ICEUM 9

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Mission Analysis Techniques For The Phase A Of ESMO And Outlooks For A Possible Phase B

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Outline

Overview

ESMO

Chemical Transfer

SEP Transfer

Outreach Target Orbit

Science Target Orbit

Phase B…

Conclusion

- Objectives and constraints on ESMO mission analysis
- Transfer trajectories to the Moon
- Lunar target orbit determination
- Tasks during the phase B
- Conclusions

Mission Objectives

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- Outreach Mission
  - Acquire images of the South Pole (200 km of altitude)
- Science Mission
  - Gravity field mapping through sub-satellite
  - 100 km circular polar frozen orbit

Mission Constraints

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- Ariane 5 (ASAP ring), into GTO orbit
- Secondary payload, no control on launch date (any day in 2011-2013)
- Study of:
  - Chemical transfer
  - Solar Electric Propulsion (SEP) transfer
  - Target Lunar Orbit selection

Chemical Transfer

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- Weak Stability Boundary (WSB) transfer
- Sun-Earth-Moon angle at injection is typically* ~ 130°
- Same transfer condition once per month
- One WSB transfer is developed in full
- A phasing strategy allows to reach the correct departure conditions from any launch date

* Belbruno, Carrico, "Calculation of Weak Stability Boundary Ballistic Lunar Transfer Trajectories"

WSB Transfer

Overview

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Phase B…

Conclusion

	Outreach mission	Science mission
Thrust	88 N	490 N
I_{sp}	285 s	310 s
Maximum initial mass of spacecraft	220 kg	

- Systematic search over the free variables
- Subsequent local optimisation

$$\min_x \left(\Delta v_E + \Delta v_M + \Delta v_{WSB} \right)$$

$$x = \left[t_0, \Omega_E, \Delta v_E, T_{E-WSB}, \Omega_M, \Delta v_M, T_{WSB-M} \right]$$

Phasing Strategy

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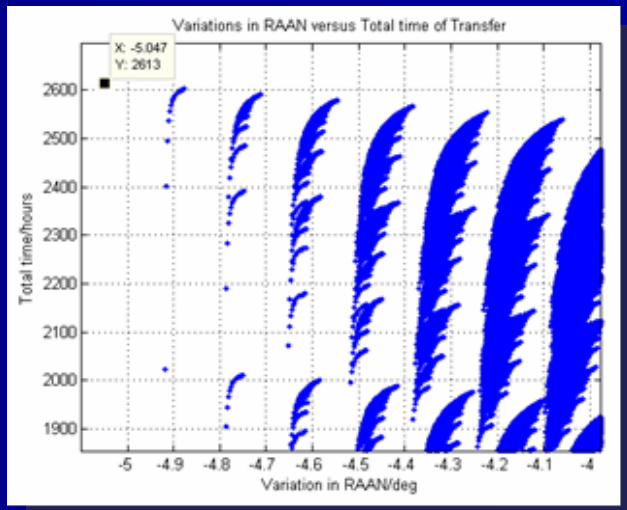
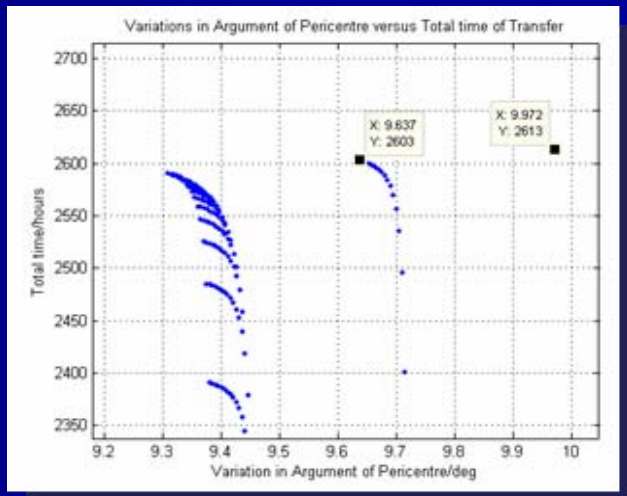
Conclusion

