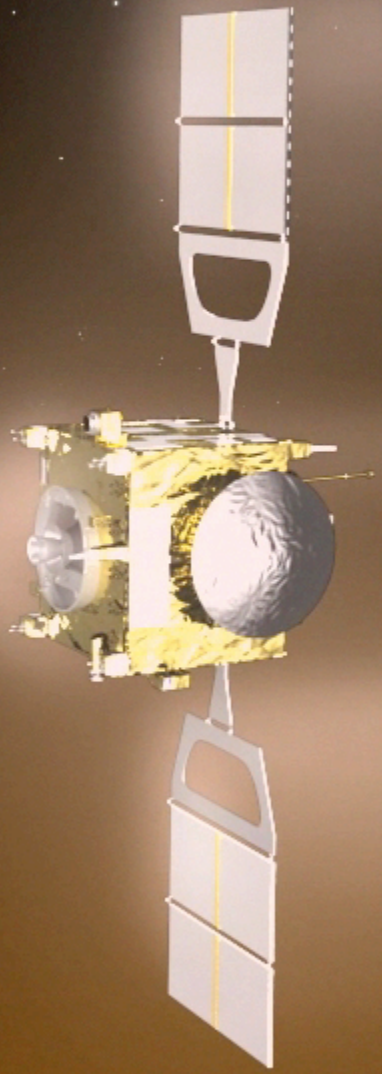
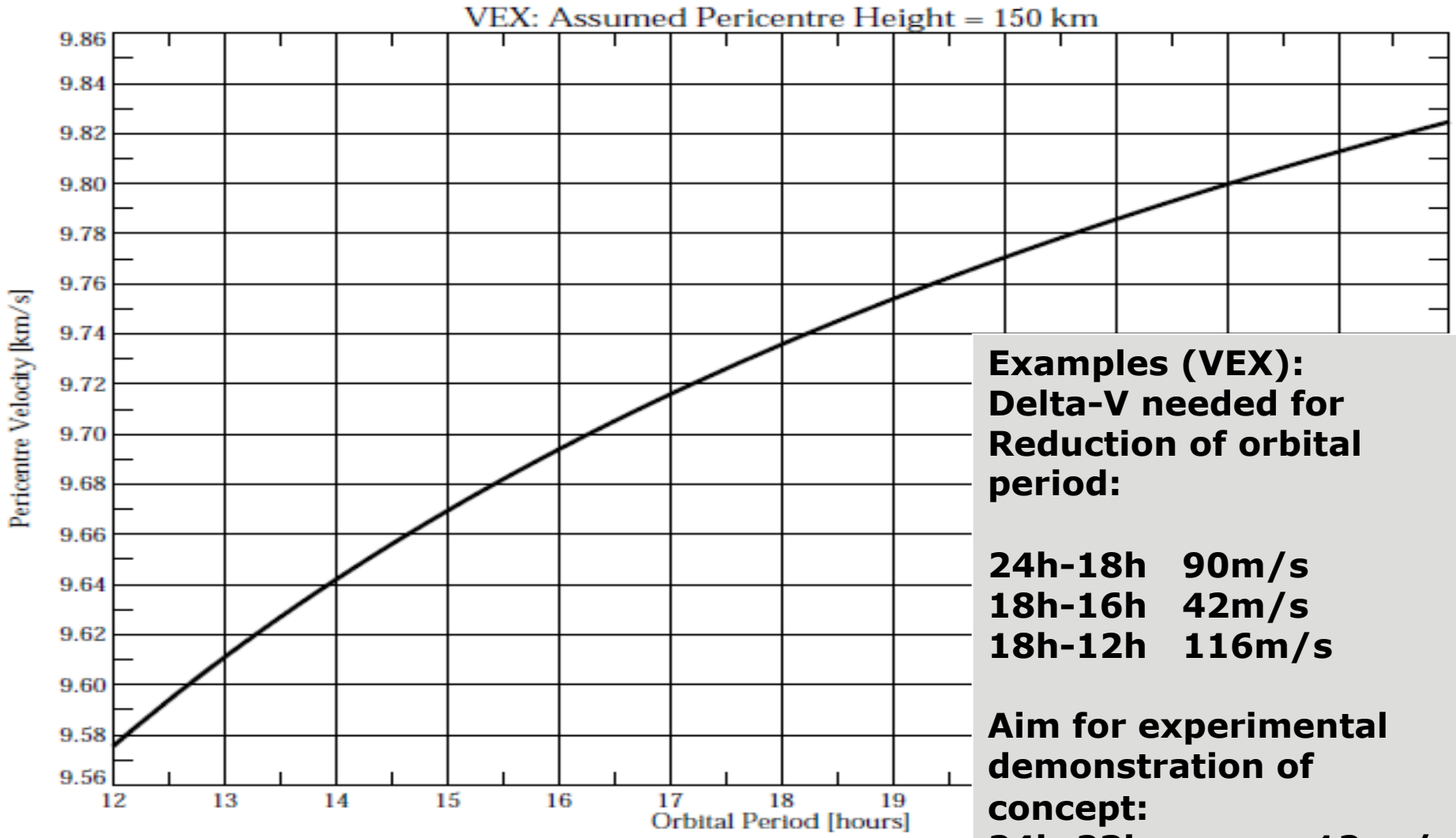


Venus Express Aerobraking and End of Mission

Håkan Svedhem
ESA/ESTEC

Pericentre velocity vs Orbital Period

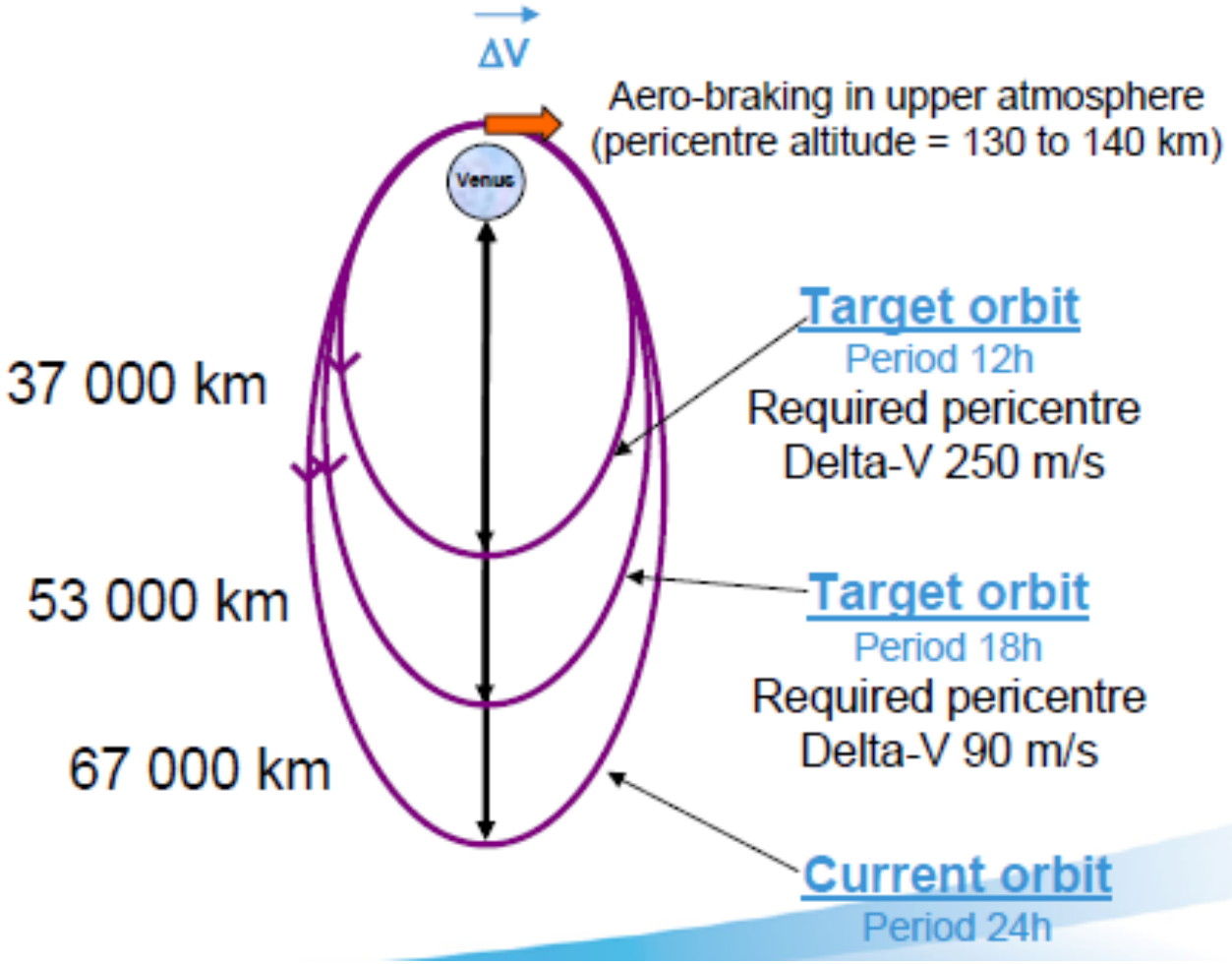


Examples (VEX): Delta-V needed for Reduction of orbital period:

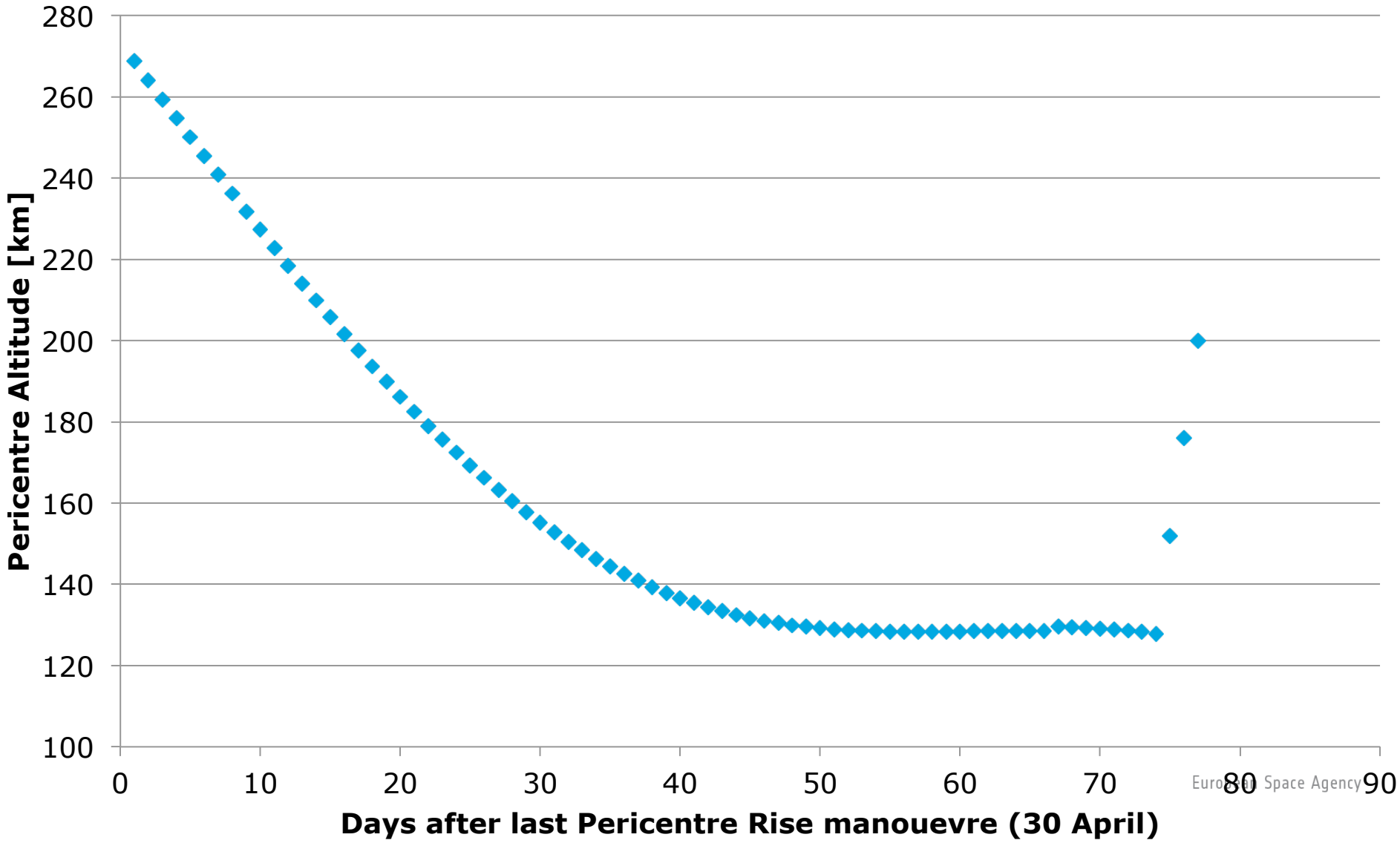
24h-18h 90m/s
18h-16h 42m/s
18h-12h 116m/s

