Venus Entry Probe Initiative

VEP Scenarios

Synthesis on VEP payloads
VEP scenario identification logic
FbP/ASR Scenario
VEO/ASR Scenario
VPO Scenario
VPO+VEO/BA Scenario
VPO+VEO/DP/BA Scenario
VPO+VEO/DP/BA/ASR Scenario
VPO+FbP/ASR Scenario

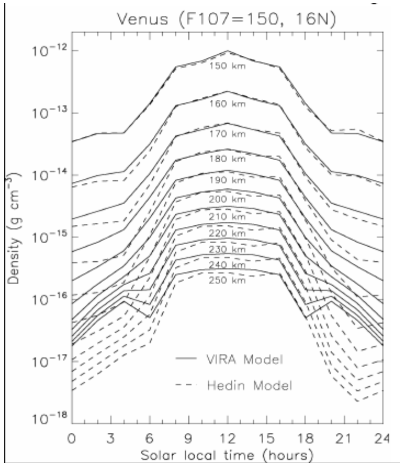
VEP: Venus Entry Probe
FbP: Fly by Plateform
ASR: Atmospheric Sample Return
VEO: Venus Elliptical Orbiter
VPO: Venus Polar Orbiter
BA: Balloon
DP: Descent Probes

Remote Sensing Payload (RS)
(4th draft of the proposal for VEPI Orbiter)

No.	Instrument	Scientific goals	Volume (cm^3)	Mass (kg)	Power (W)	Data rate	TRL (2006)	Origin
B-1	**VRS**	Crust, subsurface layering		17	64.5		6/9	USA (Smithsonian)
B-2	**X-band tr.**			2	cca. 2	Small		Europe
B-3	**EUV-FUV spectrom.**	Atoms, molecules and ions in higher atmosphere		4.5	cca. 3	60 kbits/s?	3/4	Europe (CNRS)
B-4	**N/I mass spectrom.**	No.1/2		4.6	6	<20 kbits/s		Europe
B-5	**SWI**	*Wind*, temperature, density etc and the *halogen chemistry* in the MLT region (higher atmosphere)	70x50x40	9.2	49.5	9.2 kbits/s	8/9	Europe (Max Planck)
B-6	**SAS2-VNS**	E.m. wave analyser	10x11x15 + sensors (booms)	0.7	cca. 4	4 kbits/s	6/4	Europe (Eötvös Univ.)
B-7	**SPOSH**	Meteor and lightning detection	10x10x15	2.5	10	0.5 kbits/s	6	Europe (Ger.Ae.Cent.)
B-8	**TPIV** (combined with Langmuir)	In situ plasma density, *wind* and temperature (combination with a Langmuir probe is possible)	+ sensors (booms) 80 ~ 100	0.94	1.8	1 kbits/s	9	Europe (CNRS)
B-9	**Langmuir probe**	No.5	+2 booms	0.2		0.5 kbits/s		Europe (?)
B-10	**Magnetic field**	No.5		1.0		4 kbits/s		Europe (?)
B-11	**MIMA**	Surface mineralogic composition, atm. thermal field, cloud comp.	12x13x10	1.0	$3 \leq 5$	4.4 kbits/s	3/5	Europe (INAF)
B-12	**Acc. µSTAR**	No.3	~9x12x10	1.0	1	0.2 kbits/s	3/8	Europe (ONERA)
Total :		All scientific goals and no others.*	cca.	cca. 44.6 kg *(or ~56 kg or more with FAVOURED)*	cca. W	< 200 kbits/s		Europe + + USA

Orbit for Remote Sensing payload

- ESA TRS Study
  - 2000 km/6000 km polar orbit
- Scientific need for VEP (TBC)
  - Circular polar orbit 200 km, or elliptical 1000/200 km



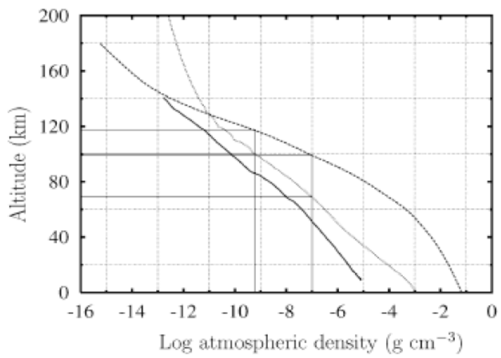


Fig. 3. Atmospheric density-height profiles for Earth (US Standard Atmosphere 1976—dotted line), Mars (Mars Pathfinder entry profile—bold line) and Venus ("nightside" atmospheric model by Seiff (1983)—dashed line). The vertical and horizontal black lines indicate the density/height range at which meteors ablating in the atmospheres of those planets are expected to be at their maximum luminosities.

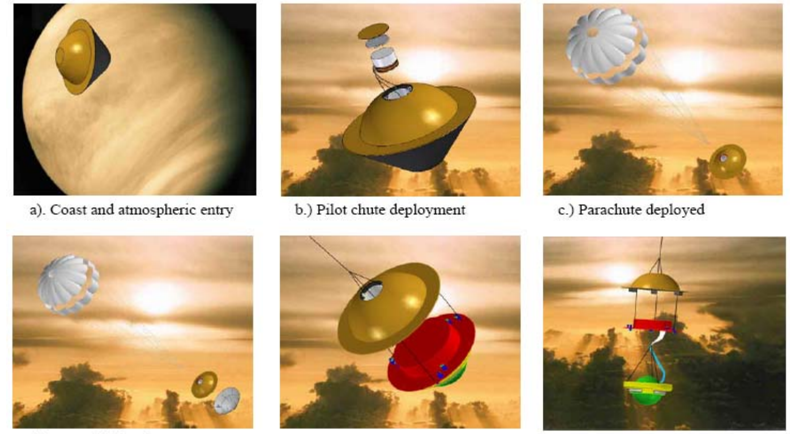
- ESA TRS Study

Table 20: Entry vehicle mass budget.

Item	Mass (kg)	Remarks
Gondola	22.7	Incl. science payload
Balloon	9.1	Incl. gas replenishment system
Gas storage system	16.8	
Parachute system	4.3	Incl. parachute mortar
Inner structure	4.2	
Back cover	8.0	Norcoat Liege ablator
Front shield	26.0	High-density ablator
Total mass Entry Vehicle	**91.1**	

Data rate : 5 kbits/s

Figure 12: Drawing of the balloon with gondola.



a). Coast and atmospheric entry
b.) Pilot chute deployment
c.) Parachute deployed
d.) Front shield release
e.) Rear aeroshell separation
f.) Inner structure release and start of balloon deployment.

Figure 11: Entry and deployment sequence.

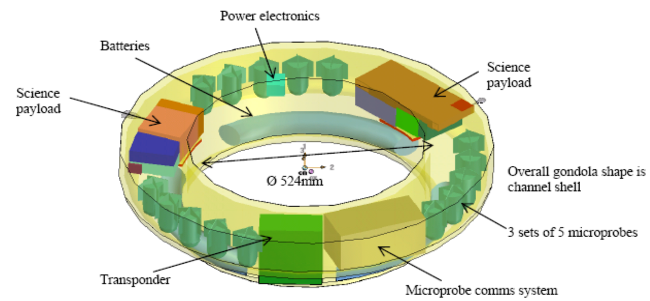
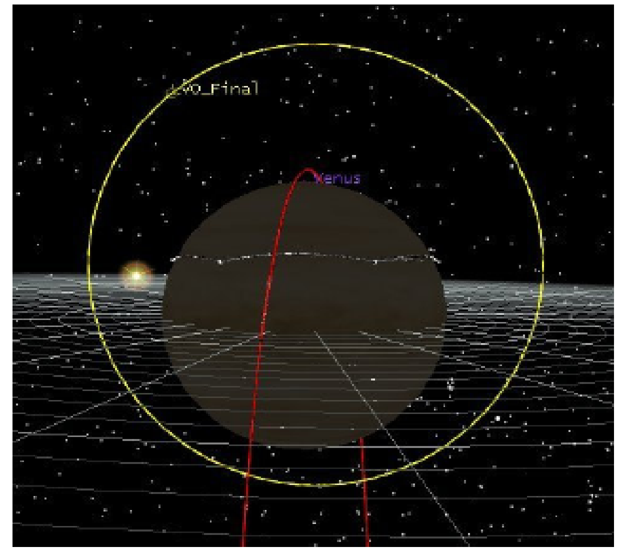


Figure 14: Gondola mechanical layout.

- JAXA Balloon
  35 kg
  Transmission directly to earth ?

Balloon trajectory

- 70 m/s (cf Vega balloon)
- 25° North (cf ESA TRS Study)
- Covers a round in 6 days
- Communications with balloon
  - in UHF (atmospheric attenuation in S or X band)
  - Emitter 10 W, antenna gain -3 dB
  - With a low orbit (200 to 1000 km)
    - reception antenna gain is low (0 dB)
    - Visibilities are short (5 to 10 min for one orbit of 100 min) and scarce (depend on the ballon speed and trajectory)
    - It's possible to transmit 250 kbps at 1000 km
    - 5 kbps of scientific TM would mean 2% of visibility
    - An on board recorder is necessary
  - With a High Elliptical Orbit (200000/200 km)
    - Reception antenna gain is higher (10 dB)
    - Visibilities are long, and can be almost permanent
    - Only 0.06 kbits/s is feasible at 200000 km (6 kbps at 20000 km)



- If there is a low orbiter, its orbit shall be > 1000 km to have enough visibility
- If there is only a High Elliptical orbiter, the data rate shall be decreased.

Descent Probes (DP) and Landers (DP+LD)

Descent probes (DP)

Table 2: Top level estimate of a Venus Descent Probe

Payload mass (kg)	5	10	20	30
Descent module (kg)	~70	~90	~110	~130[3]
Entry probe (kg)	~115	~150	~180	~210

Data rate: 10 kbits/s

Descent probes + Lander?

VEGA Lander
- Payload 117 kg
- Descent module 750 kg
- Lander 1600-1800 kg

Scientific need

- 4 Descent Probes
- Shall be scaterred on different latitudes
- 3 on day side, 1 on night side

Descent Probe trajectory

ESA TRS Study: Entry Vehicle Flight Path Angle = 40°

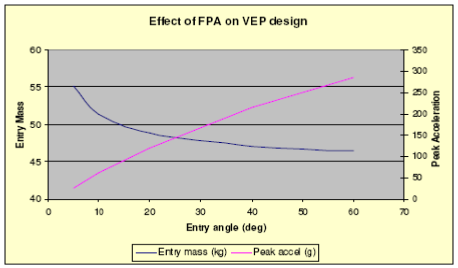


Figure 3 Effect of FPA on VEV Design

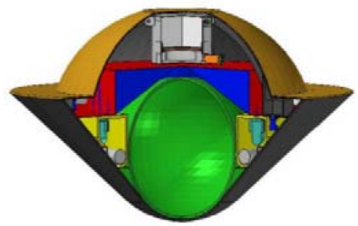
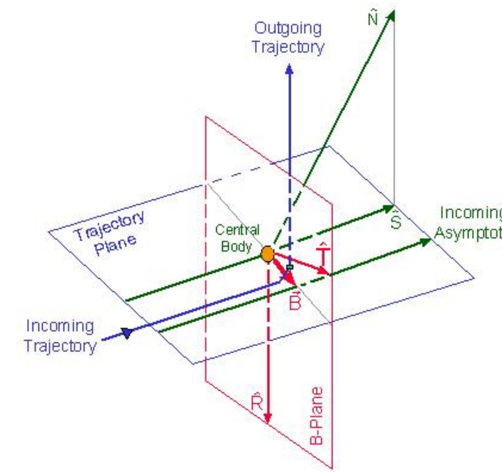
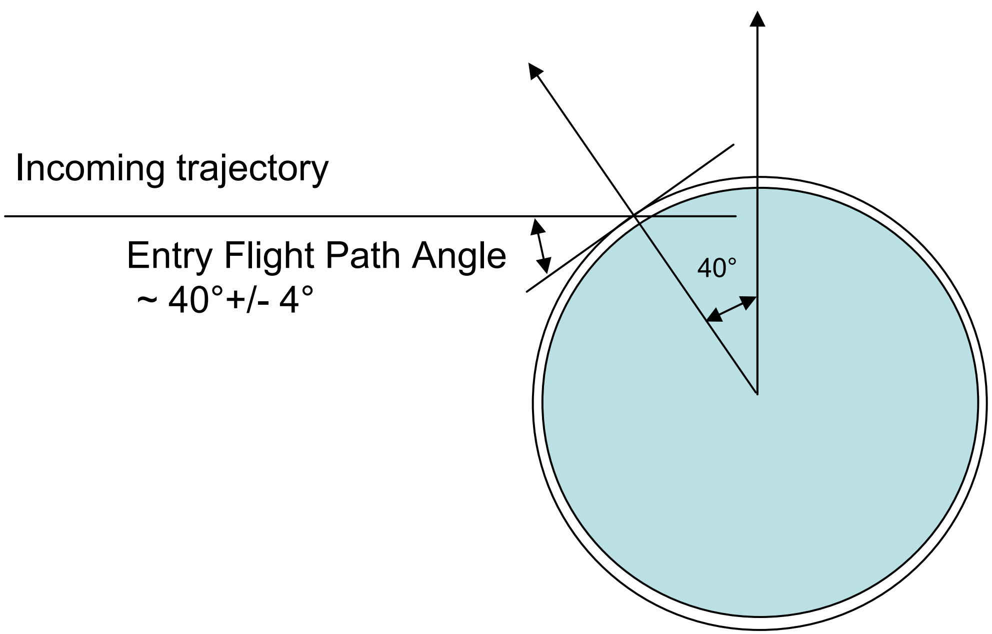
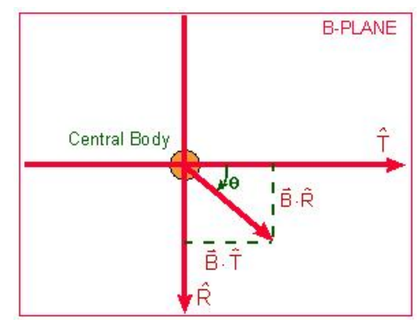


