Building a Lunar Mission: Chandrayaan 3 Orbit Design from First Principles

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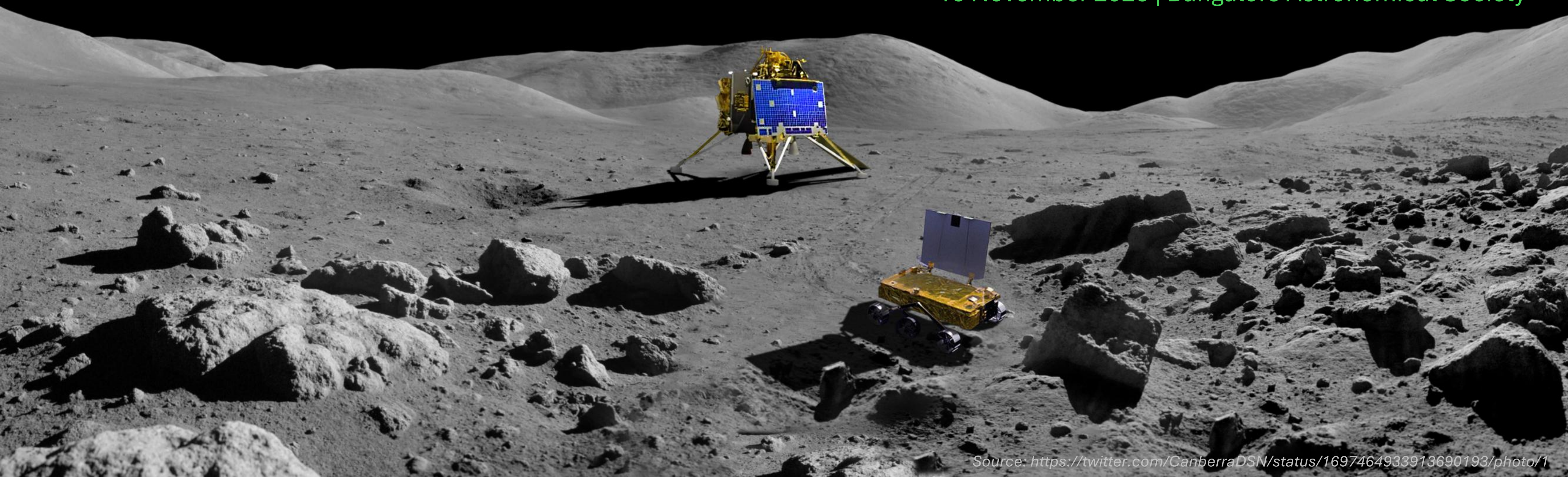
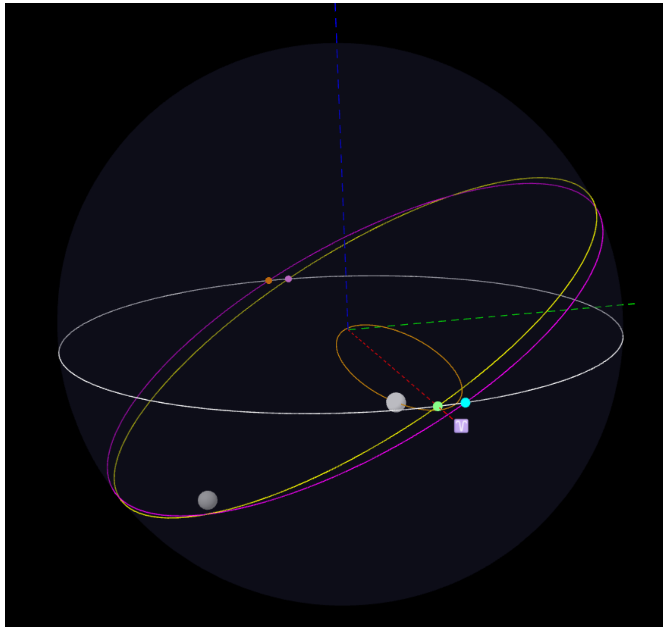
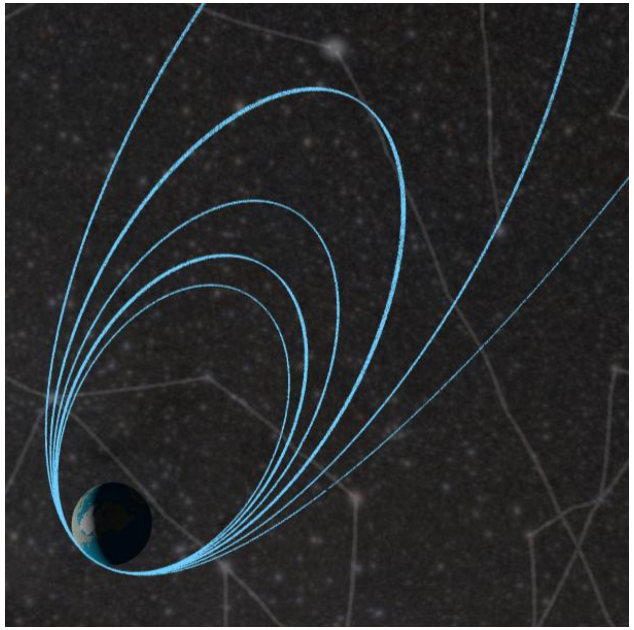
15 November 2025 | Bangalore Astronomical Society



