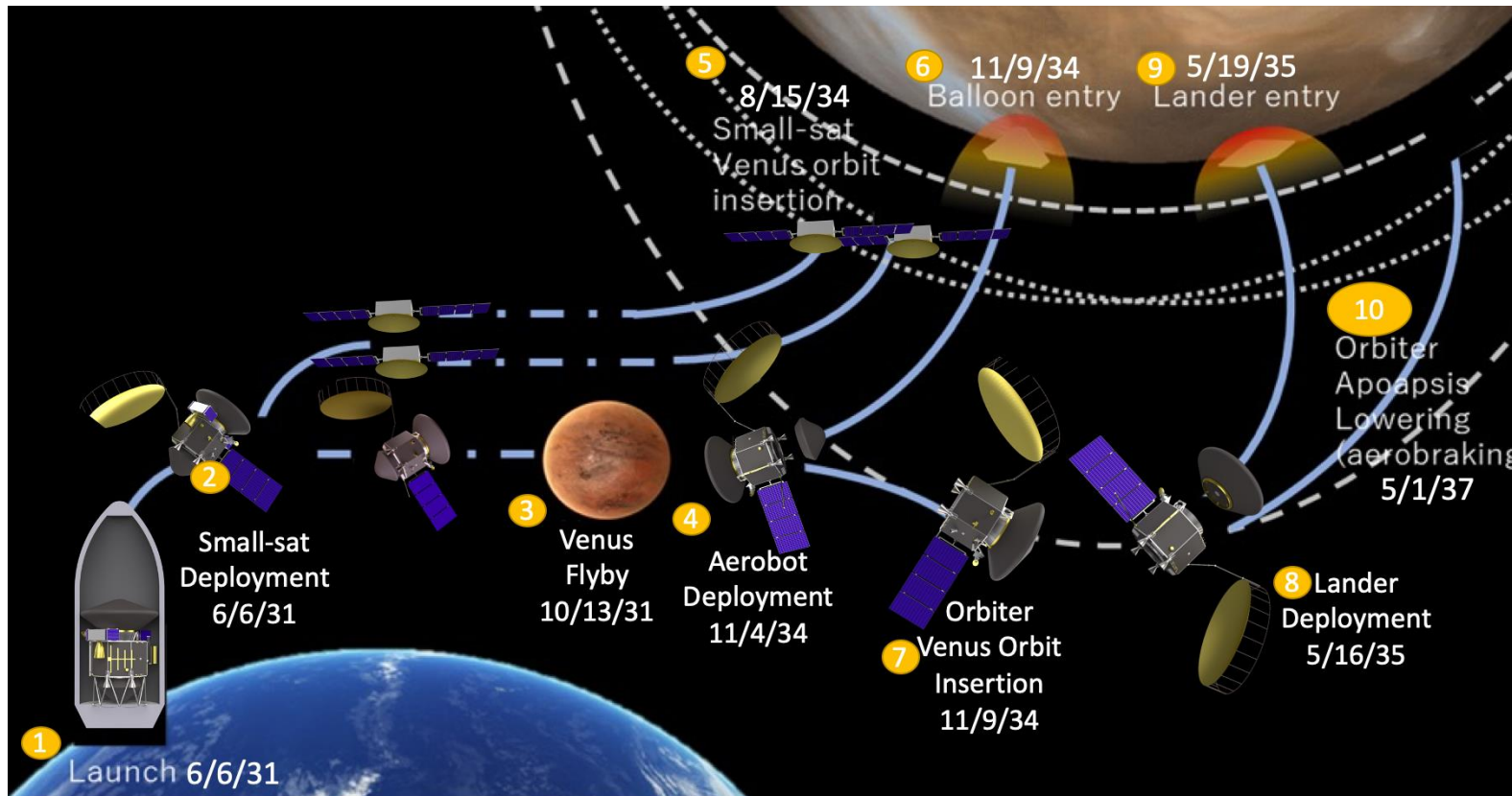
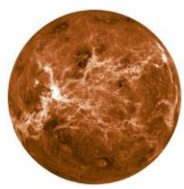


Venus Flagship Mission Design

IAC-21-C1.4.5



Bruno Sarli,
Miguel Benayas Penas,
Ryo Nakamura,
Martha Gilmore,
Richard Lynch,
Kyle Hughes,
Patricia Beauchamp



