



Moon Harbor: the Moon Base Gateway

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Moon Base Conference
The Precursor Age
November 16th – 17° 2006

2001: the Year that never was

Exploration Architecture

- **Transportation**
- **Surface Operations**
- **In-space support**

Highways to the Moon

- **Hohmann / Apollo**
- **WSB (weak stability boundary) dynamics**
- **Stable/unstable manifolds**

The L1 Lunar Gateway

- **Precursor missions**
- **Moon Harbor**

Transportation

- launch scenario
- propulsion items
- ways to the Moon

Surface Operations

- orbiting the Moon
- landing / leaving
- roving

In-space Support

- ISS exploitation
- interplanetary escape
- servicing near-Earth space

Ways to the Moon

Hohmann/Apollo

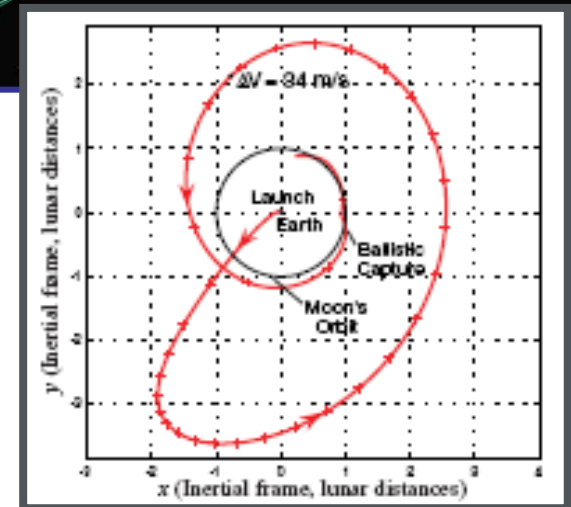
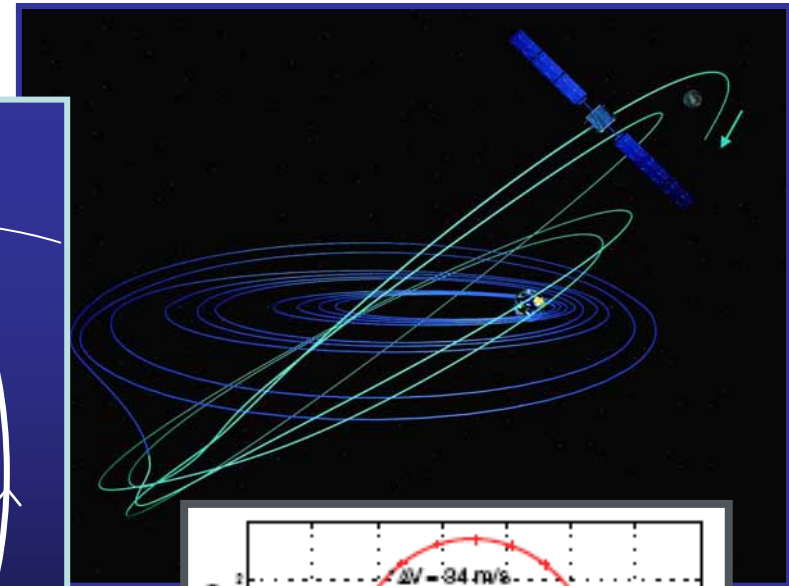
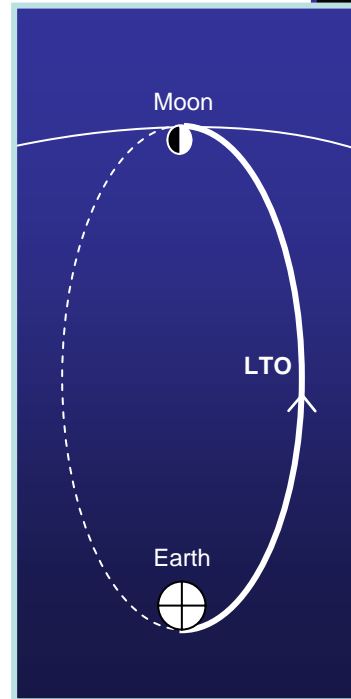
Direct transfer
Lunar Orbit Insertion
3.5 days

SMART-like

Earth-Moon L1 WSB transfer
Phase loops
Electric Propulsion
400 days

Hiten-like

Sun-Earth L1 WSB transfer
Ballistic Lunar capture
94 days

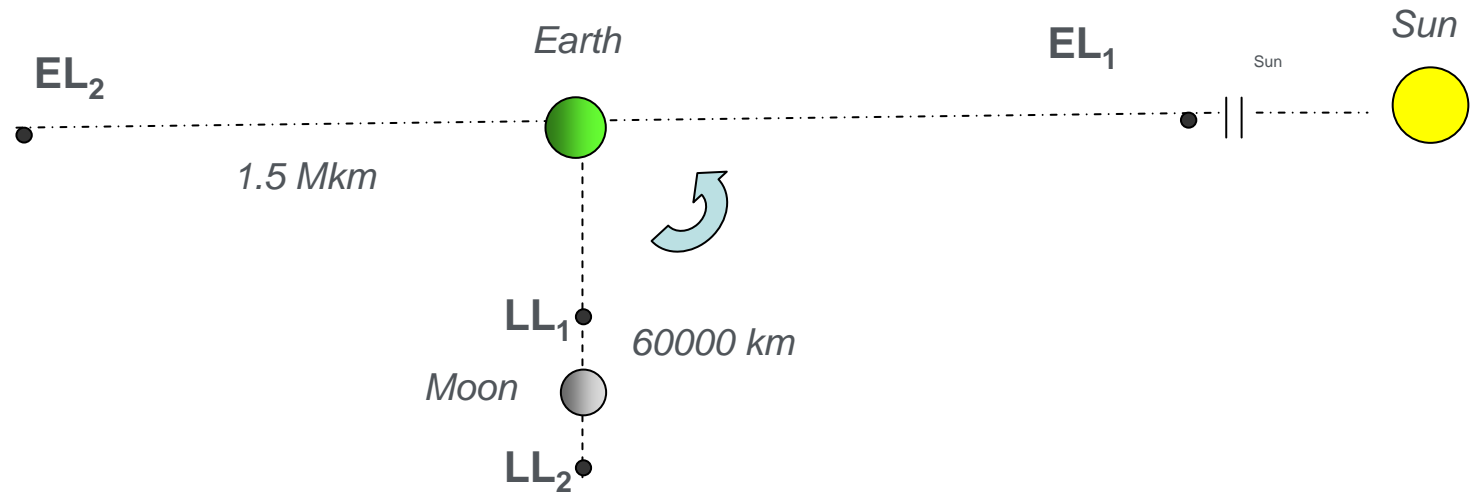
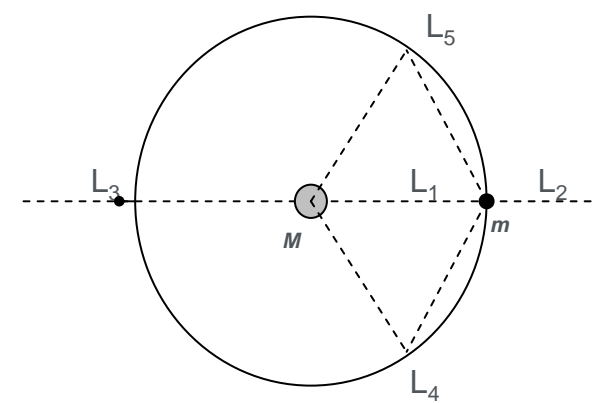


