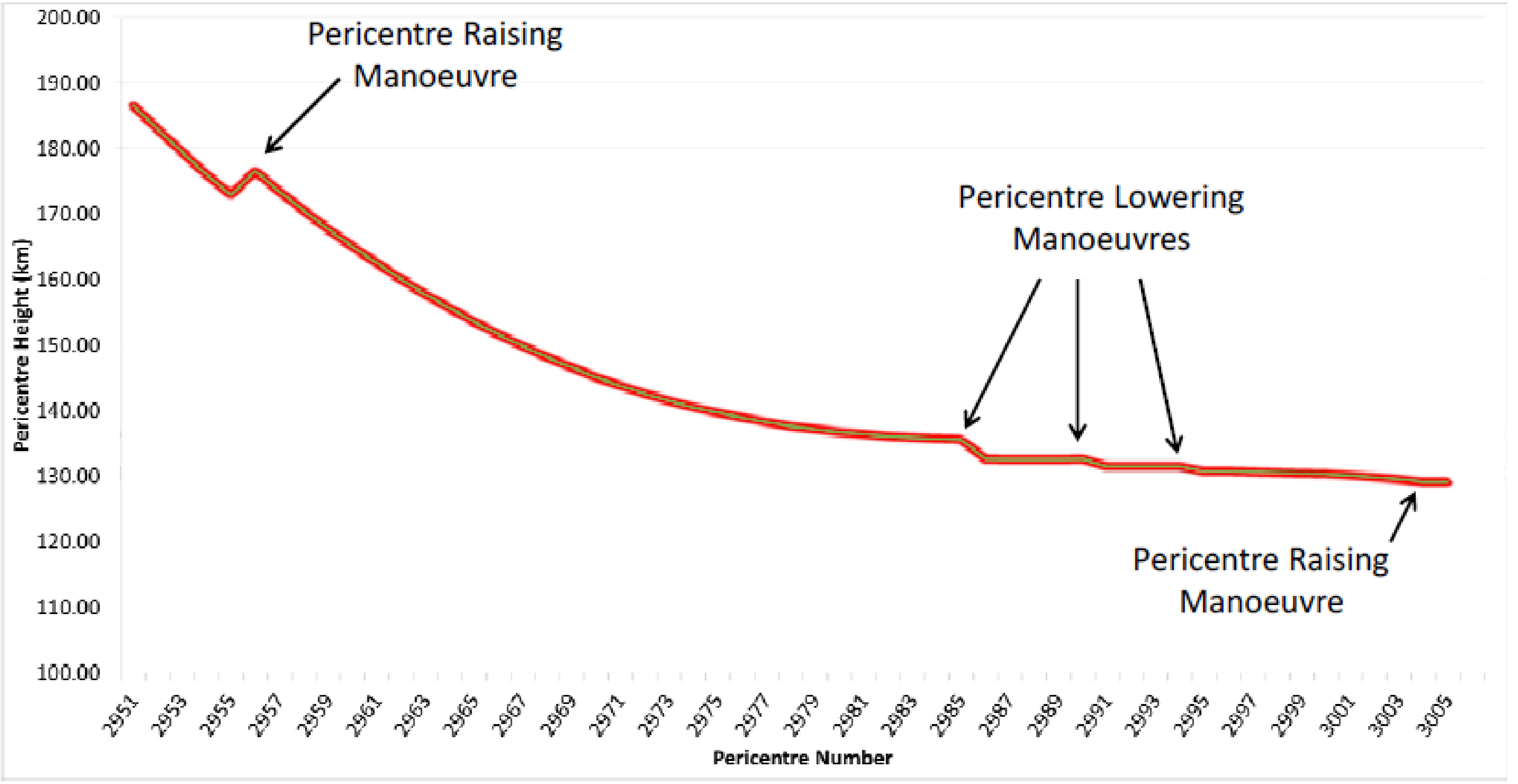
- VIRA (Venus International Reference Model), Hedin model, VTS3 model
- Measurements on Venus Express
  - Spicav, up to 130 km (only CO_2)
  - SOIR, up to 150 km (only CO_2)
  - VeRa, up to 95 km
  - Drag, by radio tracking, 165-180 km
  - Torque, 165-200 km