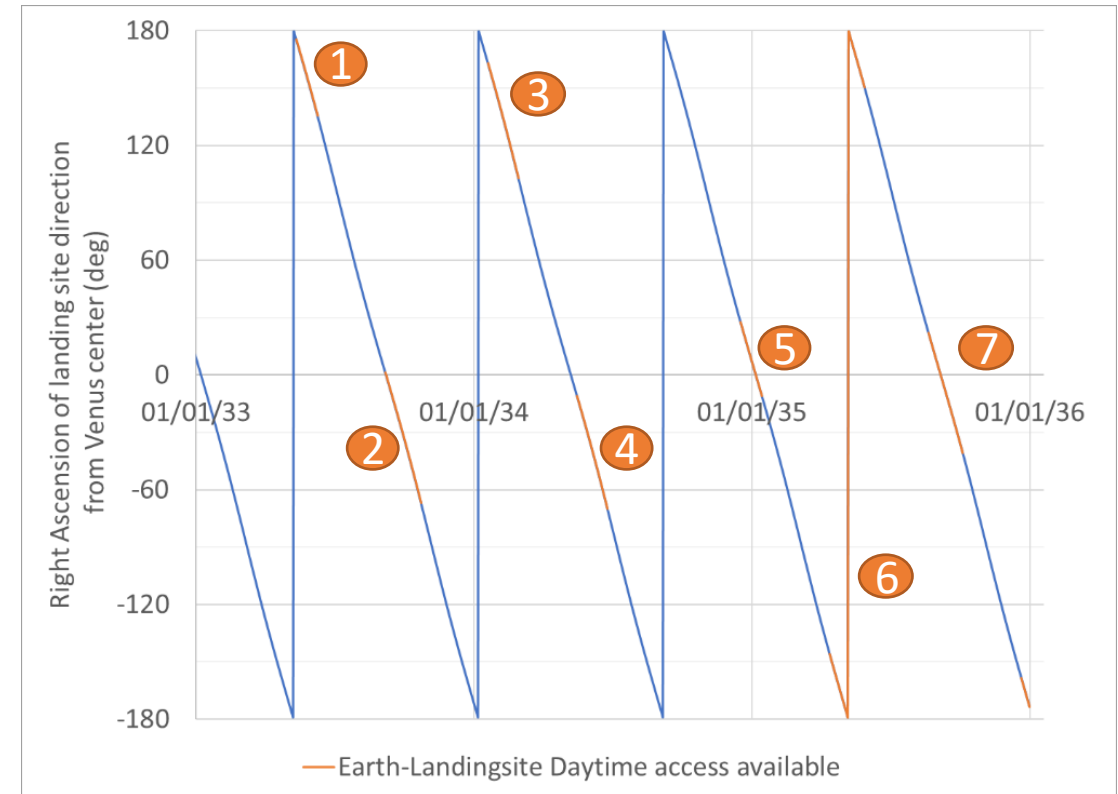
Trajectory Trade

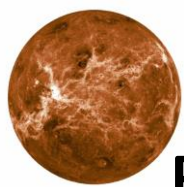
- Landing periods

Window	Start Time (UTCG)	Stop Time (UTCG)
1	05/12/2033 17:01	06/09/2033 14:44
2	09/06/2033 19:30	10/23/2033 09:15
3	01/18/2034 19:32	02/28/2034 17:40
4	05/16/2034 21:39	06/25/2034 00:38
5	12/17/2034 16:56	01/14/2035 20:29
6	04/13/2035 08:54	05/29/2035 14:21
7	08/21/2035 14:13	10/05/2035 00:32

- Launch opportunities

No	Launch date	Max. delivery mass	Landing
1	Jun. 2030	9403 kg	Window 2
2	Dec. 2030	9128 kg	Window 1
		9646 kg	Window 2
		9084 kg	Window 3
		9654 kg	Window 4
		9342 kg	Window 5
3	Jun. 2031	9637 kg	Window 6
		9427 kg	Window 7
4	Jun. 2032	9174 kg	Window 5
		9331 kg	Window 7
5	Dec. 2032	9356 kg	Window 4





Arrival conditions

Primary Trajectory

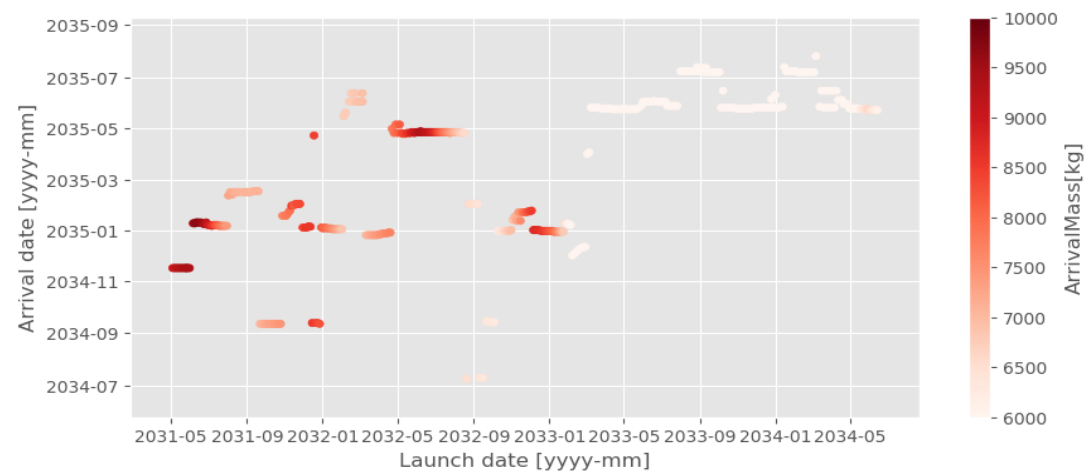
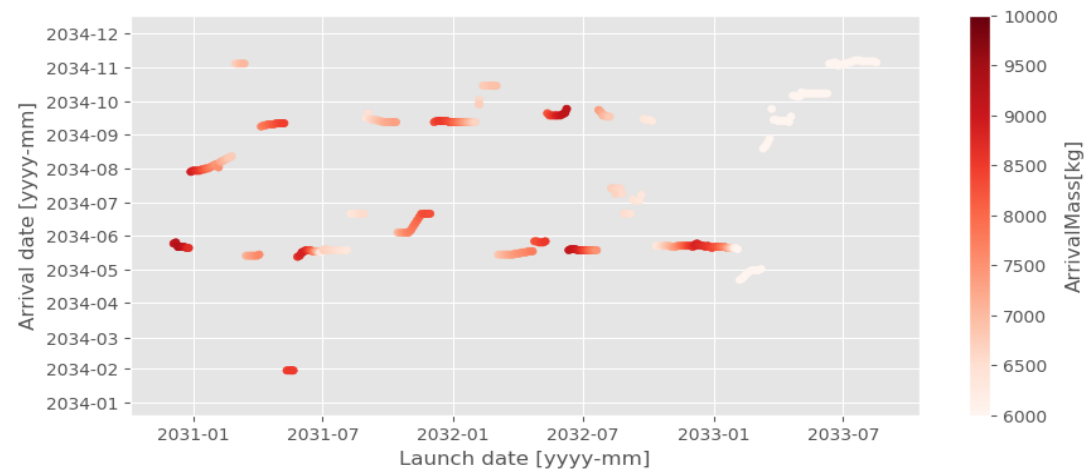
Arrival: Window 6