The Earth gravitational domain

A double Three-Body Problem

LL
lagrangian points in the Earth-Moon-S/C TBP

EL
lagrangian points in the Earth-Sun-S/C TBP

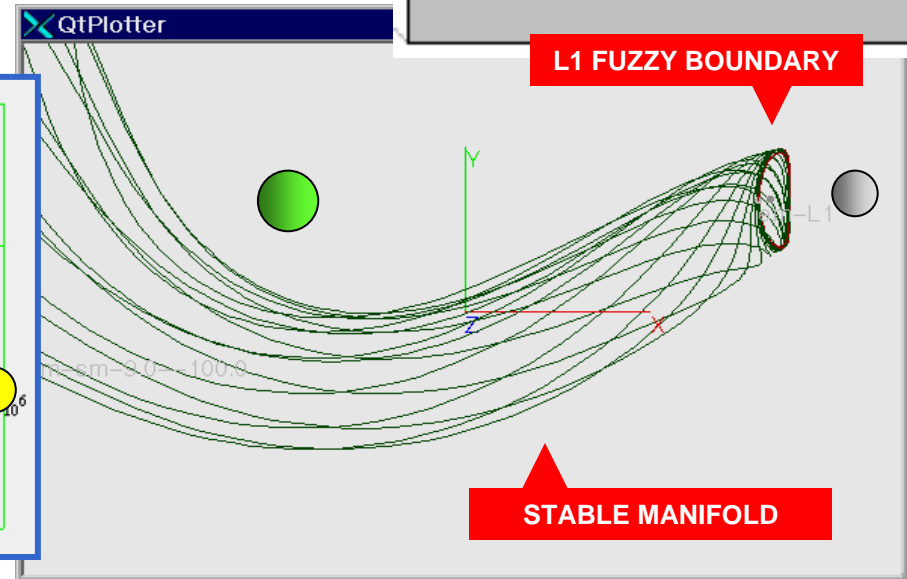
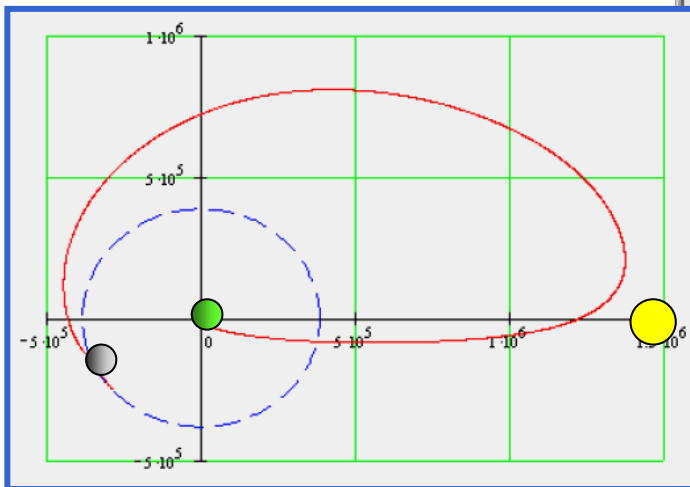
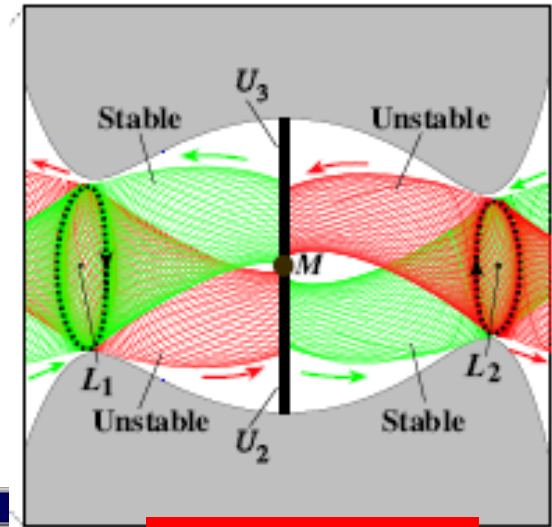


The Invariant Manifolds approach

- Ballistic lunar capture in LL1
- Ballistic LL1 halo orbit insertion
- Connecting the lagrangian points

