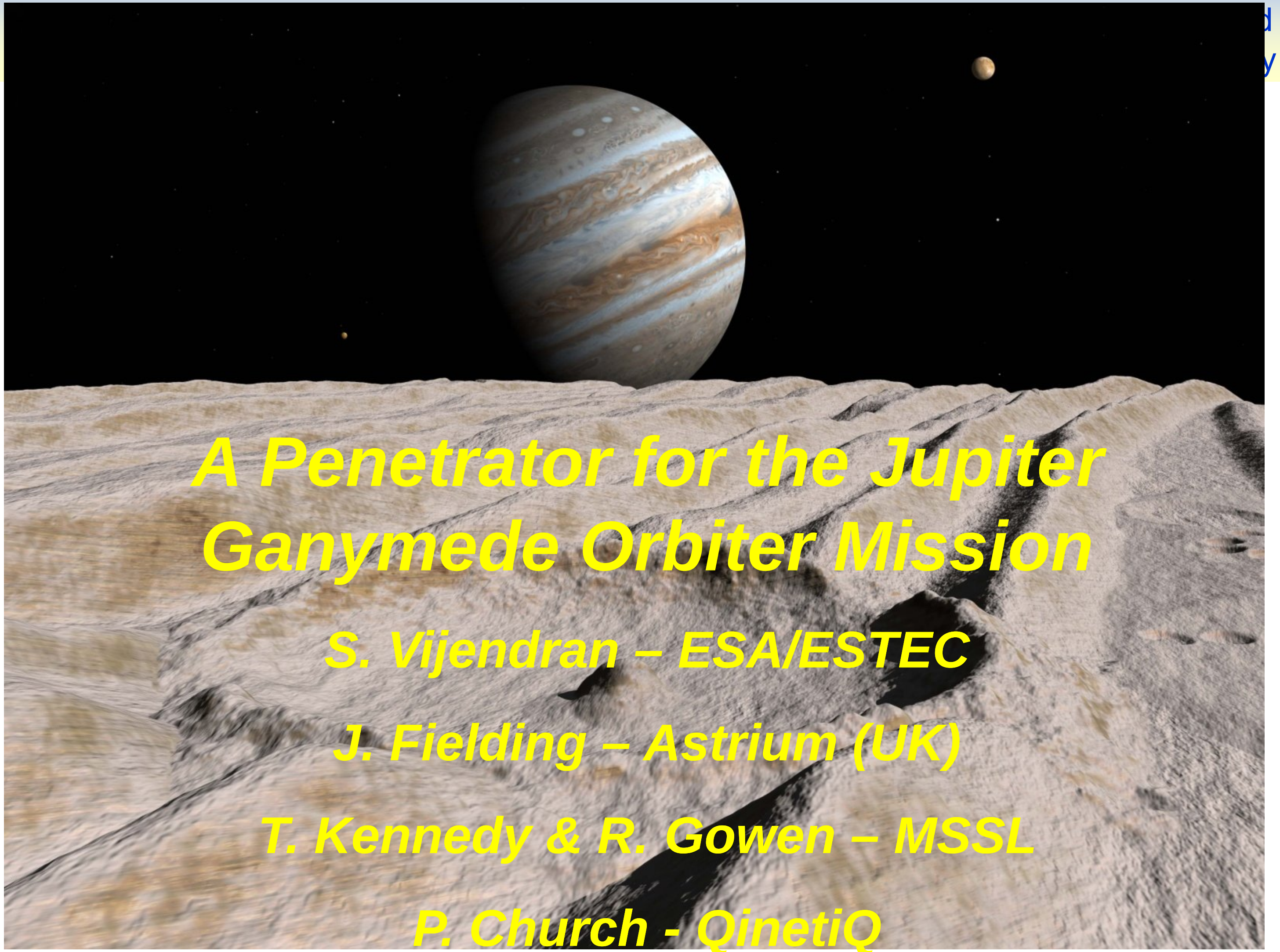

A Penetrator for the Jupiter Ganymede Orbiter Mission

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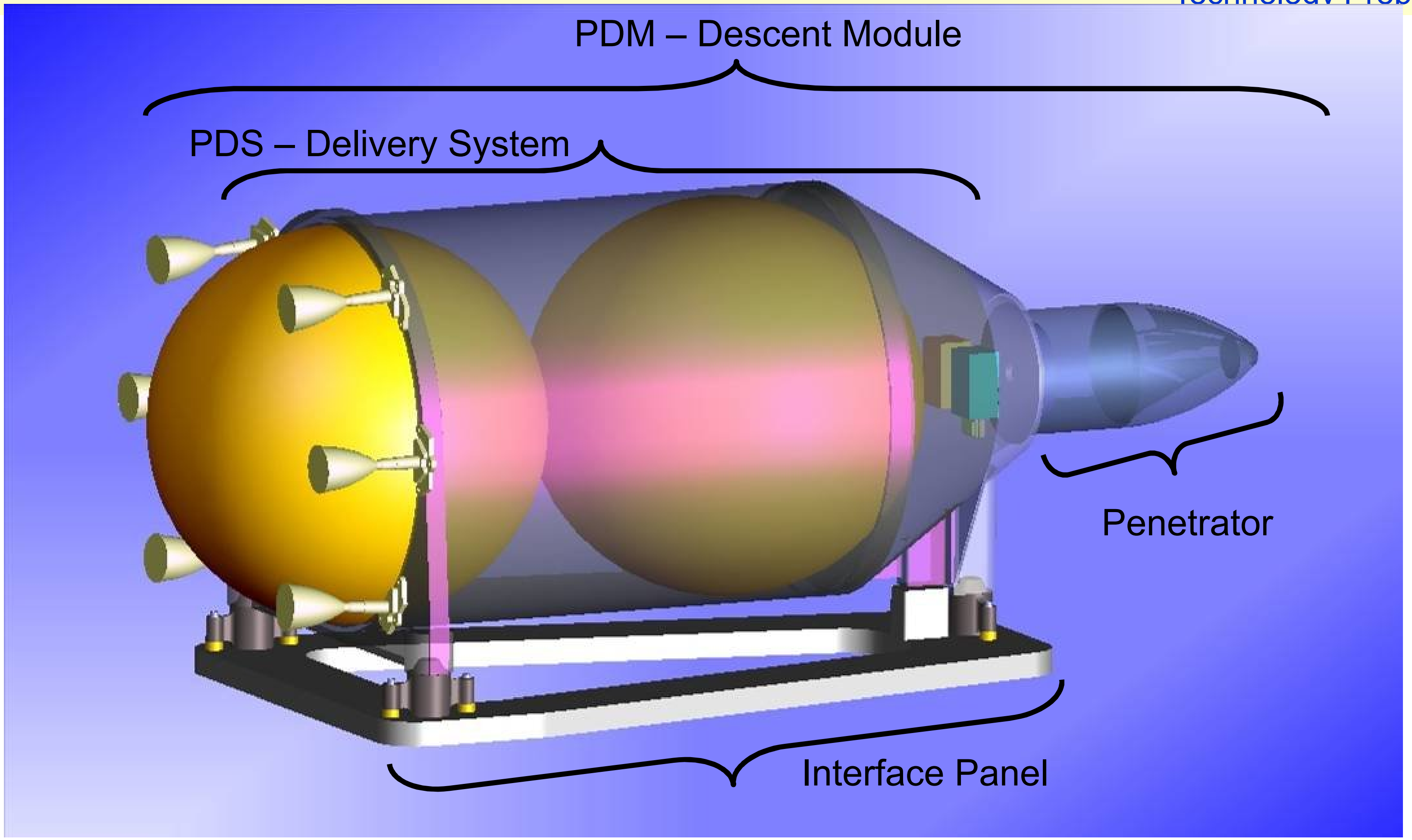
Configuration Overview