Figure 2 Venus Entry Vehicle (aerobot stowed)





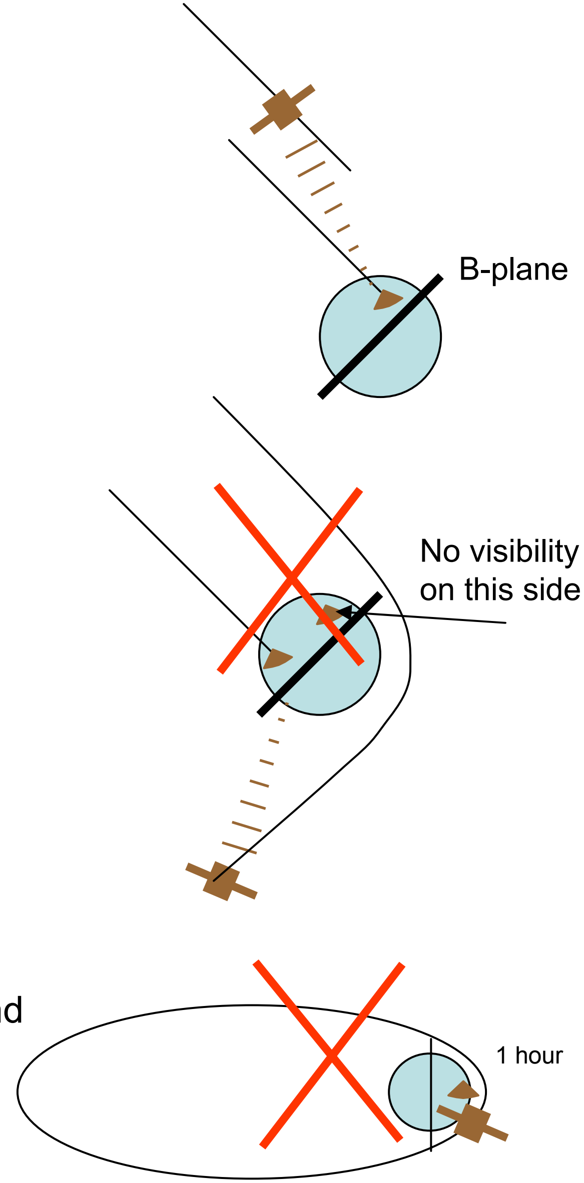
B-plane definition



Descent Probe release
Communication considerations

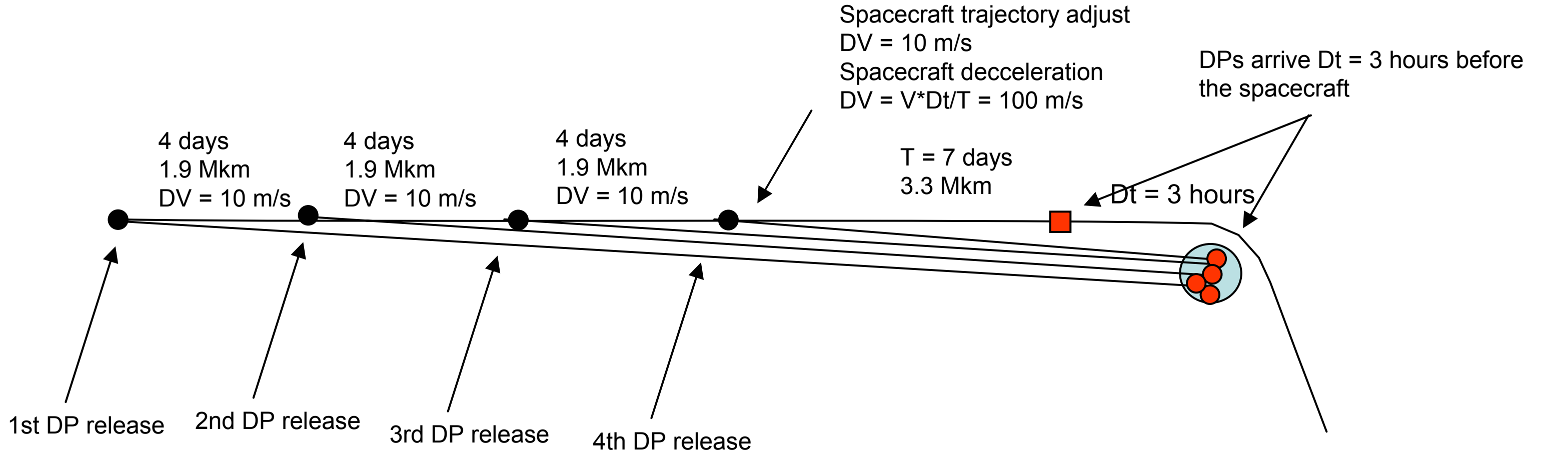
Venera descent probe release sequence :
http://www.russianspaceweb.com/venera75.html

- When shall the DP be released?
  - Descent probes are released before insertion or fly by
    - Descent probes arrive before the plateform
      - From the probe, plateform is seen 40° above the horizon which is correct.
      - If there is a Polar Orbiter on a low orbit, its period is too short to be in visibility during 2 hours
    - Descent probes arrive after the plateform
      - Only probes on a side of the planet are in visibility
  - Descent probes are released after insertion
      - Not good for DV budget, given probes mass
      - Descent Probes insertion is necessarily done at pericenter, where visibility is not possible during 2 hours (the plateform rotated à ~9 km/s at perigee and covers 180° in 1 hour



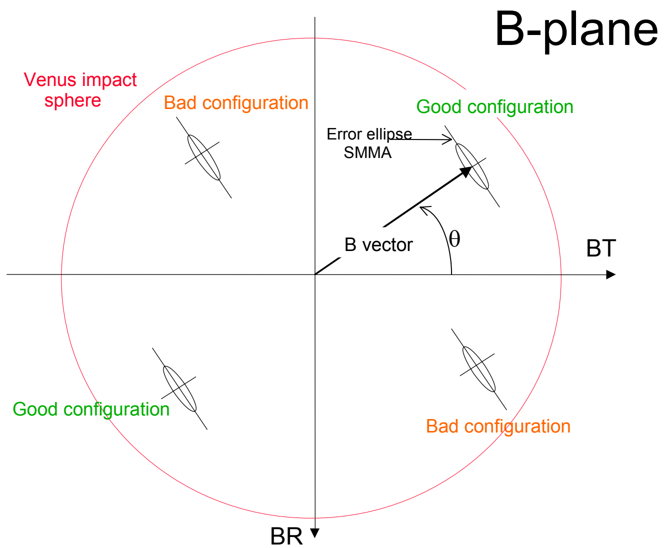
Descent Probes release
Timing and DV considerations

- Assumptions
  - Relative velocity V = 5.5 km/s (Worst case Vinf)
  - Last DP is released T = 7 days before spacecraft arrival
  - 4 days are necessary to adjust the spacecraft+DP trajectory to point the DP insertion location. DV < V*6000km/3.3 Mkm = 10 m/s
  - For telecommunication reasons, DPs shall arrive Dt = 2+1=3 hours before the spacecraft. The spacecraft shall deccelerate after last DP release DV = V*Dt/T = 100 m/s



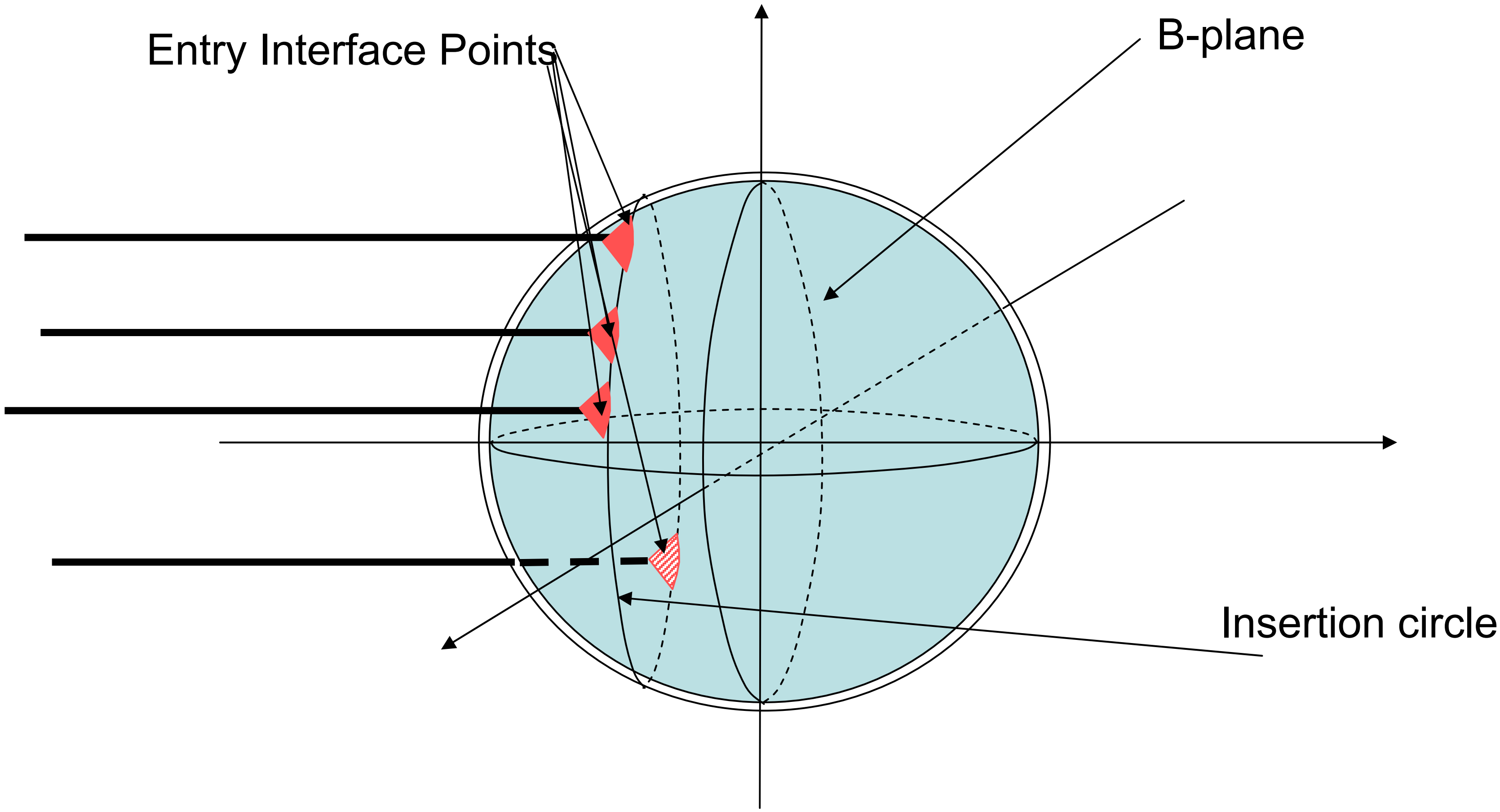
Total DV for Ndp Descent Probes release (with margins):
DV = 20*Ndp + 100 m/s

Insertion point accuracy



Due to geometrical biais in trajectory determination accuracy, the error ellipse around the targetted DP Entry Interface Point has a given orientation. To minimize the Entry Flight Path Angle error (+/- 4° TBC), only two quarters in the insertion circle are possible.