WSB Dynamics

- LL1 fuzzy boundary
- EL1-LL1 ballistic lunar capture



The Hohmann way

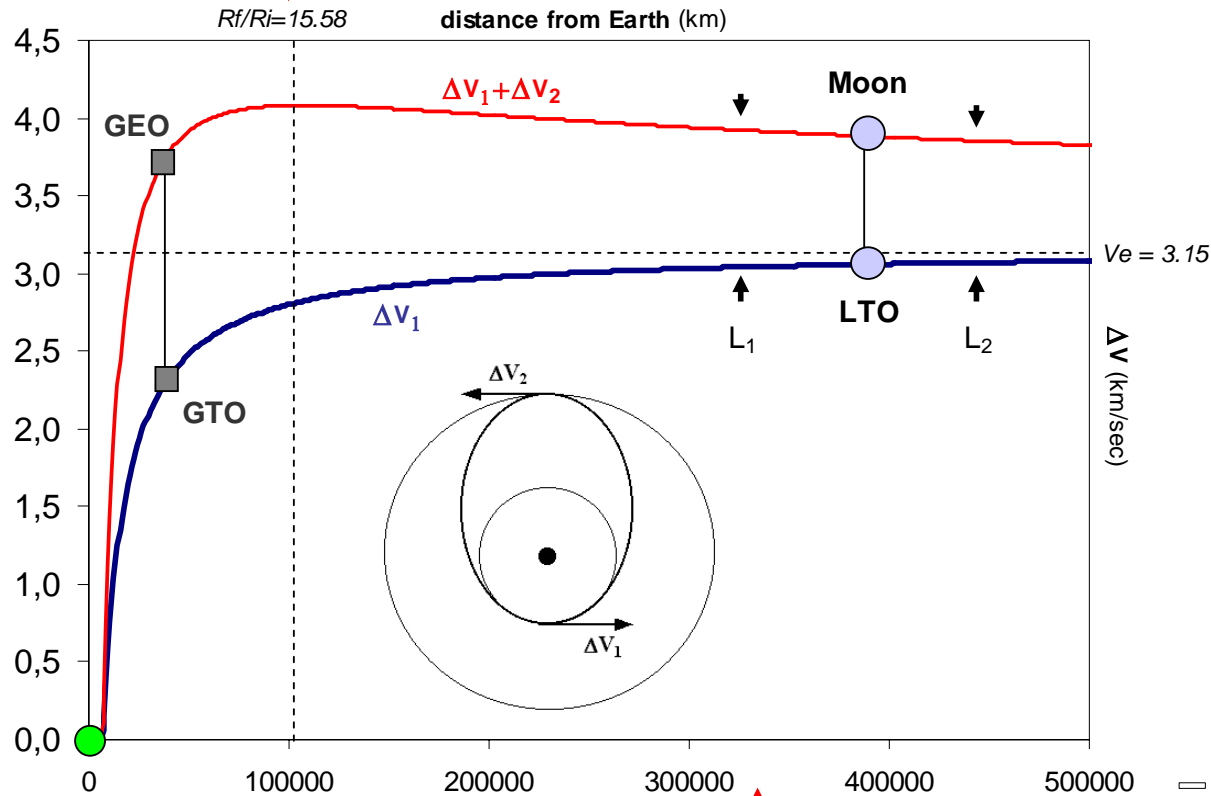
OPTIMALITY LIMIT FOR HOHMANN TRANSFERS

Earth-Moon Hplot

Blue - Hohmann transfer ellipses with perigee on a 500 km altitude starting orbit and increasing apogee distance

Red - Hohmann transfers at increasing distances from the Earth.

Both curves tend to the Earth Escape velocity V_e



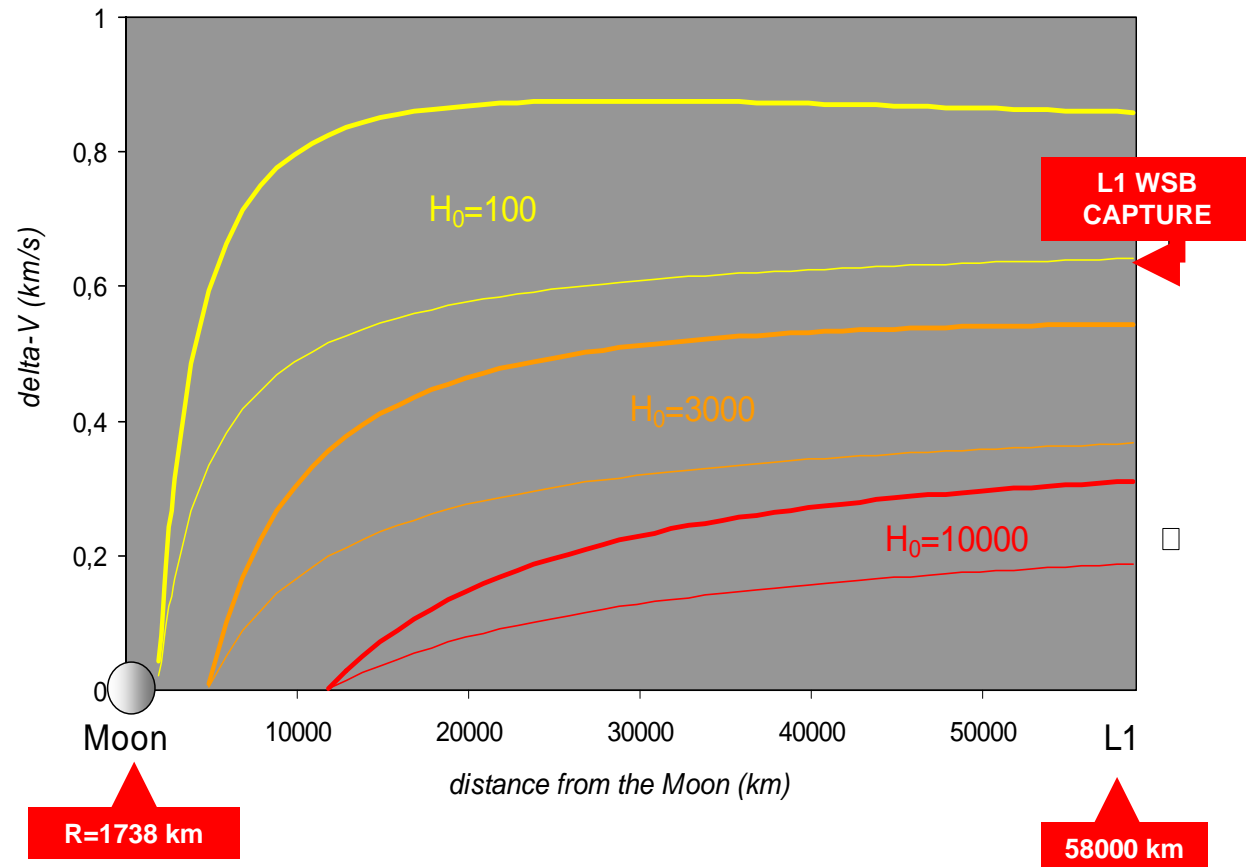
WSB BALLISTIC CAPTURE IN L1

Lunar H-plot

Hohmann transfers around the Moon for different starting orbits and distances up to L1

Transfers among low-altitude, intermediate and high altitude orbits below 1 km/s

100-km circularization of a highly elliptic WSB capture orbit requires about 0.6 km/s