Polar density, raw torque data

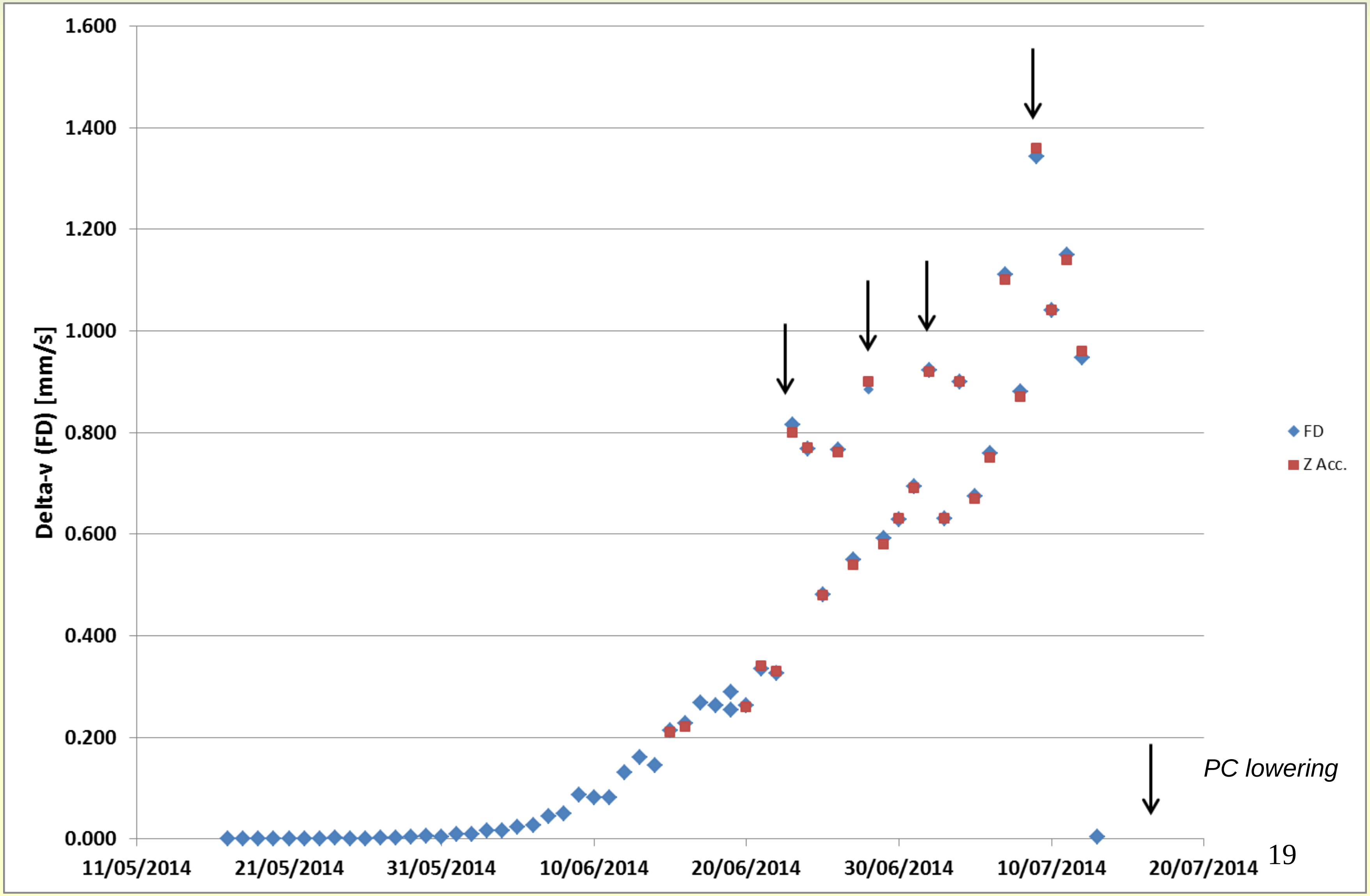


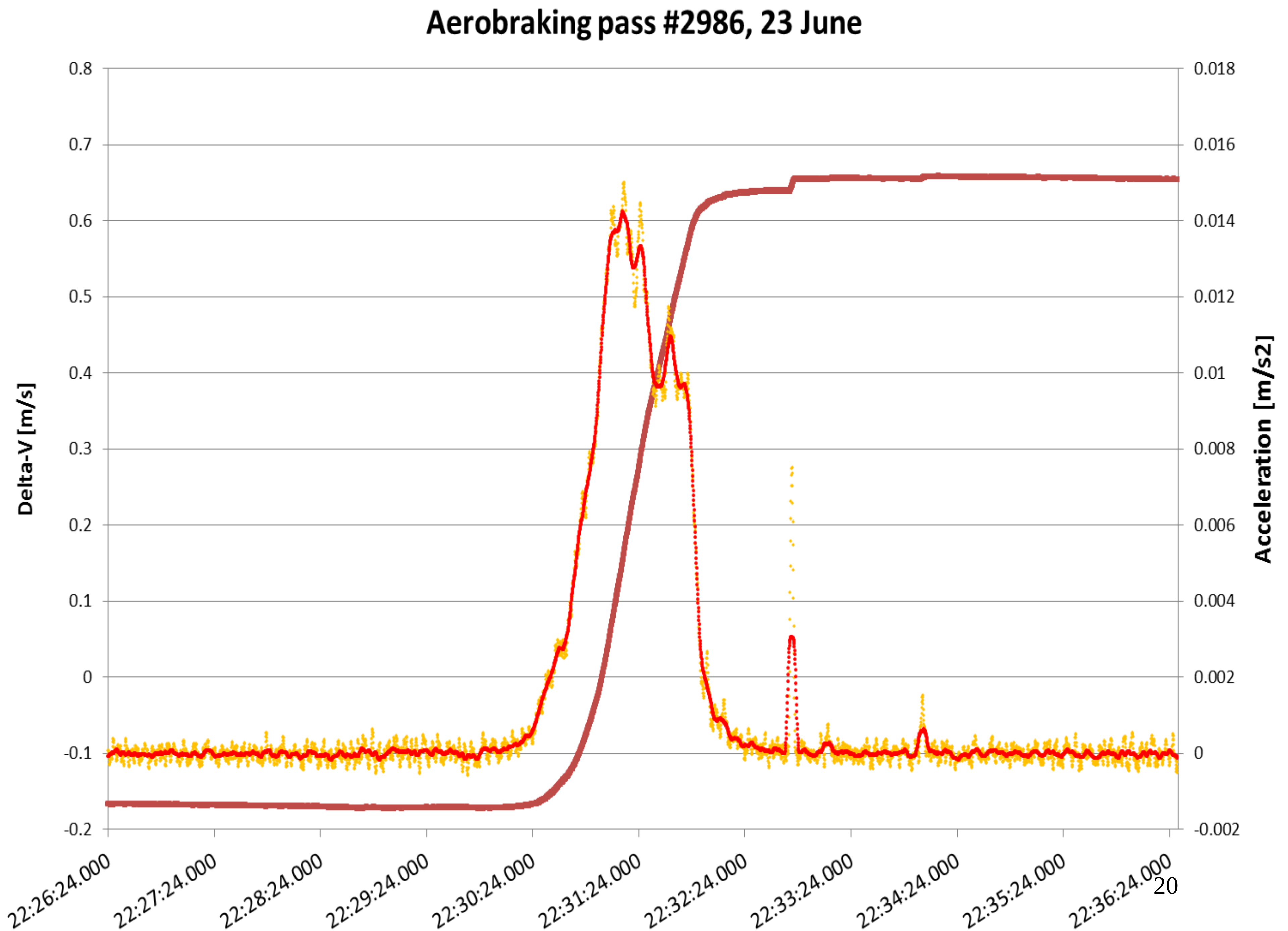

esa SCIENCE
Polar density, normalised to 90 deg SZA
Altitude [km]
250
200
150
100
1.00E-15
1.00E-14
1.00E-13
1.00E-12
1.00E-11
1.00E-10
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
Atmospheric Density [kg/m3]