Descent Probes drop sites



Communications with DP

- UHF band (due to atmospheric attenuation)
- Emitter 10W on DP (consumption 20W)
- Omnidirectional antenna (gain -3 dB)
- Spacecraft antenna gain 10 dB (length 70 cm)
- 25 kbps possible at a distance of 10000 km but 0.25 kbps at 100000 km).

3.12 Mass and power budget

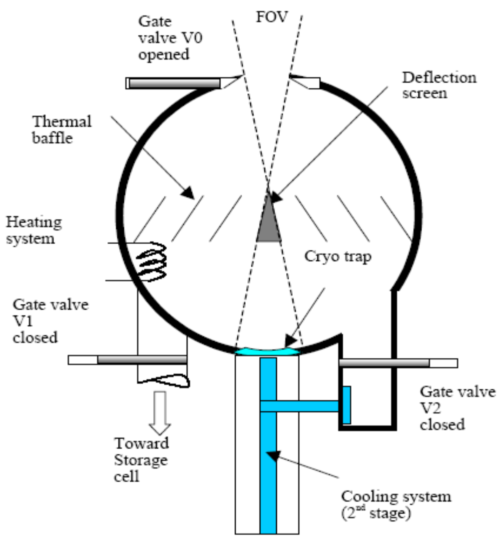
Table 12 : Mass and power budget

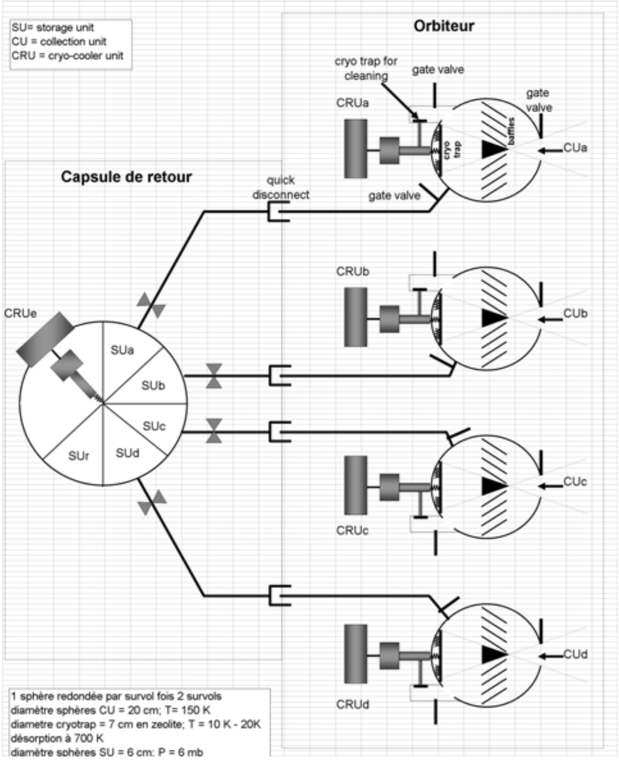
Unit	Details	Mass (kg)	Power (Watt)
Collection Unit (CU)	Cells (a,b,c,d) + transfer tubes + valves V0, V1, V2+ monitors	8	10 (valves + heating)
Cryogenic unit (CRU)	(a,b,c,d,e)	60	190 (for 3 cryosystems)
Storage unit (SU)	Cells (a,b,c,d) + valves V4 + disconnecting system	5	1
Electronic unit (EU)	Control electronics	1	1
Return capsule		25	
Micro-cameras	3 AMIE-type imagers	1.5	1
		100.5	**203**

The mass and power relative to the cryosystems are for the *20 K* cooler system developed by ASTRIUM.

Note that, if the (under development) *10 K* version of the cooler is to be used, the total mass is increased up to **150 kg**.

There is a large mass margin (>100 kg), which may be used for increasing redundancy, and/or improving the capabilities of the platform in terms of admissible drag force and other possible relevant parameters.





ASR trajectory

- Atmospheric capture at 120 km
- Spacecraft velocity is ~ 8 to 10 km/s at this altitude depending on the orbit

Payloads and orbits synthesis

Rough masses for scenario comparison

Remote Sensing (RS) payload: 50 kg
4 Descent Probes (DP) with 20 kg payload (no lander): 4*200 kg, 2 hours lifetime
Balloon (BA) (+ µprobes?): 100 kg (cf ESA TRS study), 3 weeks
ASR Payload: 100 kg
Dry Bus: 300 kg for 100 kg payload (cf ESA TRS Study)
500 kg for 1000 kg payload (First guess)

Orbits for scenario comparison

Fly by Platform: No insertion, Venus Fly by in the ecliptic plane, return to earth
Insertion or High Elliptical Orbit (no science interest) : 200km/200000km
Polar Orbit for RS : 200km/200 km

Scenario logic

Apart from the number and type of payloads (RS/DP/BA/ASR), the number of spacecrafts is the main cost driver

- One spacecraft
  - Just a Fly by -> The Fly by Plateform (FbP) can carry DP, BA and ASR
    - Potential problems for balloon telemetry during 3 weeks
  - Insertion on a High Elliptical Orbit -> Venus Elliptical Orbiter (VEO) can carry DP, BA and ASR
    - Added fuel is needed for Venus escape and return to earth (for ASR)
  - Down to a polar orbit -> Venus Polar Orbiter (VPO) can carry RS, DP and BA
    - ASR is not possible (escape from a low polar orbit is not realistic for fuel consumption reasons, even with electrical propulsion)
- Two spacecrafts
  - Plateform1 (PF1) goes down to polar orbit for RS -> VPO/RS
    - Might release part of the other payloads (DP and/or BA)
  - Plateform2 (PF2) carries all or part of DP/BA/ASR payloads
    - PF2 stays on a High Elliptical Orbit -> The Venus Elliptical Orbiter (VEO) can carry BA and DP
    - PF2 performs an added Venus escape and can carry the ASR payload
    - PF2 performs just a Fly by -> FbP can carry BA, DP and ASR

VEP scenarios

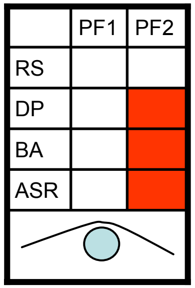
	One spacecraft			Two spacecrafts			
	FbP/ASR	**VEO/ASR**	**VPO**	**VPO (RS)** **VEO (BA)**	**VPO (RS)** **VEO (DP/BA)**	**VPO (RS)** **VEO (DP/BA/ASR)**	**VPO (RS)** **FbP (DP/BA/ASR)**
Remote sensing RS	-	-	50 kg	50 kg	50 kg	50 kg	50 kg
4 Descent probes DP (+Lander?)	4x200 kg	4x200 kg	4x200 kg	-	4x200 kg	4x200 kg	4x200 kg
Balloon BA (+ µprobes?)	100 kg	100 kg	100 kg	100 kg	100 kg	100 kg	100 kg
Atmos. Sample Return ASR	100 kg	100 kg	-	-	-	100 kg	100 kg
VPO Bus	-	-	Dry: 500 kg	Dry: 300 kg	Dry: 300 kg	Dry: 300 kg	Dry: 300 kg
VEO Bus (or FbP)	Dry: 500 kg	Dry: 500 kg	-	Dry: 300 kg	Dry: 500 kg	Dry: 500 kg	Dry: 500 kg
Wet Mass							
Comments				**TRS ESA study**			

Delta V estimation

- All Chemical propulsion (dual mode bi-ergol + hydrazine)
  - Bi-ergol Isp = 320 s
  - Hydrazine Isp = 220 s
  - Better to release DP and BA before insertion (lighter mass for insertion)
  - Insertion to HEO or escape : 0.6 to 1.2 km/s depending on launch date (1.2 km/s for sizing i.e Venus Express)
  - Insertion to polar orbit : Aerobraking + 500 m/s
  - 4 DP and 1 BA release : 5 * 20 + 100 = 200 m/s
- Electrical main propulsion (ionic propulsion + hydrazine)
  - Ionic Isp = 3300s, P = 92 mN, P = 2.3 kW (cf Deep Space 1)
  - Hydrazine for attitude and high thrust Isp = 220 s
  - Cruise to venus with electrical propulsion: ~ 3 km/s (arrival at Vinf = 0 km/s)
  - Insertion to HEO or escape with Electrical propulsion: ~ 300 m/s
  - Insertion to Polar Orbit with electrical propulsion: ~ 5 km/s (include gravity losses)
  - 4 DP and 1 BA release with hydrazine: 5*20+100 = 200 m/s