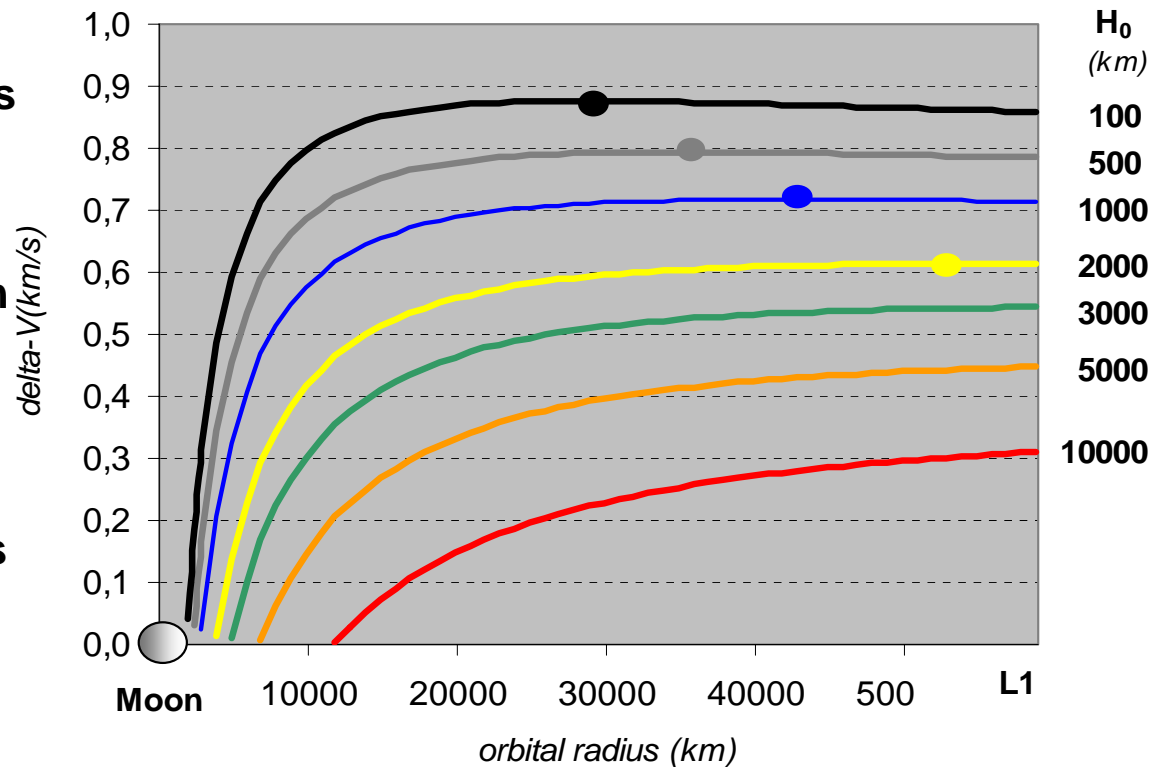


Energy

Hohmann transfers between two circular orbits are optimal only if $R_f/R_i < 15.58$ (full circles)

If $H_{\max} = H_{L1}$, this condition is always satisfied for transfers between orbits with $H > 2500$ km

If one of the two orbits has $H < 2500$ km there could be optimal transfer strategies different from Hohmann (e.g. bi-elliptic)

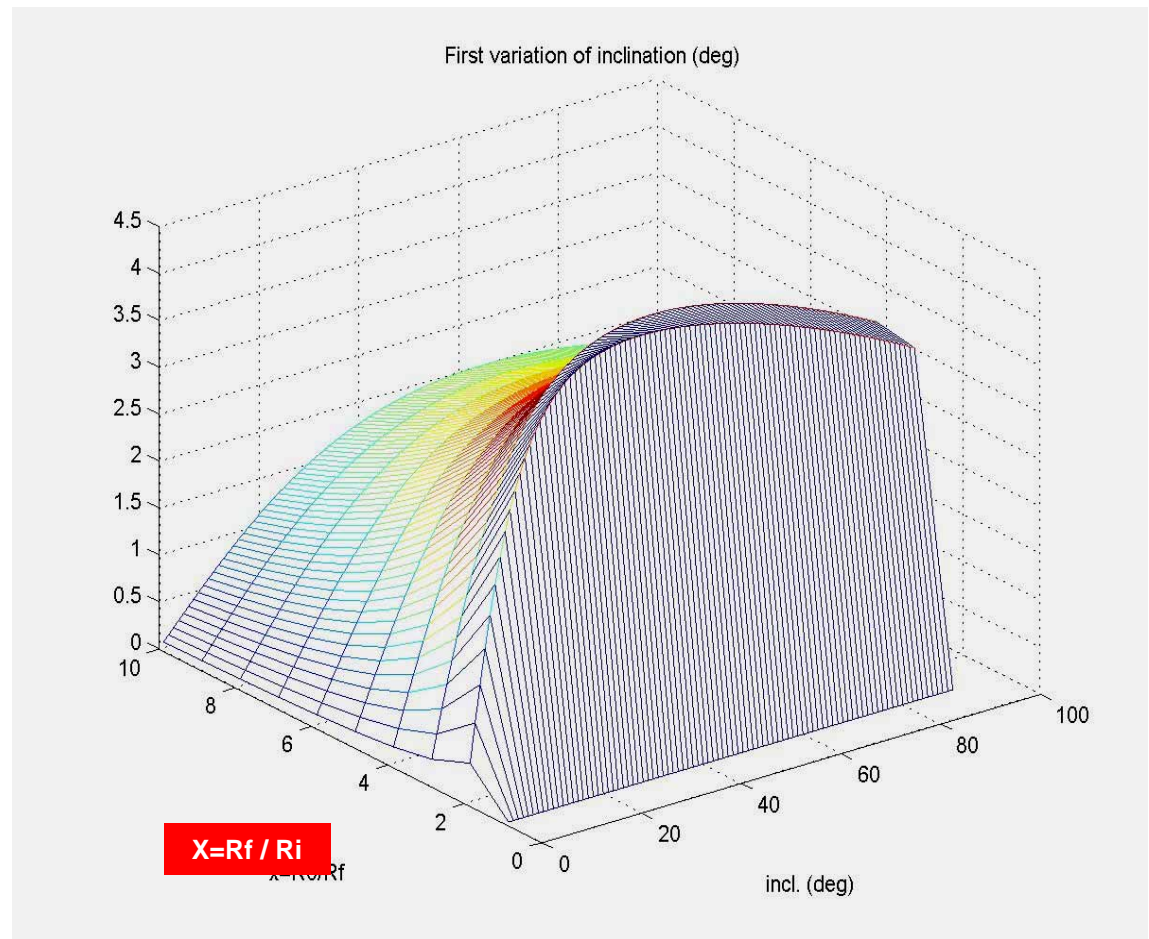


Angular momentum

First plane variation (in deg) performed at perigee of the hohmann transfer as a function of the ratio of the final to the initial orbit radius and the total inclination change

The maximum first plane variation is below 4 deg and occurs for orbits relatively close ($X=2$)