Study inputs & Constraints

- Compatible with JGO mission configuration
- Minimum science payload with a GEOPHYSICS focus (for Ganymede)
- Mass limit of 100kg
- Technologies at TRL5 by 2012
- Feasible and low risk

"Release Location" Scenario Comparison

Single Penetrator

- Hyperbolic Approach
  - Callisto Pseudo Orbit
  - Ganymede Final Orbit

Target	Mission phase	Impulsive De-orbit Delta-V (m/s)
Hyperbolic cases		
Ganymede	Pre-capture	**7698**
Callisto	Callisto Pseudo orbit tour	**3192**
Ganymede	Final approach	**2864**
Ganymede "final orbits"		
Ganymede	Elliptical orbit	**2474**
Ganymede	**Circular orbit**	**1955**

"Applied Science Approach " Scenario Comparison

- **Trade-off between**
  - Single Penetrator (baseline cases for each release location)
  - Multiple Penetrators
  - Multiple Moons
  - Semi-Hard Landers

Baseline Scenario Selection

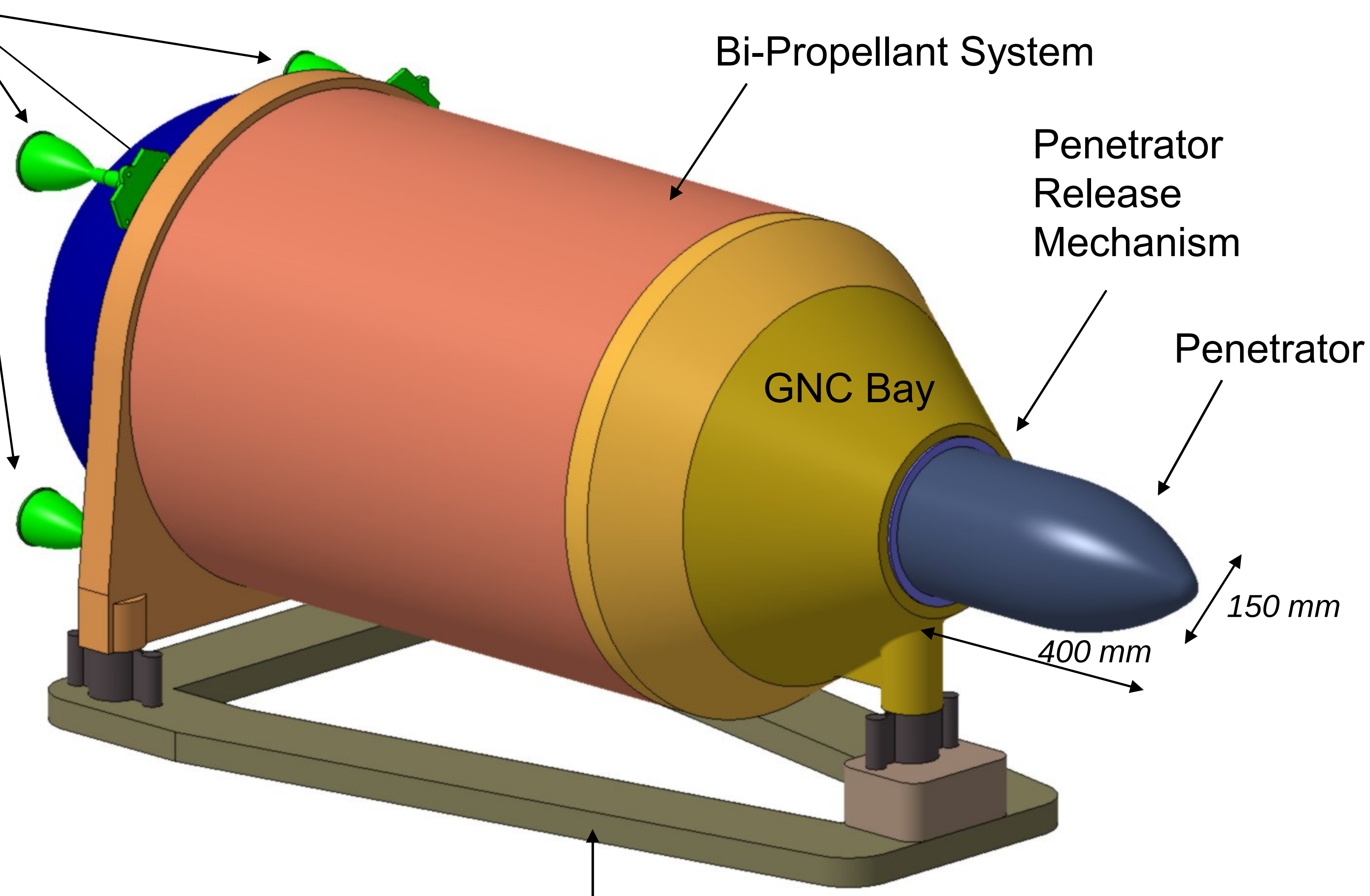
- **A Single Penetrator, released from Ganymede 200km circular orbit is proposed**

- **No other scenario is considered feasible assuming a 7.5kg Penetrator landed element and a maximum 100kg of system (Penetrator + PDS) mass.**

- **Smaller Penetrators (~ few kg) are not considered feasible:**
  - tiny payload,
  - large heat loss

→ multiple penetrator / multiple targets not possible.