$$M_{wet} = M_{dry} \cdot \exp(DV/(g \cdot Isp))$$

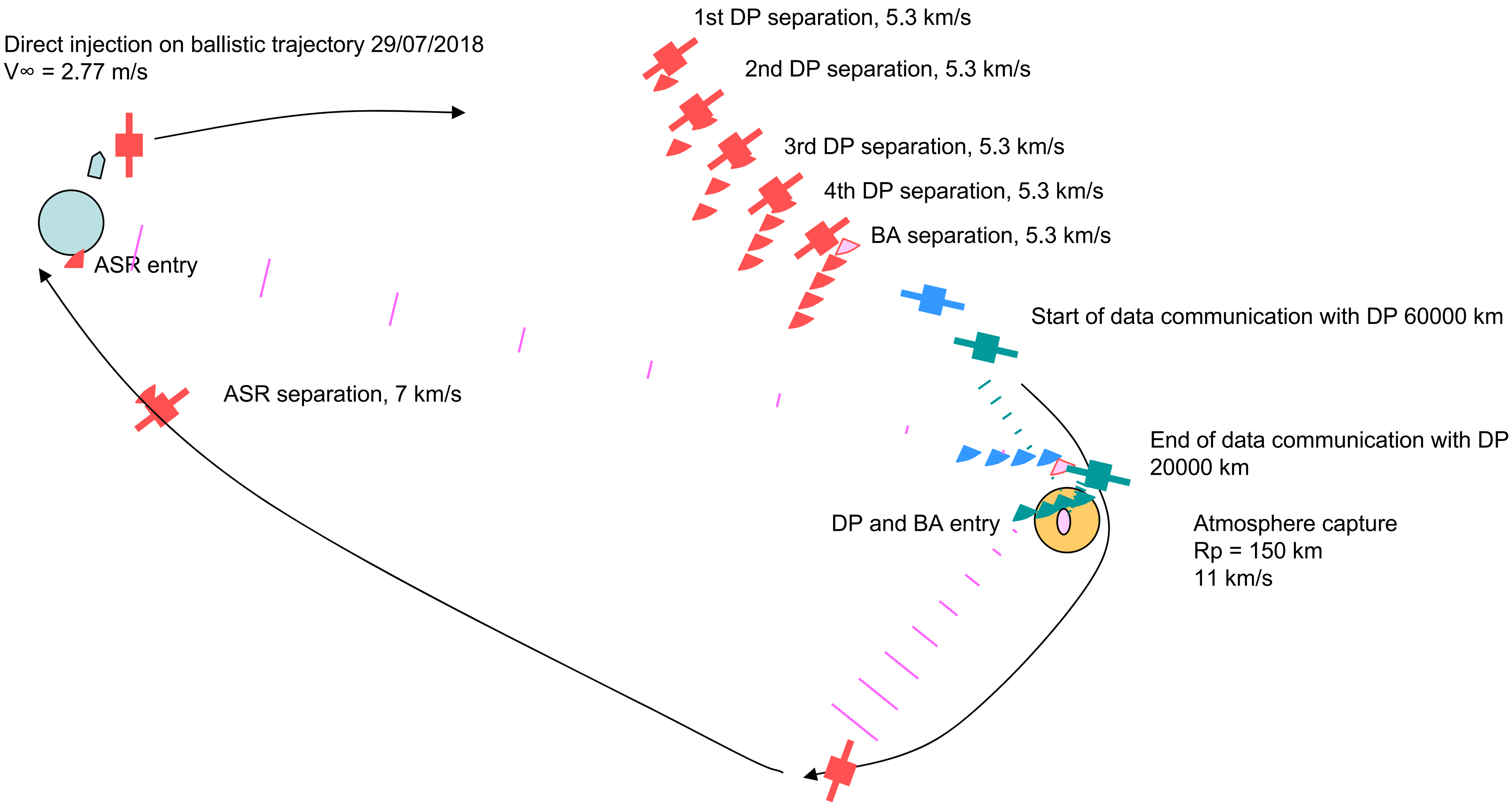
FbP/ASR Scenario



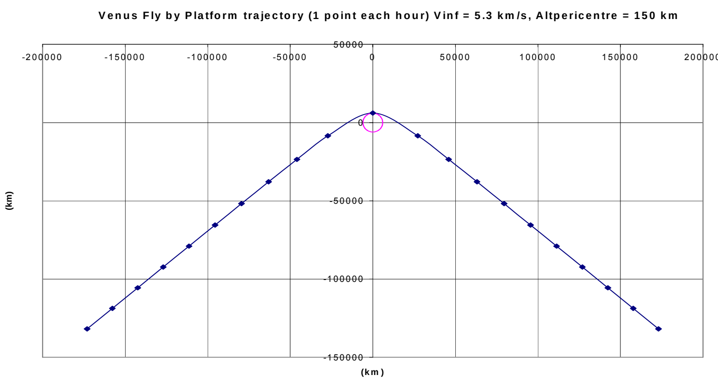
FbP/ASR Scenario

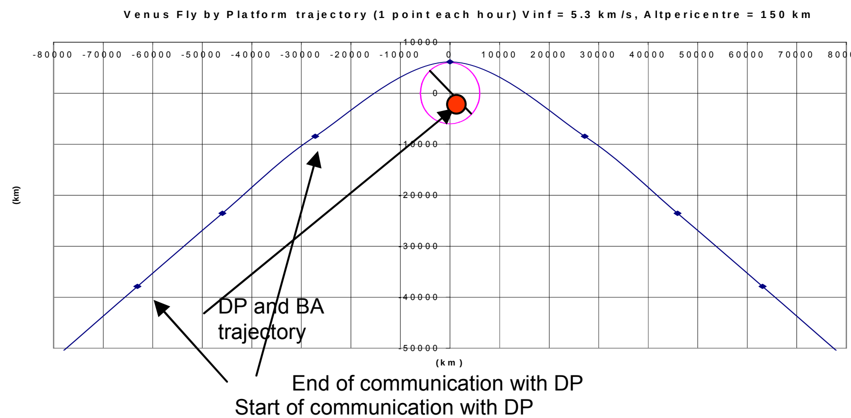
- Earth – Venus - Earth ballistic trajectory
- Total DV = 0 km/s
- Mission duration 1 year
- Sequence
  - Launch on 29/07/2018, relative velocity: 2.77km/s
  - Descent Probes and Balloon release 20 days before arrival
    - DP and BA arrive before the plateform
    - Communication with DP between 60000 km and 20000 km
  - Venus fly-by on 27/11/2018, v_∞ = 5.3 km/s, atmospheric capture at pericenter
  - Return on 31/07/2019, relative velocity: 7.06km/s
  - ASR entry vehicule release

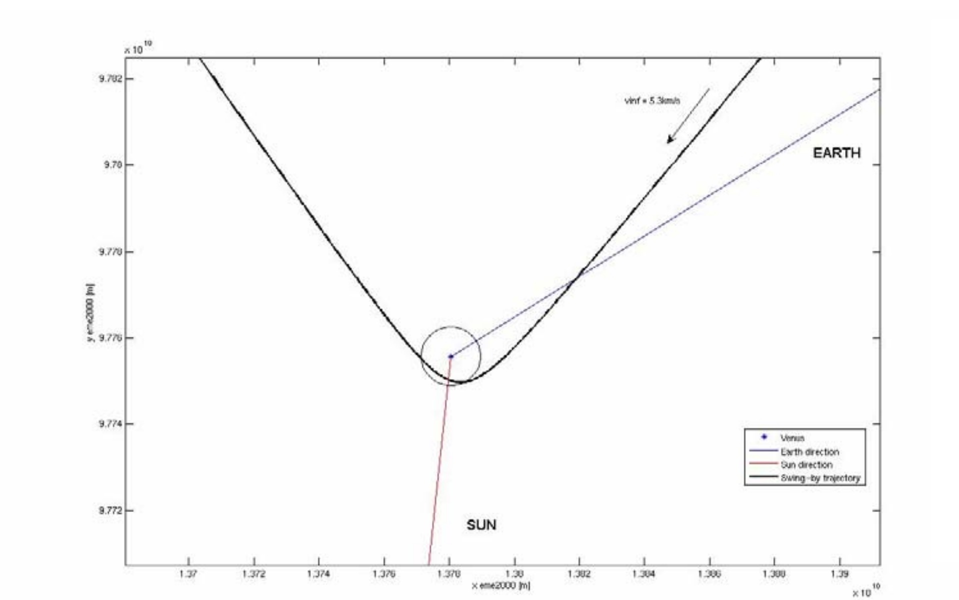
FbP/ASR scenario

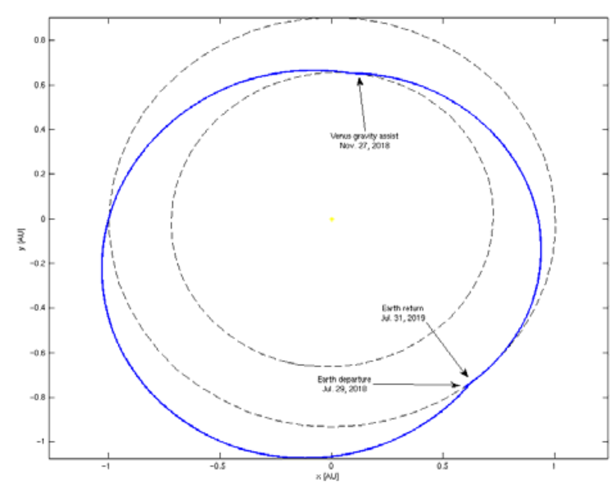


Fly by Platform trajectory









FbP/ASR Scenario
Mass estimate

- RS: None
- DP: 4 x 200 = 800 kg
- BA: 100 kg
- ASR: 100 kg
- Dry Bus: 500 kg

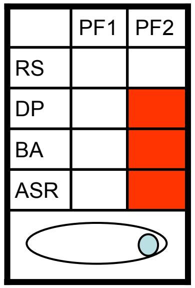
- Dry mass: 1500 kg
- Ergol (hydrazine)
  - DP/BA release 200 m/s : 150 kg

- TOTAL mass = 1650 kg

Critical points for FbP/ASR Scenario

- Communications
  - Not possible to have 10 kbps with DP
    - Communication data rate should be adjusted to the distance: 1 kbps at the beginning, 10 kbps at the end.
    - Emitter 10 W (20 power consumption) during 2 hours (40 Wh)
  - Not possible to have 5 kbps with BA
    - Plateform moves away at 5.3 km/s and is very far after 3 weeks (10 Mkm). Communications are no more possible
    - Direct communications with earth?

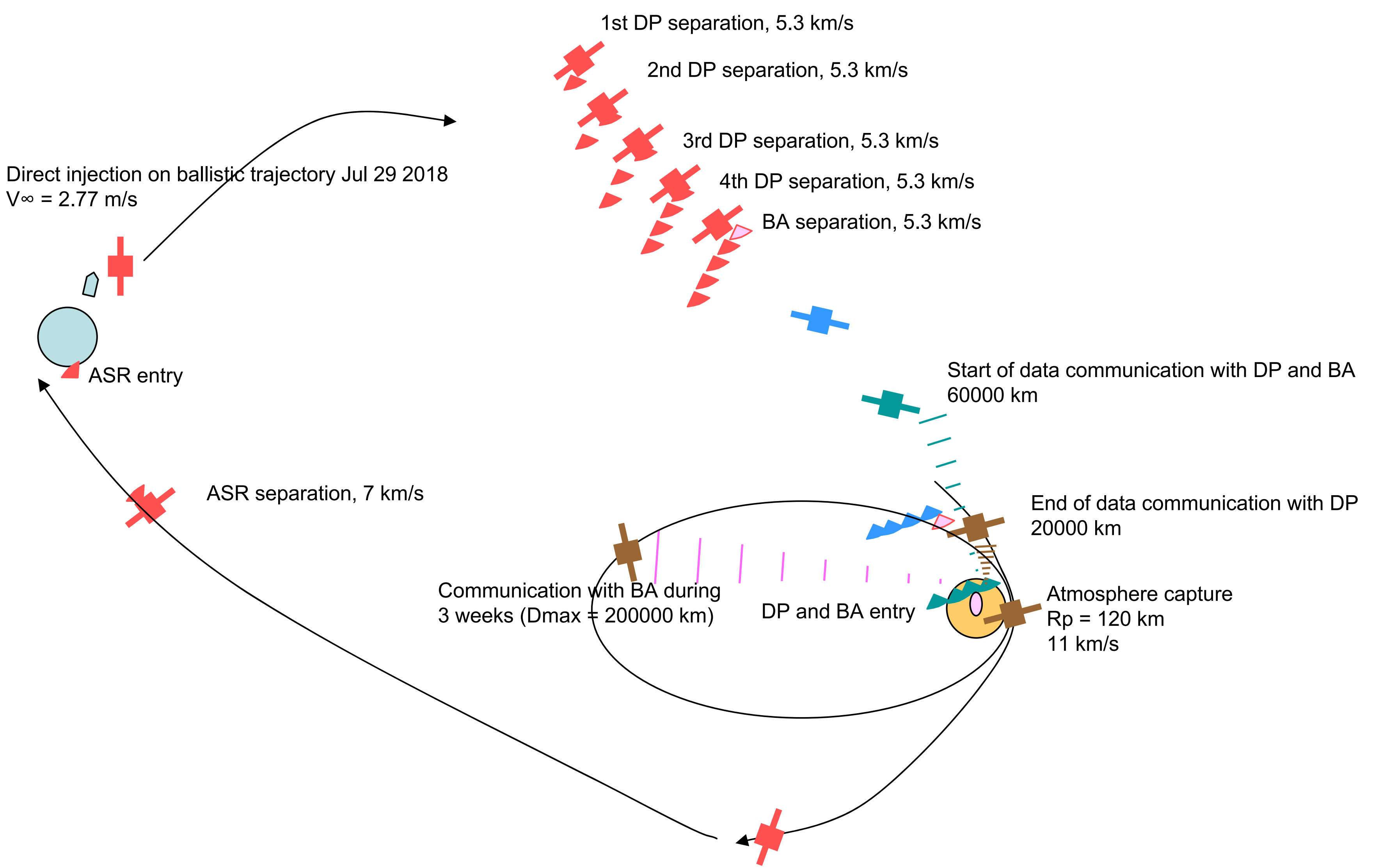
VEO/ASR scenario



VEO/ASR scenario

- This is an alternative for FbP/ASR scenario as it carries the same payload
- Sequence
  - Launch 8/12/2016 v∞ = 3.384km/s, δ∞ = 32deg (optimum for Venus insertion DV)
  - Ballistic trajectory to Venus 6 month
  - Descent Probes and Balloon release 20 days before arrival
    - DP and BA arrive 3 hours before the plateform
  - PF arrival 18/05/2017 : v∞ = 2.678km/s
  - Insertion manoeuver on HEO: <1200 m/s
  - Communications with DP (2 hours) and BA (3 weeks)
  - Manoeuver to lower the pericenter at 120 km
  - Atmosphere capture (one or several tries)
  - Escape manoeuver: 1200 m/s 29/08/2018 v∞ = 2.955km/s
  - Return on 18/12/2018 , relative velocity: v∞ = 4.413km/s
  - ASR entry vehicule release AD days before earth arrival
- Advantages
  - Communications with the balloon are easier than FbP/ASR scenario
  - Several tries are possible for ASR
- Drawbacks
  - DV is needed for insertion plus escape (1200 m/s + 1200 m/s)