Most of the plane variation is performed at apocenter

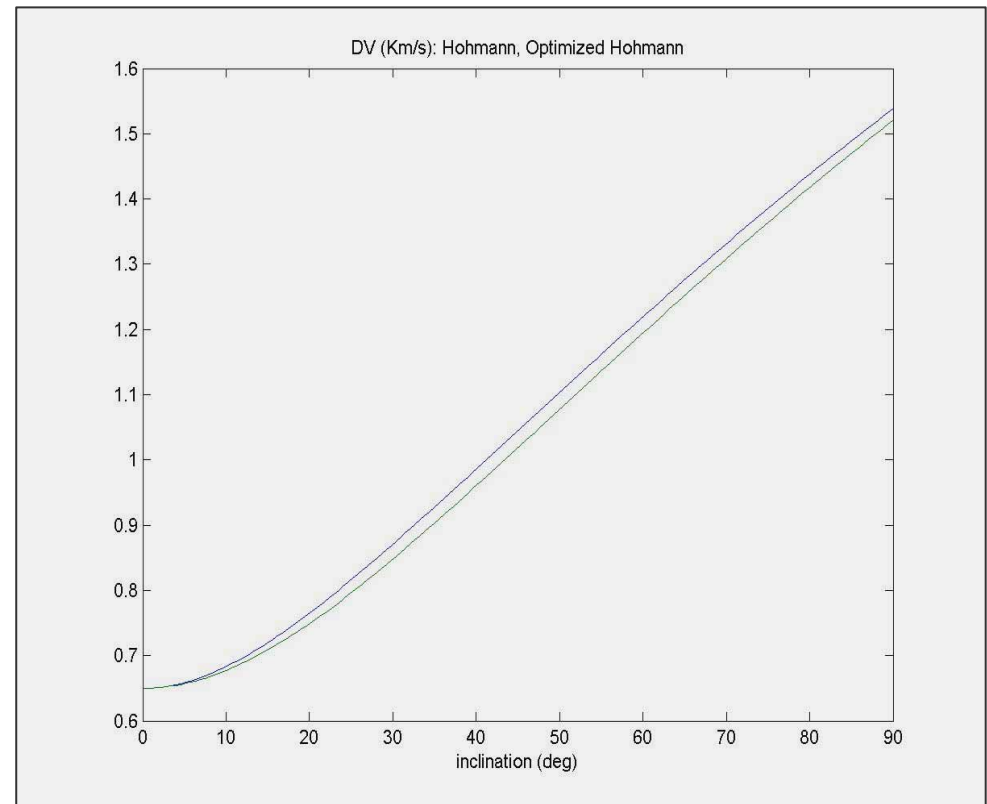


Doubling the Orbit radius

Since the inclination change is performed together with the energy variation, parametrization on the delta-V needed to double the orbit radius for different inclination changes has been implemented

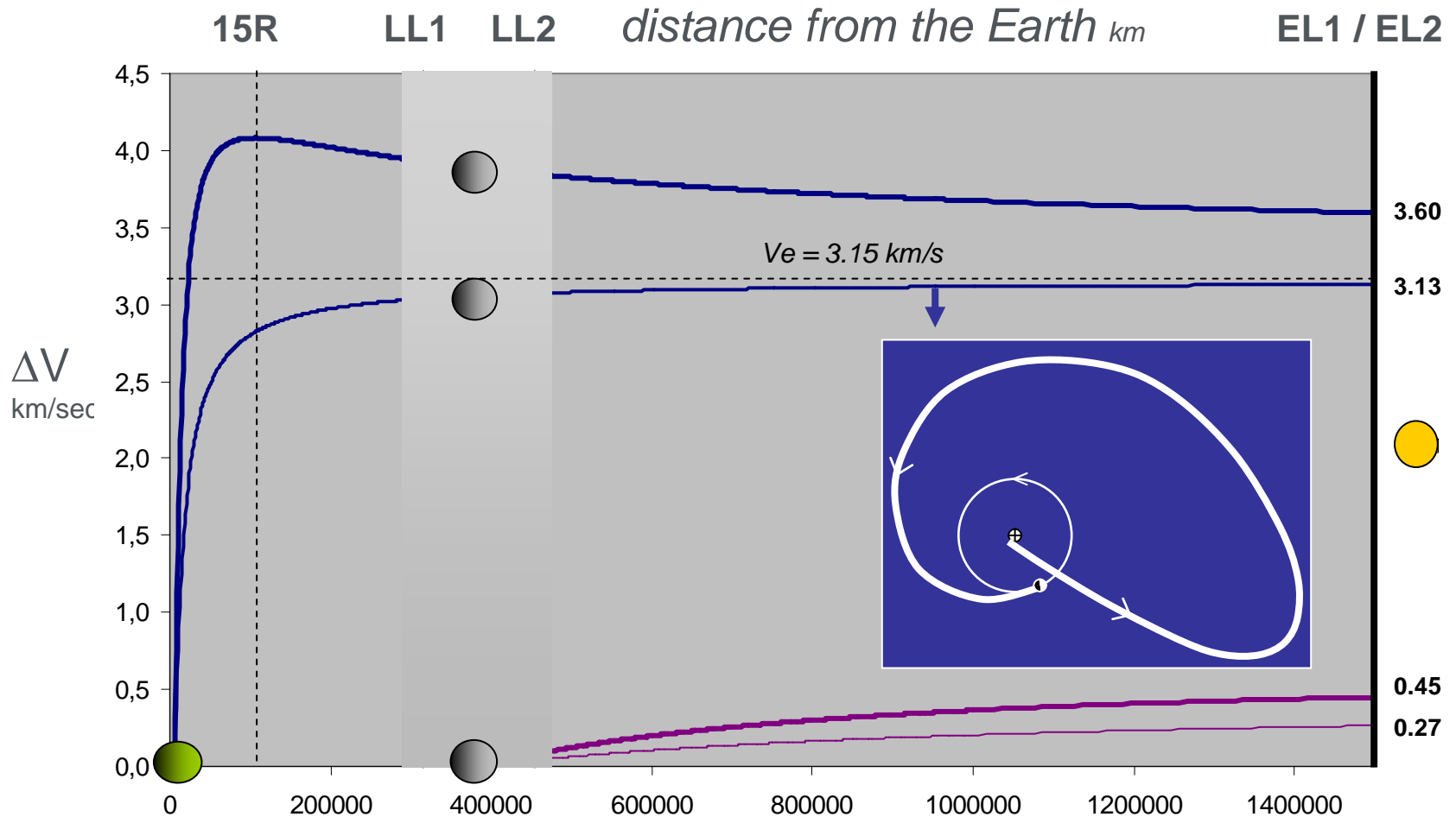
Delta-V expenditures obtained by using an inclination combined (upper curve) and optimized (lower curve) strategies

orbit of initial radius 2000 km
($H_0=260$ km)