PDM configuration

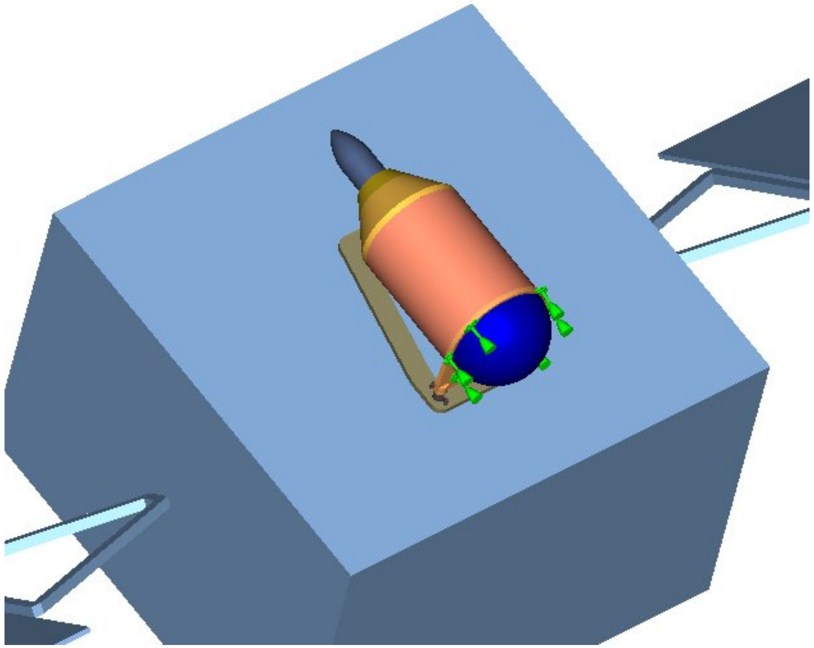


Accommodation on JGO

Dimension	Value
Mounted Length	1200 mm
Mounted Width	500 mm
Height	700 mm

Limited power (14W) and data will be required from JGO during cruise

Shared Planetary Protection categorisation of II+ with JGO



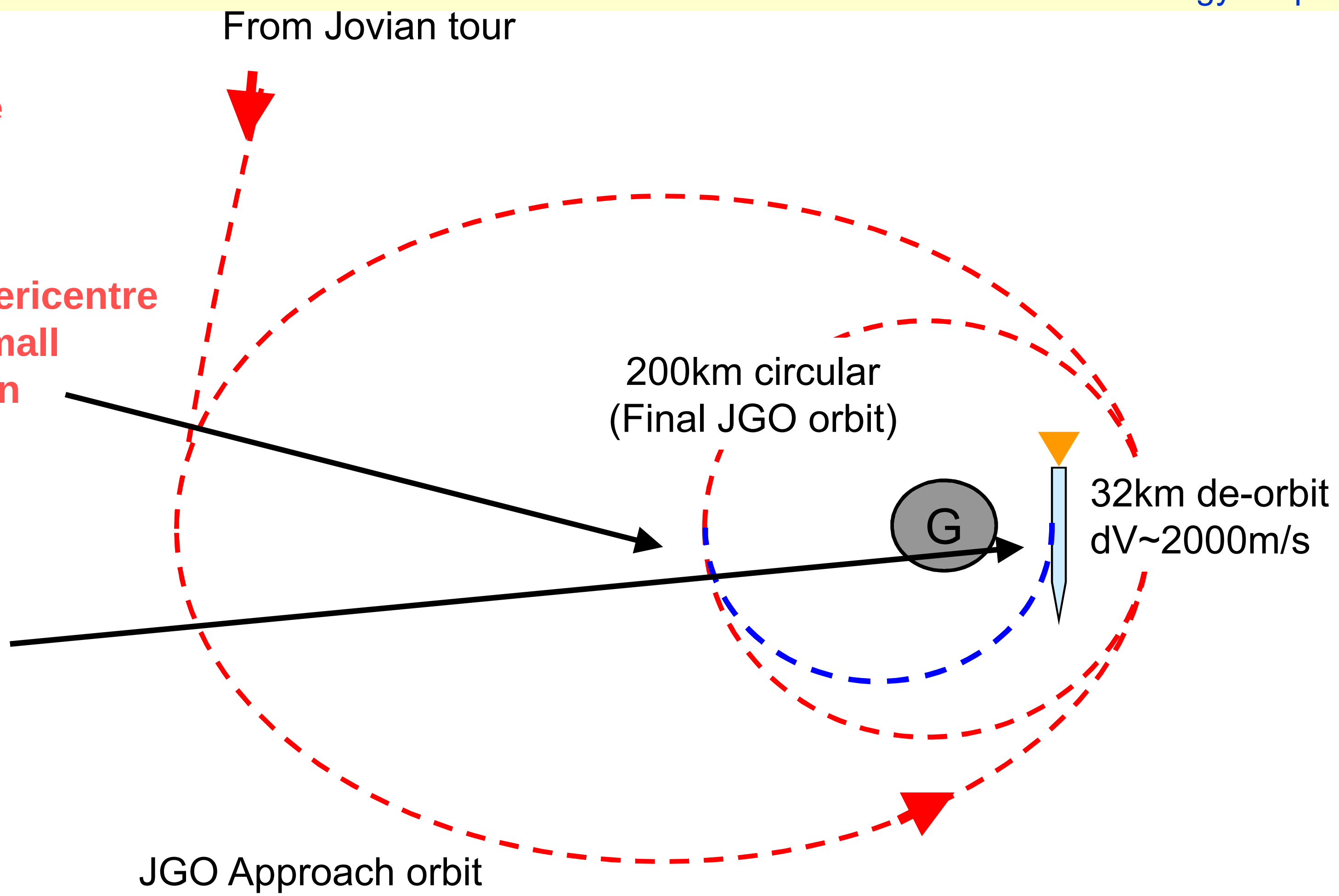
Interface Panel simplifies interface to JGO

Simplified Release Sequence (Impulsive case)