RA of Periapsis = 155 ~ 205 deg
Latitude of periapsis: -9 deg
Flight time < 4 years

Backup Trajectory

Arrival: Window 5 and 7



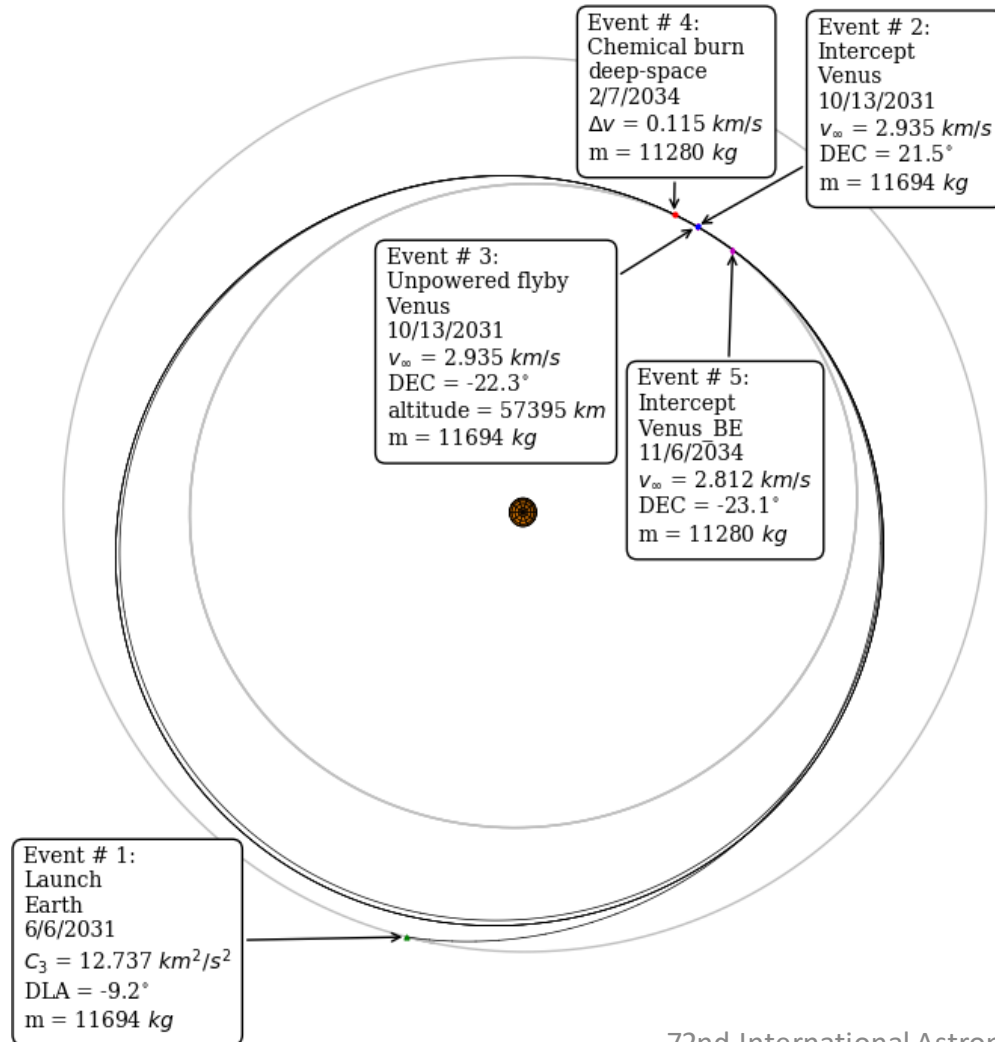
RA of Periapsis = -5 ~ 20 deg
Latitude of periapsis: -9 deg
Flight time < 4 years