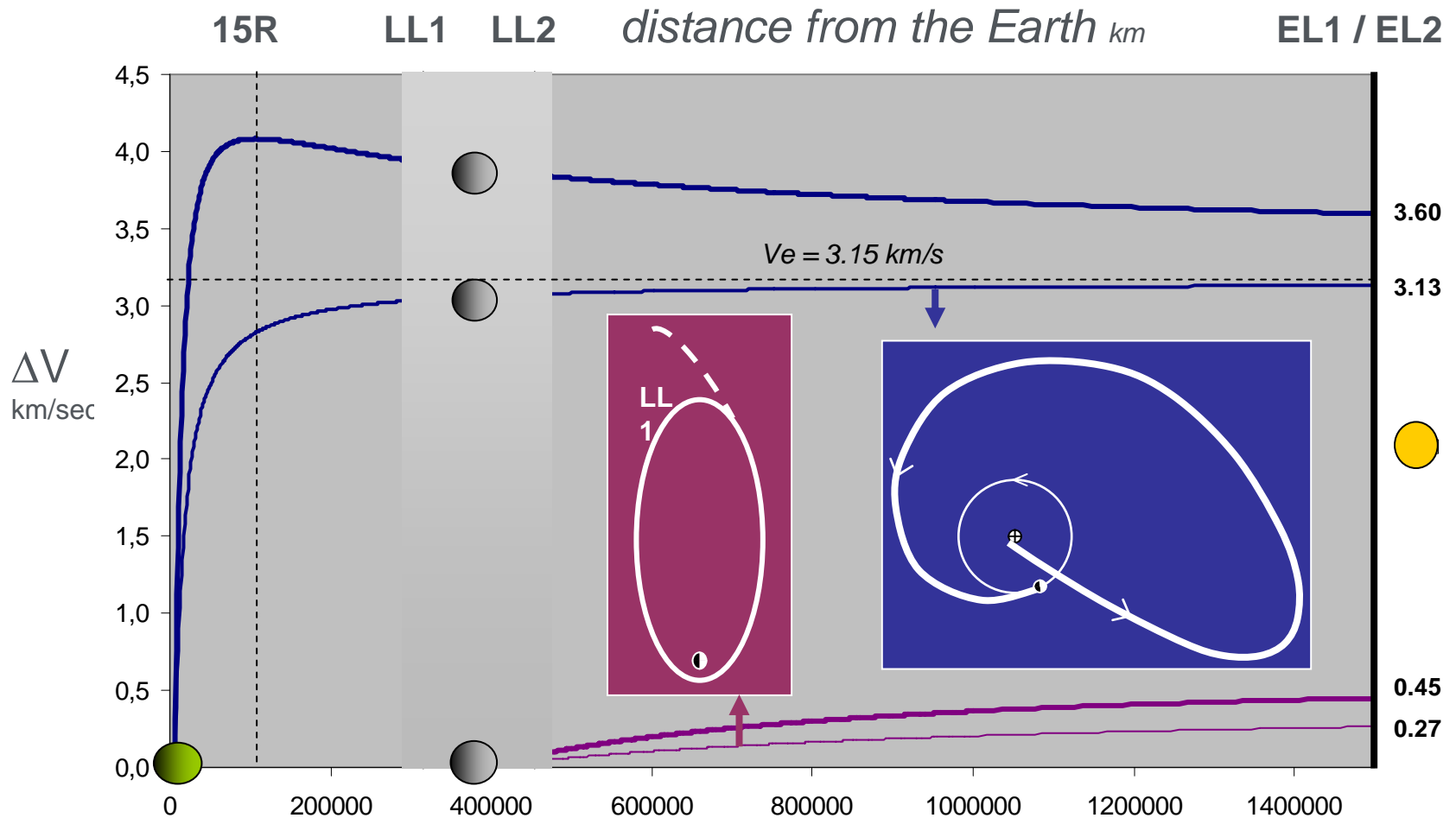
From LEO to LLO: step 1

WSB ballistic capture



From LEO to LLO: step 2

circularization



The Accessibility of the Moon

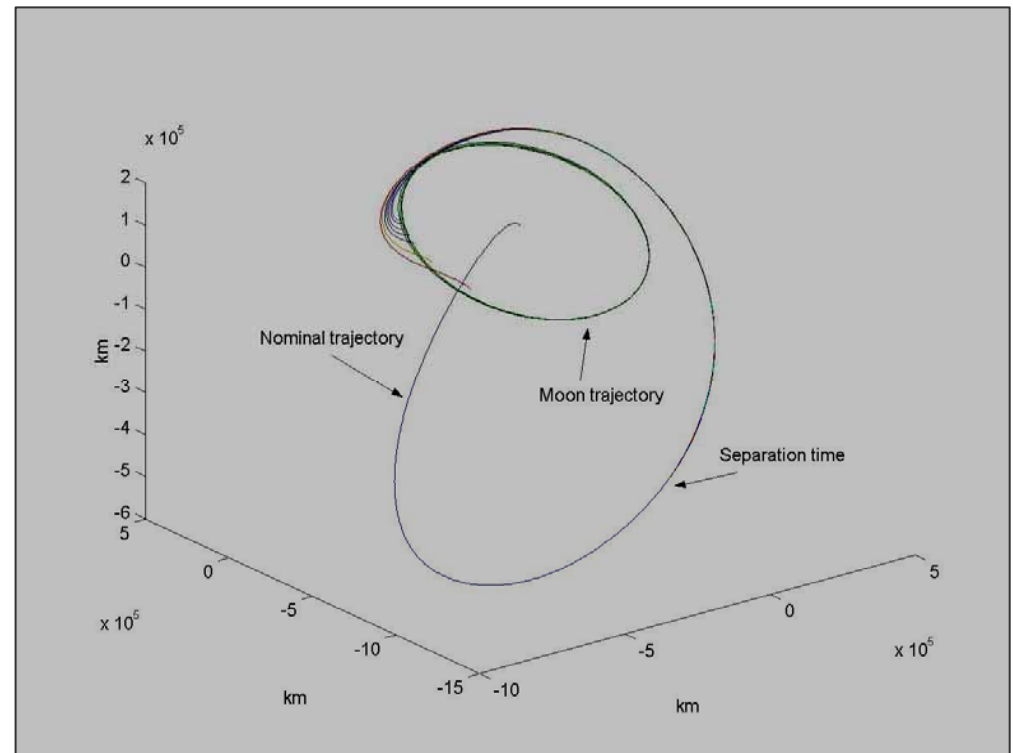
Mission profiles

160 km LEO ▼ 100-km LLO	Earth Injection ΔV (km/s)	Moon Insertion ΔV (km/s)	Total ΔV (km/s)	Average Transfer Time (days)	Gravity field
Hohmann	3,140	0,819	3,959	4 - 5	<i>Earth</i>
Bi-elliptic	3,232	0,714	3,946	50	<i>Earth, Moon</i>
Invariant Manifolds	3,235	0,644	3,879	80 - 120	<i>Earth, Moon, Sun</i>
Weak Stability Boundary (WSB)	3,187	0,651	3,838	80 - 120	<i>Earth, Moon, Sun</i>