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

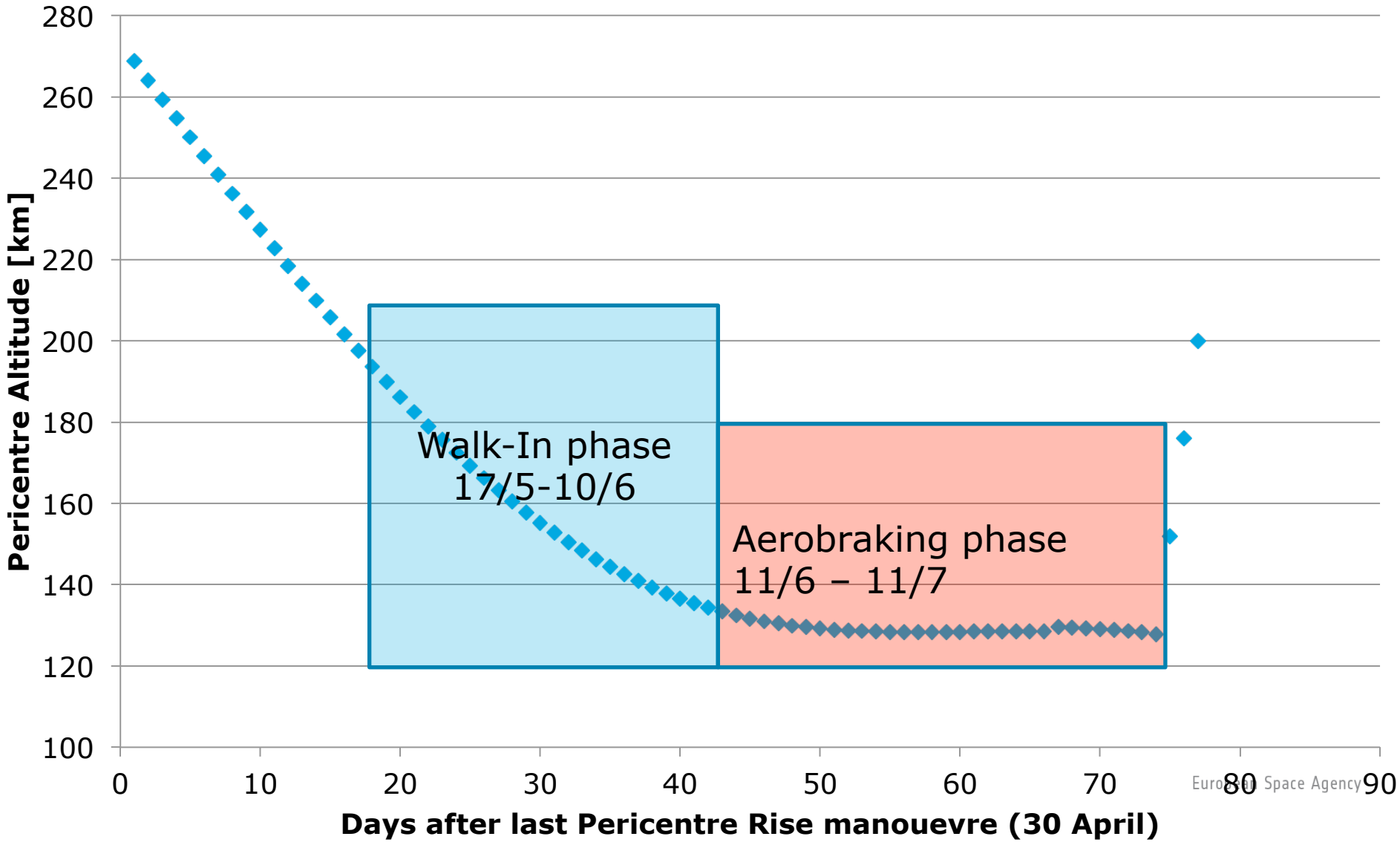
Reducing Apocentre altitude



Pericentre Altitude [km]

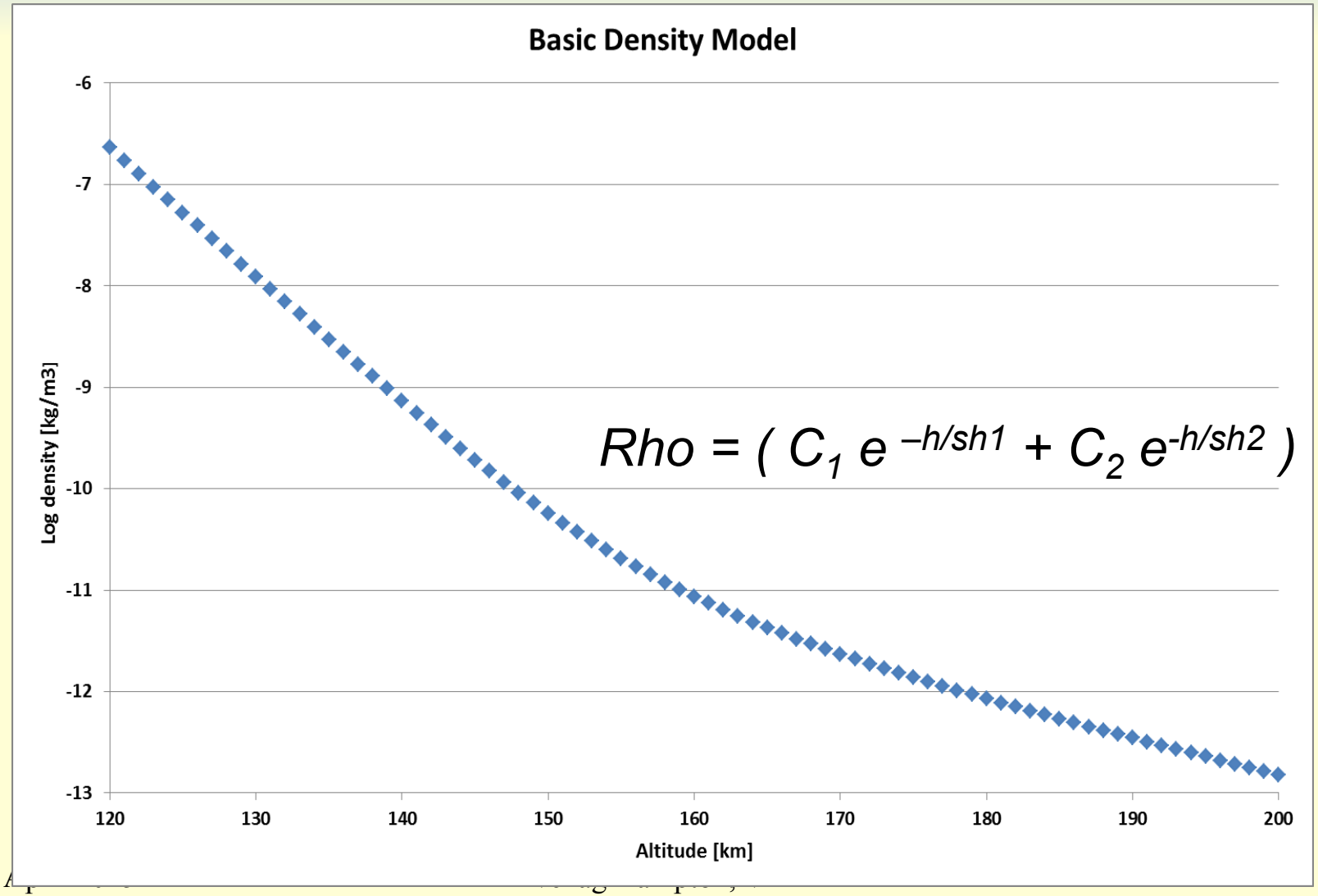


Pericentre Altitude [km]