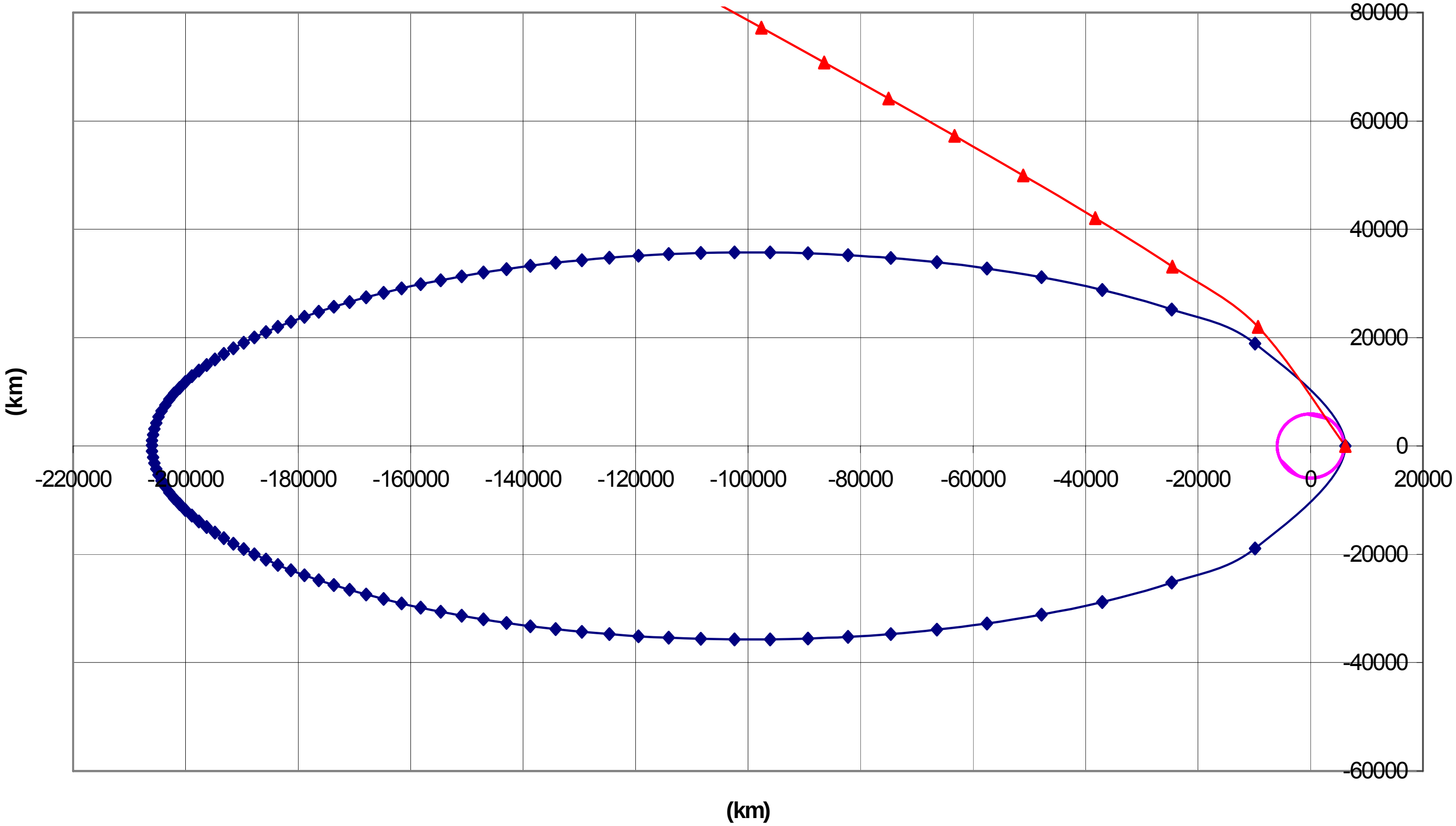
VEO/ASR scenario



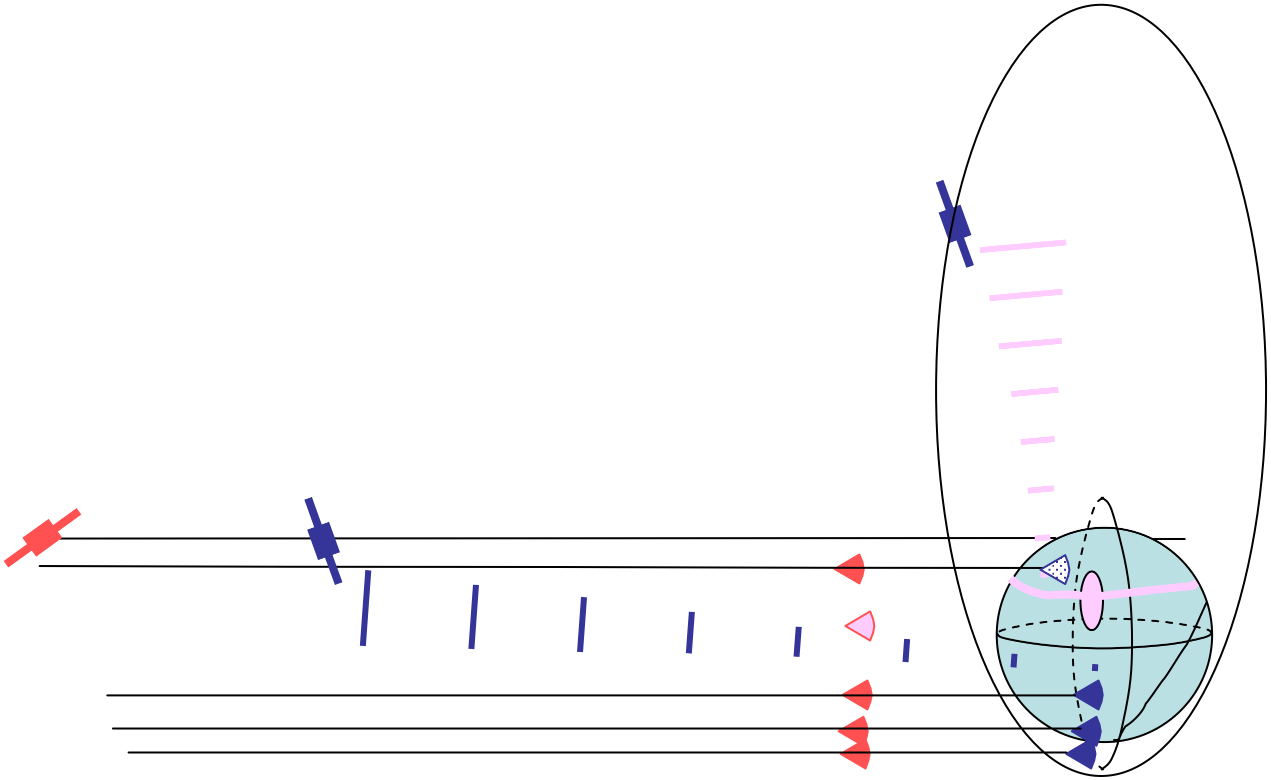
VEO/ASR Scenario
Chemical propulsion

VENUS

Arrival orbit: hyperbolic Vinf=2.7 km/s, alt pericenter 200 km
Insertion orbit 200/200000 km
One point each hour



VEO/ASR scenario



VEO/ASR Scenario
Mass estimate

- RS: None
- DP: 4 x 200 = 800 kg
- BA: 100 kg
- ASR: 100 kg
- Dry Bus: 500 kg

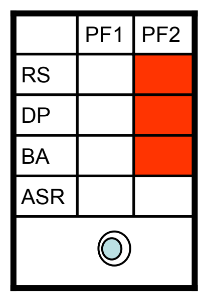
- Dry mass: 1500 kg
- Ergol (bi-ergol)
  - Probes release: 200 m/s for 1500 kg -> 100 kg
  - Insertion/escape: 2400 m/s for 600 kg -> 670 kg

- TOTAL mass = 2270 kg

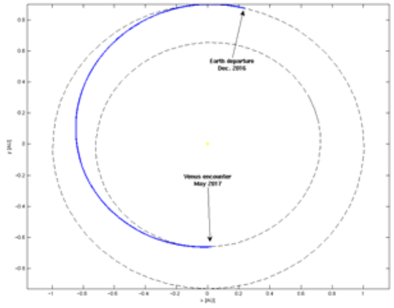
Critical points for VEO/ASR Scenario

- Communications
  - Not possible to have 10 kbps with DP
    - Communication data rate should be adjusted to the distance: 1 kbps at the beginning, 10 kbps at the end.
    - Emitter 10 W (20 power consumption) during 2 hours (40 Wh)
  - With BA
    - Communications are difficults with a High elliptical orbit.
    - Orbit Apocenter could be lowered (down to 30000 km to get 2.5 kbps), that means an added 600 m/s (130 kg propellant for 600 kg)