Source: https://twitter.com/CanberraDSN/status/1697464933913690193/photo/1

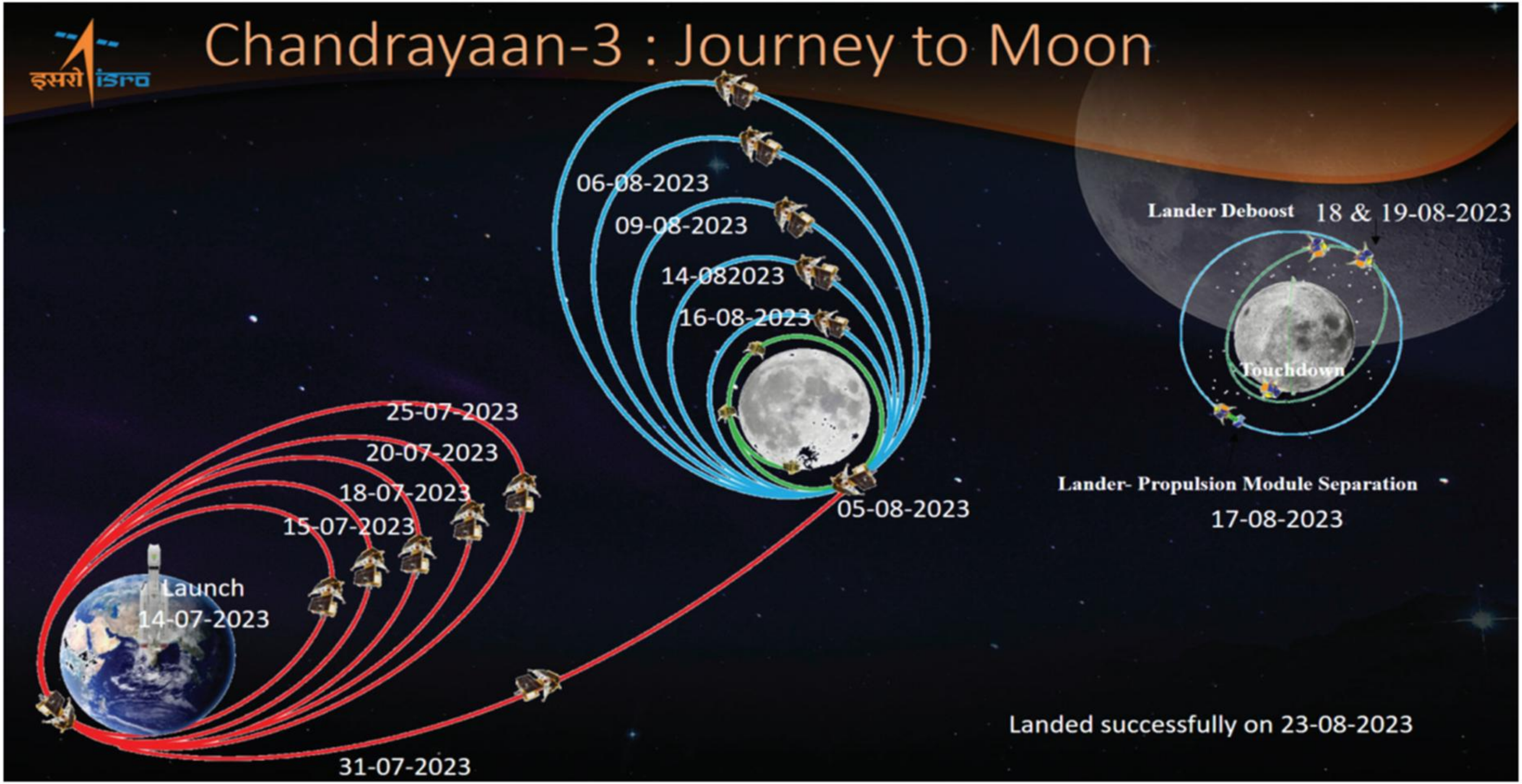




Talk Slides
https://github.com/kvsankar/talks

Mission Design Animation
Live URL: https://kvsankar.github.io/chandrayaan-mission-design/
Source Code: https://github.com/kvsankar/chandrayaan-mission-design

Chandrayaan 3 Animation
Live URL: https://sankara.net/chandrayaan3.html
Source Code: https://github.com/kvsankar/chandrayaan3


Chandrayaan-3 : Journey to Moon
इसरो isro
06-08-2023
09-08-2023
14-082023
16-08-2023
05-08-2023
Lander Deboost
18 & 19-08-2023
Touchdown
Lander- Propulsion Module Separation
17-08-2023
25-07-2023
20-07-2023
18-07-2023
15-07-2023
Launch
14-07-2023
31-07-2023
Landed successfully on 23-08-2023




Goals

- Can we design the Chandrayaan 3 orbit ourselves?
  Can we at least attempt it?
  - First principles
  - Foundational geometry and physics
  - Intuition
- Can we develop an appreciation for the complexities involved?
- Can we kindle our interests? Get inspired?

Non Goals

- Not a crash course in astrodynamics or rocket science
- Not a comprehensive or rigorous treatment of CY3 orbit design
- Does not cover CY3 science payloads