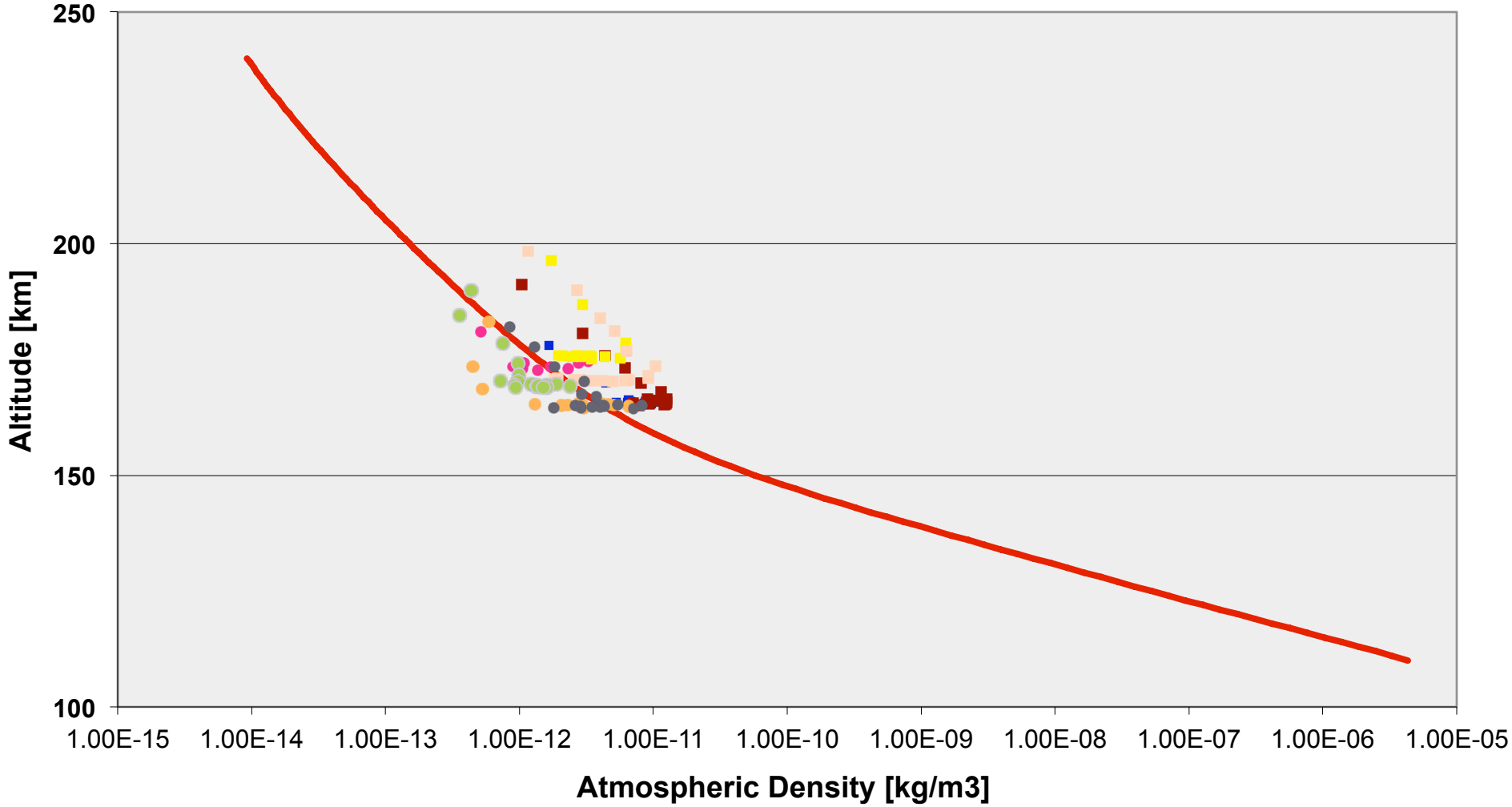


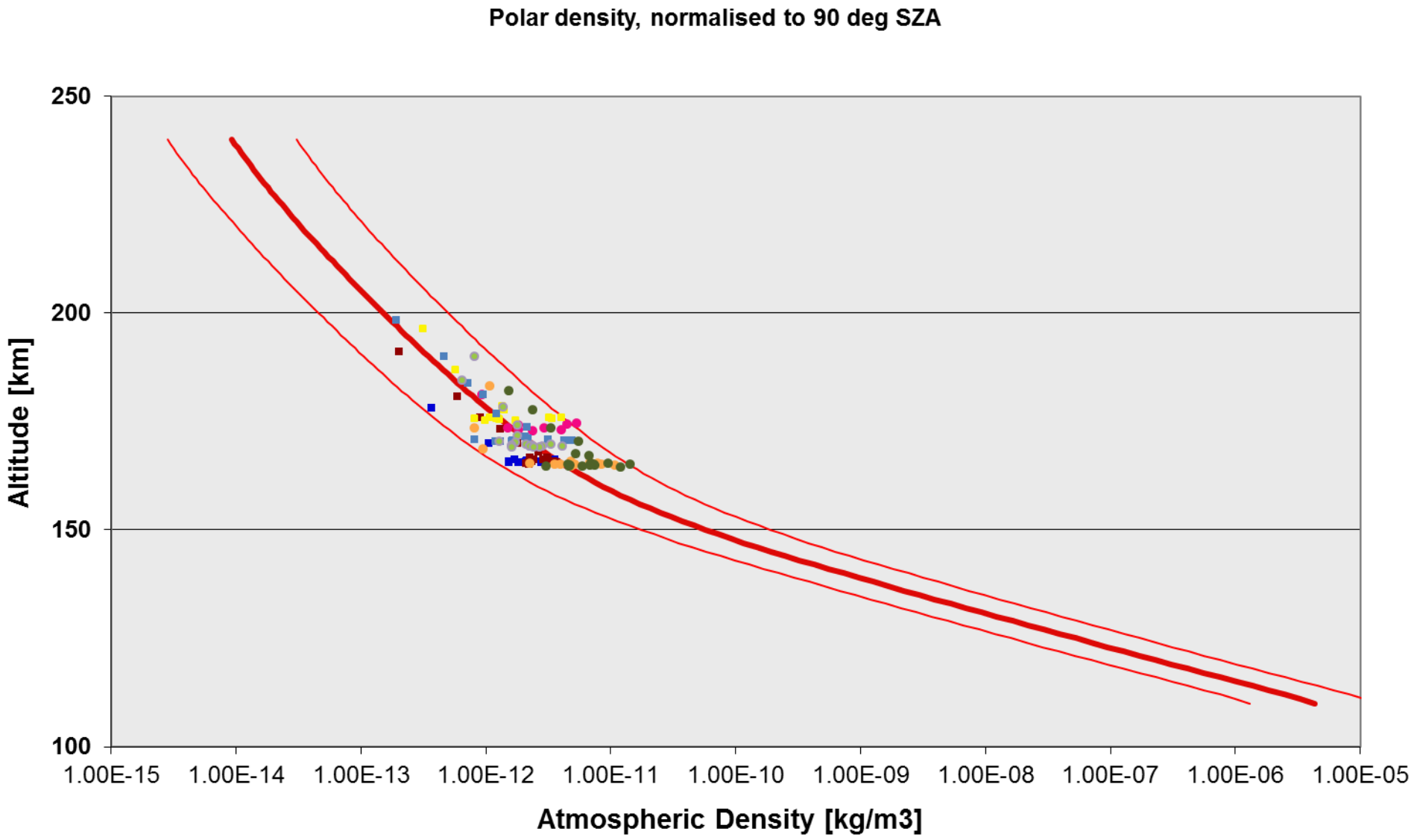
Models and measurements of density and temperature

- 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

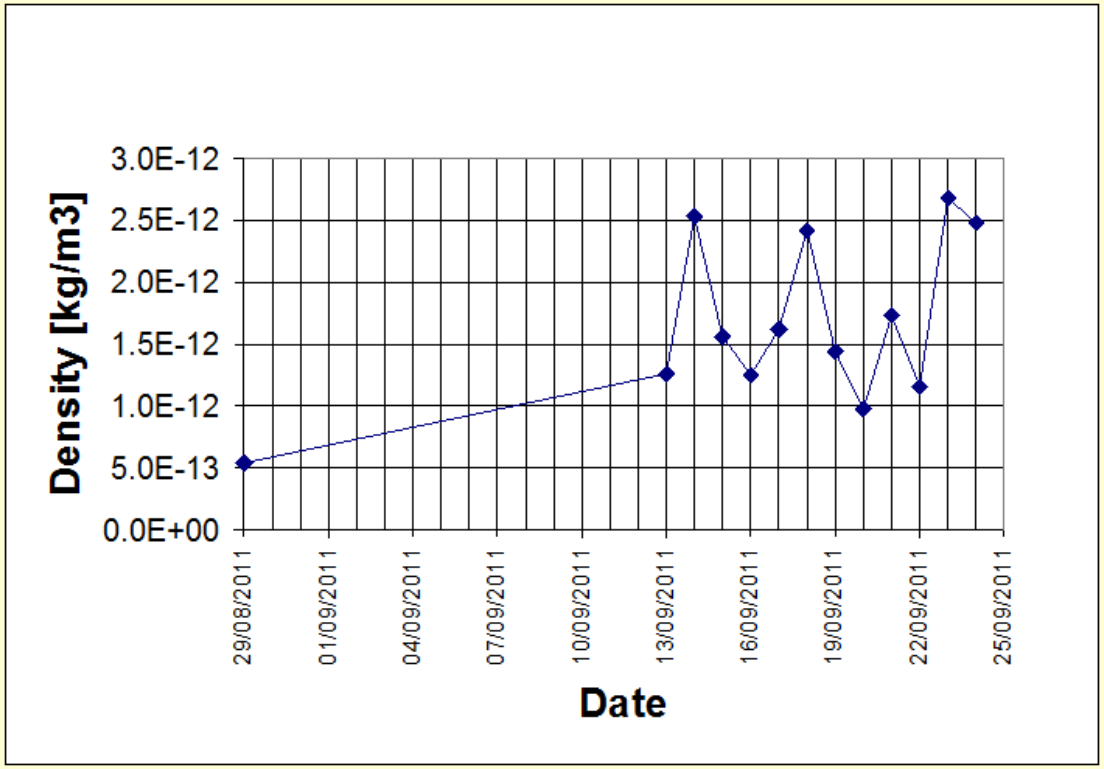

Basic Density Model
-6
-7
-8
-9
-10
-11
-12
-13
Log density [kg/m3]
120
130
140
150
160
170
180
190
200
Altitude [km]
Rho = (C1 e −h/sh1 + C2 e-h/sh2)

Polar density, raw torque data

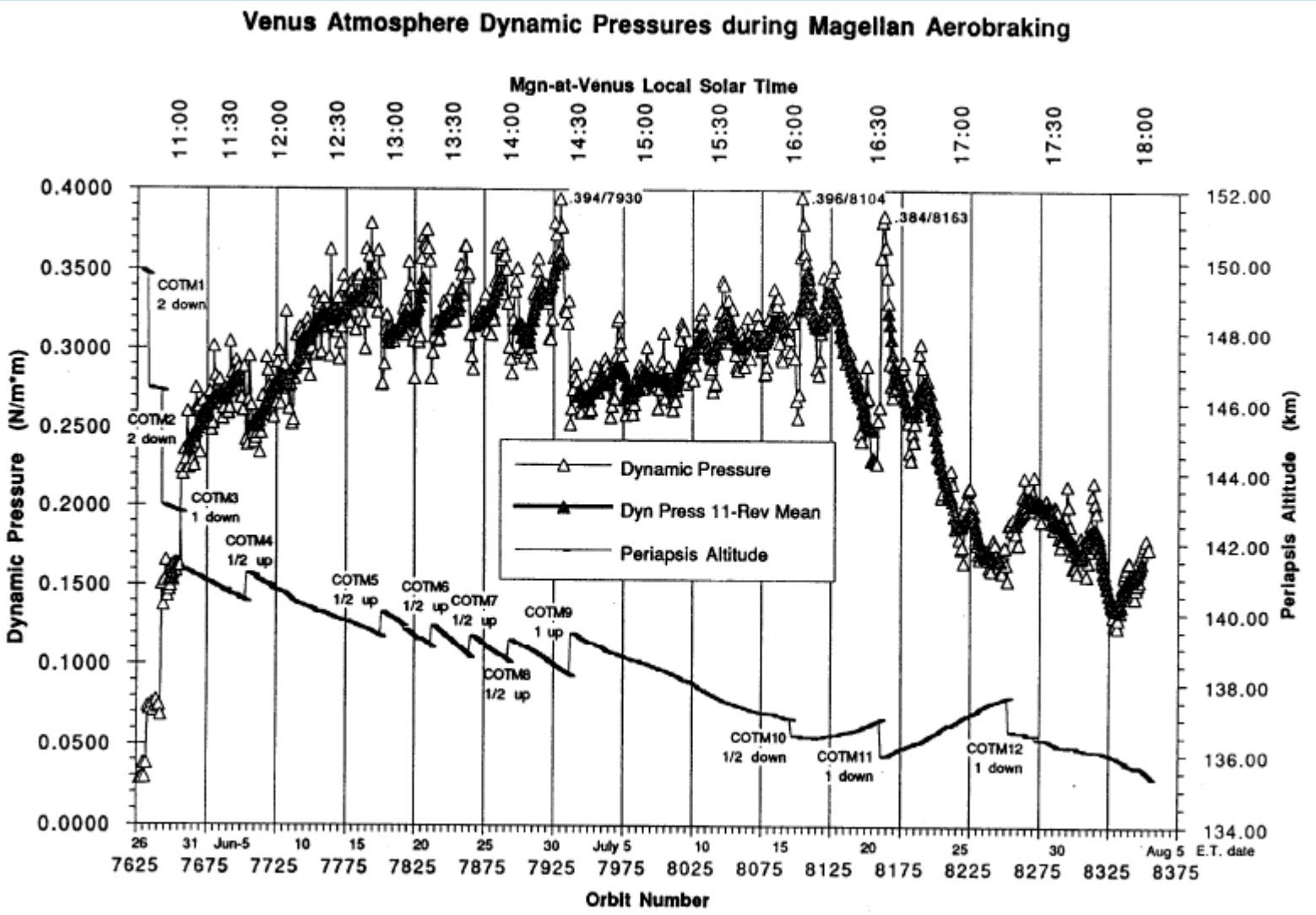



Polar density, normalised to 90 deg SZA
250
200
150
100
Altitude [km]
1.00E-15
1.00E-14
1.00E-13
1.00E-12
1.00E-11
1.00E-10
1.00E-09
1.00E-08
1.00E-07
1.00E-06
1.00E-05
Atmospheric Density [kg/m3]