Baseline Trajectory

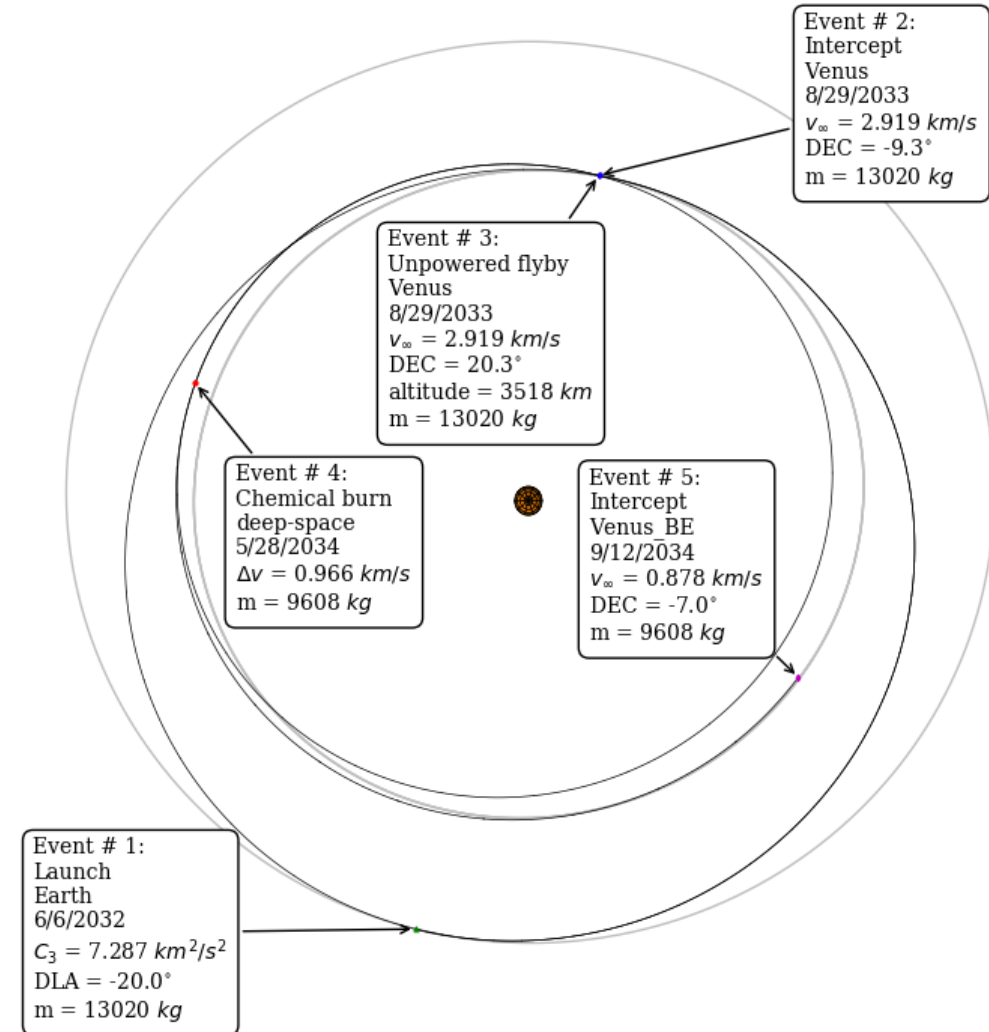
Primary Trajectory

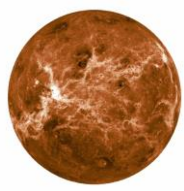
Departure: June 2031



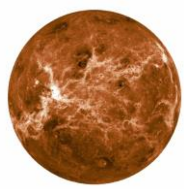
Backup Trajectory

Departure: June 2032



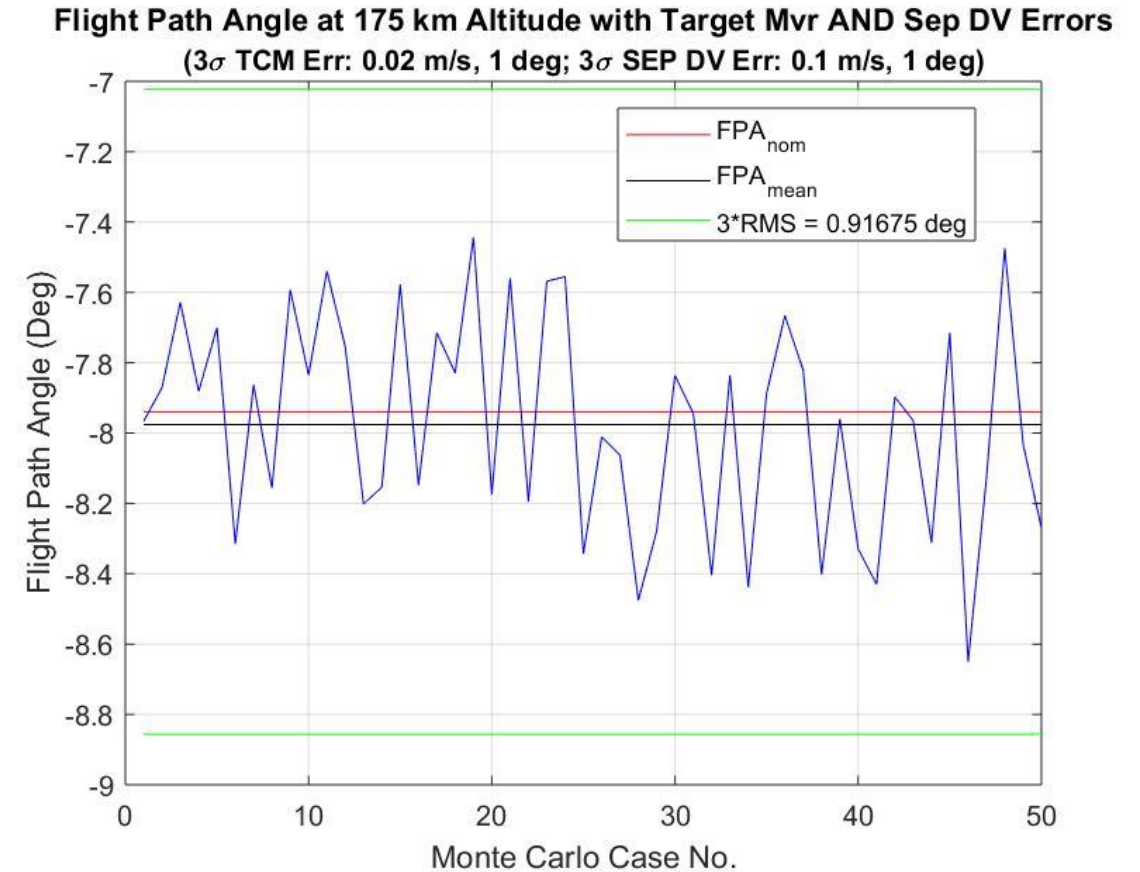
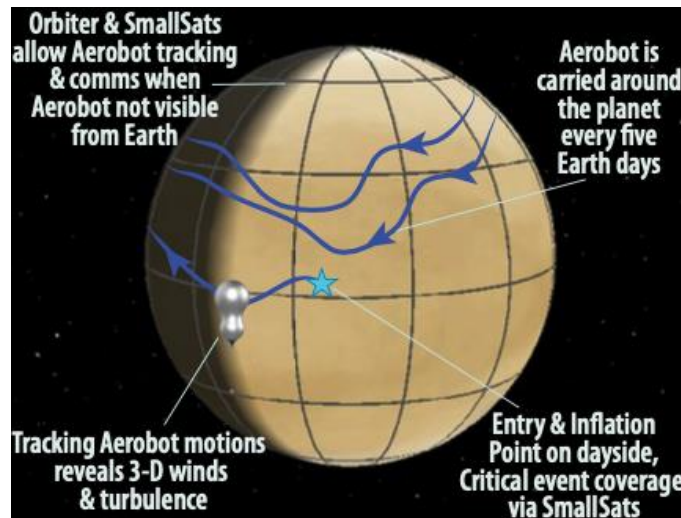