Precursor missions

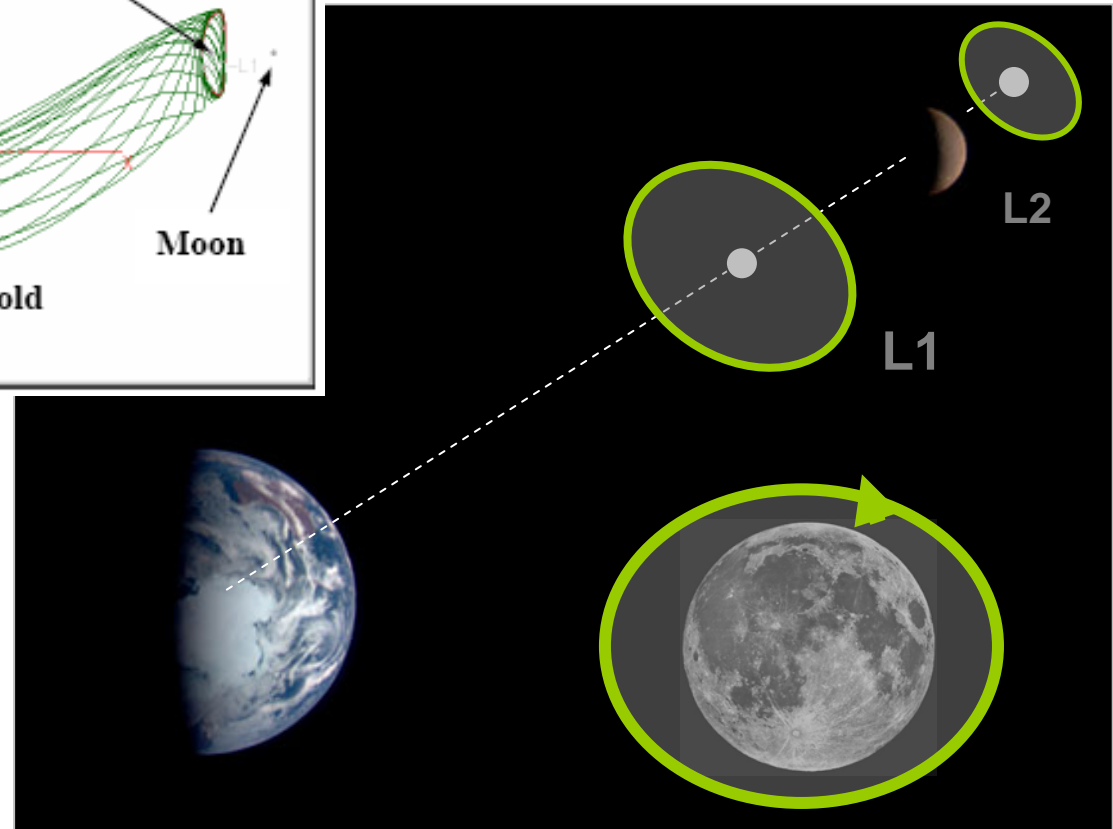
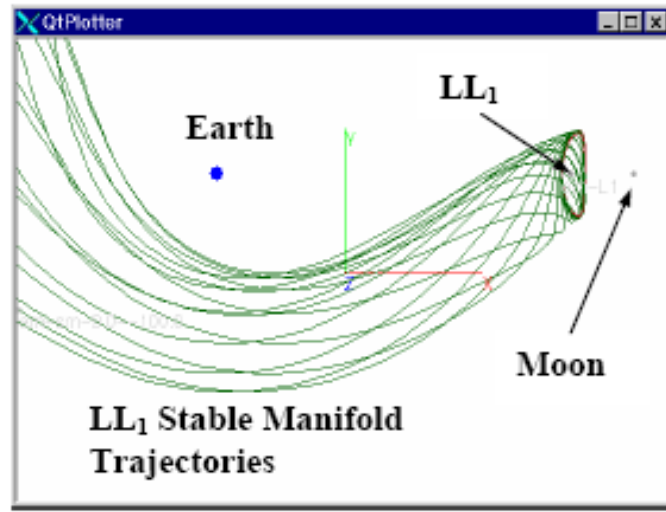
take advantage of the weak stability dynamics in order to reach widely different lunar orbits with small ΔV expenditure

Exploiting high eccentricity orbits for lowering orbit insertion manoeuvre thus increasing the payload