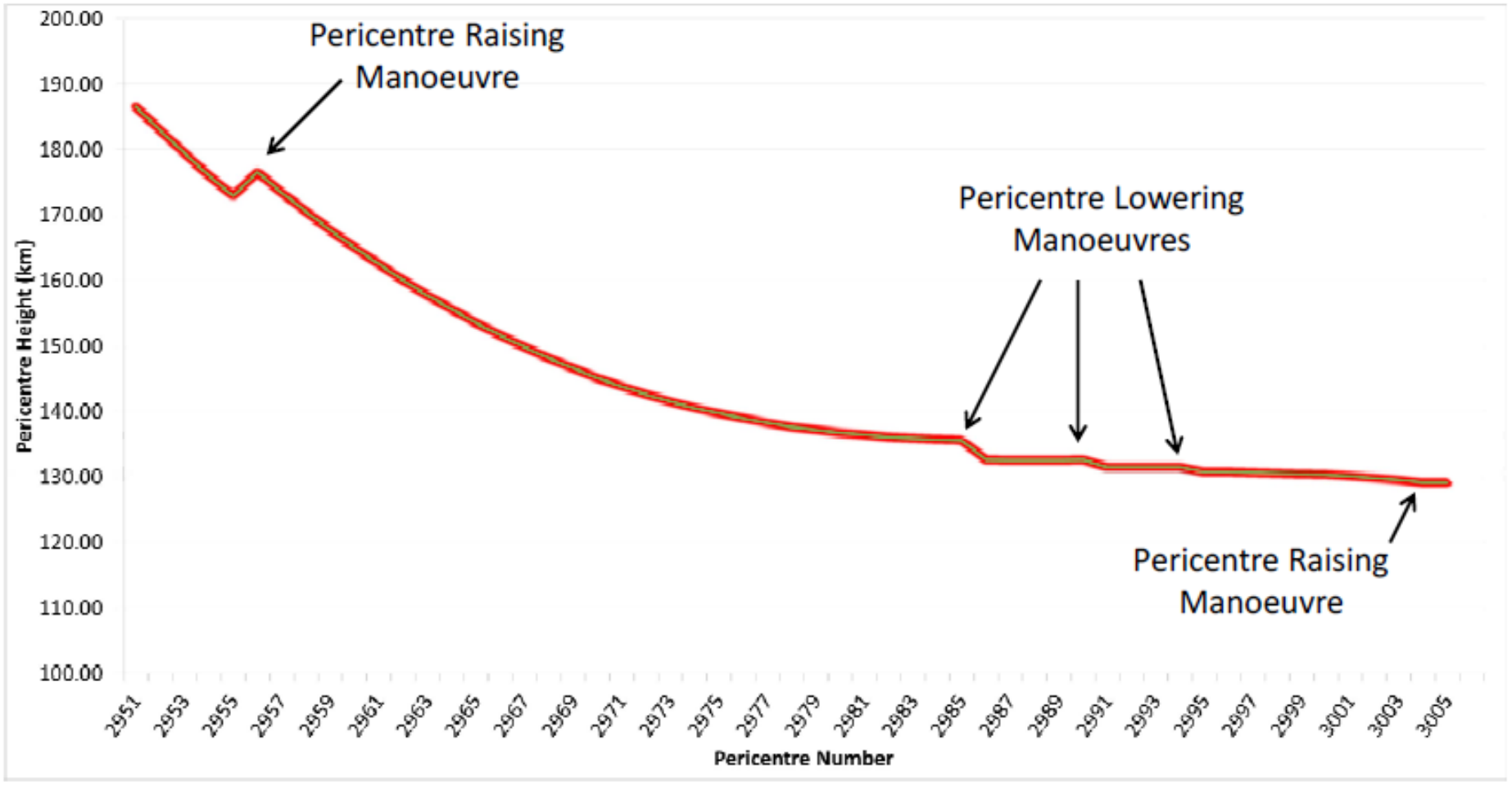
High day to Day variablity from Drag/ Torque measurements at 165km