- J2, Sun, Moon Perturbations
- Sequence of burns at perigee of parking orbit
- Different time spent on consequent orbits

- Combinations of variations of ω, RAAN and *t*





Outreach

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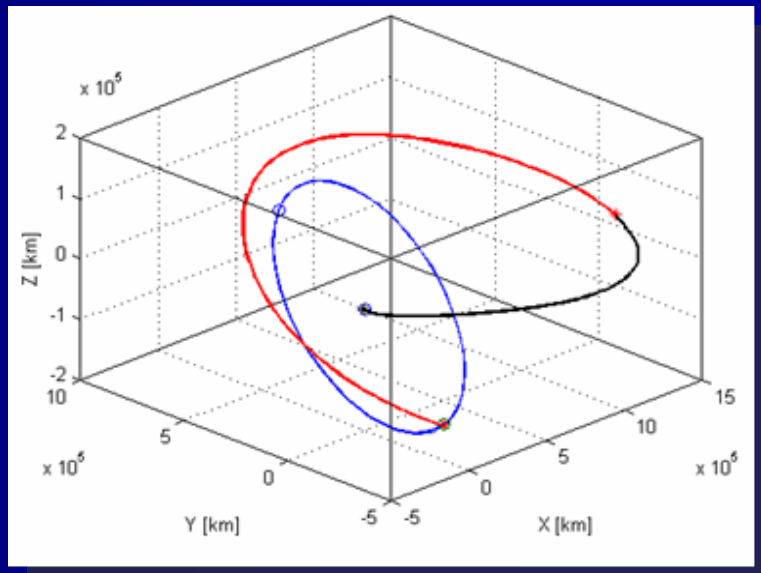
Transfer manoeuvres	Δv [m/s]
GTO	737.75
WSB point	14.05
Lunar Injection	296
Sub-total	**1047.8**
Gravity losses (5%)	52.4
Total	**1100.2**



Transfer leg	Time of Flight [d]
GTO – WSB point	39.91
WSB point – lunar injection	53.78
Total	**93.68**

Science

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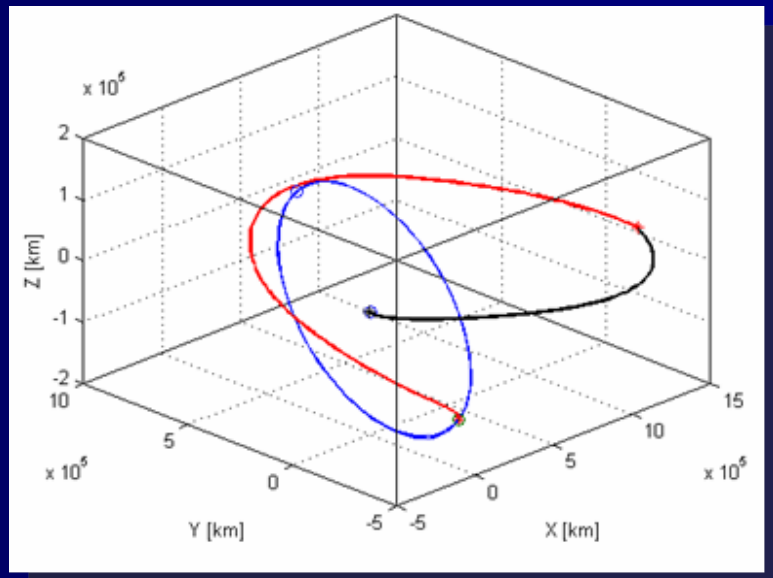
Transfer leg	Time of Flight [d]
GTO – WSB point	38.41
WSB point – lunar injection	57.25
Total	**95.66**



Transfer manoeuvres	Δv [m/s]
GTO	737.9
WSB point	54
Lunar Injection	667.5
Sub-total	**1459.4**
Gravity losses (2%)	29.2
Total	**1488.6**