Point A to Point B | No Gravity

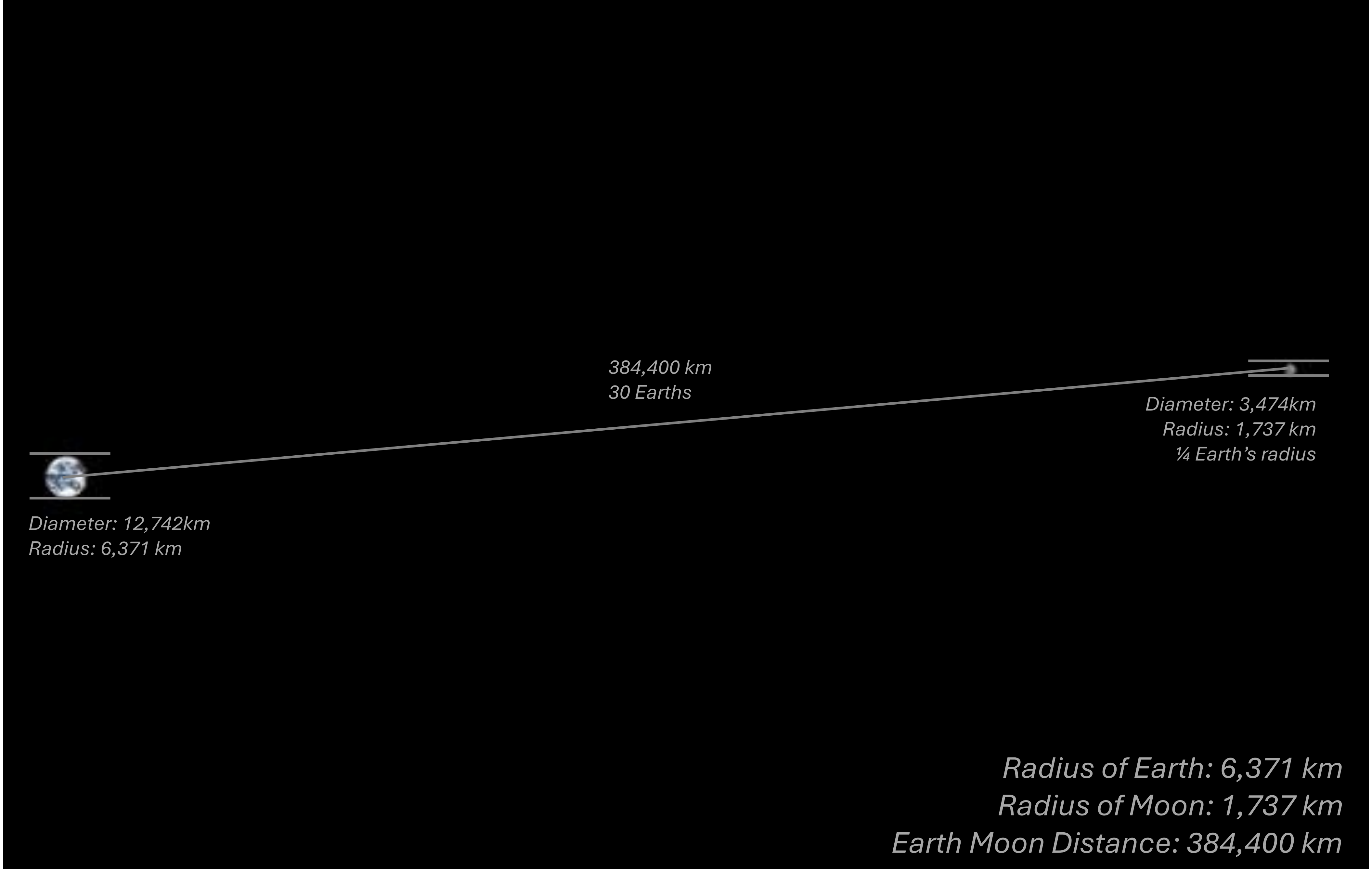
IBSF
aramith

Source: https://c1.peakpx.com/wallpaper/427/549/95/plastic-balls-color-colorful-balls-wallpaper.jpg

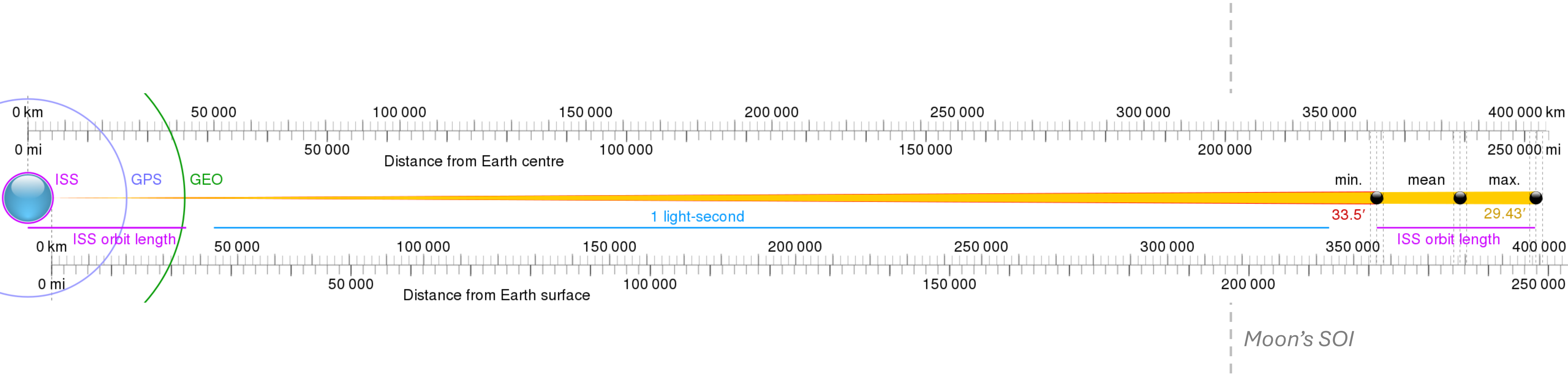
White thermocol ball – 8 cm diameter
Smaller balls – 2 cm diameter

White thermocol ball – 6 cm diameter
Smaller marble – 1.5 cm diameter

Australia is ~4000km wide.
Moon is ~3500km wide.