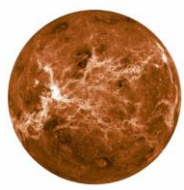
Orbiter Mission Characteristics



Aerobot Release and Entry

OD for at least 20 days after the DSM	BE-30 days
Balloon entry targeting TCM1 (~ 10 m/s)	BE-10 days
4 days to update OD, plan, command TCM2	
Balloon entry targeting TCM2 (~ 2 m/s)	BE-6 days
Balloon deployment and separation (~ 5 m/s)	BE-5.5 days
Orbiter VOI targeting mvr (~ 20 m/s)	BE-5 days
3 days to update OD, plan, command TCM	
Orbiter VOI targeting TCM (~ 5 m/s)	BE-2 days
Balloon entry (BE)	BE+0 days





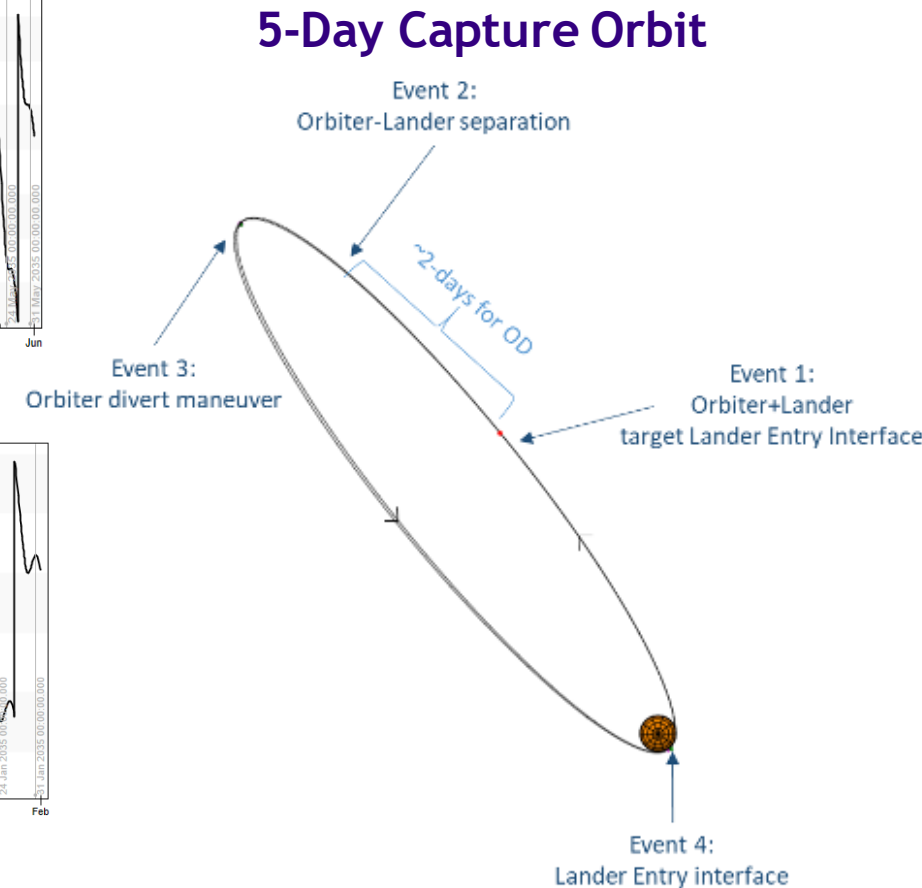
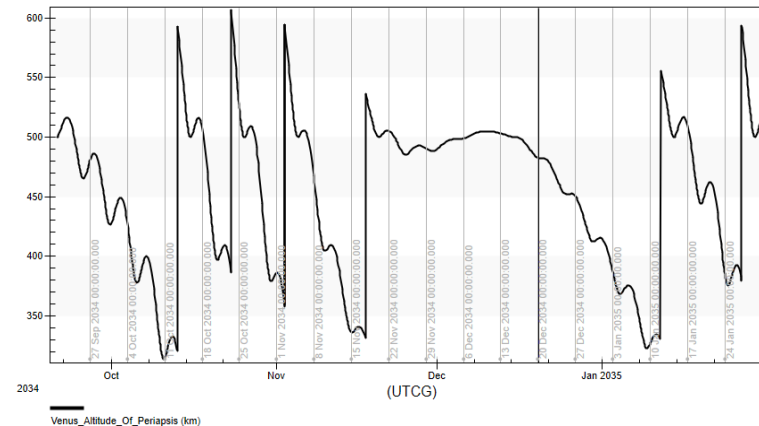
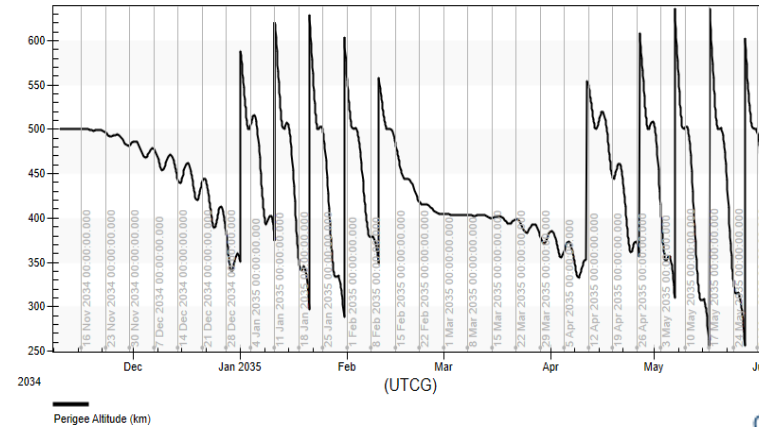
Baseline Polar Orbit Maintenance

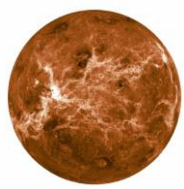
- Periapsis altitude keeping is needed
 - Altitude decreases due to the solar gravity
- Primary Trajectory