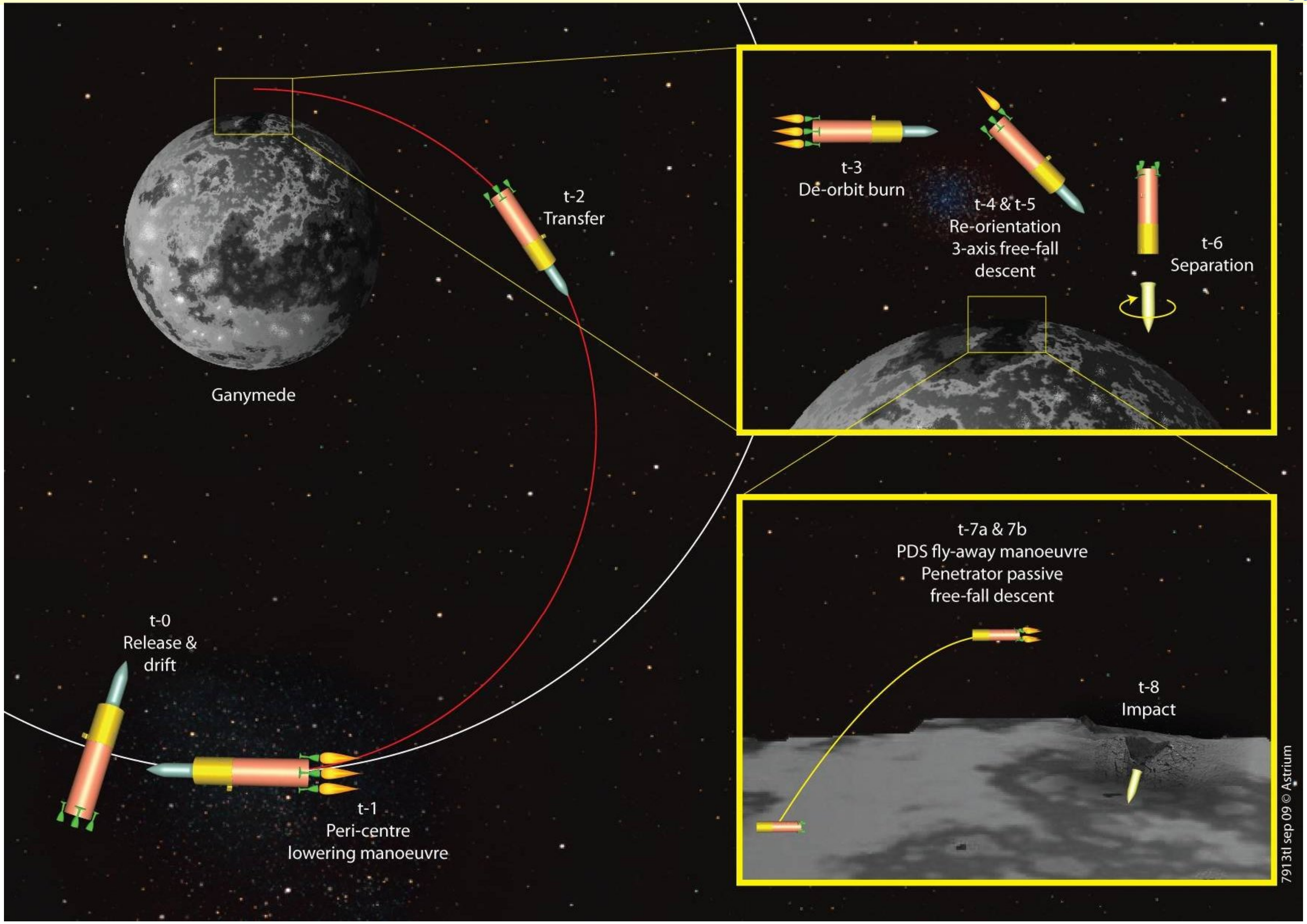
200km release

Manoeuvre-1
PDM lowers pericentre to 32km via small apocentre burn (~30m/s)

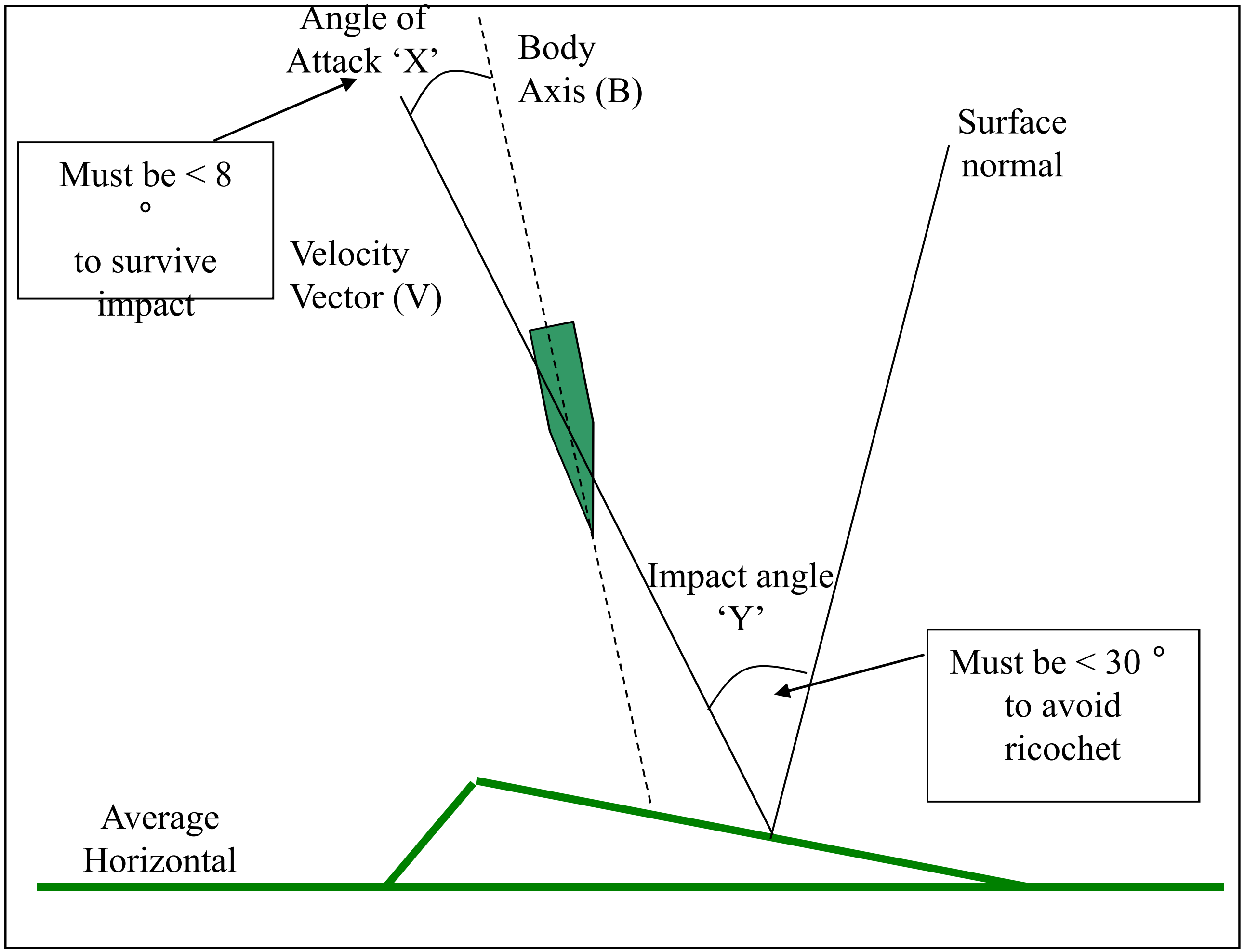
Manoeuvre-2
Large de-orbit manoeuvre at pericentre