SEP Transfer

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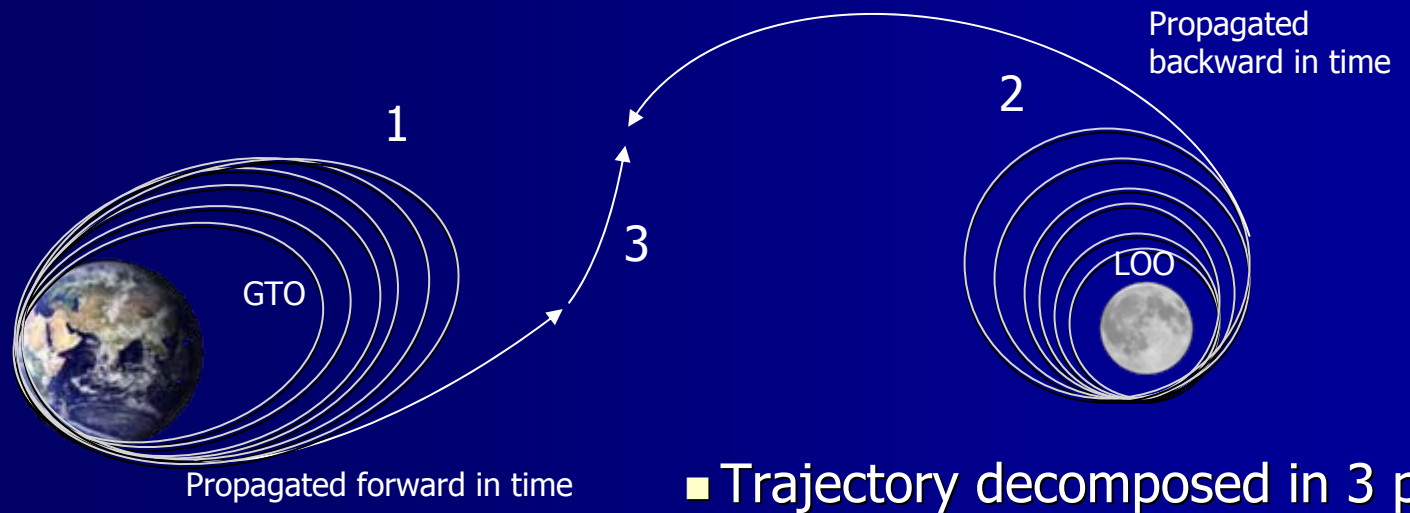
- Low-thrust transfer
- Preliminary analysis over all 2011 launch dates
- Worst cases for Outreach and Science optimised completely

T5 Gridded Ion thruster		
	Outreach	Science
Thrust	20 mN	
I_{sp}	3250 s	
Initial mass of the spacecraft	180 kg	200 kg



- Trajectory decomposed in 3 phases

Earth Spiralling-up

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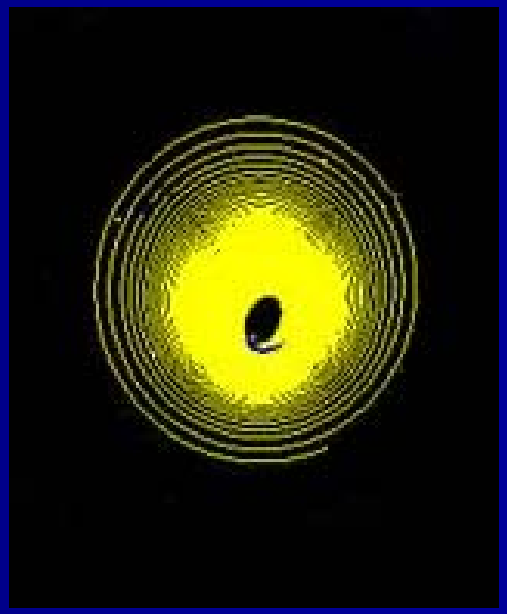
- For each launch date
- Starting from GTO
- Forward propagation in time
- Continuous tangential thrust
- Up to r_a = 280,000 km