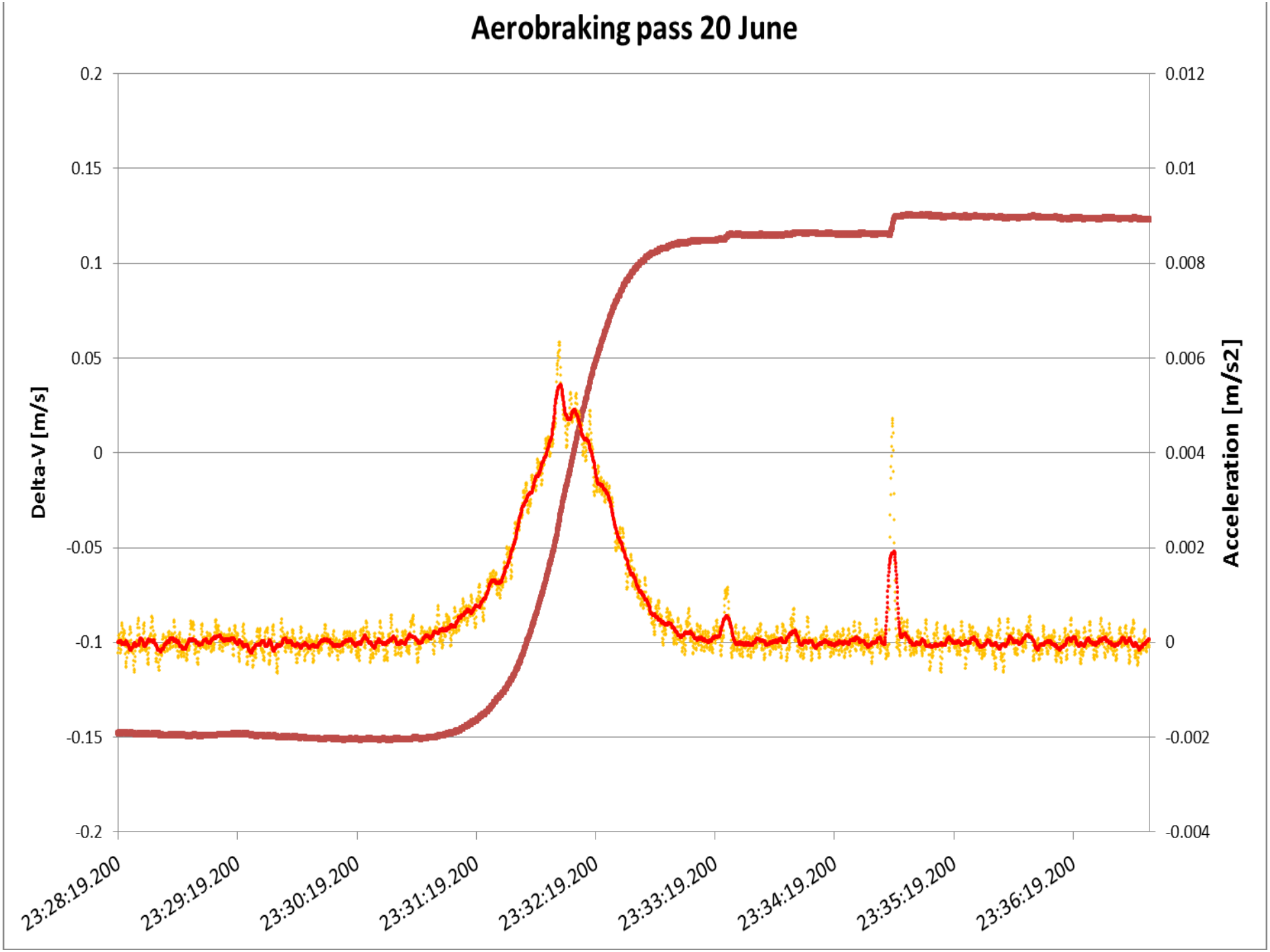


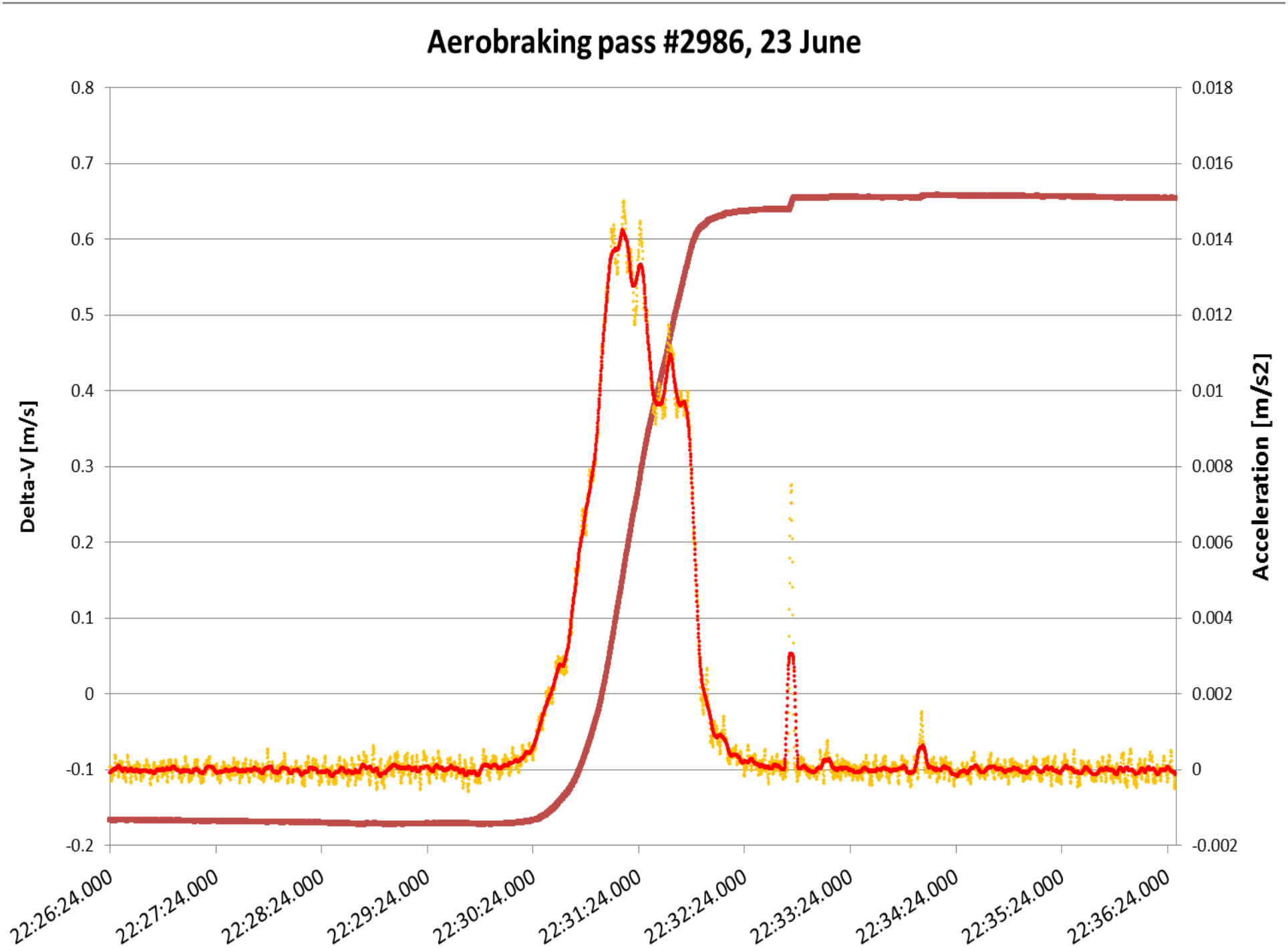
Example from Magellan

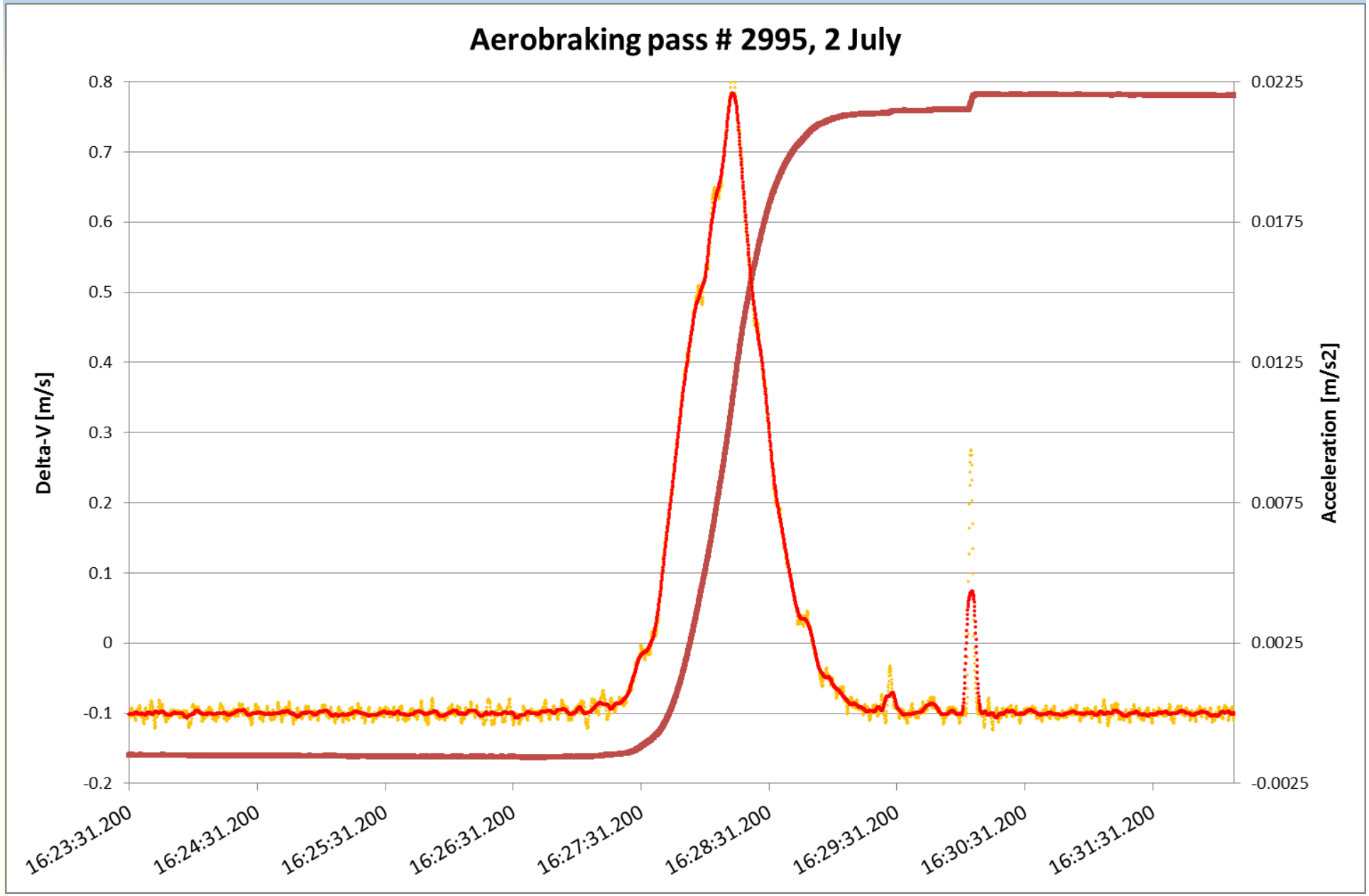


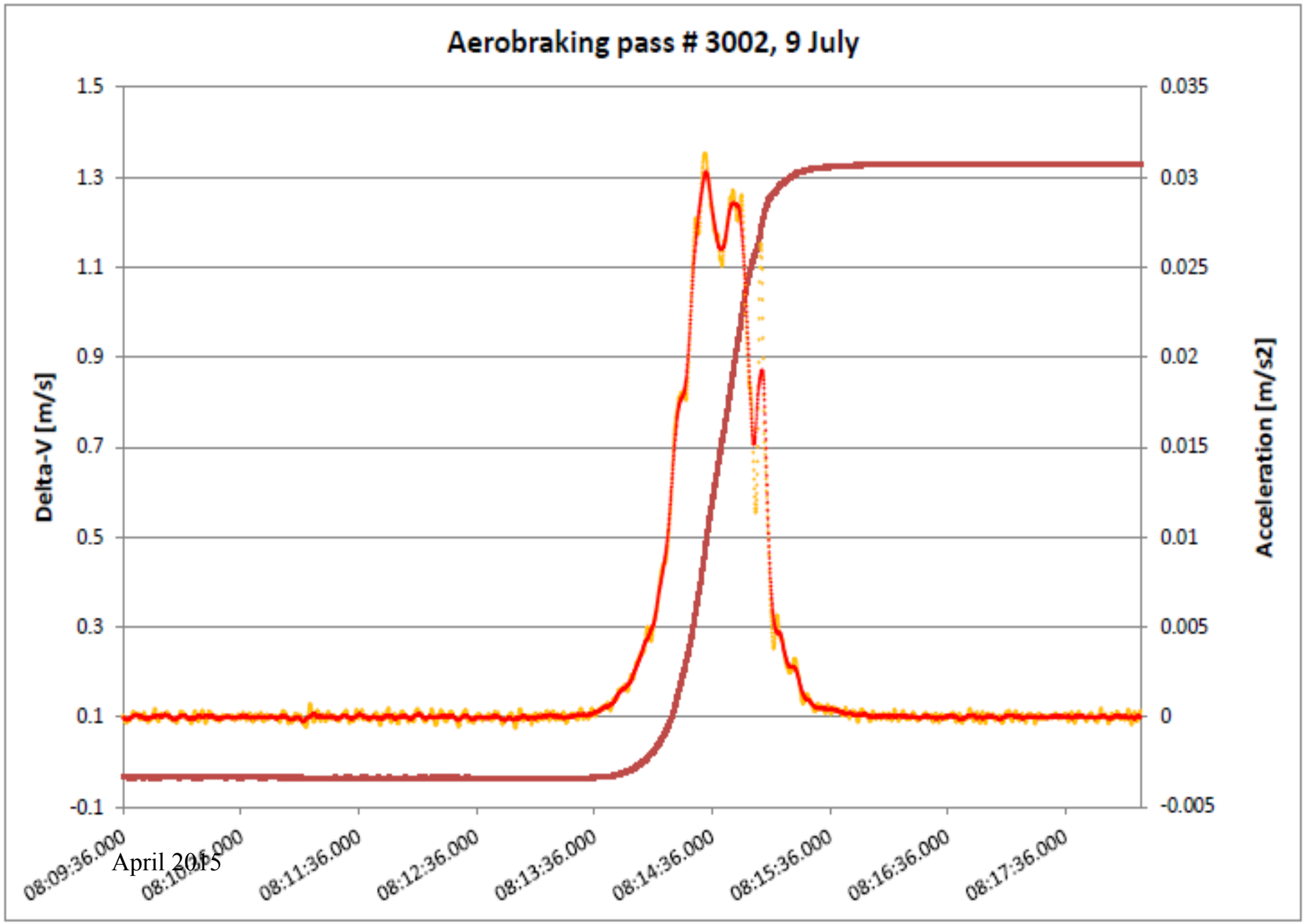
Pericentre Altitude evolution



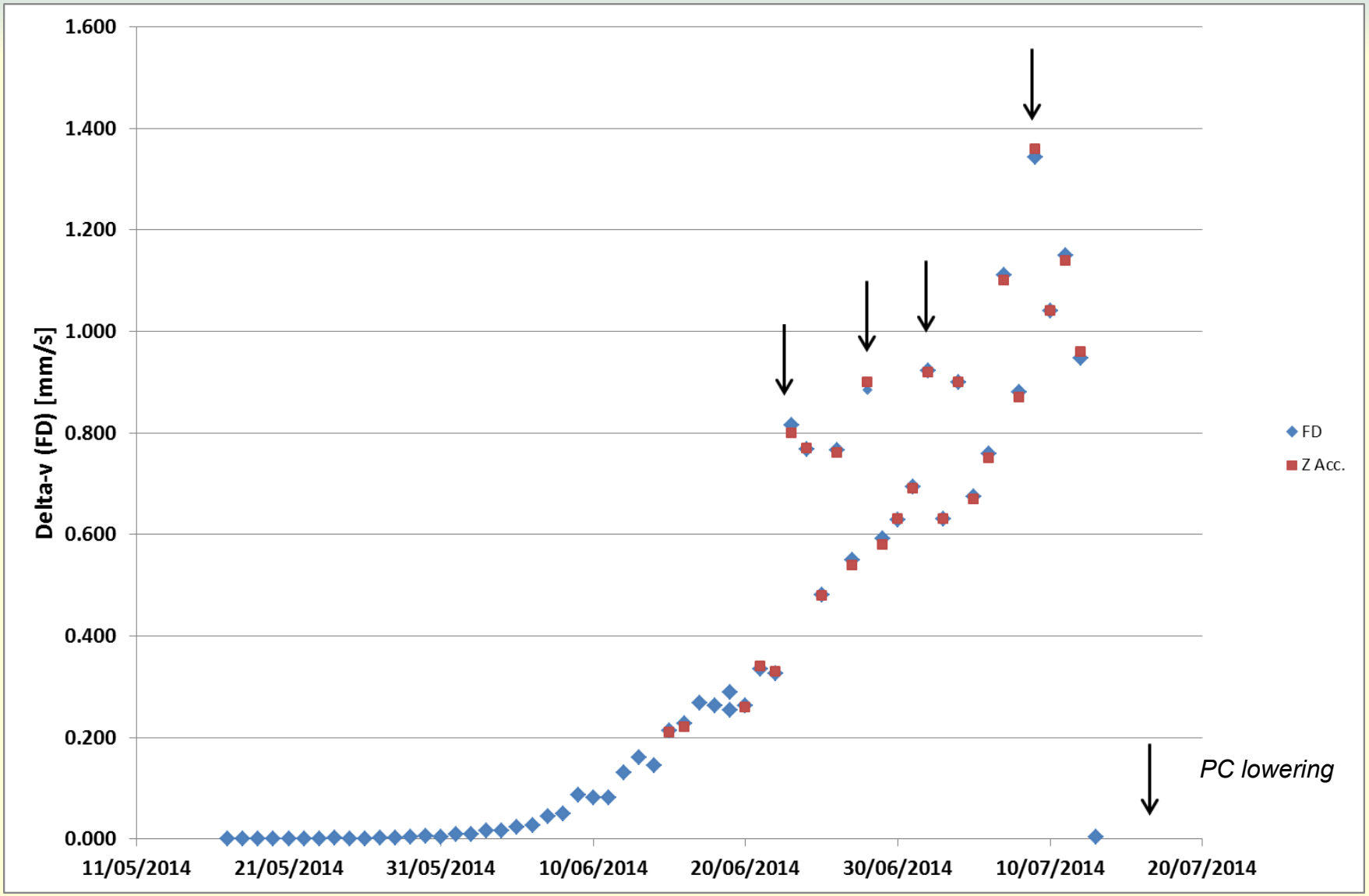

Aerobraking pass 20 June
Delta-V [m/s]
Acceleration [m/s2]
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
23:28:19.200
23:29:19.200
23:30:19.200
23:31:19.200
23:32:19.200
23:33:19.200
23:34:19.200
23:35:19.200
23:36:19.200