VPO Scenario

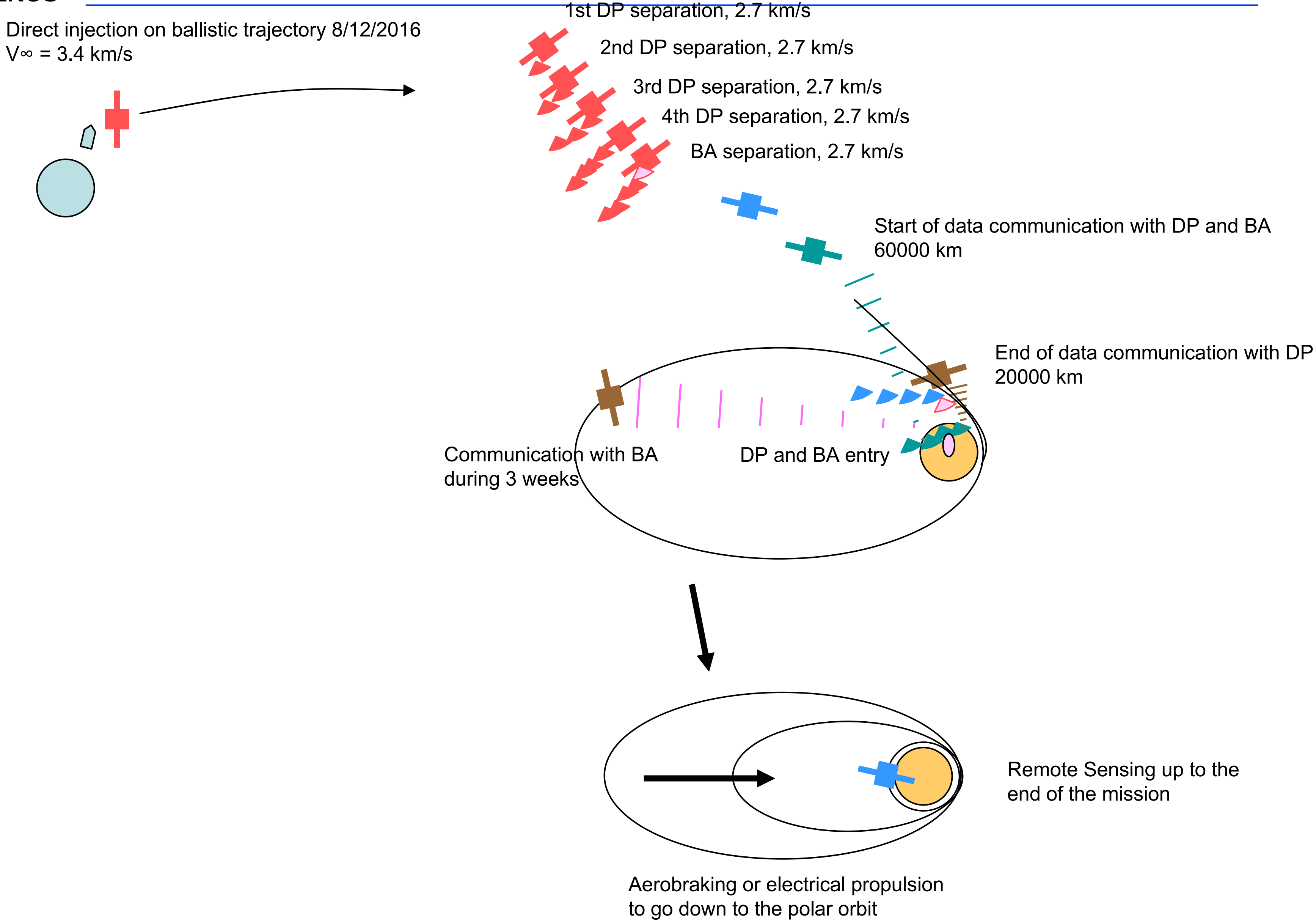


VPO Scenario

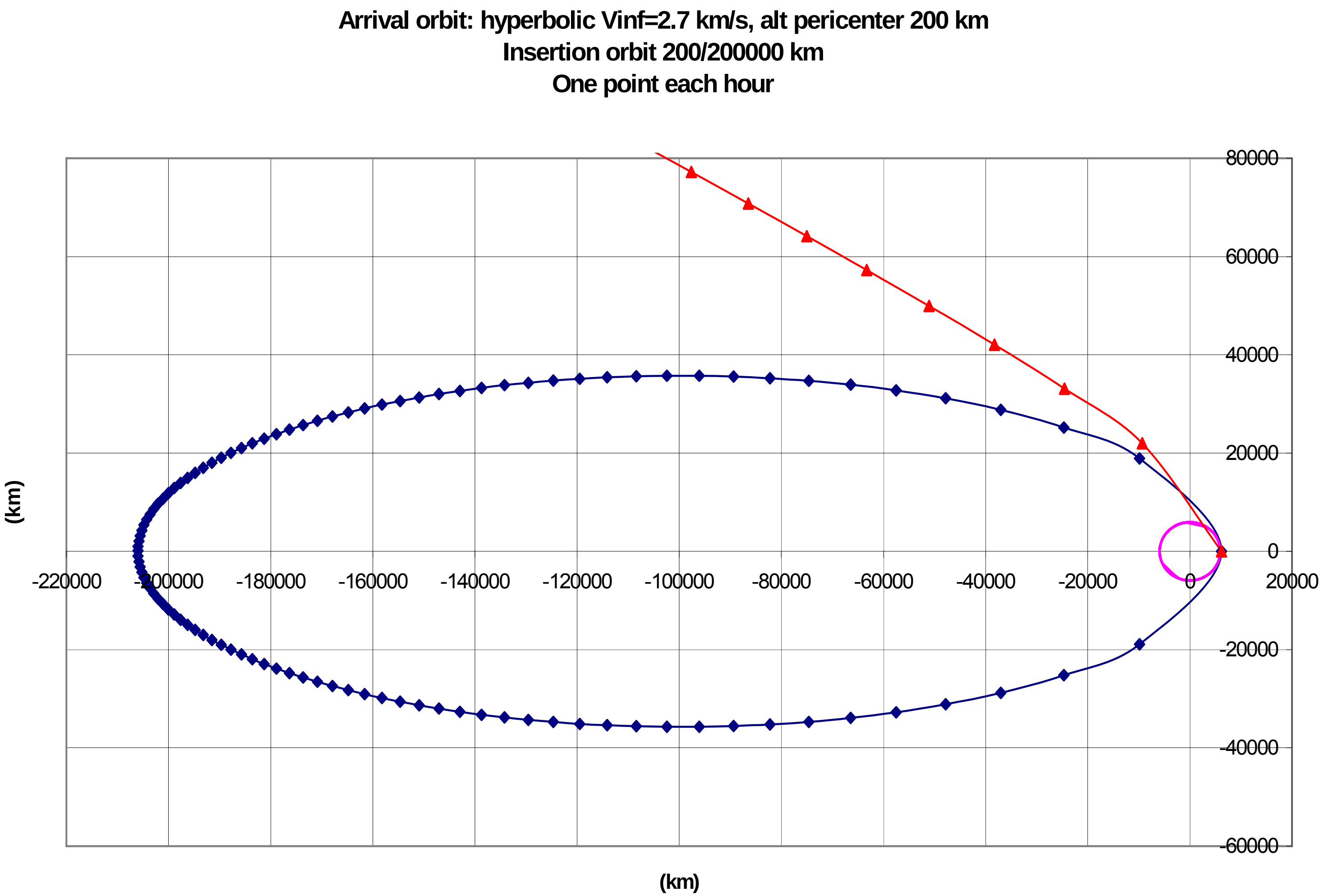


- Chemical propulsion
  - Launch 08/12/2016, v∞ = 3.384km/s, δ∞ = 32deg
  - Ballistic trajectory to venus 6 months
  - Arrival 18/05/2017, v∞ = 2.678km/s
  - Descent probes and balloon release 20 days before arrival (TBC)
  - Communication with DP during 2 hours before pericenter Fly by
  - Insertion on a HEO (DV at pericenter < 1200 m/s)
  - Communications with balloon during 3 weeks
  - Aerobraking to lower the apocenter down to 200 km (5 months)
  - Remote sensing for the rest of the mission
- Electrical propulsion
  - Launch 08/12/2016, v∞ = 3.384km/s, δ∞ = 32deg
  - Electrical propulsion to decrease the speed (DV = 3 km/s)
  - Arrival with v∞ = 0 km/s
  - Descent probes and balloon release 20 days before arrival (TBC)
    - DV = 200 m/s for 4 DP + BA with chemical propulsion
  - Communication with DP during 2 hours before pericenter Fly by
  - Insertion on a HEO (electrical propulsion)
  - Communications with balloon during 3 weeks
  - Electrical propulsion to lower the apocenter down to 200 km (5 months)
  - Remote sensing for the rest of the mission

VPO scenario



VPO Scenario



VPO Scenario
Mass estimate

- RS: 50
- DP: 4 x 200 = 800 kg
- BA: 100 kg
- Dry Bus: 500 kg

- Dry mass: 1450 kg

Chemical propulsion Dual mode Bi-ergol + Hydrazine
- Probes release: 200 m/s for 1450 kg -> 100 kg
- Insertion to HEO: 1200 m/s for 550 kg -> 250 kg
- Insertion to Polar orbit for 550 kg (aerobraking + 500 m/s) -> 100 kg

Electrical propulsion Ionic + Hydrazine
- Cruise to Venus (Electric): 3 km/s for 1450 kg -> 140 kg
- Probes release (Hydrazine): 200 m/s for 1450 kg -> 140 kg
- Insertion to HEO (Electric): 300 m/s for 550 kg -> 10 kg
- Insertion to Polar Orbit (Electric): 5 km/s for 550 kg -> 90 kg

TOTAL mass (chemical prop.): 1900 kg

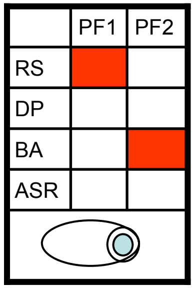
TOTAL mass (elect. Prop): 1830 kg

→ No real advantage for electrical propulsion

Critical points for VPO Scenario

- Communications
  - Not possible to have 10 kbps with DP
    - Communication data rate should be adjusted to the distance: 1 kbps at the beginning, 10 kbps at the end.
    - Emitter 10 W (20 power consumption) during 2 hours (40 Wh)
  - With BA
    - Communications are difficults with a High elliptical orbit.
    - Orbit Apocenter shall be lowered (down to 30000 km to get 2.5 kbps) : 600 m/s or 120 kg propellant.

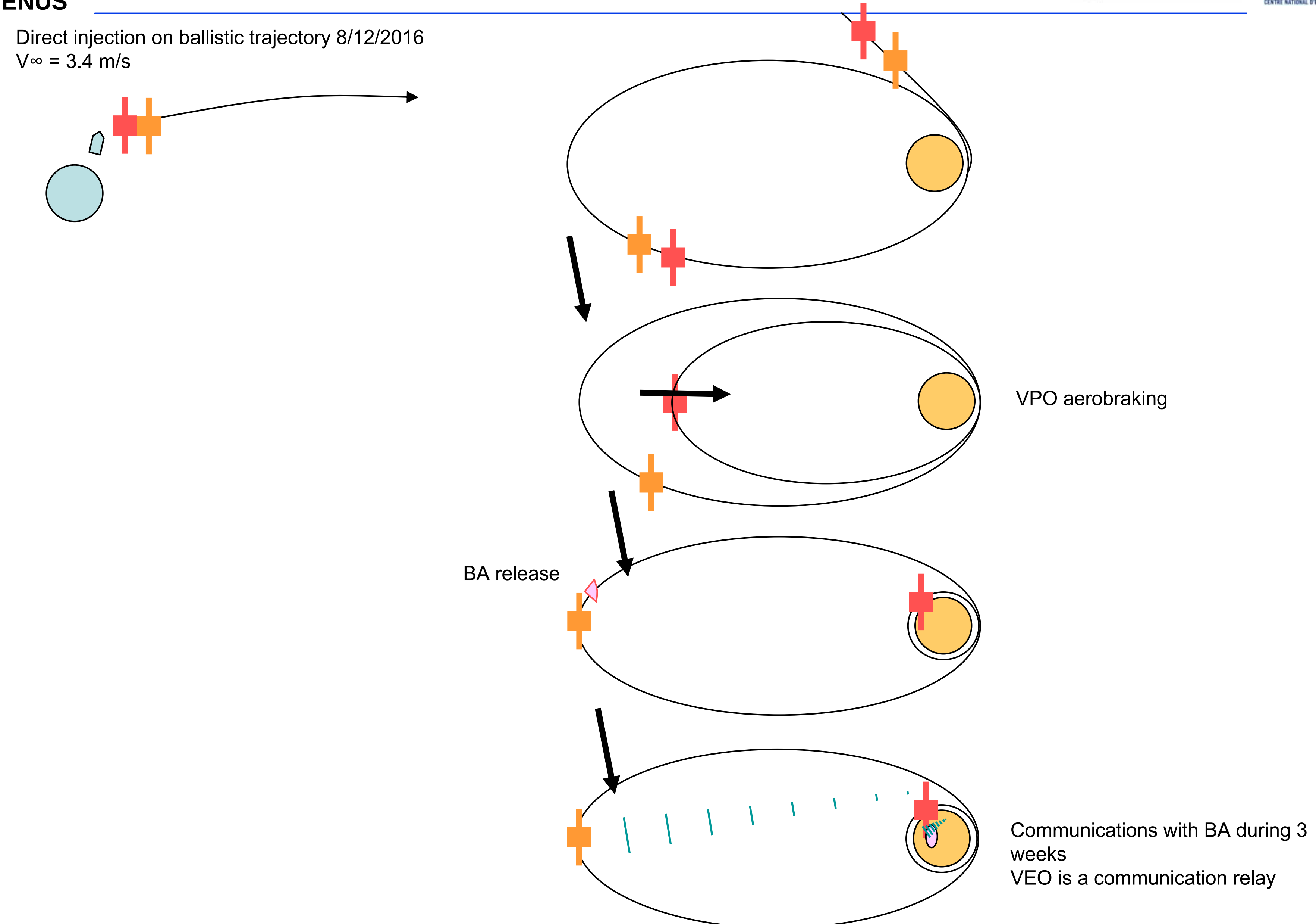
VPO+VEO/BA Scenario



VPO+VEO/BA Scenario

- This scenario corresponds to the ESA TRS Study (plus aerobraking)
- VPO carries the RS payload
- VEO carries the BA payload
- Sequence (dual launch)
  - VPO and VEO launched on 8/12/2016 v_∞ = 3.384km/s, δ_∞ = 32deg
  - VPO and VEO arrival on 18/05/2017 v_∞ = 2.678km/s
  - VPO and VEO insertion on a HEO
  - VPO down to Polar Orbit with aerobraking
  - BA release by VEO
  - Communications with BA during 3 weeks
  - Remote Sensing the rest of the mission

VPO+VEO/BA Scenario



VPO+VEO/BA Scenario
Mass estimate

- RS: 50 kg
- DP: None
- BA: 100 kg
- ASR: None
- Dry Bus PF1: 300 kg
- Dry Bus PF2: 300 kg

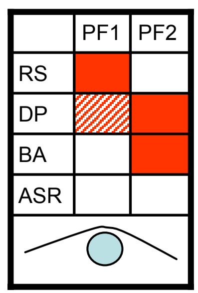
Dry mass VPO: 350 kg
Propulsion: bi-ergol
Insertion to HEO 1200 m/s : 160 kg
Transfer to Polar Orbit (aerobraking + 500 m/s): 60 kg

Dry mass VEO: 400 kg
Propulsion: bi-ergol
Insertion to HEO 1200 m/s : 180 kg

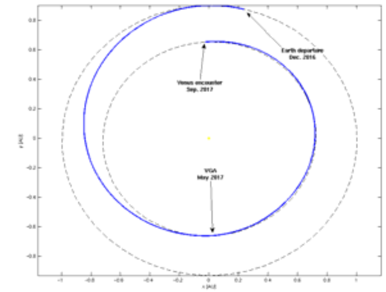
TOTAL mass: VPO 570 kg
VEO 580 kg
TOTAL: 1150 kg

NB :ESA TRS study mass estimate : 1463 kg including
- 20% margin on dry mass
- 837 kg of propellant (no aerobraking)