Pericentre Altitude evolution



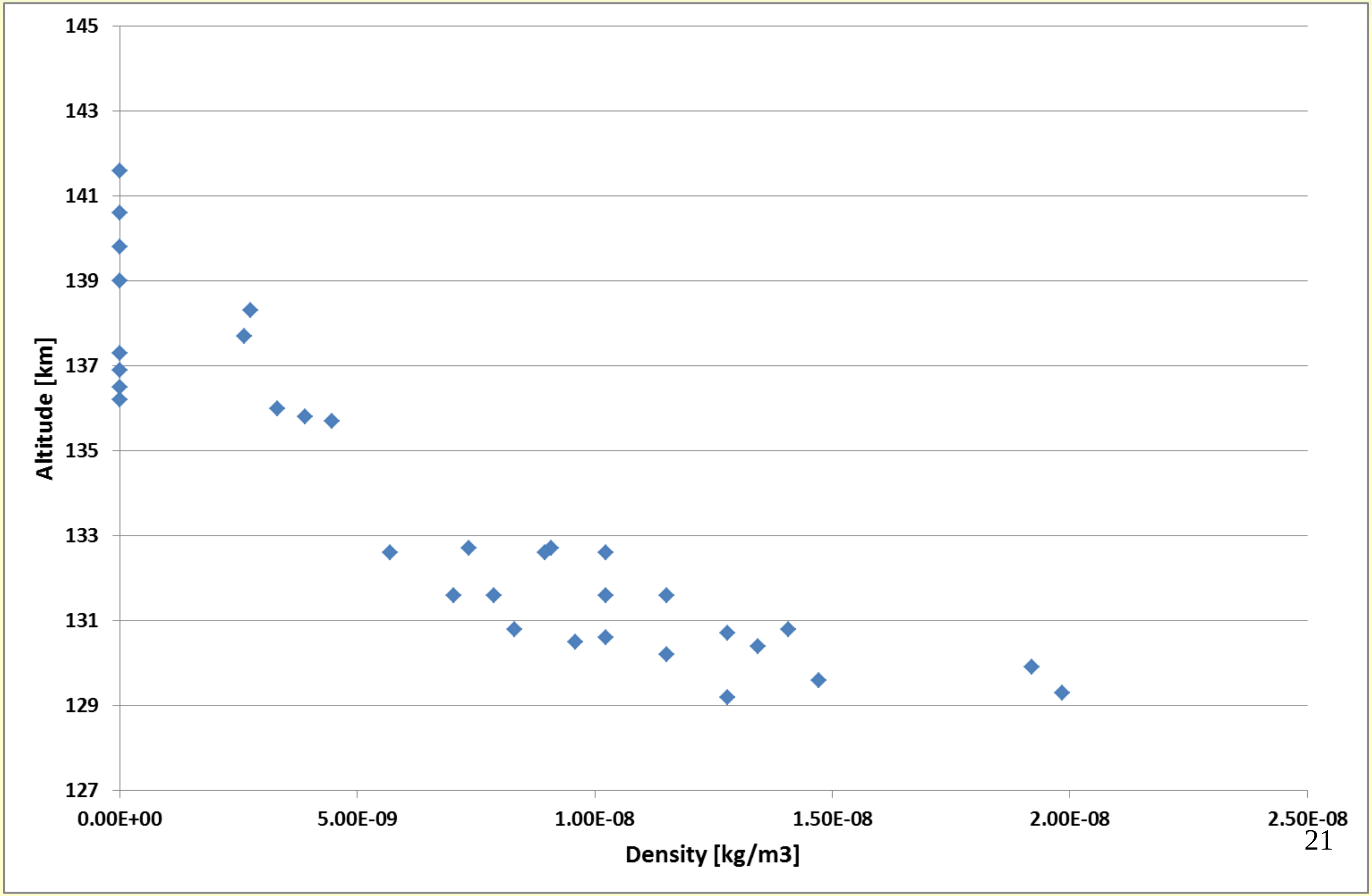
Delta-v vs date



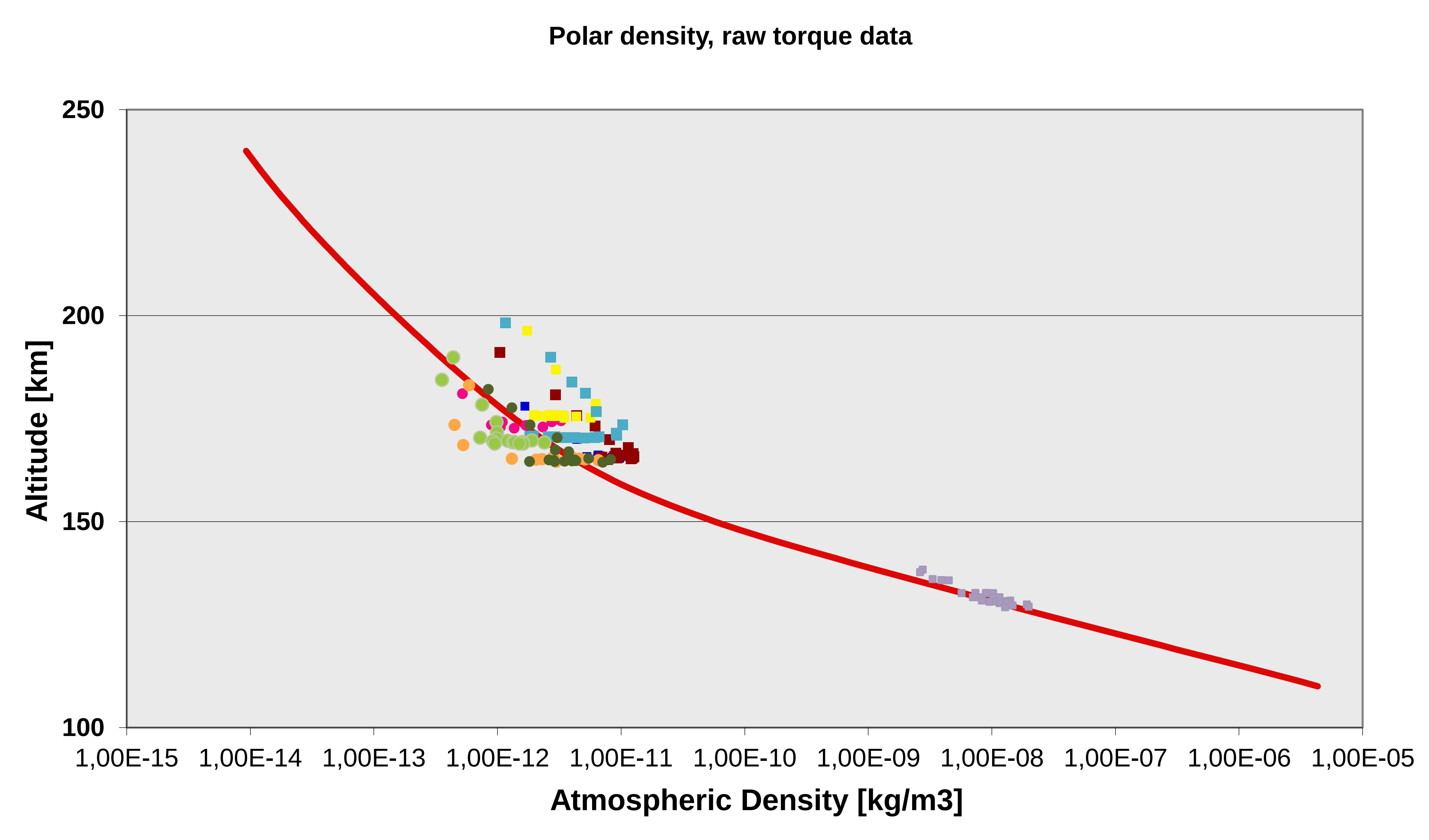


Aerobraking pass #2986, 23 June
Delta-V [m/s]
Acceleration [m/s2]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
22:26:24.000
22:27:24.000
22:28:24.000
22:29:24.000
22:30:24.000
22:31:24.000
22:32:24.000
22:33:24.000
22:34:24.000
22:35:24.000
22:36:24.000

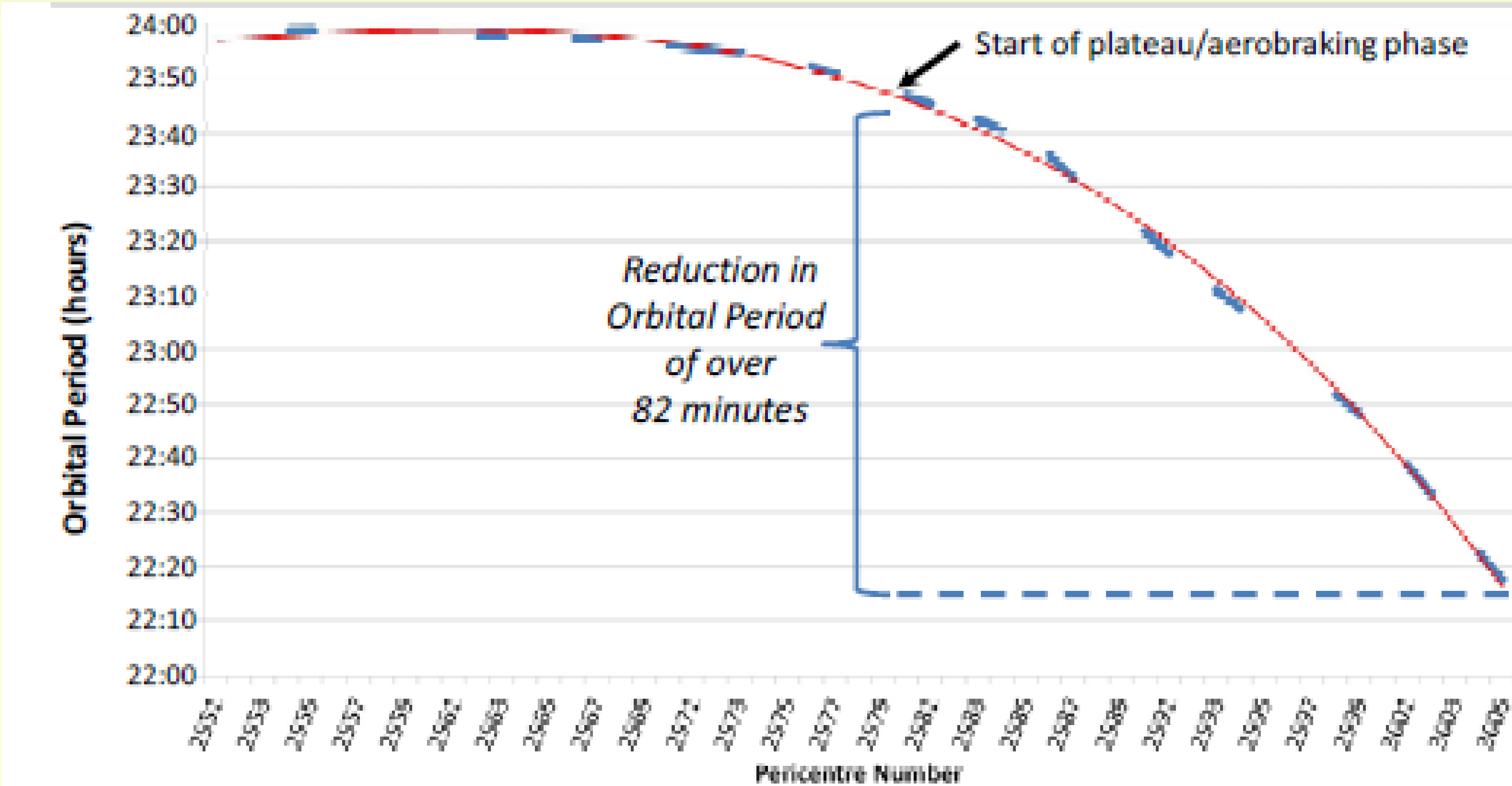
Atmospheric Density



Measurements vs. Model results



Evolution of Orbital Period



Conclusion on VEX Test

- Efficiency of aerobraking demonstrated: 1 hour 20 min reduction in orbital period in 4 weeks.
- Spacecraft capability and robustness confirmed, even at a maximum dynamic pressure of 0.7N/m^2 and a heat input of near 7 kW/m^2. No damage or reduced performance was observed.
- Operational procedures confirmed.
- Unique scientific results, providing atmospheric densities in an unchartered region. Actual densities turned out less than half of what was predicted by previous models.