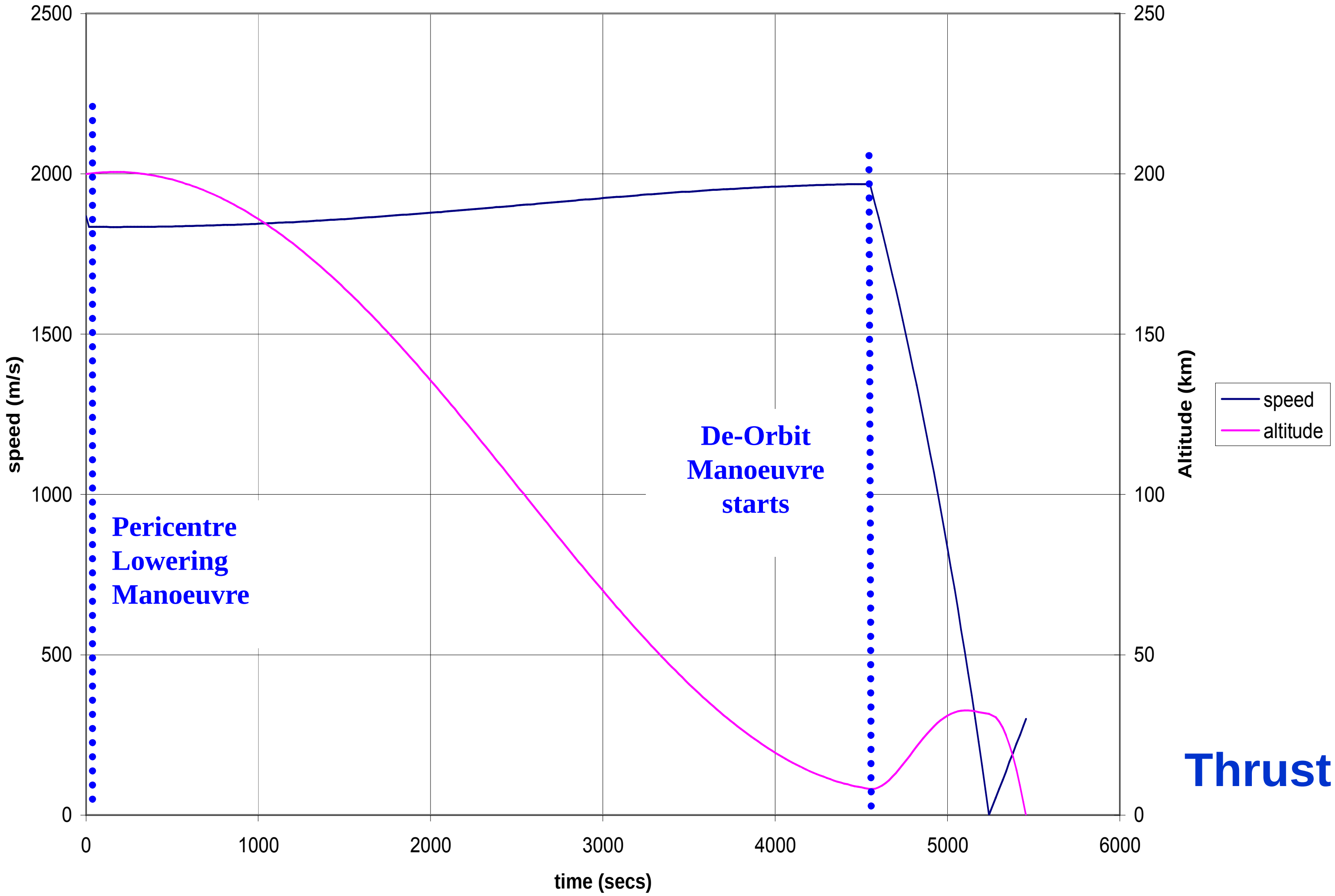
JGO Penetrator – Baseline Descent Scenario



PDS Delivery Constraints



PDM Descent Sequence ('Real' Non-Impulsive case)



Thrust = 180N

Propulsion and GNC solution

Propulsion

- Blow-down Bi-Prop System
- 6-off 22N Thrusters (running over-pressure to achieve 31N each)
- Off-axis canted to provide 3-axis control