VPO (RS) + VEO (DP/BA) Scenario



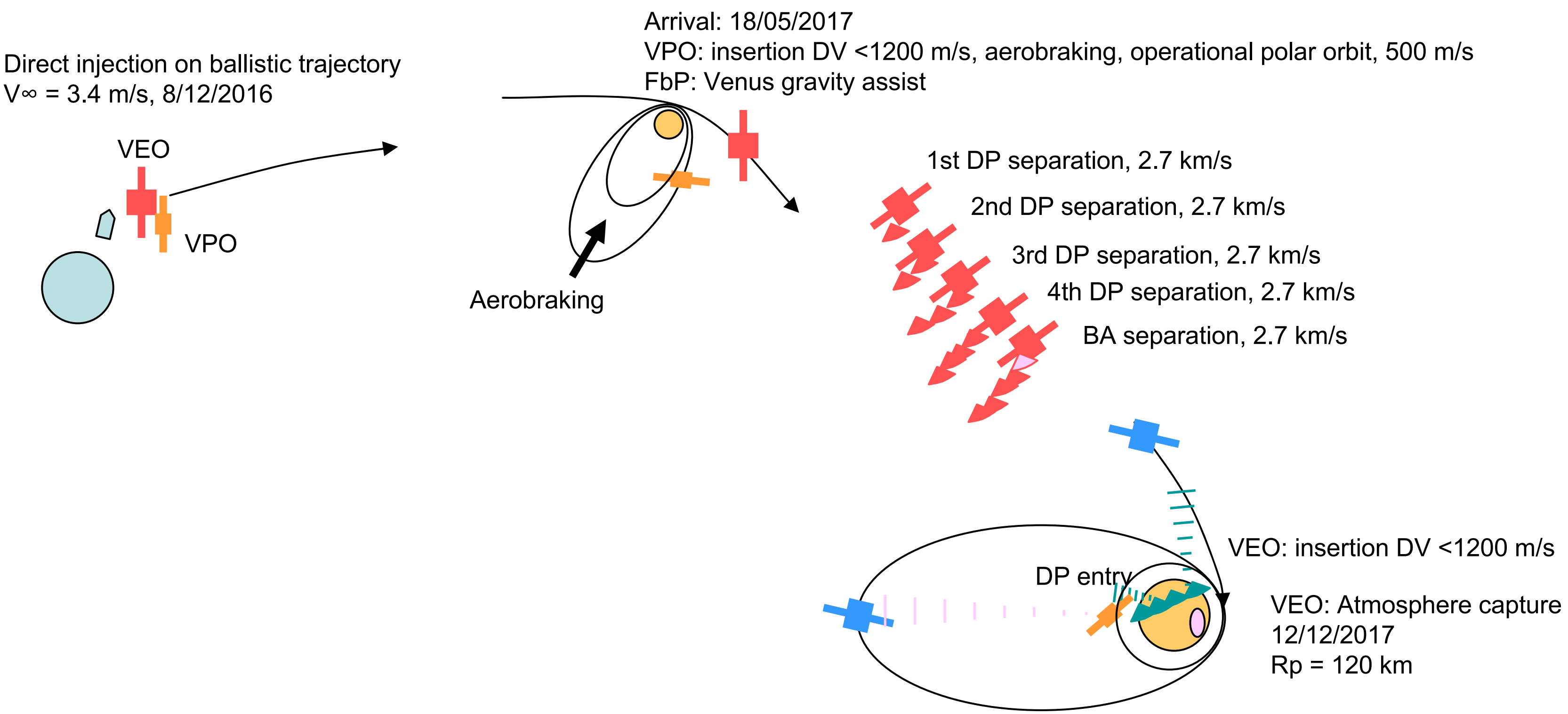
VPO (RS) + VEO (DP/BA) Scenario



- Same scenario as ESA TRS study, but with Descent Probes
- VPO carries the RS payload
- VEO carries the BA payload and 4 Descent Probes
- Sequence (dual launch)
  - VPO and VEO launched on 8/12/2016 v_∞ = 3.384km/s, δ_∞ = 32deg
  - VPO and VEO arrival on 18/05/2017 v_∞ = 2.678km/s
  - VPO insertion on a HEO and aerobraking down to Polar Orbit (5 months)
  - VEO swings by Venus (Venus Gravity Assist)
  - VEO arrival on 12/12/2017 v_∞ = 2.678km/s
  - Descent probes and balloon release 20 days before arrival (TBC)
  - Communications between VEO/VPO and DP during 2 hours before VEO arrival
  - BA released by VEO
  - Communications with BA during 3 weeks
  - Remote Sensing for the rest of the mission

VENUS

VPO (RS) + VEO (DP/BA) scenario



VPO (RS) + VEO (DP/BA) Scenario

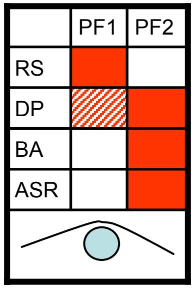
- RS: 50 kg
- DP: 4*200 = 800 kg
- BA: 100 kg
- ASR: None
- Dry Bus PF1: 300 kg
- Dry Bus PF2: 500 kg

Dry mass VPO: 350 kg
Propulsion: bi-ergol
Insertion to HEO 1200 m/s : 160 kg
Transfer to Polar Orbit (aerobraking + 500 m/s): 60 kg

Dry mass VEO: 1400 kg
Propulsion: bi-ergol
DP/BA release: 200 m/s for 1400 kg: 100 kg
Insertion to HEO 1200 m/s for 500 kg: 230 kg

TOTAL mass: VPO 570 kg
VEO 1730 kg
TOTAL: 2300 kg

VPO (RS) + VEO (DP/BA/ASR) Scenario



VPO (RS) + VEO (DP/BA/ASR) Scenario

- VPO carries the RS payload
- VEO carries the BA payload, 4 Descent Probes and the ASR payload
- Sequence (dual launch)
  - VPO and VEO launched on 8/12/2016 v_∞ = 3.384km/s, δ_∞ = 32deg
  - VPO and VEO arrival on 18/05/2017 v_∞ = 2.678km/s
  - VPO insertion on a HEO and aerobraking down to Polar Orbit (5 months)
  - VEO swings by Venus (Venus Gravity Assist)
  - VEO arrival on 12/12/2017 v_∞ = 2.678km/s
  - Descent probes and balloon release 20 days before arrival (TBC)
  - Communication with DP during 2 hours before pericenter Fly by
  - Communications with BA during 3 weeks, VEO is a data relay
  - Remote Sensing for the rest of the mission with VPO
  - Atmosphere capture at pericenter with VEO, escape and return to earth

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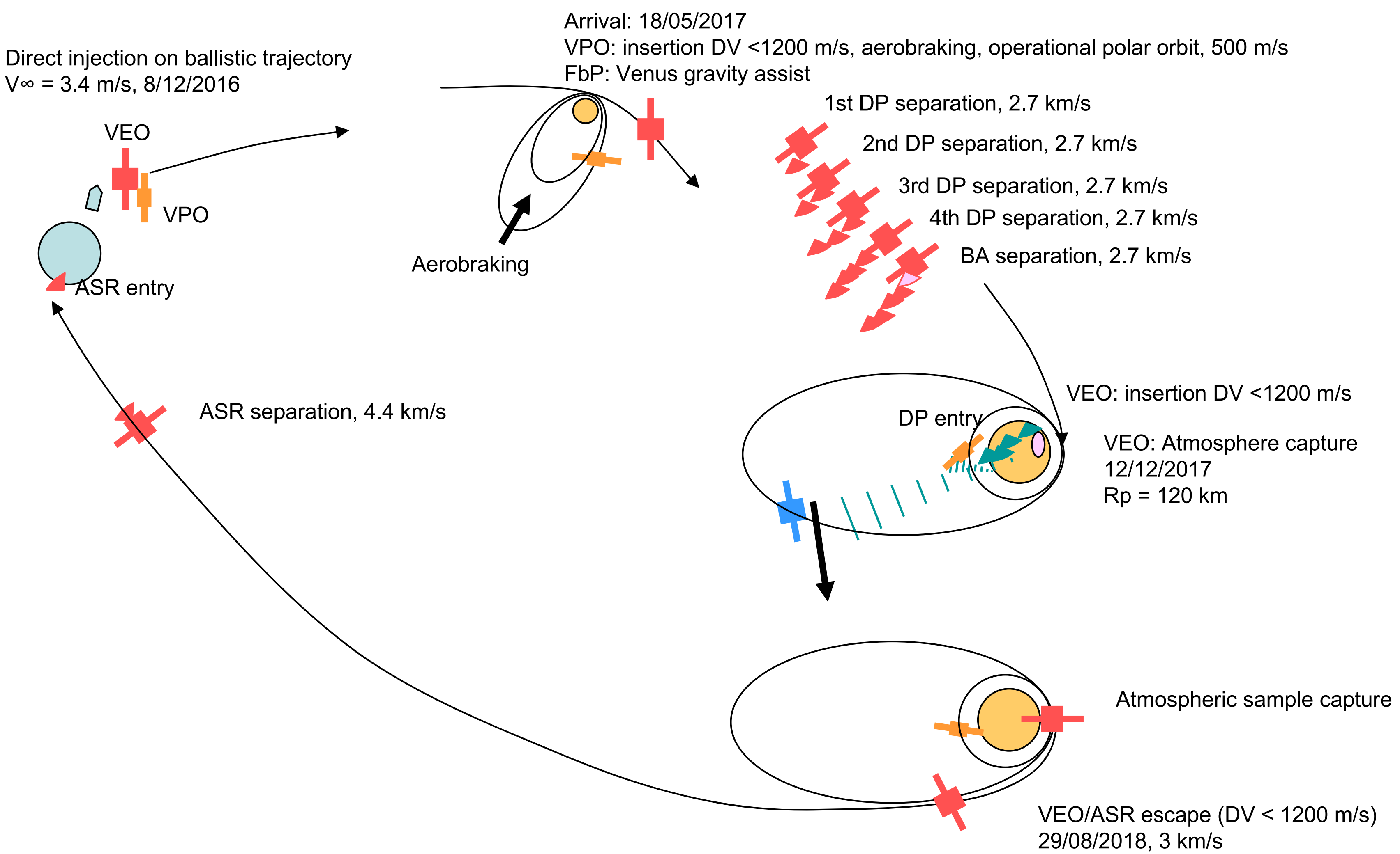
VPO (RS) + VEO (DP/BA/ASR) scenario



VPO (RS) + VEO (DP/BA/ASR) Scenario

- RS: 50 kg
- DP: 4*200 = 800 kg
- BA: 100 kg
- ASR: 100 kg
- Dry Bus PF1: 300 kg
- Dry Bus PF2: 500 kg

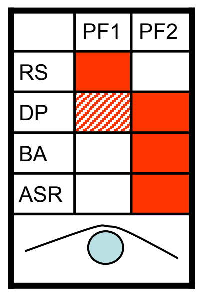
Dry mass VPO: 350 kg
Propulsion: bi-ergol
Insertion to HEO 1200 m/s : 160 kg
Transfer to Polar Orbit (aerobraking + 500 m/s): 60 kg

Dry mass VEO: 1500 kg
Propulsion: bi-ergol
DP/BA release 200 m/s for 1500 kg: 100 kg
Insertion to HEO 1200 m/s for 600 kg: 270 kg
Escape from HEO 1200 m/s for 600 kg: 270 kg

TOTAL mass: VPO 570 kg
VEO 2140 kg
TOTAL: 2710kg

VPO (RS) + FbP (DP/BA/ASR) Scenario

- **Dual launch**
- **Two launches**



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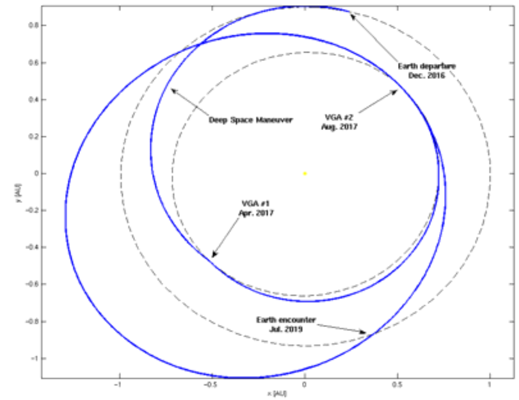
VPO (RS) + FbP (DP/BA/ASR) Scenario Dual launch

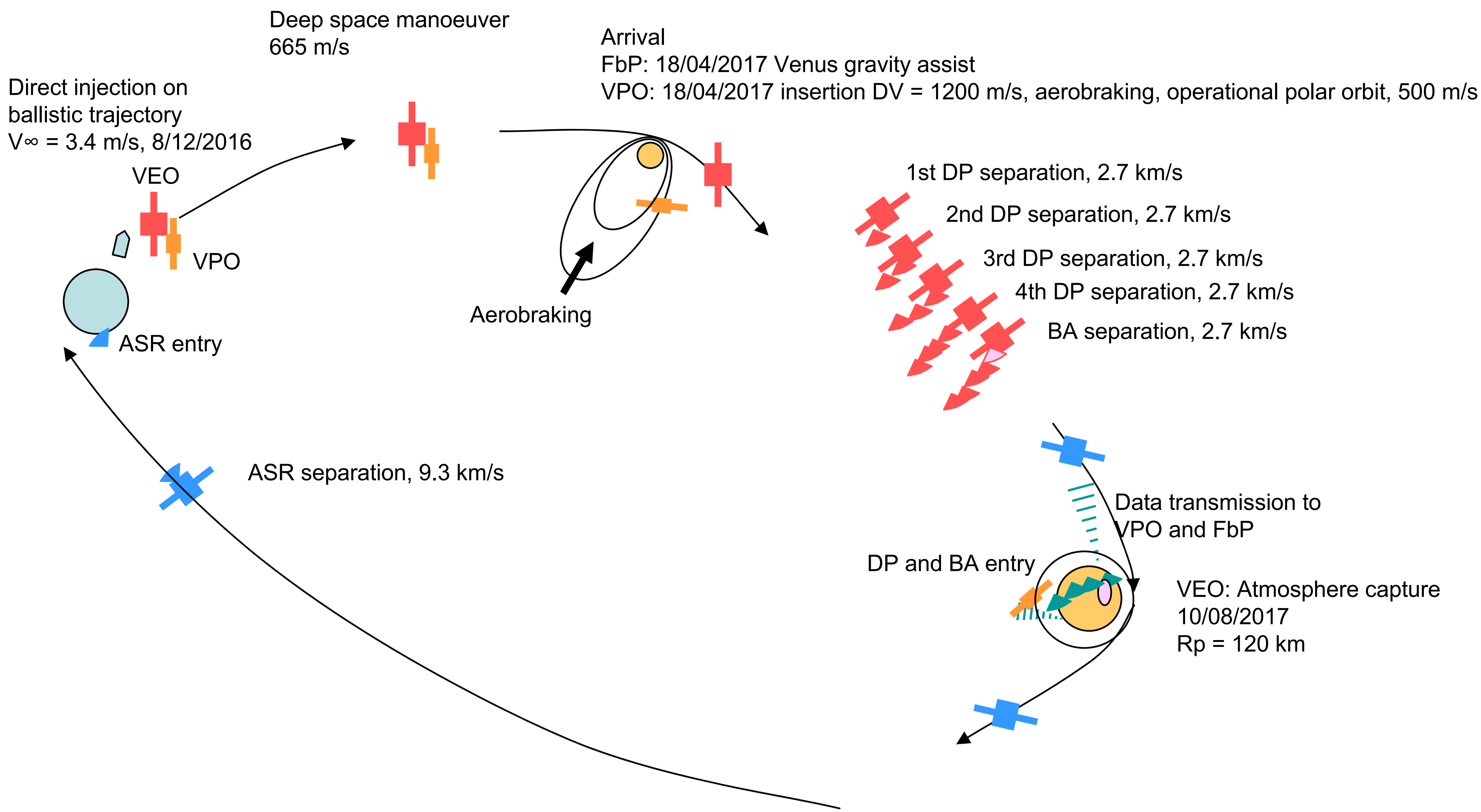


- VPO carries the RS payload
- FbP carries the BA payload, 4 Descent Probes and the ASR payload