ExoMars and the Trace Gas Orbiter

- The TGO is the first part of the ExoMars mission, to be followed by the ExoMars Rover and Surface platform to be launched in July 2020
- ExoMars is an ESA - Roscosmos joint programme
- ExoMars is funded within the European Exploration Envelop Programme (E3P) and is a part of the ESA HRE directorate with support from SCI
- The TGO is a very large spacecraft, with a total mass of 3700kg. The launch mass was 4300kg (including the Schiaparelli, the Entry Descent and Landing Demonstration Model). The height of TGO is about 3.2 m and the Solar array tip-to-tip length is 17.5m

Application of aerobraking to ExoMars Trace Gas Orbiter

[Aerobraking animation]

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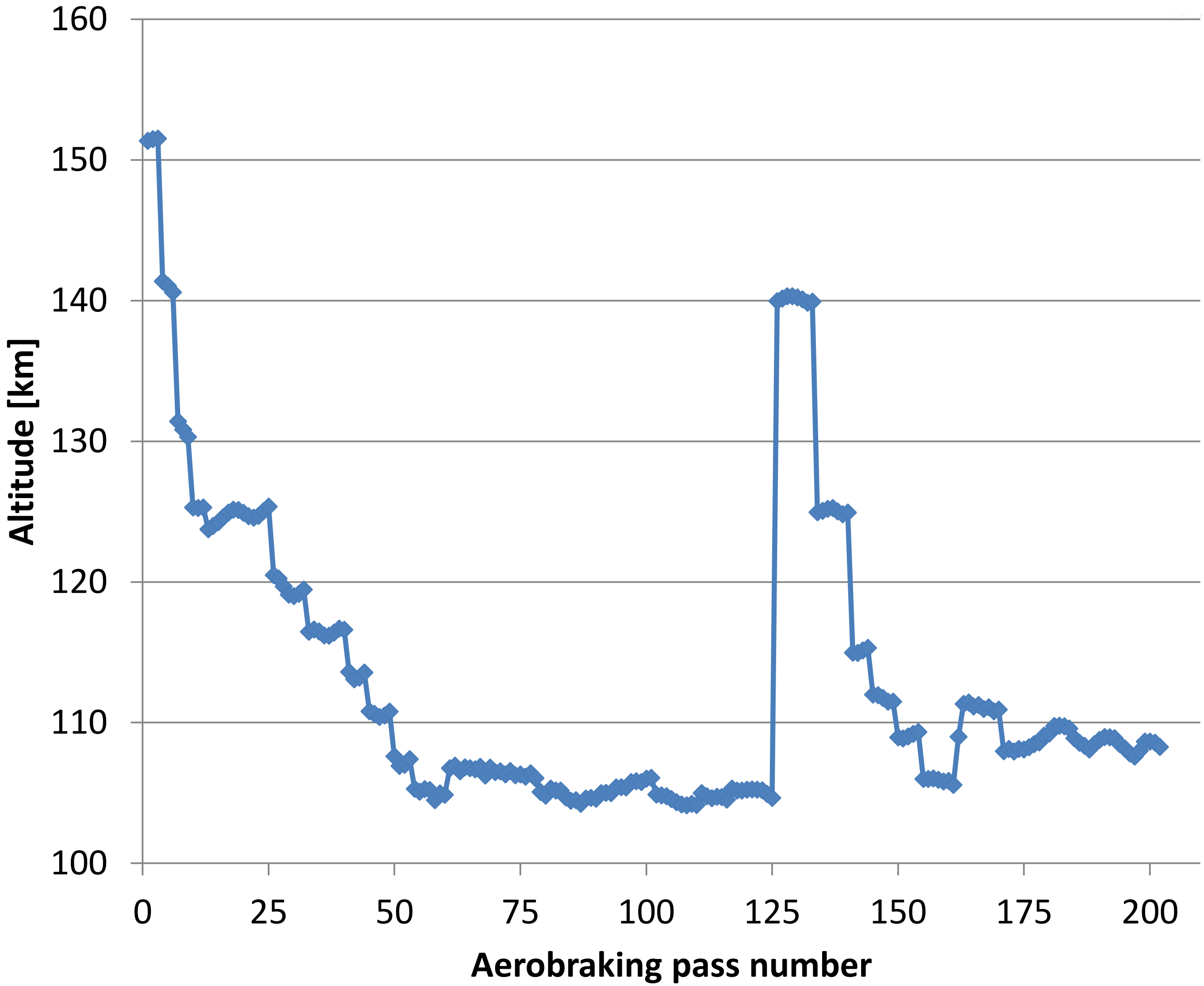
Aerobraking altitude evolution



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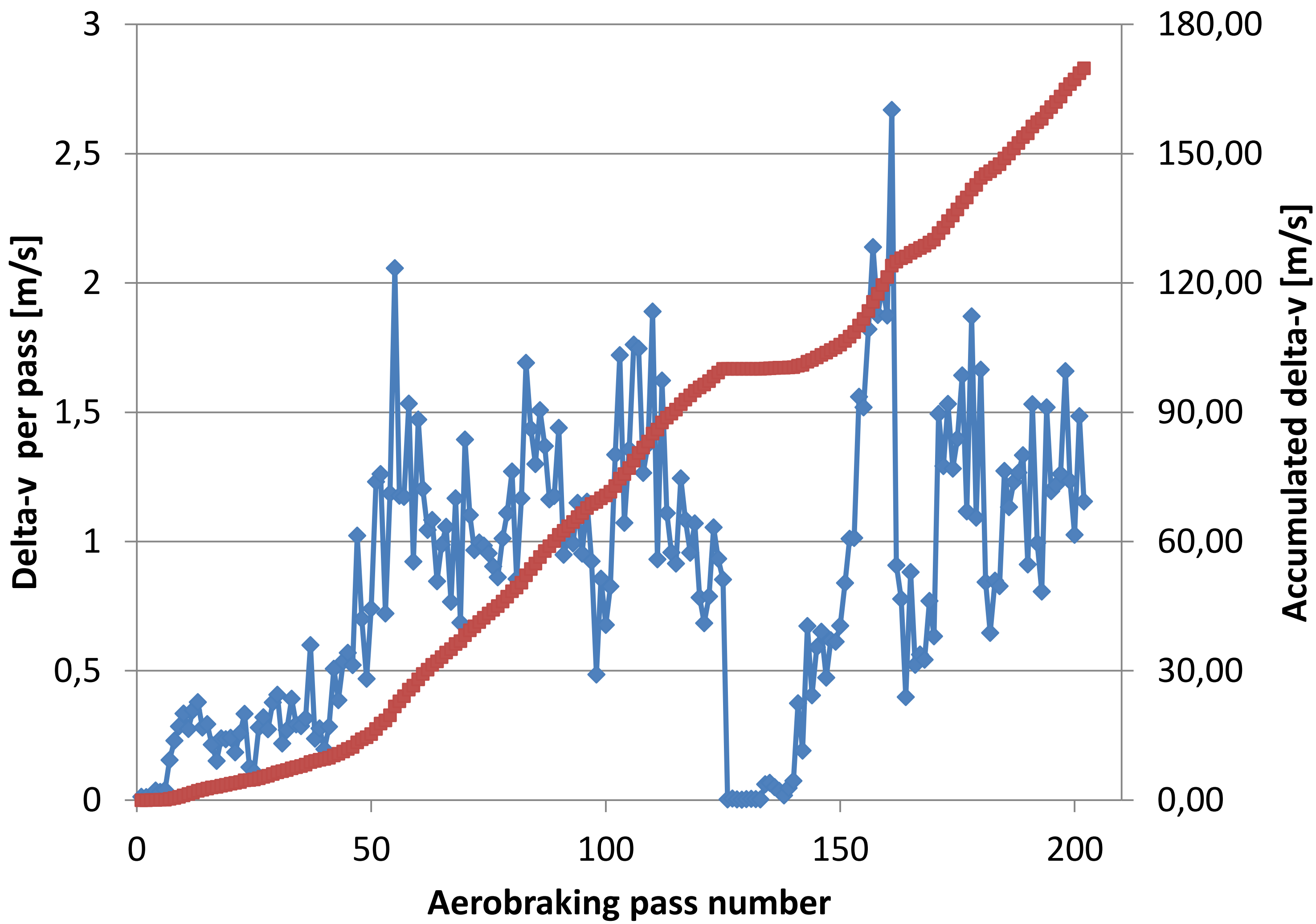
Delta-v per pass