Moon Spiralling-down

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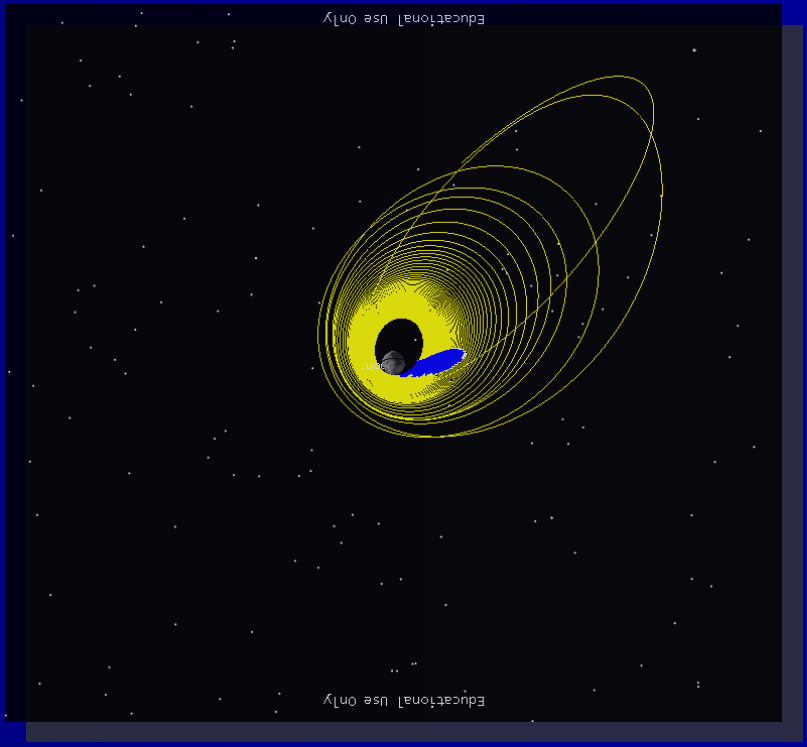
Phase B…

Conclusion

- For different possible Lunar operational orbits
- Starting from the Lunar injection condition
- Backward propagation in time
- Continuous tangential thrust
- Up to r_a = 60,000 km
- Final mass guess:
  156 kg (Outreach)
  174 kg (Science)



Phasing segment

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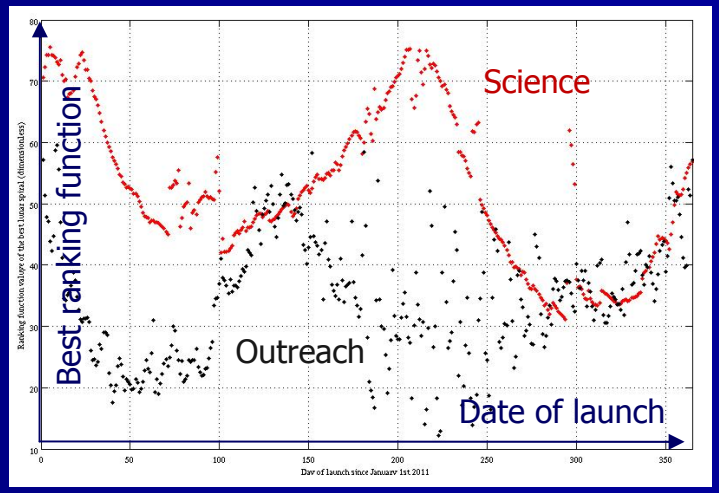
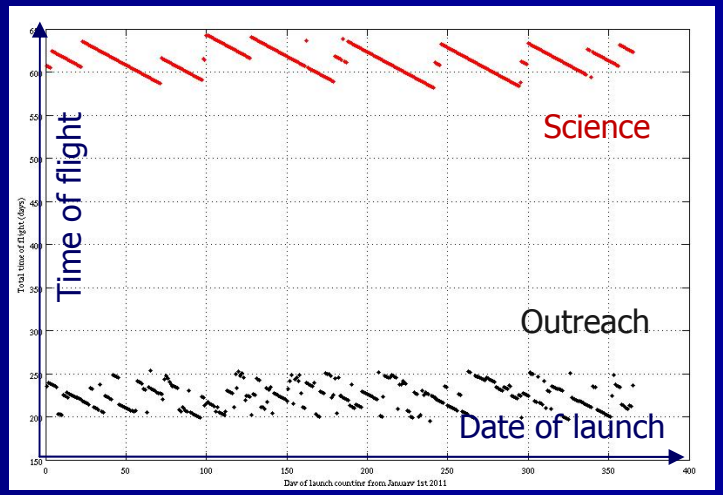
- For each Earth spiral, a Moon spiral is selected through a ranking function:

$$R_{t_{launch}}\left(t_{arrival}, \Omega_{arrival}\right) = \alpha\left(r_{pM} - r_{pE}\right)^2 + \beta\left(i_M - i_E\right) + \gamma\left(\Omega_M - \Omega_E\right)^2$$

$$t_M - t_E \in \left[70, 120\right]\text{d}$$

- Worst launch dates considered
- The thrust profile for phasing segment found with DITAN (Direct Interplanetary Transfer Analysis)





Outreach

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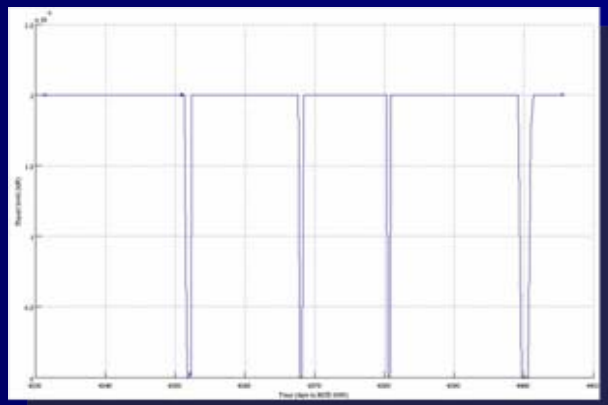

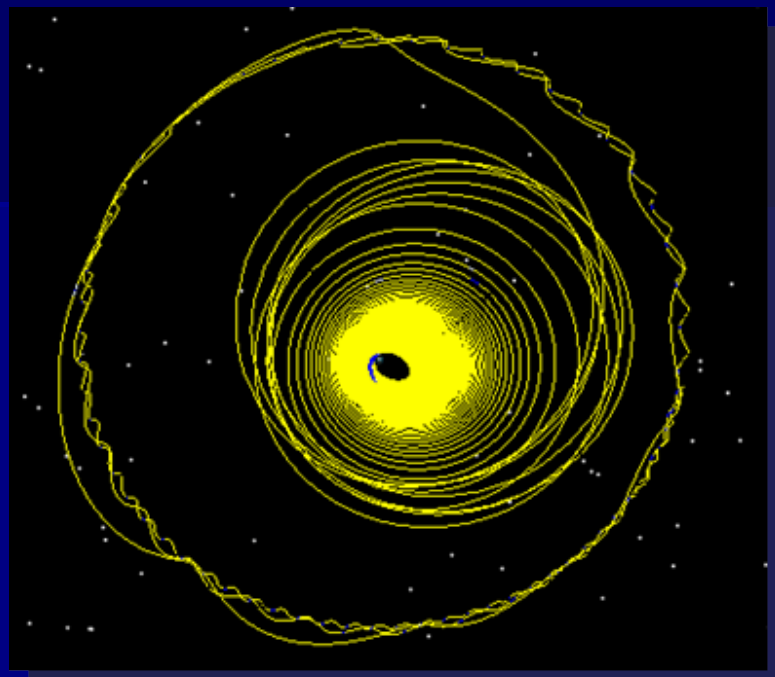

Phase	Propellant mass [kg]	Δv [km/s]	Time of flight [d]
Spiralling-up from GTO	15.9	3.0	304.8
Phasing segment	3.9	0.8	84.4
Spiralling-down to lunar orbit	3.9	0.8	72.9
Sub-total	**23.7**	**4.5**	**462.1**
Orbit correction margin (5%)	1.1850	-	-
Additional system margin (2%)	0.4740	-	-
Total	**25.36**	**4.5**	**462.1**