Date [UTC]	Delta V [m/s]	
9 Nov 2034 12:47:08.745	529.676829	Orbiter VOI
31 Dec 2034 23:04:45.432	5.088827	
11 Jan 2035 00:09:28.996	5.22893	
21 Jan 2035 01:33:08.849	7.07365	
31 Jan 2035 03:08:57.403	6.789112	
10 Feb 2035 04:47:11.189	4.492094	
11 Apr 2035 13:44:51.732	4.328001	
26 Apr 2035 18:06:29.645	5.427822	
6 May 2035 21:36:14.781	6.909071	
Total	45.337507	

- Backup Trajectory

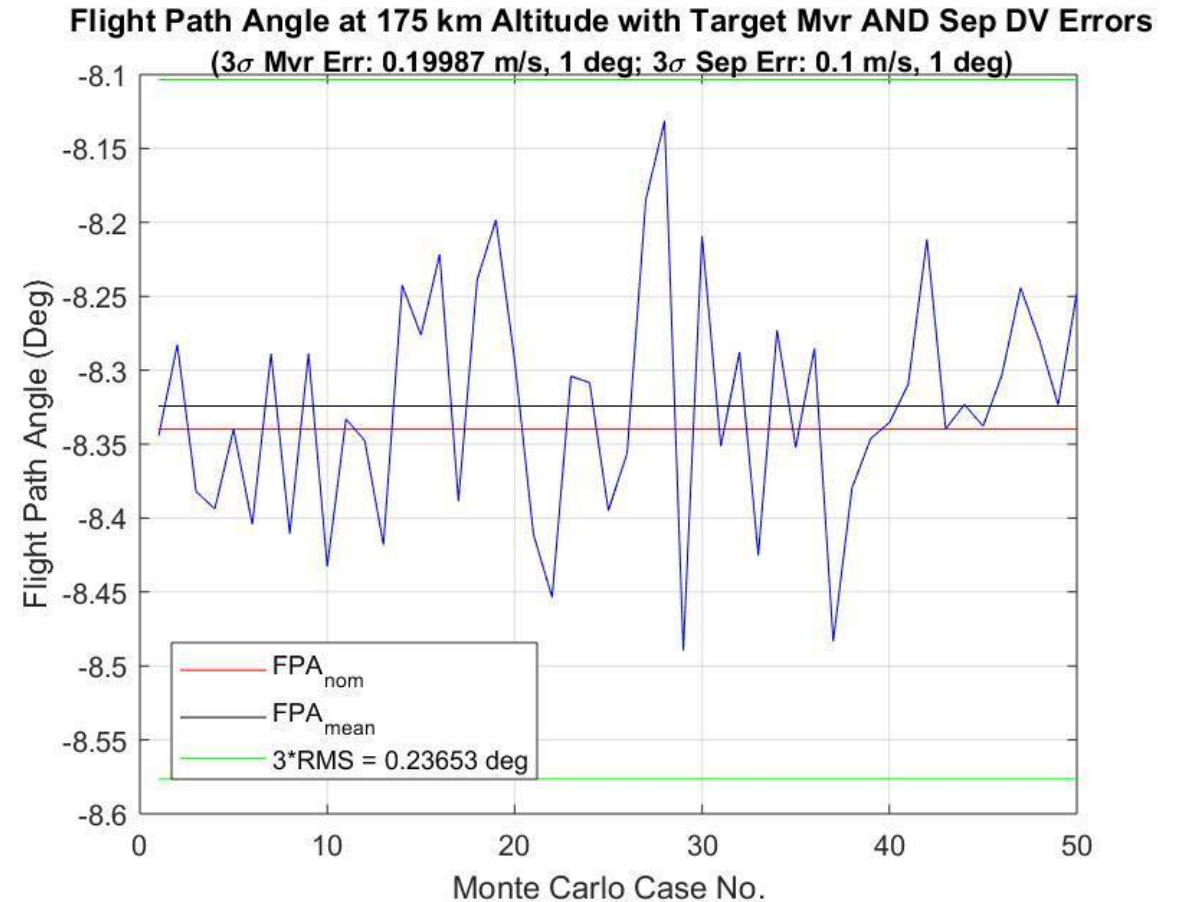
Date [UTC]	Delta V [m/s]	
20 Sep 2034 17:36:44.053	157.607062	Orbiter VOI
13 Oct 2034 08:06:19.636	5.795453	
23 Oct 2034 09:54:21.387	4.695284	
2 Nov 2034 11:52:05.301	5.018622	
17 Nov 2034 14:36:02.725	4.363974	
11 Jan 2035 22:39:47.718	4.829876	
27 Jan 2035 02:59:18.864	4.529397	
Total	29.232606	



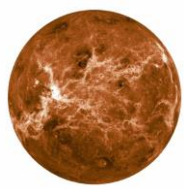


Lander Release Sequence

- Orbiter periapsis adjustment to 300 km
 - $\Delta v = 45.67$ m/s
- Entry corridor target maneuver
 - Targets the entry point for the probe
 - $\Delta v = 23.03$ m/s
 - Land (from interface to ground) ~1 hour
- Divert maneuver and communications
 - 80 minutes access time
 - Access starts ~8 min after landed
 - $\Delta v = 130$ m/s
- Polar orbit
 - Insert into a polar orbit for mapping
 - Same apoapsis, periapsis of 200 km
 - $\Delta v = 491.48$ m/s
 - Aerobrake Δv not yet evaluated