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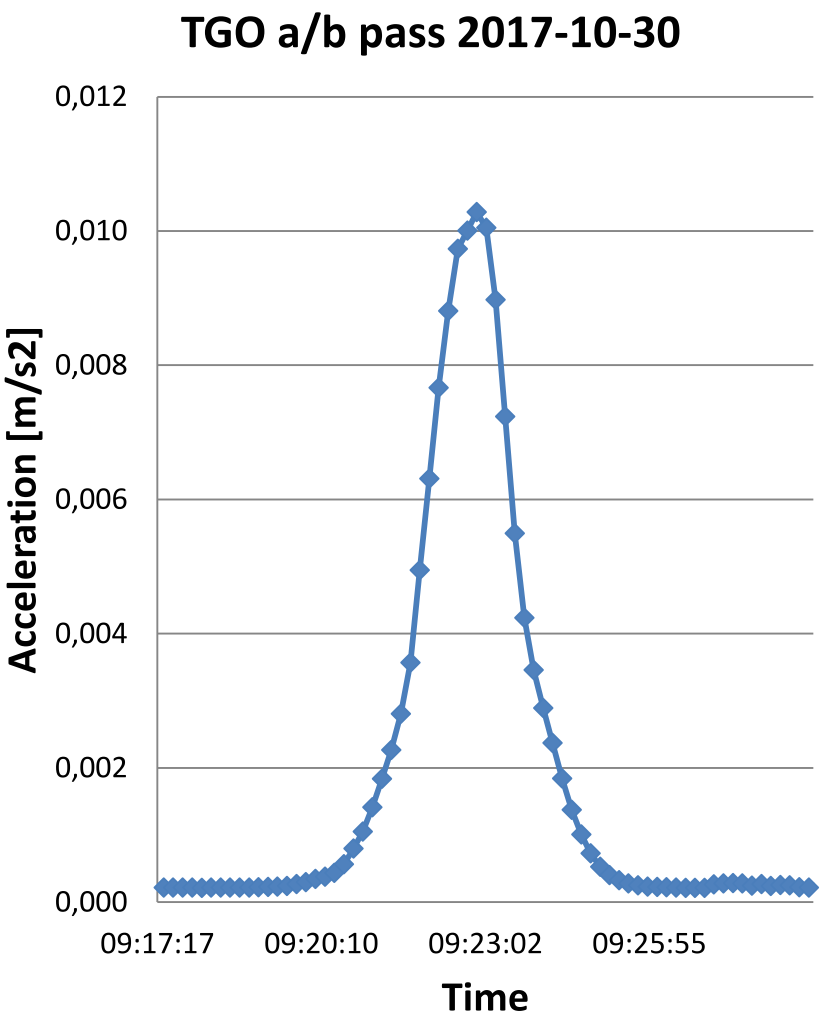
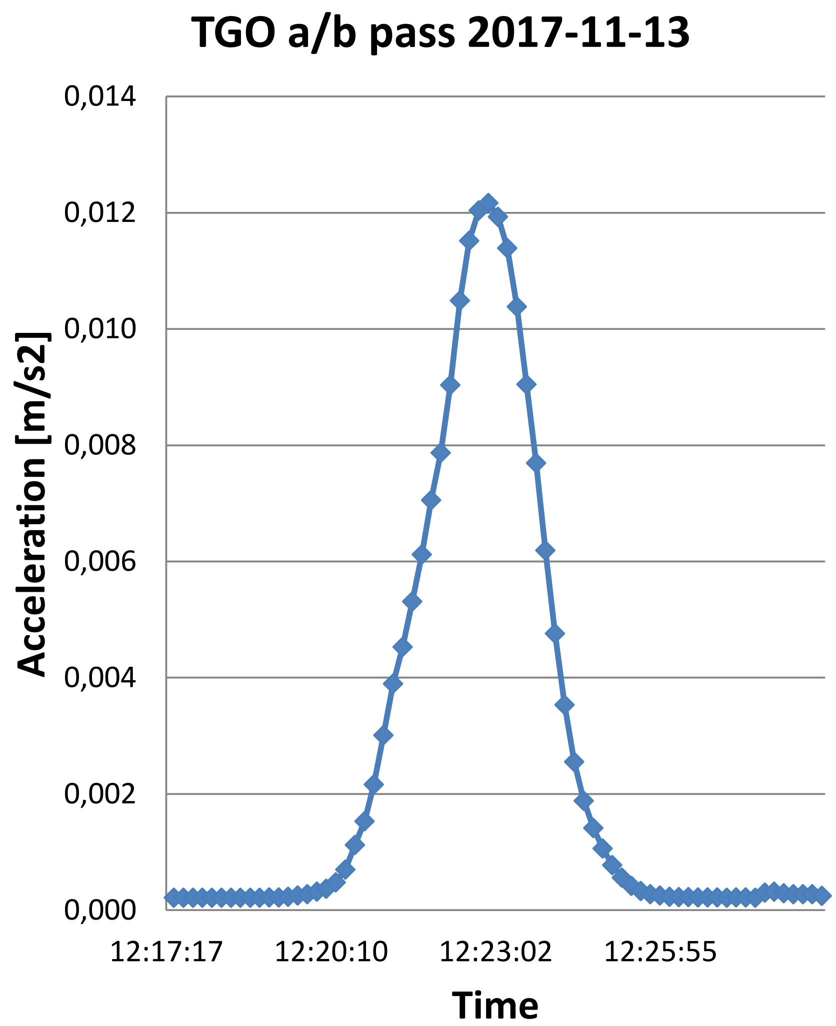
Two typical TGO a/b passes