Science

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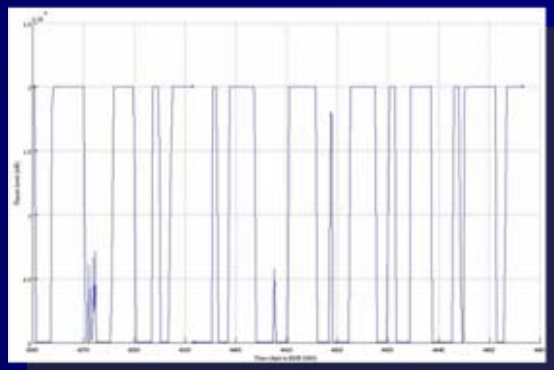

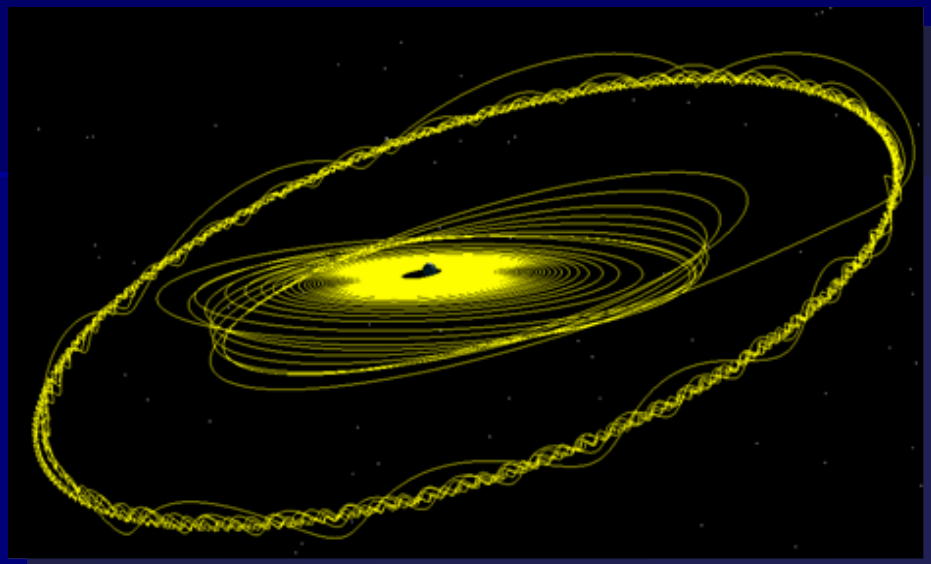

Phase	Propellant mass [kg]	Δv [km/s]	Time of flight [d]
Spiral-up from GTO	17.9	3.0	340.7
Phasing segment	2.8	0.5	106.5
Spiral-down to Science orbit	7.2	1.3	201.9
Sub-total	**27.9**	**4.8**	**649.1**
Orbit correction margin (5%)	1.395	-	-
Additional system margin (2%)	0.558	-	-
Total	**29.853**	**4.8**	**649.1**

Outreach Target Orbit

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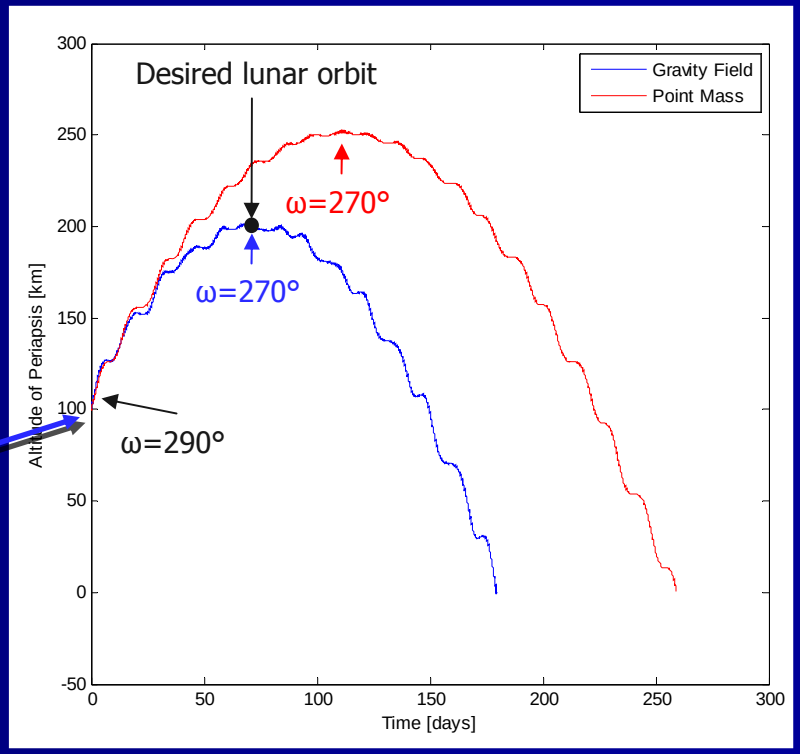
- Minimum lifetime: 180 days
- No station keeping
- h_p = 200 km
- ω = 270° (south pole)