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

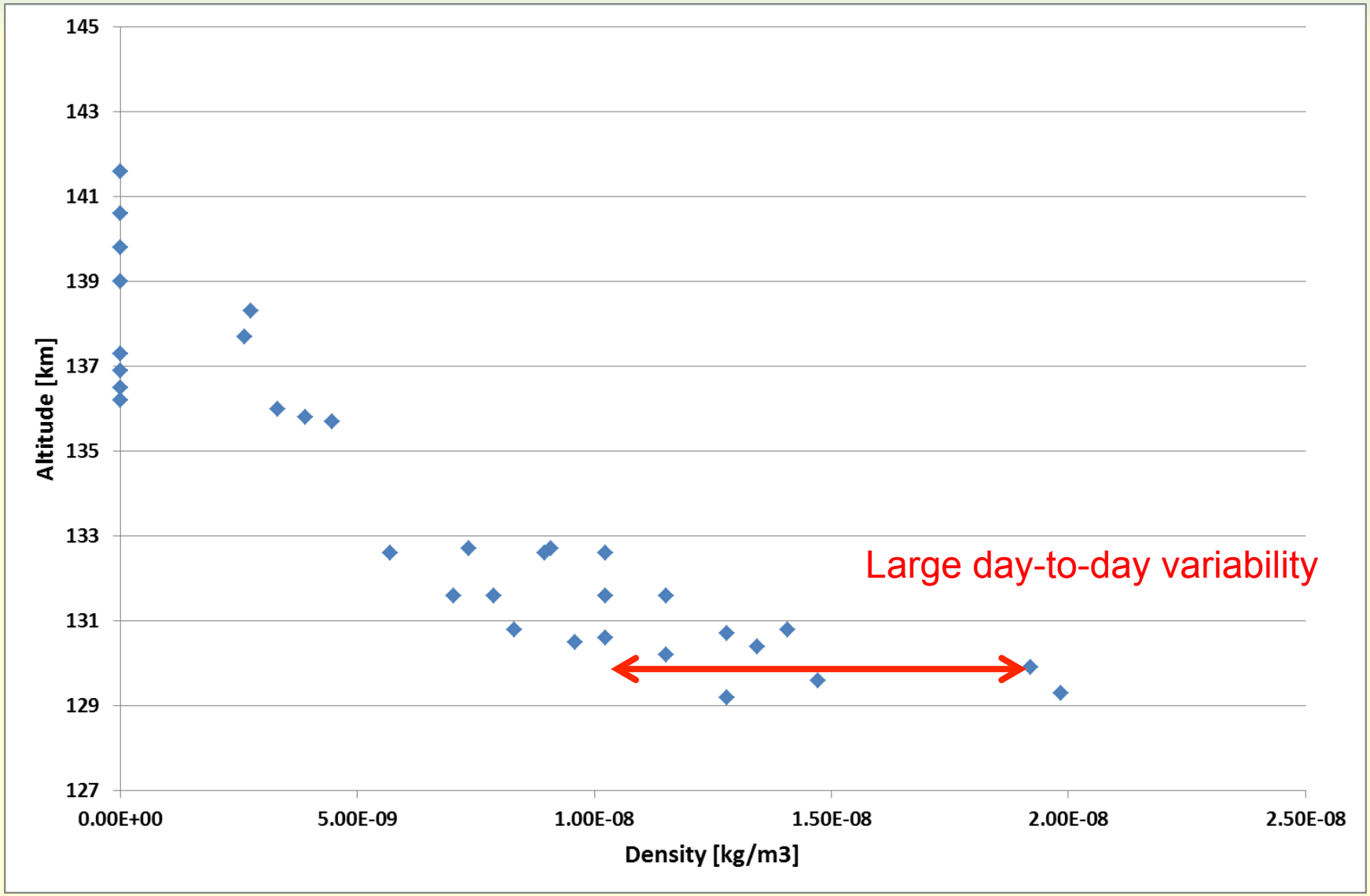

Aerobraking pass # 2995, 2 July
Delta-V [m/s]
Acceleration [m/s2]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
0.0225
0.0175
0.0125
0.0075
0.0025
-0.0025
16:23:31.200
16:24:31.200
16:25:31.200
16:26:31.200
16:27:31.200
16:28:31.200
16:29:31.200
16:30:31.200
16:31:31.200


Aerobraking pass # 3002, 9 July
Delta-V [m/s]
Acceleration [m/s2]
1.5
1.3
1.1
0.9
0.7
0.5
0.3
0.1
-0.1
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
08:09:36.000
08:10:36.000
08:11:36.000
08:12:36.000
08:13:36.000
08:14:36.000
08:15:36.000
08:16:36.000
08:17:36.000