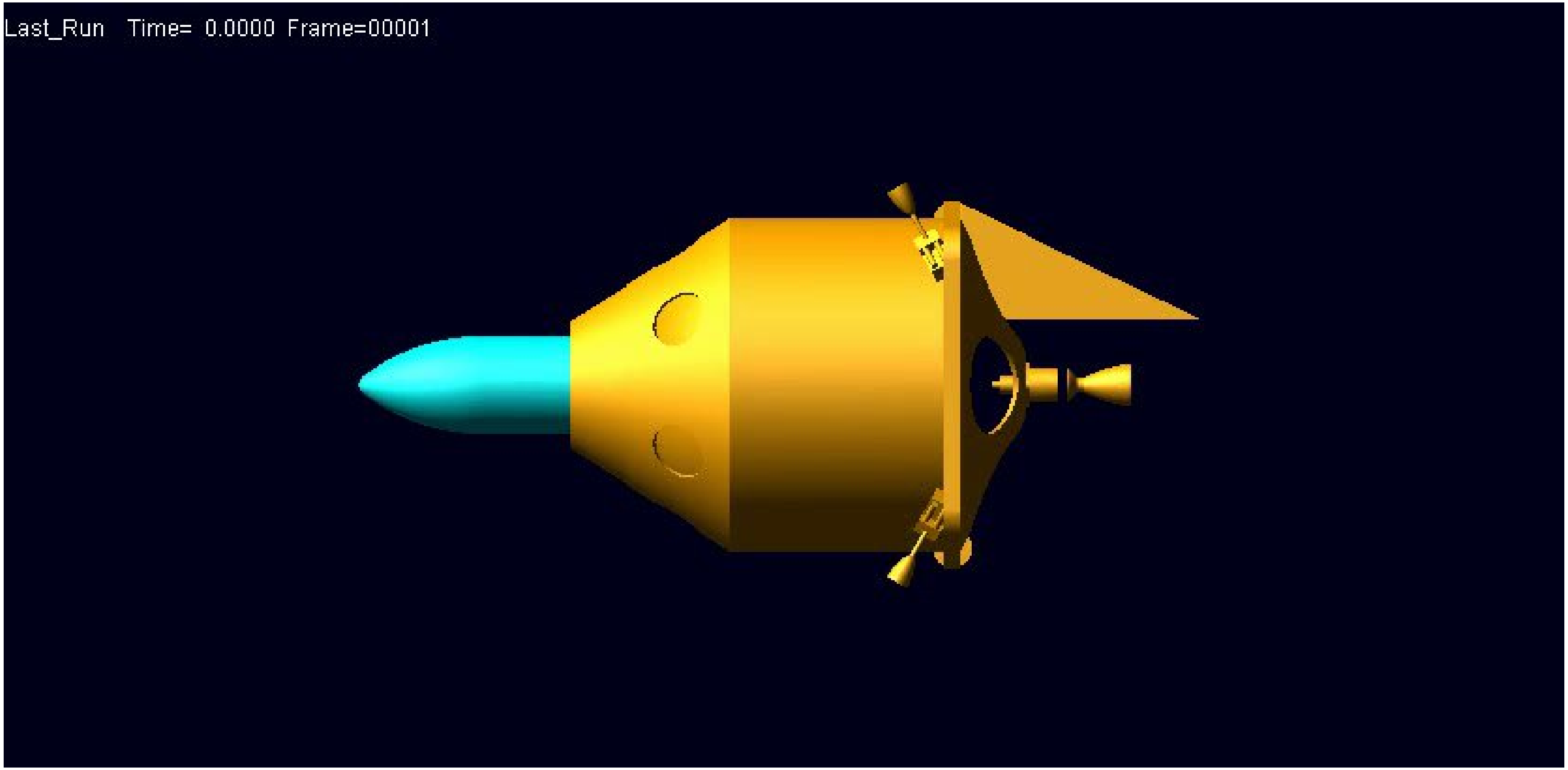
GNC

- MEMS Inertial System (QRS11 x 3 + 1 for redundancy = 4 total)
- Miniature Star Tracker
- 3-axis Control throughout following an initial attitude acquisition

All technologies compatible with TRL 5 by 2012

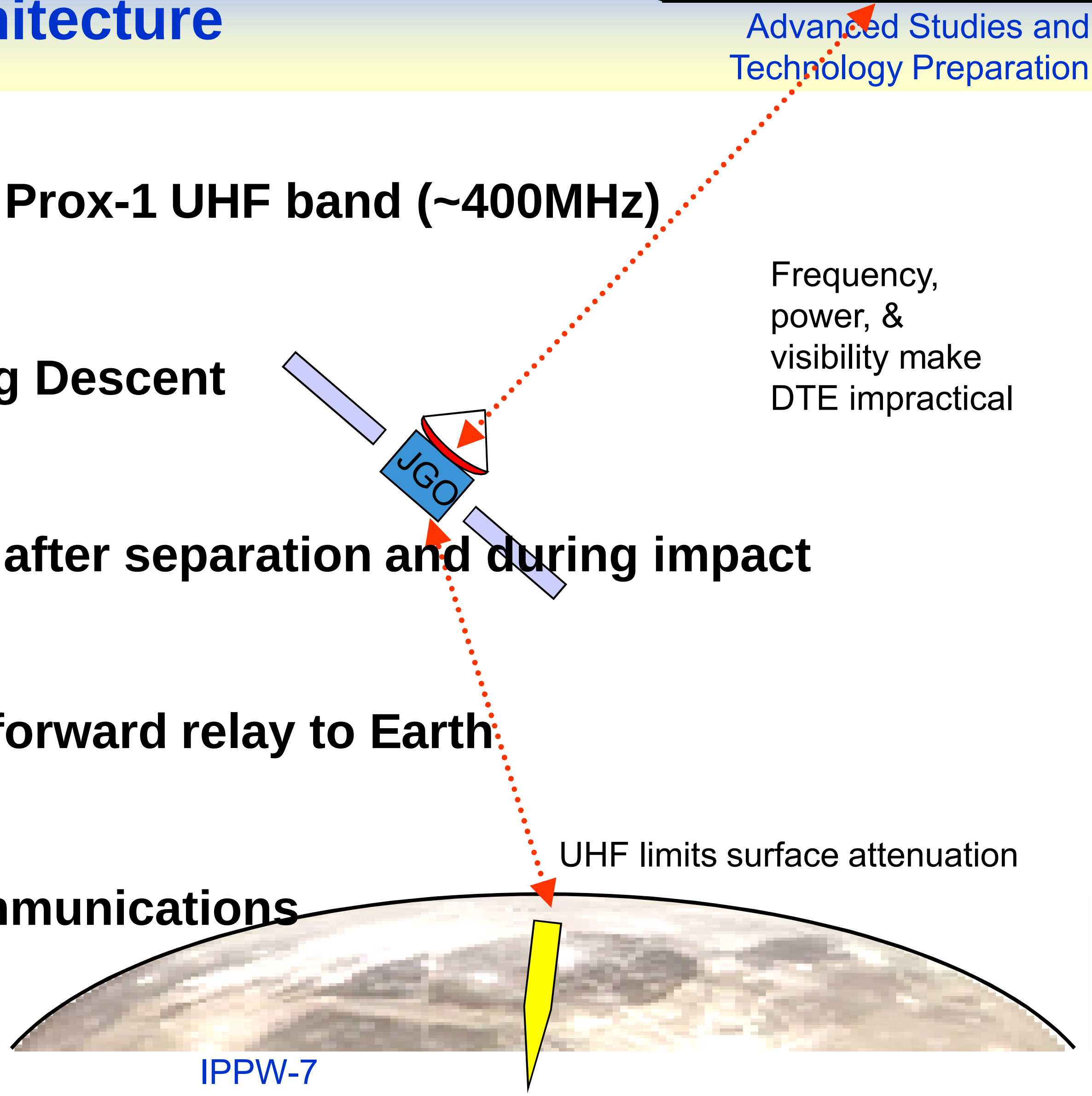
Conclusions on GNC analysis

- **Mission achievable from AOCS perspective**
- **Sensor architecture:**
  - **Micro Star tracker plus rate sensor is a viable solution**
  - **Accommodation issues (mass, power, space) limit redundancy options**
- **Control architecture:**
  - **Same basic architecture can be used from JGO separation to spin-up phase**
  - **Following spin-up, open loop control is possible, but relies on high spin-rate**
- **Performance:**
  - **Goal performances for descent angle (<7°) & AoA (< 8°) and landing ellipse (< 15km) can be met**