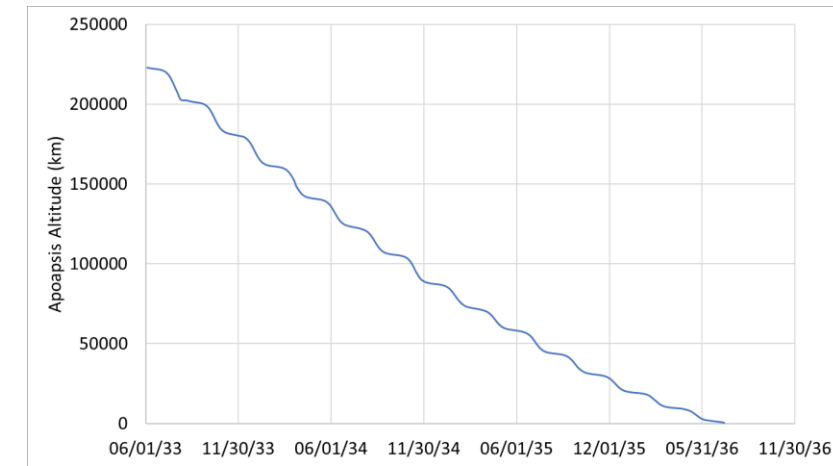
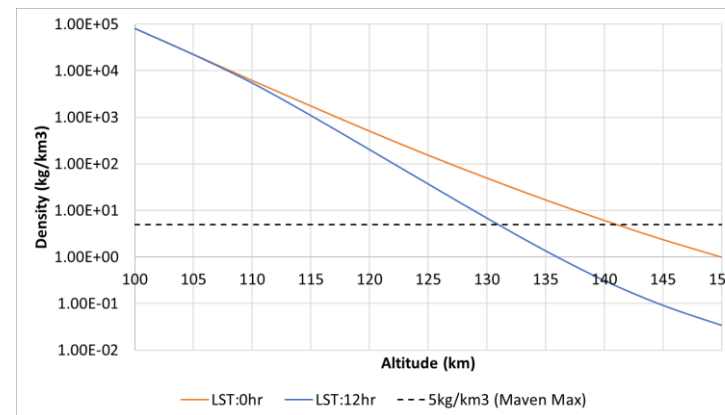
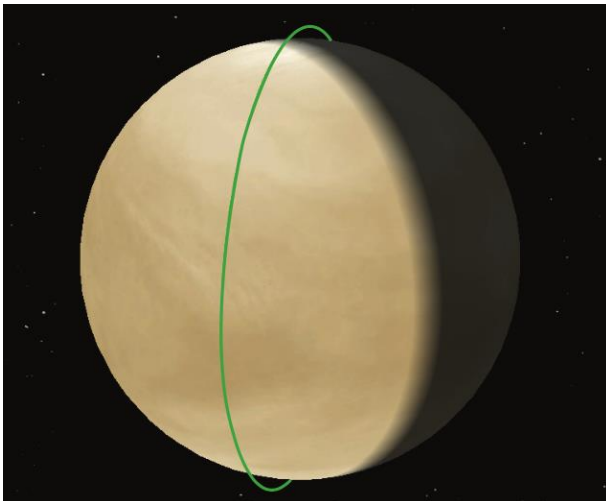
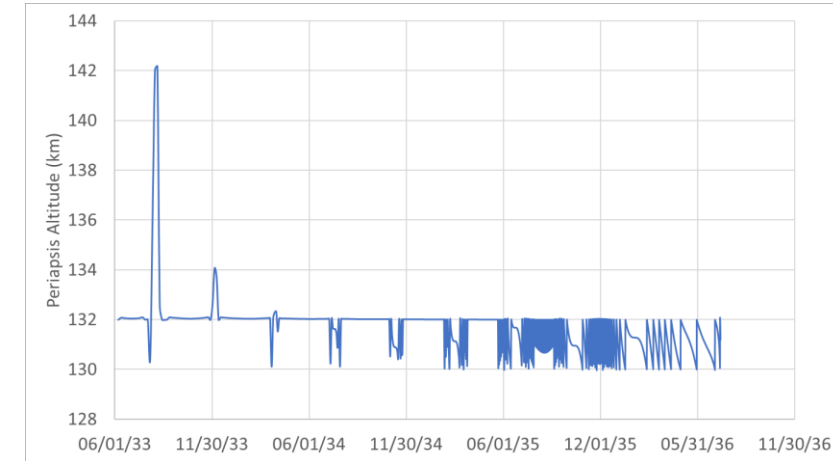


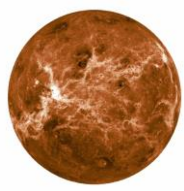
	Lander entry interface [UTC]	Lander operations start [UTC]	Access start [UTC]	Access end [UTC]	total time
Lander	1 Feb 2034 07:51:45.745	1 Feb 2034 08:51:45.745			1 hour
Orbiter			1 Feb 2034 07:59:45.592	1 Feb 2034 09:19:45.586	80 min



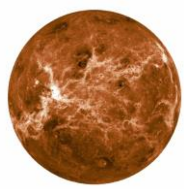
Science Orbit Aerobraking

- Periapsis altitude for aerobraking : 130km-132km
 - Atmospheric density at 130km is 6.85 kg/km³ on the dayside and 49.7 kg/km³ on the night side (MAVEN's max. atmospheric density ~ 5 kg/km³)
 - Max. velocity at periapsis 10.1 km/s (MAVEN's max. velocity ~ 4.2 km/s)
- Periapsis lowered for aerobraking
 - From altitude of 7000 km to 130 km
 - $\Delta V = 116$ m/s
- It takes 2 years to lower the apoapsis to 300km.
- Requires 376 maneuvers and total ΔV of 215 m/s to maintain the periapsis altitude