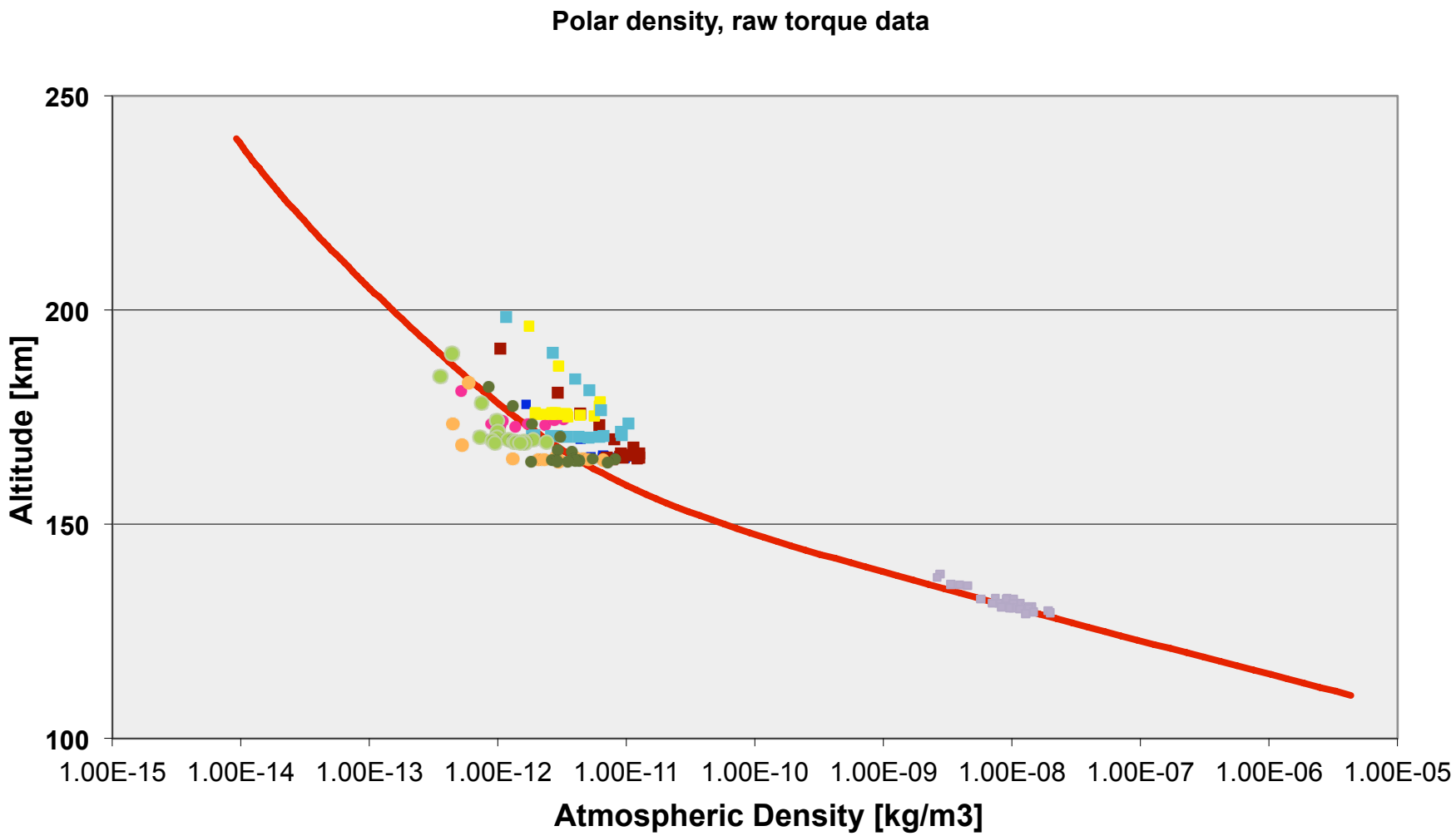
Delta-v vs date



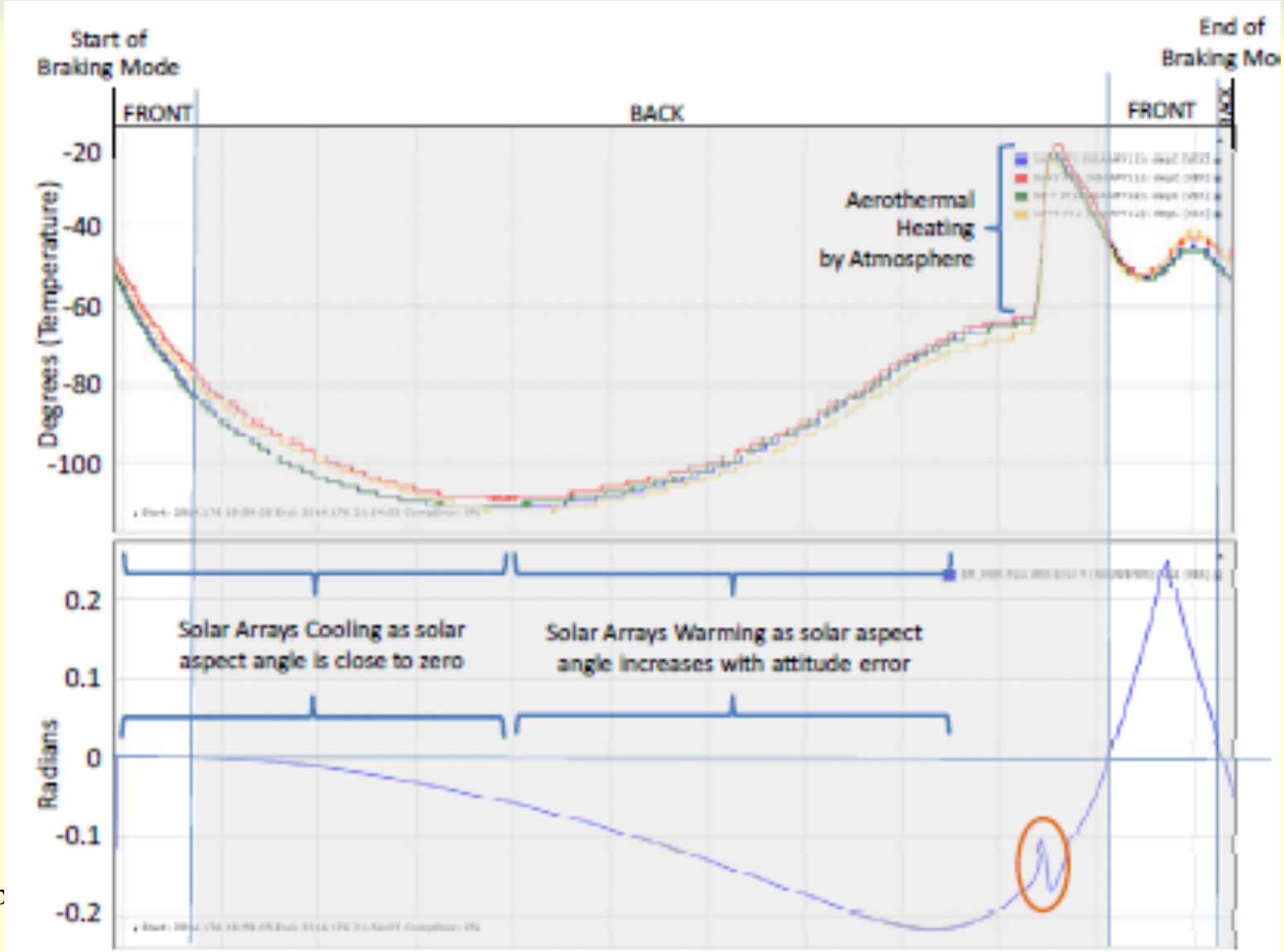
Atmospheric Density



Measurements vs. Model results

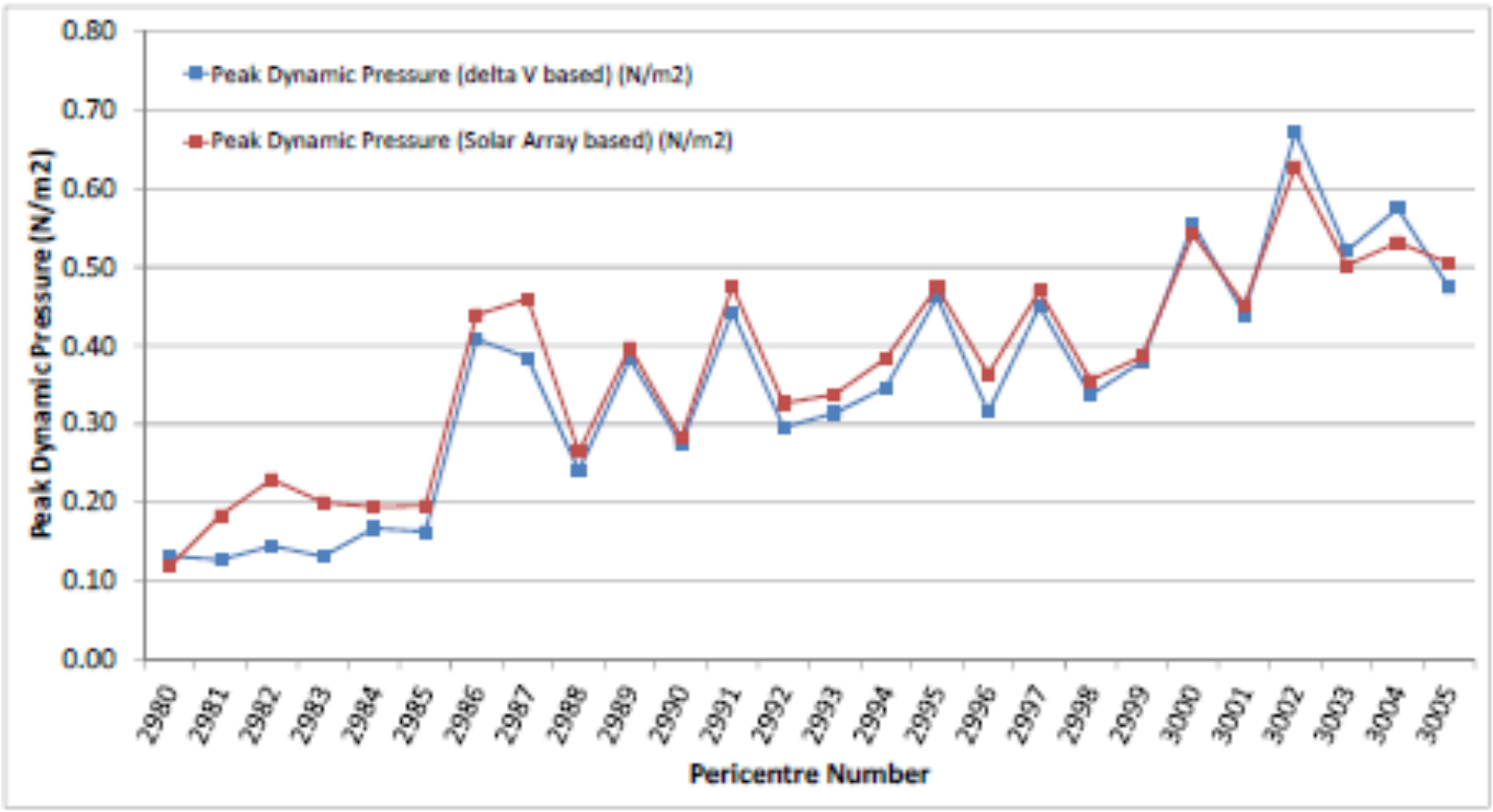


Solar Array response to aerobraking

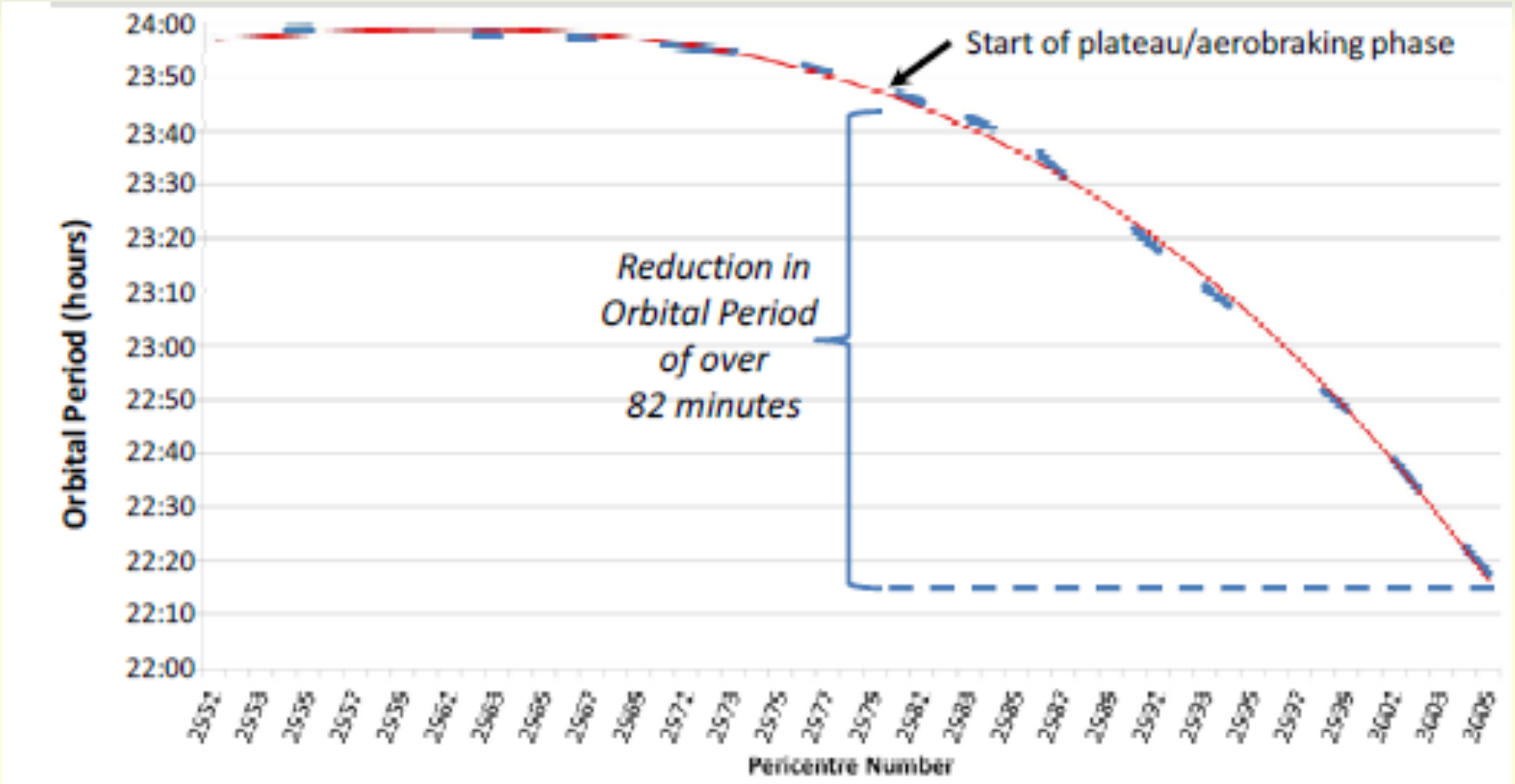


Ap

Using Solar Array temperature as a proxy for Dynamic Pressure



Evolution of Orbital Period



Success criteria for Venus Express aerobraking experiment 18/5 - 11/7 2014

- Scientific criteria
  - S1. Record accelerometer data of the maximum density at a signal to noise ratio of at least 5 for a minimum of 20 pericentre passes below 150 km altitude, to enable new models and studies of the atmospheric structure at these altitudes. DONE
  - S2. Record traces of the full accelerometer signal below 150 km for at least ten pericentre passes where the pericentre altitude is below 140 km, to study spatial variability and wave phenomena in the atmosphere. DONE
  - S3. Record ground station tracking data (off pericentre) for orbital arcs sufficient to allow calculation of orbital decay, for at least 25 orbits with pericentre passes below 155 km altitude, in order to determine the integrated delta-v per pass, to investigate the time variability of the atmosphere. DONE

Success criteria for Venus Express aerobraking experiment 18/5 - 11/7 2014

- Technical criteria
  - T1. Achieve a reduction of the orbital period of at least 0.5 hour during the plateau between 18 June and 11 July, to demonstrate the efficiency of aerobraking. DONE
  - T2. Make at least six pericentre passes at a dynamic pressure of at least 0.4 N/m^2 including at least 3 passes at a dynamic pressure of at least 0.5 N/m^2, to demonstrate the robustness of the s/c. DONE
  - T3. Record temperatures of the solar panel thermal sensors of at least ten pericentre passes below 140 km altitude, in order to evaluate the thermal effects of aerobraking on the solar panels and to verify existing models. DONE

Success criteria for Venus Express aerobraking experiment 18/5 - 11/7 2014

- Technical criteria (cont.)
  - T4. Record data on s/c attitude and thruster firing during Braking Mode of at least ten pericentre passes below 140 km altitude, to analyse s/c dynamic stability. DONE
  - T5. Record temperatures of ~7 platform sensors before, during and after aerobraking, in order to evaluate possible damage and/or deterioration of MLI. DONE
  - T6. Record data on the electrical performance of the solar panels, to enable comparison of charging characteristics before and after aerobraking, and to evaluate possible damage and/or deterioration of the solar panels. DONE

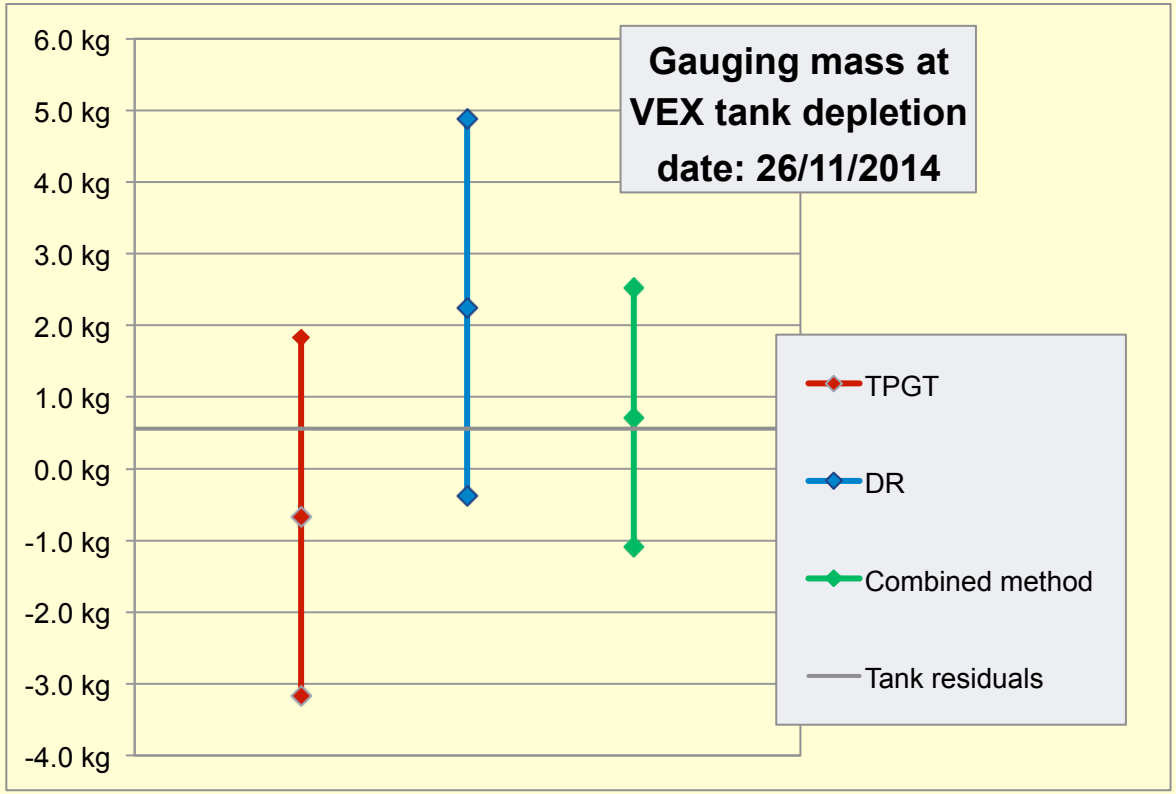
Conclusions

- ESA's first aerobraking campaign concluded with great success
- Spacecraft design proven to be very robust
- Efficiency of aerobraking clearly demonstrated
- Collection of atmospheric data of Venus in a region not accessible by other methods, including discovery (preliminary) of atmospheric gravity waves at these higher than expected altitudes
- Experience gained for future missions (ExoMars, M4 Venus proposal…)
- New record on low altitude aerobraking at Venus
- New record in high dynamic pressure at any planet