Last_Run Time= 0.0000 Frame=00001

Communications Architecture

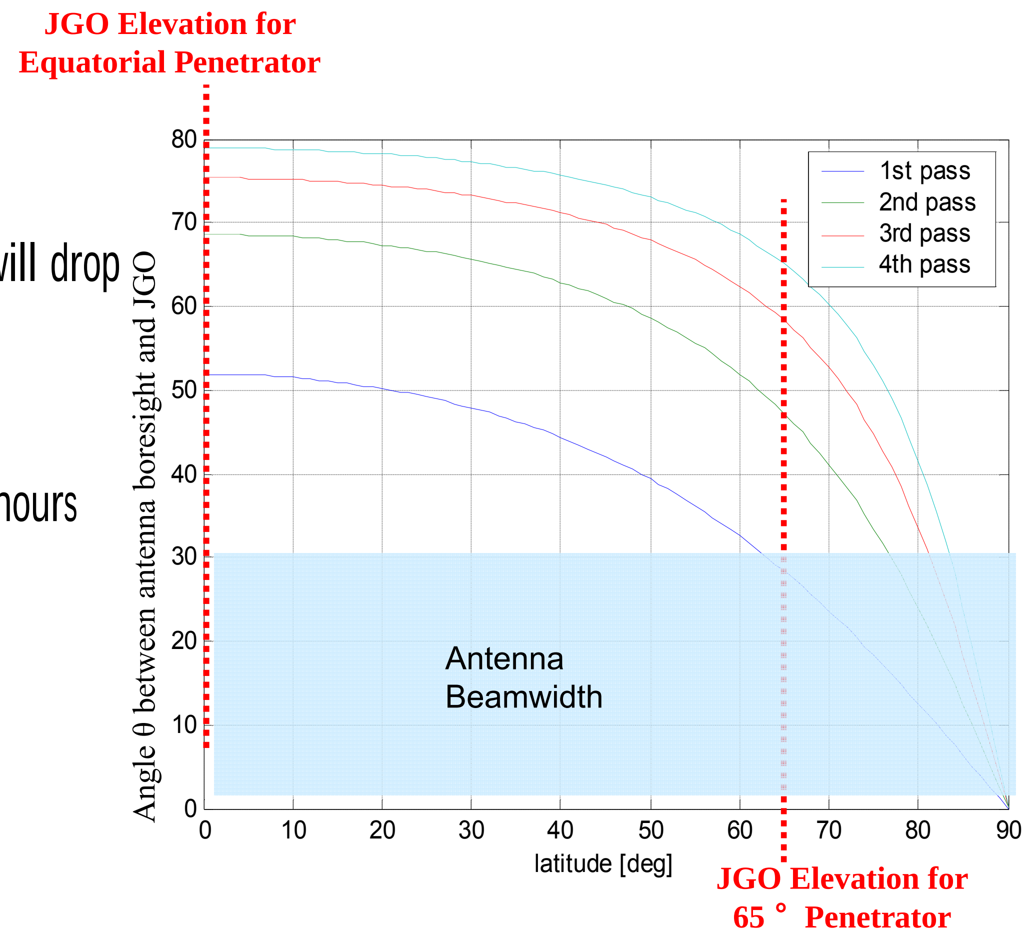
- PDM / Penetrator uses Prox-1 UHF band (~400MHz)
- PDM to JGO link during Descent
- Penetrator to JGO link after separation and during impact
- JGO provides store & forward relay to Earth
- No Direct to Earth Communications



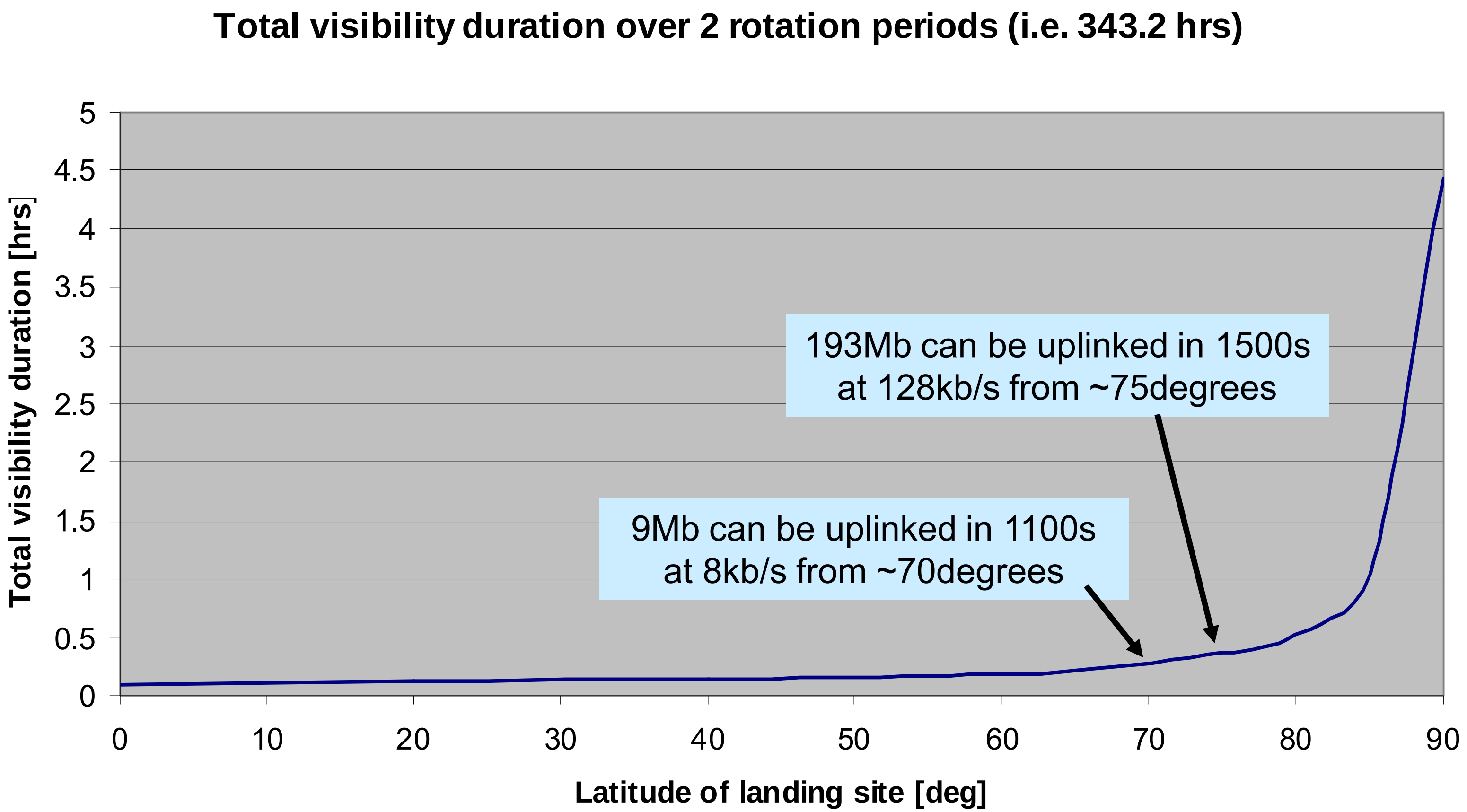
Communications on the 2nd Pass

- 2nd Orbit ~3 hours after impact
- Next 'overhead' pass ~3.5 Earth days later
- If thermal system fails, then core temperature will drop below operating range in a few hours
- If battery outlives the baseline mission, then an extended mission is unlikely to last 3.5 days (few hours max)