Small Satellites (SmallSats) Mission Design



Small Satellites Trajectory Design



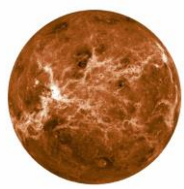
- SmallSats requirements:
 - Need to be in place before the balloon 9 Nov 2034 12:42:36.196 UTC
 - Each need to provide 4 hrs of communications to the lander
 - Total communication time 8 hrs (2 x 4 hrs)
 - Lander atmospheric interface contact 19 May 2035 14:16:52.538 UTC
- Interplanetary transfer with arrival spiral (primary)
 - Start (separates shortly after launch): 6/6/2031
 - Venus arrival: 1/09/2034
 - End of upper spiral: 2/28/2034
 - Dry mass: 175.1 kg
 - Phase propellant: 79.543 kg (10% margin already included with duty cycle 90%)
99.931 kg (backup)
- Spiral down requires
 - Phase duration: 32.65 days
 - Phase propellant: 18.15 kg of Xenon (10% margin included)
- Orbit adjustment from circular to elliptical requires
 - Phase duration: 135.00 days
 - Phase propellant: 7.2 kg of Xenon (10% margin already included)

Small-sat 1 (Venus ICRF)

- Apoapsis altitude: 18494.4 km
- Periapsis altitude: 500 km
- Period: 5.937 hr
- Inclination: 22.5 deg
- RAAN: 0 deg
- Arg. of per.: 340.2 deg

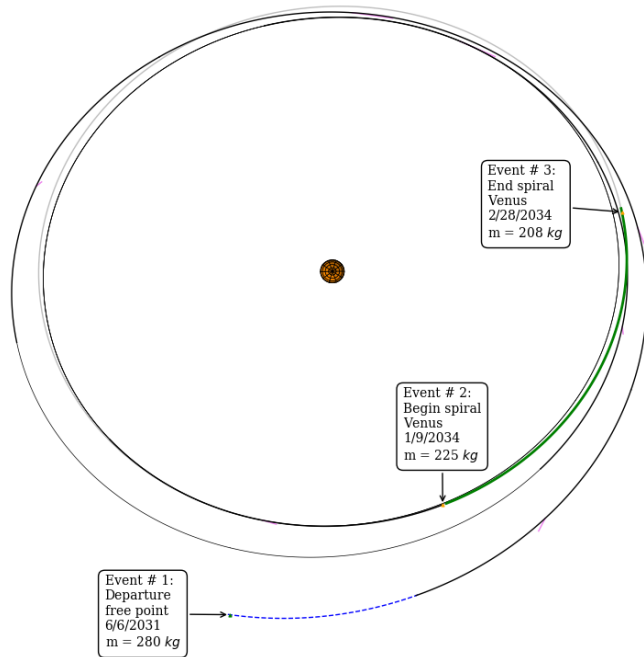
Small-sat 2 (Venus ICRF)

- Apoapsis altitude: 18494.4 km
- Periapsis altitude: 500 km
- Period: 5.937 hr
- Inclination: 65 deg
- RAAN: 347.726 deg
- Arg. of per.: 351.056 deg



Small Satellite Specifications

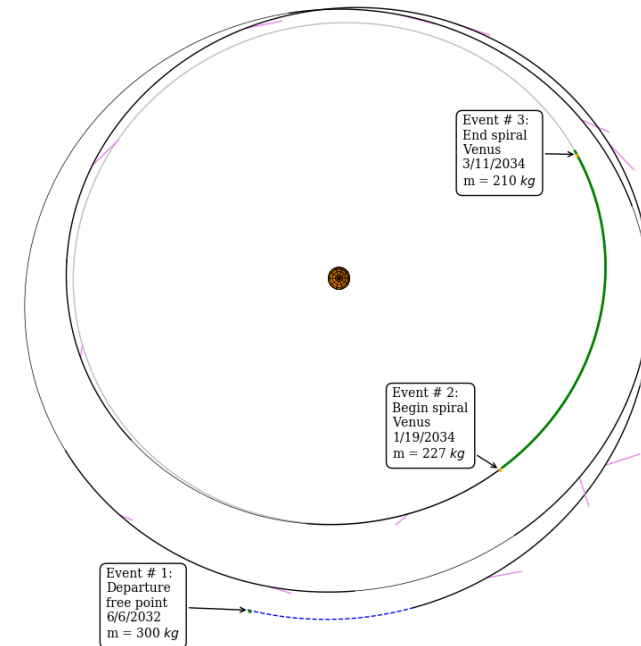
June 2031 Solution



Primary Trajectory

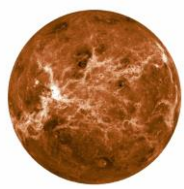
- Wet mass: 279.993 kg
- Dry mass: 175.1 kg
- Engine: 2xBTH600
 - Thrust: 0.0674 N
 - Isp: 1750 s
- Power: 1kW array, 200W bus
- Launch date: 6 June 2031 10:47:38.66 UTC
- Final orbit arrival date: 15 Aug 2034 12:30:40.44 UTC
- No station keeping needed

June 2032 Solution



Backup Trajectory

- Wet mass: 300.381 kg
- Dry mass: 175.1 kg
- Engine: 2xBHT600
 - Thrust: 0.0674 N
 - Isp: 1750 s
- Power: 1kW array, 200W bus
- Launch date: 6 June 2032 00:01:26.4 UTC
- Final orbit arrival date: 24 Aug 2034 15:38:52.46 UTC
- No station keeping needed



Conclusions

- This work proves the feasibility of a Venus Flagship Mission with a single launch vehicle
 - The design considered the most challenging configuration, with four platforms
 - To a pre-phase A level of fidelity, such mission is possible with current technology and within the capabilities of operational launch vehicles
- Mission would be possible as early as June 2031 with a backup launch opportunity in June 2032.
- The orbiting platforms (Orbiter and SmallSats) can be placed in orbits which satisfy the required science goals as well as provide adequate communication access link to all planet bound platforms (Aerobot and Lander).
- It was shown that a propellant-efficient design exists for a Lander released from Orbit as opposed to the more traditional “release upon arrival” used in other missions
 - A one-of-a-kind Venus aerobraking campaign was identified as a mission enabler

Overall, the designed mission architecture complies with science and operational requirements. Such architectural success is driven primarily by its timeline requiring each platform to be in place prior to the execution of the next phase.