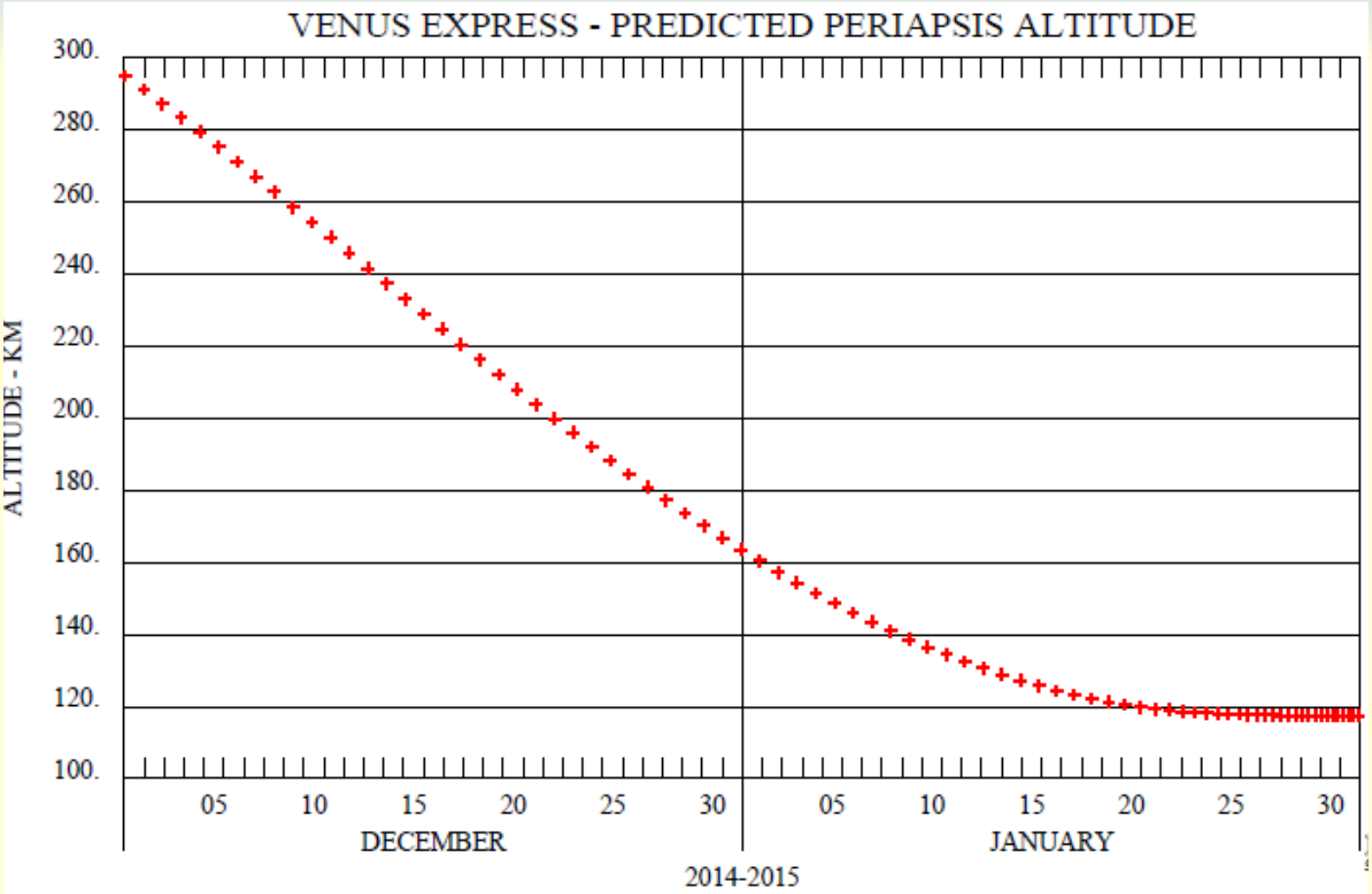
End of Mission

- During a pericentre rise manoeuvre on 28 November the thrusters ran out of fuel and the spacecraft attempted to go to safe mode.
- Safe mode was only partially achieved due to insufficient fuel.
- Pointing was not good and no telemetry could be received but the carrier could be followed for several weeks before finally disappearing 19 January 2015.

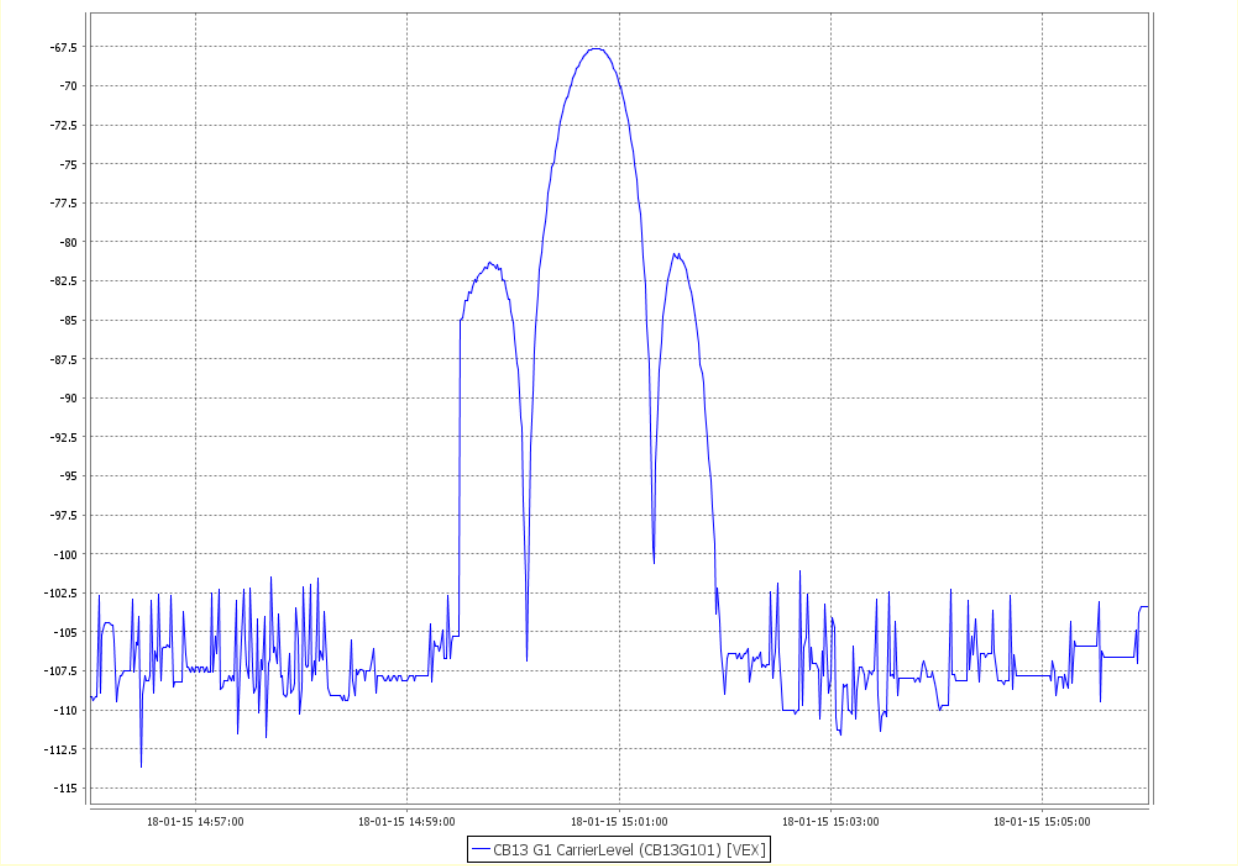
Fuel estimates

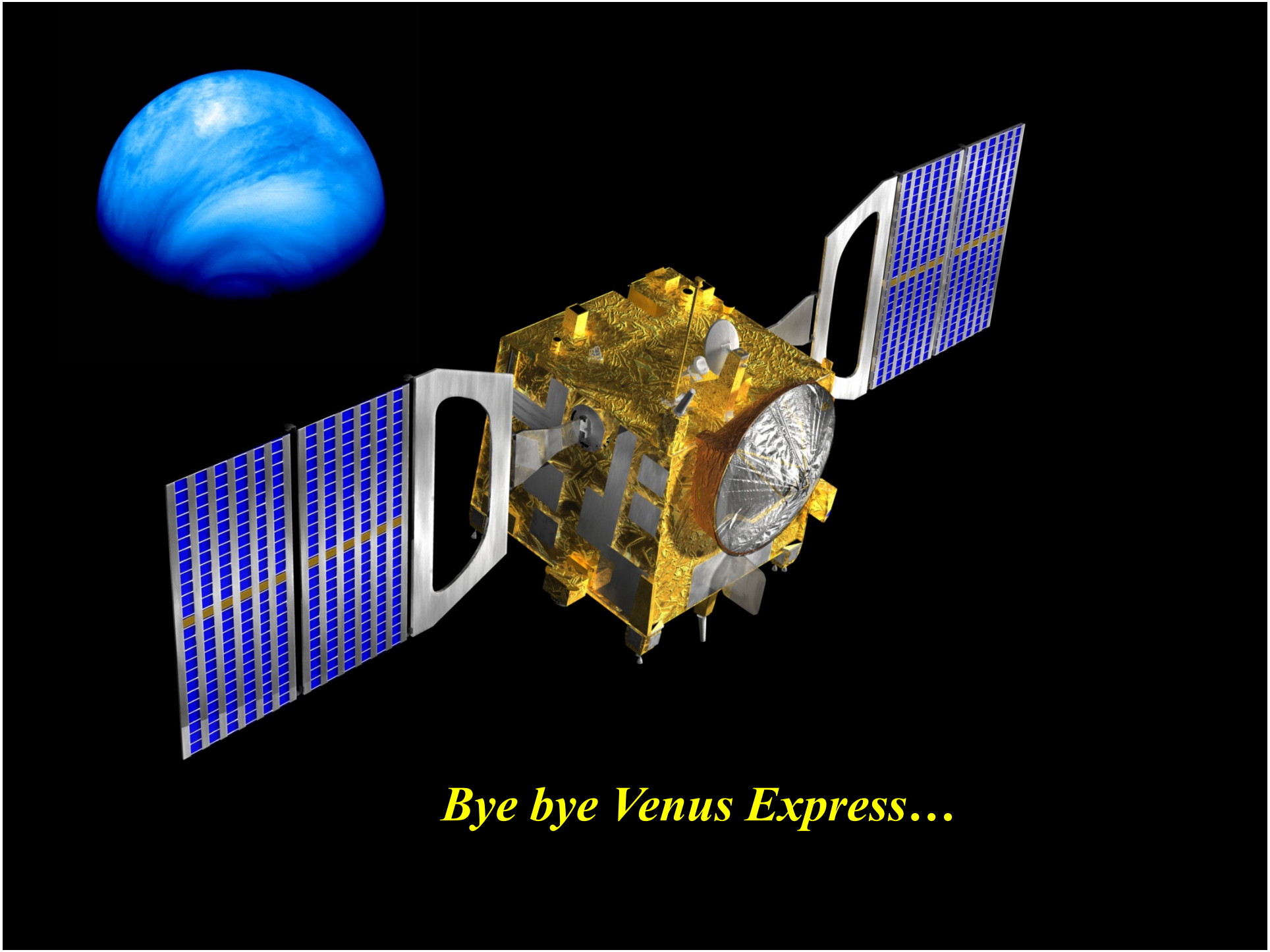


VEX Final Descent



Final contact




Bye bye Venus Express…

esa
SCIENCE
esa