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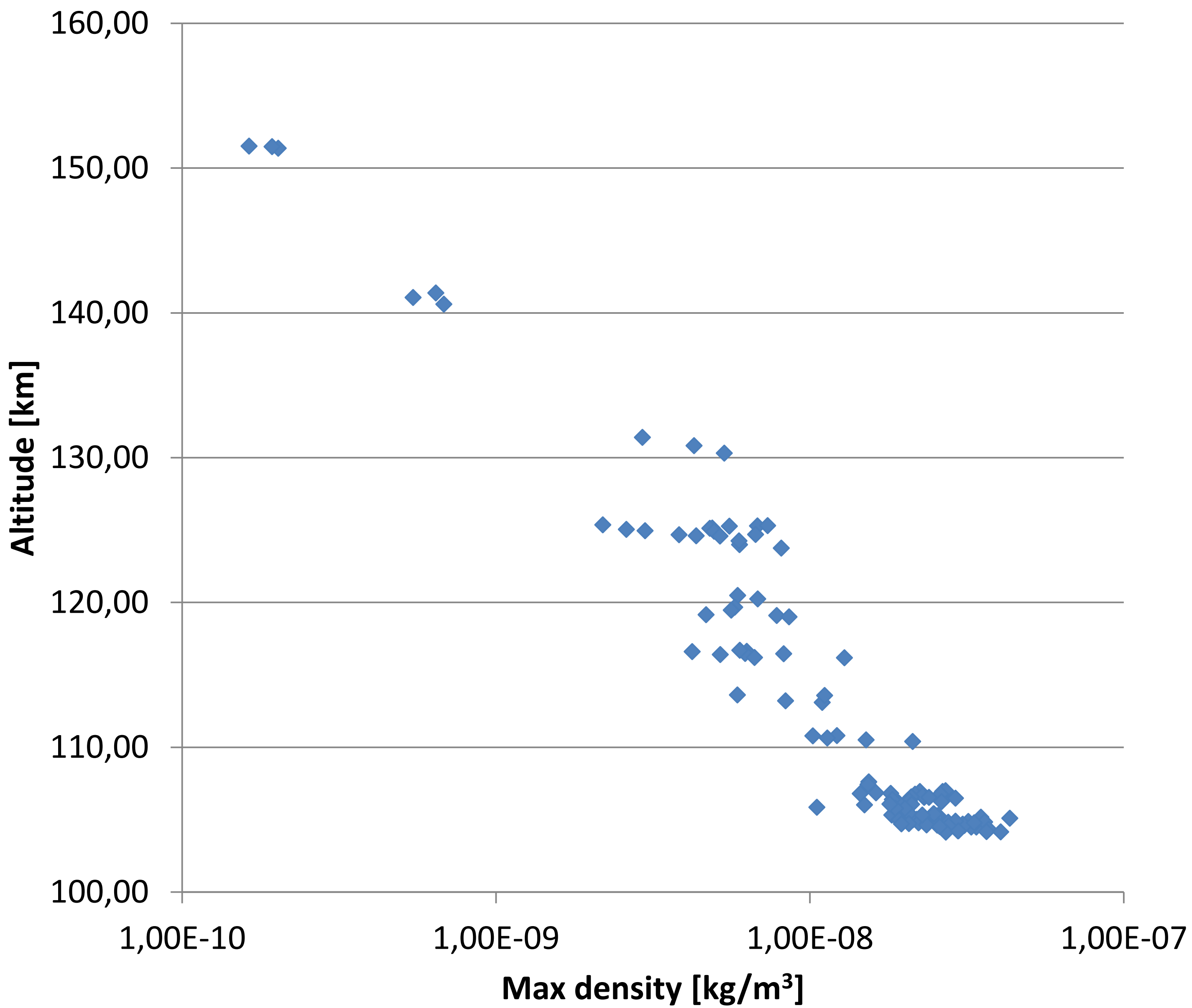
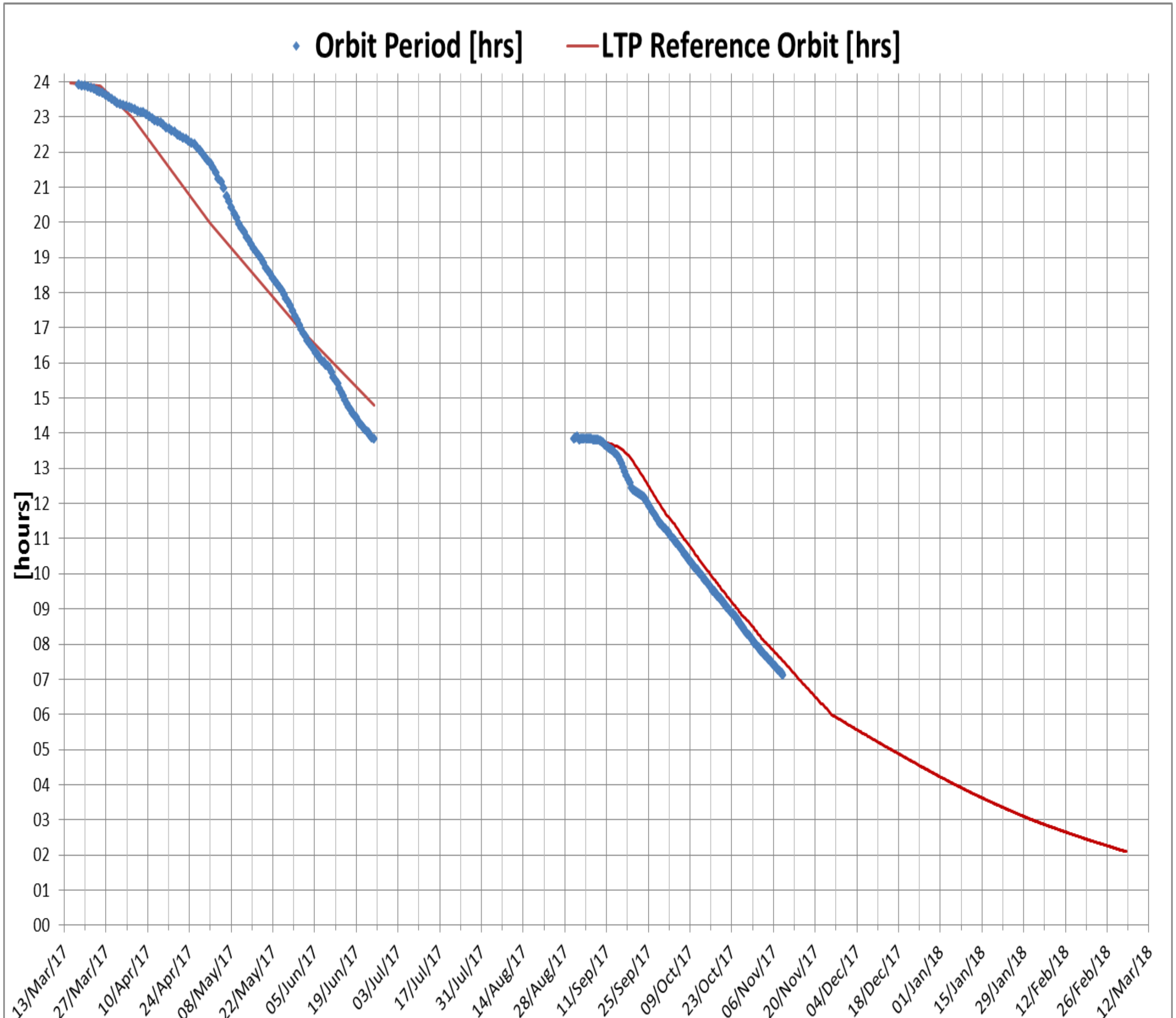
TGO Aerobraking , determined max density