Injection at:
h_p = 100 km, ω = 290°
Longer lifetime



Resulting Injection

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	Injection state	Target state
Date	April 9th 2011 55660.5 MJD	July 1st 2011 55743.5 MJD
Z_p [km]	1738.2 + 100	1738.2 + 200
i [deg]	89.858	90
e	0.439	0.408
RAAN [deg]	294.868	295
ω [deg]	292.844	270
Collision	October 6th 2011	
Lifetime [days]	179.662	
Time during which the altitude of periapsis is between 190 km and 210 km [d]	43	
Intervals of ω during which the altitude of periapsis is between 190 and 210 km [deg]	278.6–266	

Science Target Orbit

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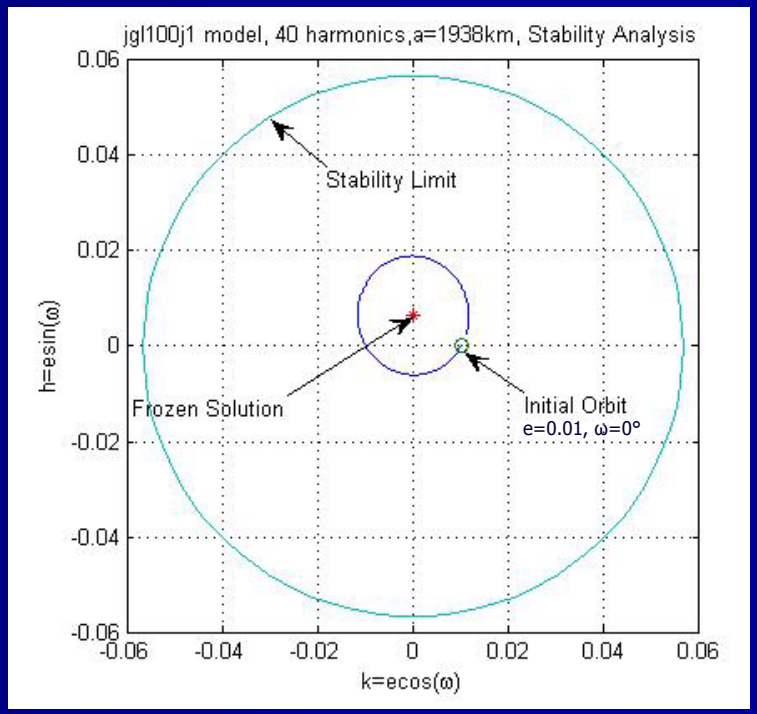
- Frozen orbit
- Konopliv spherical harmonic model, 40 coefficients

Semi-major axis	1856 km
Periselenium altitude (h_p)	100 km
Aposelenium altitude (h_a)	135 km
Eccentricity	0.0092
Inclination	90°
RAAN	90°
Argument of periapsis (ω)	270°



Stability analysis

What next if there is a Phase B?

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Chosen baseline: Chemical Science mission

- Refine studies: launcher dispersion, phasing strategy, sensitivity analysis for maneuvers, etc.
- Plan for contingencies: engine underperformance, injection into wrong orbits, etc.
- Think of a possible disposal strategy

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- Efficient method to assess many launch dates
- Trajectories satisfy ESMO Phase A requirements
- Future iterations on system design (phase B?) imply more analyses and refinements

Thank You for Your Attention

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