- Sequence (dual launch)
  - VPO and FbP launched on 08/12/2016 v∞ = 3.384 km/s
  - Deep Space Manoeuver for FbP : DV = 665 m/s
  - FbP arrival on 18 April 2017, v∞ = 5.49 km/s
    - FbP swings by Venus at 300 km (Venus Gravity Assist)
  - VPO arrival on 18 May 2017 v∞ = 2.678 km/s
    - VPO insertion on a HEO and aerobraking down to Polar Orbit (5 months)
  - 2nd FbP arrival on 10/08/2017 v∞ = 5.49 km/s
  - Descent probes and balloon release 20 days before arrival (TBC)
  - Communication with DP during 2 hours before pericenter Fly by
  - FbP flies by Venus at 120 km and collects an atmospheric sample
  - Communications with BA during 3 weeks (to VPO and transmitted to earth)
  - Remote Sensing for the rest of the mission with VPO
  - FbP returns to earth (14 July 2019) with ASR payload

VPO (RS) + FbP (DP/BA/ASR) scenario Dual launch

VENUS



VPO (RS) + FbP (DP/BA/ASR) Scenario Dual launch

- RS: 50 kg
- DP: 4*200 = 800 kg
- BA: 100 kg
- ASR: 100 kg
- Dry Bus PF1: 300 kg
- Dry Bus PF2: 500 kg

Dry mass VPO: 350 kg
Propulsion: bi-ergol
Insertion to HEO 1200 m/s : 160 kg
Transfer to Polar Orbit (aerobraking + 500 m/s): 60 kg

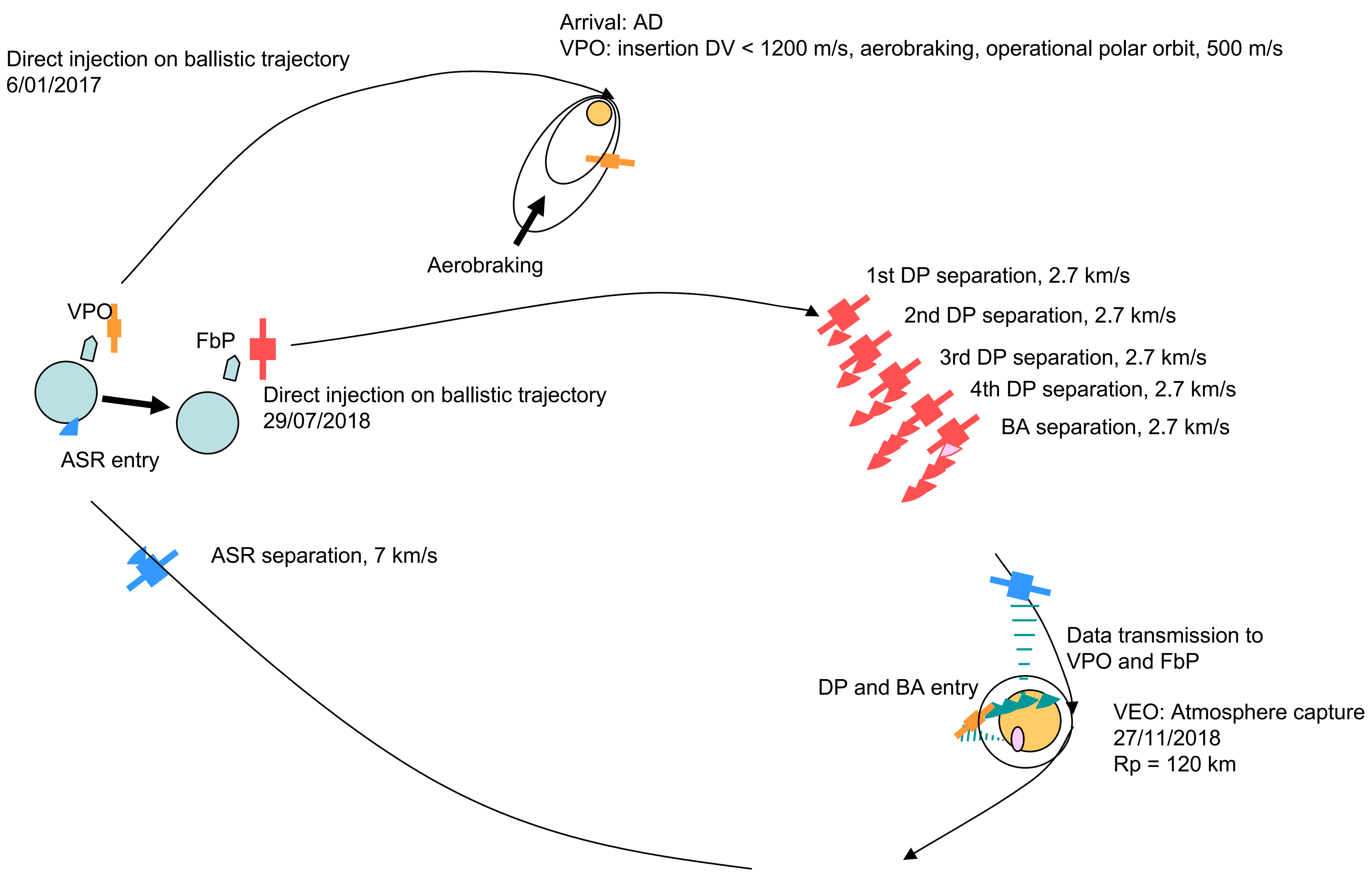
Dry mass FbP: 1500 kg
Propulsion: bi-ergol
Deep Space manoeuver 665 m/s: 350 kg
DP and BA released 200 m/s: 100 kg

TOTAL mass: VPO 570 kg
FbP 1950 kg
TOTAL: 2520 kg

VPO (RS) + FbP (DP/BA/ASR) scenario
Two launches

- This scenario with two separate lanches is the combination of
  - The FbP/ASR scenario (launch on 29/07/2018)
  - A single VPO whose launch date is chosen at least 5 months before FbP launch (for aerobraking delay time), therefore not optimized (06/01/2017 for instance)

VPO (RS) + FbP (DP/BA/ASR) scenario
Two launches



VPO (RS) + FbP (DP/BA/ASR) Scenario
Two launches

- RS: 50 kg
- DP: 4*200 = 800 kg
- BA: 100 kg
- ASR: 100 kg
- Dry Bus PF1: 300 kg
- Dry Bus PF2: 500 kg

Dry mass VPO: 350 kg
Propulsion: bi-ergol
Insertion to HEO 1200 m/s : 160 kg
Transfer to Polar Orbit (aerobraking + 500 m/s): 60 kg

Dry mass FbP: 1500 kg
Propulsion: hydrazine
DP and BA released 200 m/s: 150 kg

TOTAL mass: VPO 570 kg
FbP 1650 kg

Possible launchers

Hypothesis : C3 = 10 km²/s²

Launcher	Performance	Fairing diameter	Dual launch structure diam	Adapter mass	Dual launch structure	Cost	Remarks
Ariane 5E-CA	< 5300 kg	4.57 m	4.00 m	125-190 kg	425 kg	130 M€	Pour -5 deg d'inclinaison. 4.6 pour 5 deg. La perfo s'écroule très vite si l'on augmente la déclinaison
Soyuz	1430 kg	3.86 m	≥ 2.6 m	40-110 kg	540 kg	45-65 M€	OK pour 32 deg (réallumable)
Atlas V	2150-5300 kg	3.75-4.57 m	/	45-95 kg	/	95-125 M$	
Delta2	490-1235 kg	2.54-2.74 m	2.33 m	?	?	65-85 M$	
Delta4	2000-7800 kg	3.75-4.57 m				85-160 M$	
HII-A	1700-1900 kg	3.7-4.6 m	3.7	80-150 kg		70-85 M$	
Land Launch	3000 kg	3.7 m	/	50-60 kg		?	
LM2-C	650 kg	3.00 m	/	55 kg	/	20-25 M$	
LM3-A	950 kg	3.00 m	/		/	45-55 M$	
LM3-B	2600 kg	3.65 – 3.85 m	/		/	50-70 M$	
Proton M	4580 kg	3.8 m	/	110-140 kg	/	70-80 M$	OK pour 32 deg (réallumable) 4100kg à C3=15
Sea Launch	2800-3000 kg	3.75 m	/			70-80 M$	

VEP scenarios

	One spacecraft			Two spacecrafts				
	FbP/ASR	VEO/ASR	VPO	VPO (RS) VEO (BA)	VPO (RS) VEO (DP/BA)	VPO (RS) VEO (DP/BA/ASR)	VPO (RS) FbP (DP/BA/ASR) Dual launch	VPO (RS) FbP (DP/BA/ASR) Two launches
Remote sensing RS	-	-	50 kg	50 kg	50 kg	50 kg	50 kg	50 kg
4 Descent probes DP	4x200 kg	4x200 kg	4x200 kg	-	4x200 kg	4x200 kg	4x200 kg	4x200 kg
Balloon BA (+ µprobes?)	100 kg	100 kg	100 kg	100 kg	100 kg	100 kg	100 kg	100 kg
Atmos. Sample Return ASR	100 kg	100 kg	-	-	-	100 kg	100 kg	100 kg
VPO Bus	-	-	Dry: 500 kg	Dry: 300 kg	Dry: 300 kg	Dry: 300 kg	Dry: 300 kg	Dry: 300 kg
VEO Bus (or FbP)	Dry: 500 kg	Dry: 500 kg	-	Dry: 300 kg	Dry: 500 kg	Dry: 500 kg	Dry: 500 kg	Dry: 500 kg
Propellant	150 kg	770 kg	450 kg	VPO: 220 kg VEO: 180 kg	VPO: 220 kg VEO: 330 kg	VPO: 220 kg VEO: 640 kg	VPO: 220 kg FbP: 450 kg	VPO: 220 kg FbP: 150 kg
Wet Mass	**1650 kg**	**2270 kg**	**1890 kg**	VPO: 570 kg VEO: 580 kg **TOTAL: 1150 kg**	VPO: 570 kg VEO: 1730 kg **TOTAL: 2300 kg**	VPO: 570 kg VEO: 2140 kg **TOTAL: 2710 kg**	VPO: 570kg VEO: 1950 kg **TOTAL: 2520 kg**	**VPO: 570 kg** **VEO: 1650 kg**
Comments	**Less DP to get Soyouz perfo?** **Pb of comm. With BA**	**Back up for FbP/ASR but which launcher?** **Low data rate with BA**	**120 kg added propellant to lower the insertion orbit for BA comm**	**TRS ESA study Soyouz launch**				

Recommandations

- For communications reasons
  - The VPO orbit shall be higher (circular polar 1000/1000 km)
  - The VEO orbit shall be lower (60000/200 km)
- Decrease the data rate with balloon for scenarios without VPO but with a VEO only (1 kbps)
- Adjust the data rate for Descent Probes from 0.2 to 20 kbps

Points to be assessed

- Payloads
  - Descent Probes payloads (mass, size)
  - Balloon type and choice
  - ASR mecanisms, cryosystem and mass
- Entry vehicles
  - Descent Probes Entry Vehicule design and mass
  - Balloon Entry Vehicule design and mass
  - ASR Entry Vehicule design and mass
- System
  - Telecommunications
  - Sequences and trajectory control (DP/BA/ASR release)
  - DP landing sites
  - Launcher capacity and choice
- Bus
  - Propulsion
  - Interfaces with payloads/entry vehicules
  - Structure