$\Delta V = \pm 20$ cm/s at separation obtained using springs

The L1 Lunar Gateway




Halo orbits

Ballistic LL1 halo orbit insertion

Orbit maintainance:
10 m/sec per year

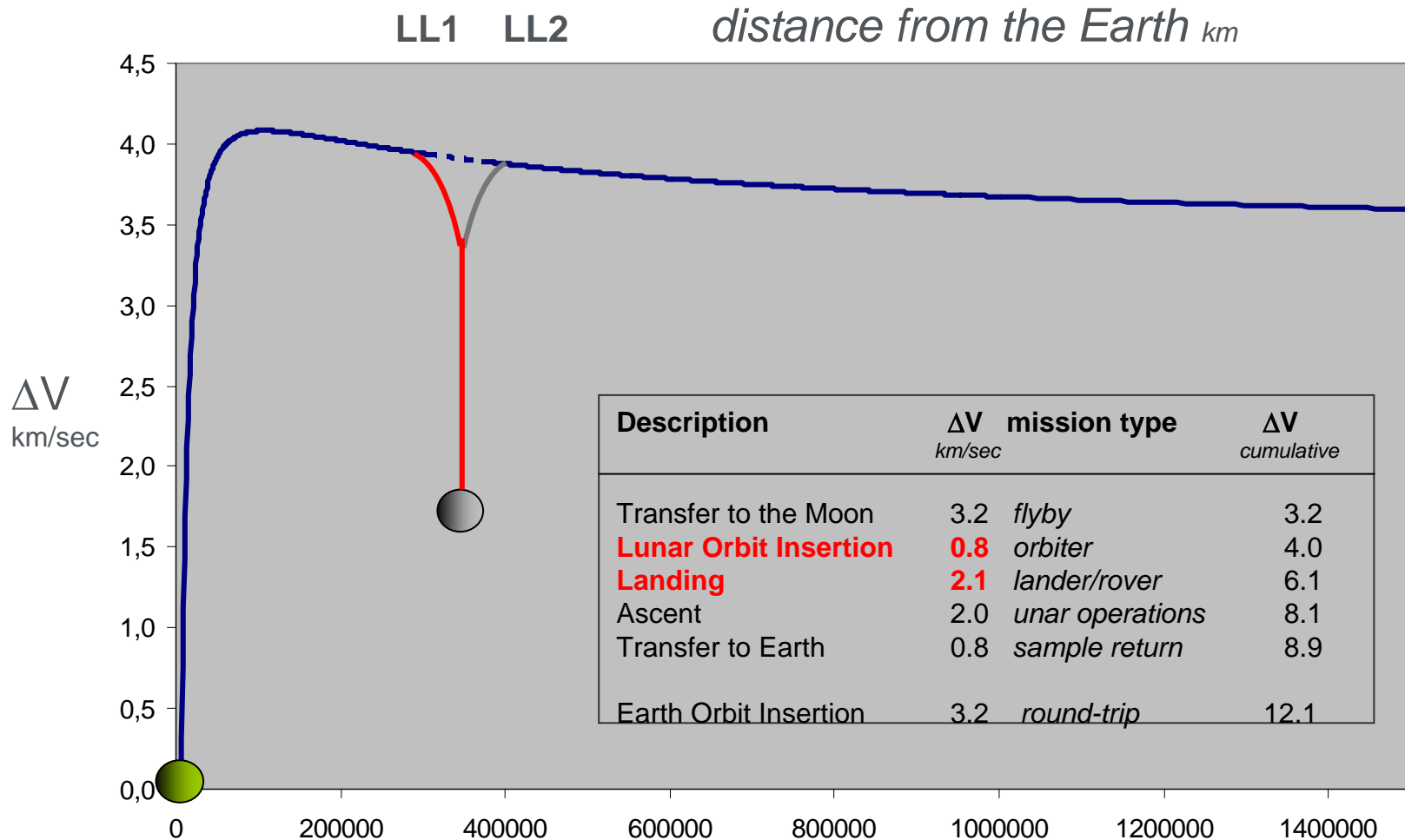
The Accessibility of LL1

160 km LEO  LL1	Earth Injection ΔV <i>(km/s)</i>	Halo Insertion ΔV <i>(km/s)</i>	Total ΔV <i>(km/s)</i>	Gravity fields
Hohmann	3,132	0,618	3,750	<i>Earth</i>
Bi-elliptic	3,232	0,300	3,532	<i>Earth, Moon</i>
Invariant Manifolds	3,235	0	3,235	<i>Earth, Moon, Sun</i>

Halo orbit maintainance: 10 m/sec per year

The L1 Lunar Gateway

circularization

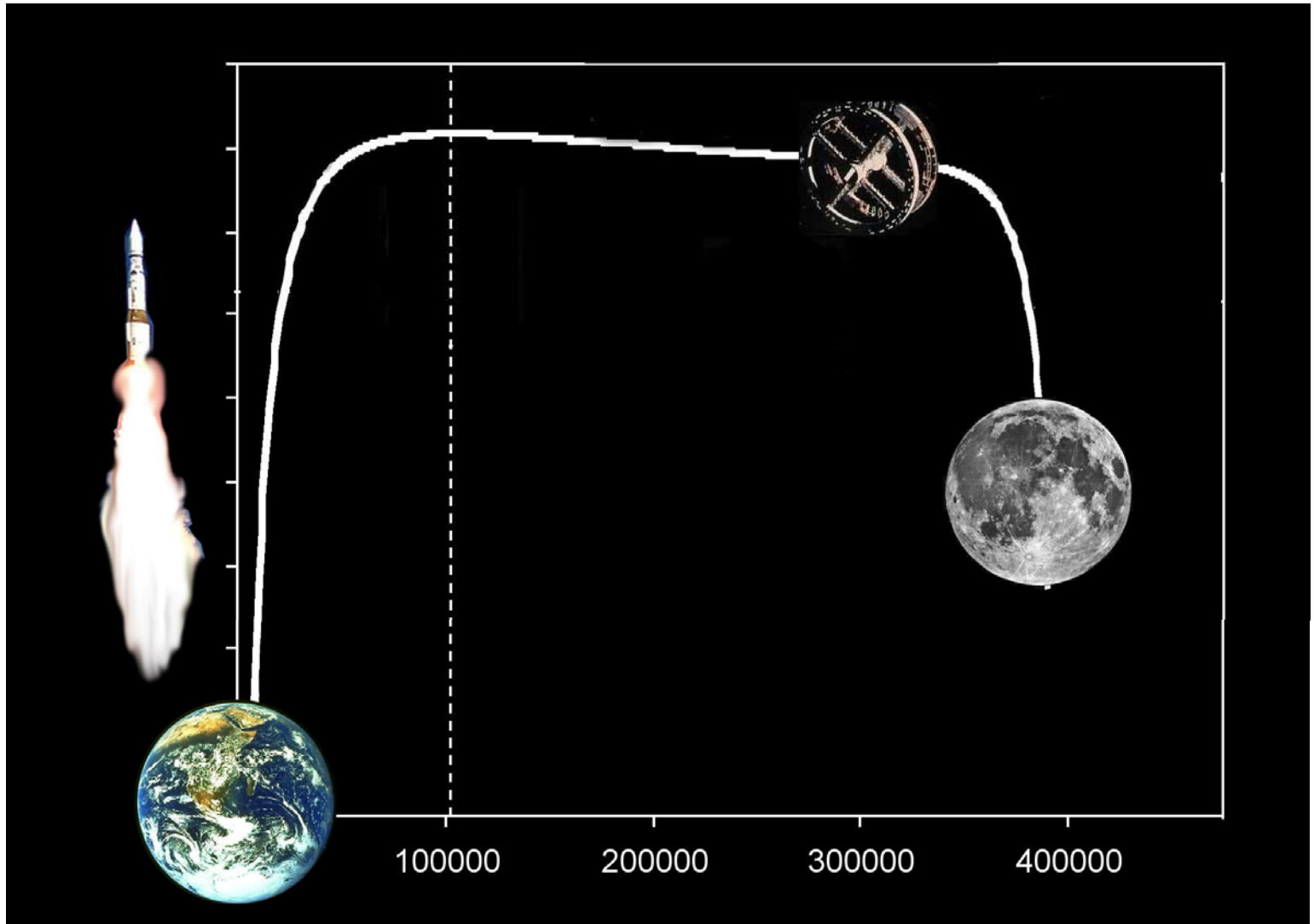


Moon Harbor

LL1 halo orbiting infrastructure for manned/unmanned missions support

- **express lunar surface delivery (within hours)**
- **extremely low ΔV Interplanetary access**
- **space elevator terminal (2 km/s gain)**
- **lunar ISR delivery to Earth (e.g. fuel)**
- **servicing Near- Earth Space missions (from 100000 to 1500000 km - e.g. space telescopes in EL2)**

The Moon Harbor



**Matter tells Space how to curve
and
Space tells Matter how to move**

Douglas Adams

The Hitch-Hiker's Guide to the Galaxy



References

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