Evolution of orbital period for planned vs actual aerobraking

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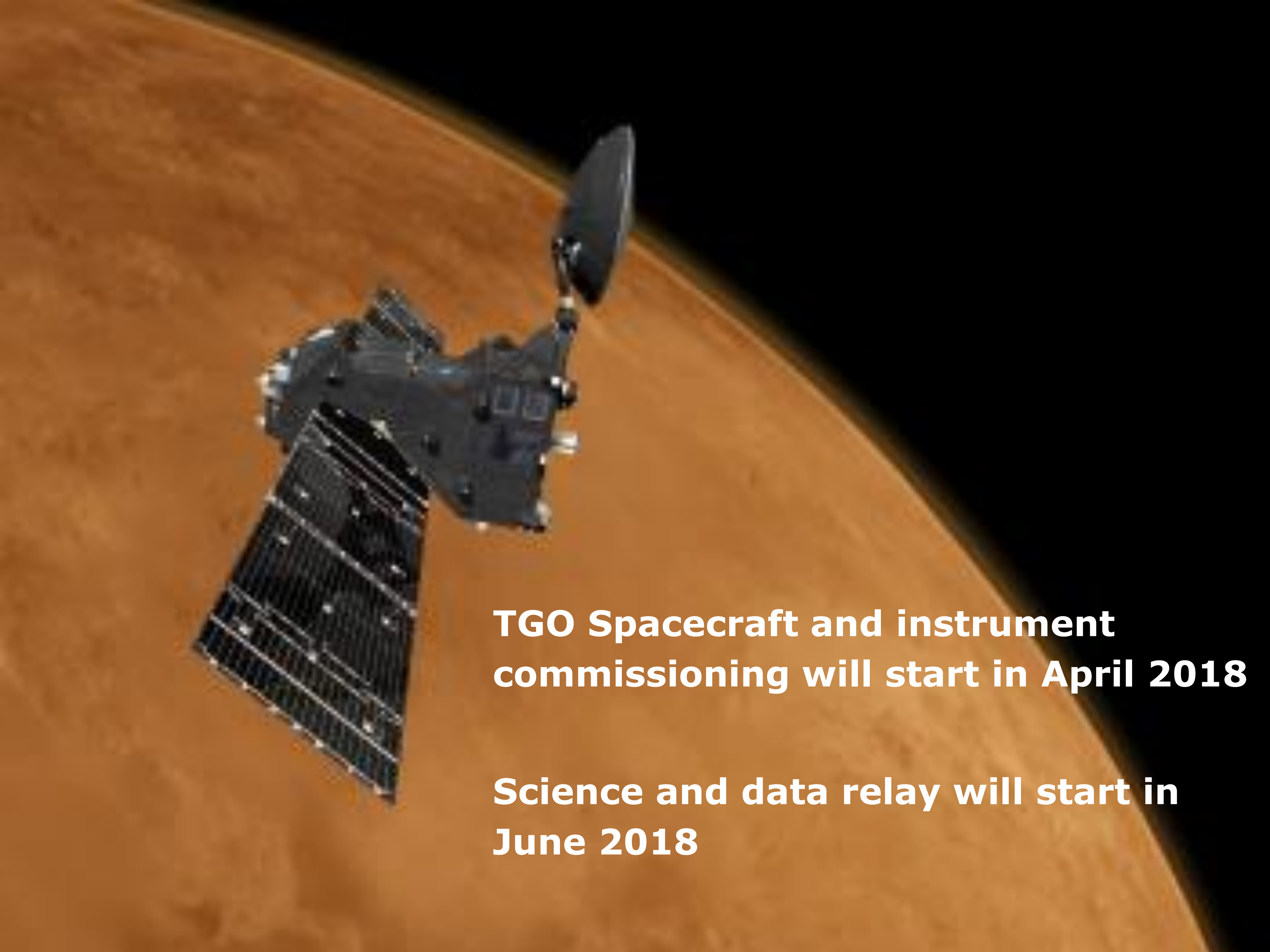

TGO Spacecraft and instrument commissioning will start in April 2018

Science and data relay will start in June 2018