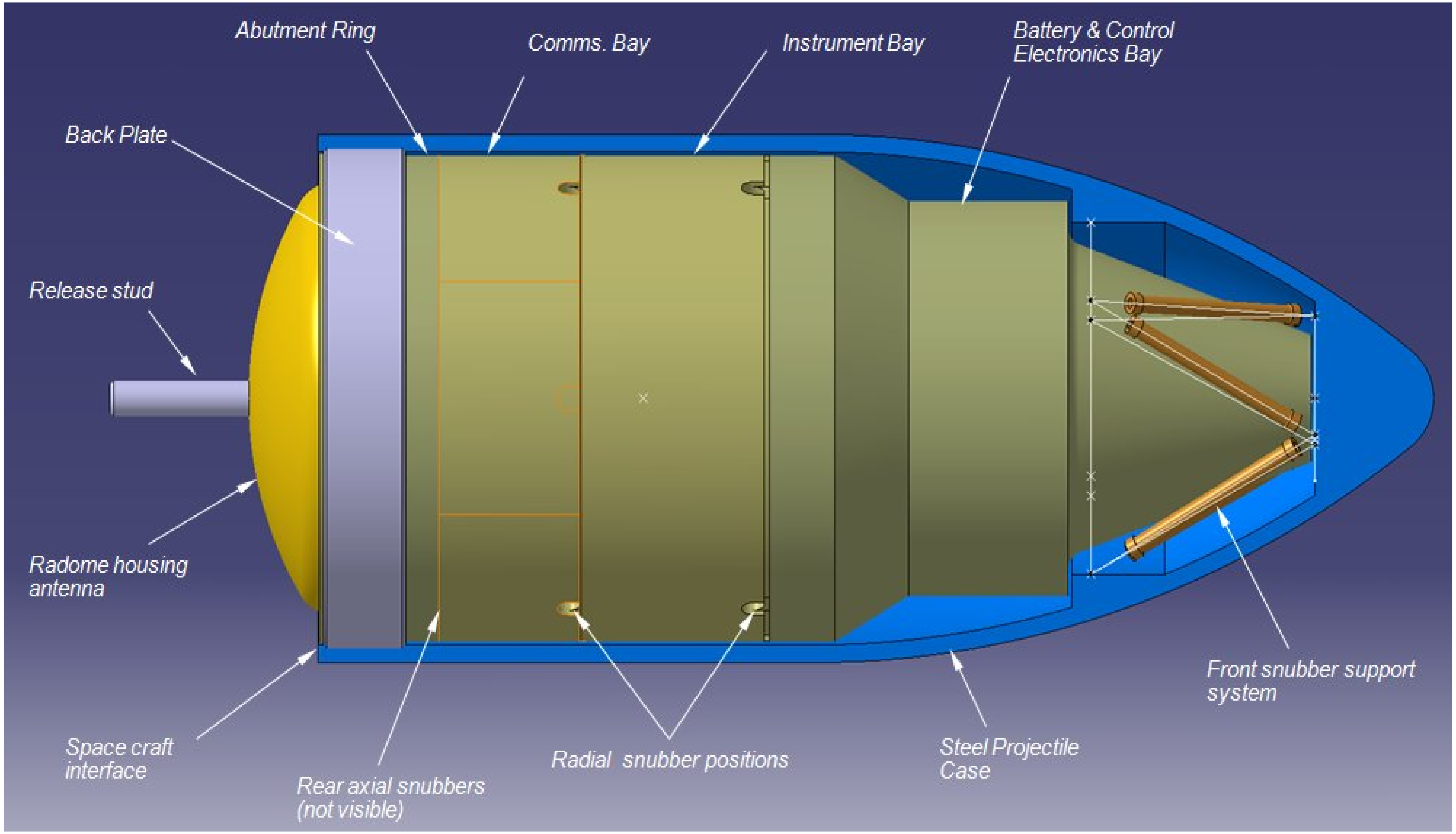
2nd Orbit visibility taken as a requirement



Data Volumes



JGO Penetrator



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Penetrator Mass breakdown

Penetrator Sub-Systems	Margin	System Mass [Kg]
Instruments only Mass	50%	0.8 kg
Sub-System + Instruments Mass Excluding Shell		7.0 kg
System Margin	20%	
Sub-System + Instruments Mass WITH MARGIN		8.4 kg
Penetrator Shell Mass (no margin)		6.1 kg
System Margin	20%	
Penetrator Shell WITH MARGIN		7.3 kg
PENETRATOR TOTAL MASS		15.7 kg

Penetrator + Delivery System Mass

Subsystem	Margin [%]	System Mass [Kg]
PDS Dry Mass (no Penetrator)		**22.8 kg**
System Margin	20%	
PDS Dry Mass Including margin		**27.3 kg**
Propellant mass		43.6 kg
PDS TOTAL MASS (no Penetrator)		**70.9 kg**
Penetrator mass (incl. Margin)		15.7 kg
PDM Dry Mass (incl Pen.)		**43.0 kg**
DESCENT MODULE TOTAL MASS		**86.6 kg**

System mass sensitivity

Wet PDS mass to deliver itself (w/o Penetrator) to surface = 40kg

Multiplication factor for propulsion elements for a given Penetrator dry mass is about 3 (fuel, thrusters, tanks, supports).

5kg Penetrator + 10kg propulsion = 15kg .... System mass => 40+15 = 55kg
10kg Penetrator + 20kg propulsion = 30kg .... System mass => 40+30 = 70kg
15kg Penetrator + 30kg propulsion = 45kg .... System mass => 40+45 = 85kg

With some additional resource-sharing, potentially the PDS mass could be reduced by max a few kgs, thus saving max 5kg on the system mass.

Bottom line: For JGO-Penetrator, 65kg (incl. margin) would be the absolute bottom limit to deliver a meaningful (10kg) Penetrator to the surface.

Major risks

- **Developmental – TRL 5 by 2012**
  - Penetrator Battery
  - Instrumentation shock tolerance
- **Limited FDIR**
  - e.g. Single Thruster failure – limited chance of recovery
- **Thermal Short**
  - Lifetime of hours only
- **Surface unknowns**
  - Over-steep terrain (risk of ricochet)
  - Out of range material hardness (impact survival, cratering, penetration depth)
  - Out of range dielectric properties (RF attenuation)
  - **Ultimately, unknowns about the surface material properties remain and add significant risk to the mission**

Conclusions

- Penetrators for the Outer Moons are possible, but THEY WON"T BE TINY…
- In order to maintain a small package, not all risks can be mitigated, so a mission will be INHERENTLY MORE RISKY than soft landers.
- Lack of atmospheres, hard surfaces, low temperatures and large delta-Vs make the use of Penetrators on the Jovian moons VERY CHALLENGING.
- NICHE OPPORTUNITIES EXIST when small mass margin on an orbiter mission is available and offers LIMITED BUT UNIQUE SCIENCE RETURN.