Source: https://aerospaceweb.org/question/astronomy/q0262.shtml



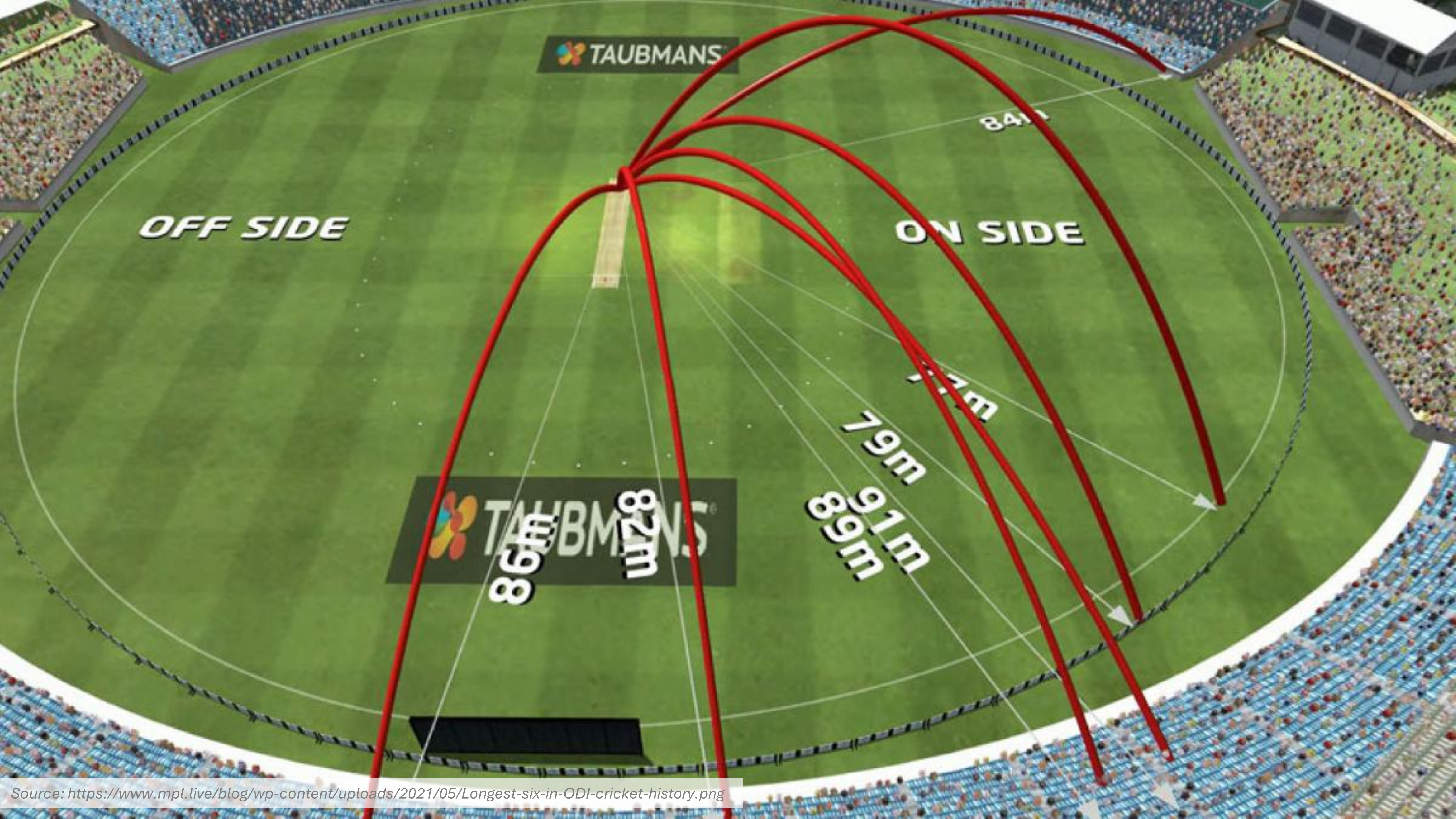
Source: https://en.wikipedia.org/wiki/Orbit_of_the_Moon#/media/File:Moon_distance_range_to_scale.svg

Gravity Constraints

Point A to Point B | No Gravity

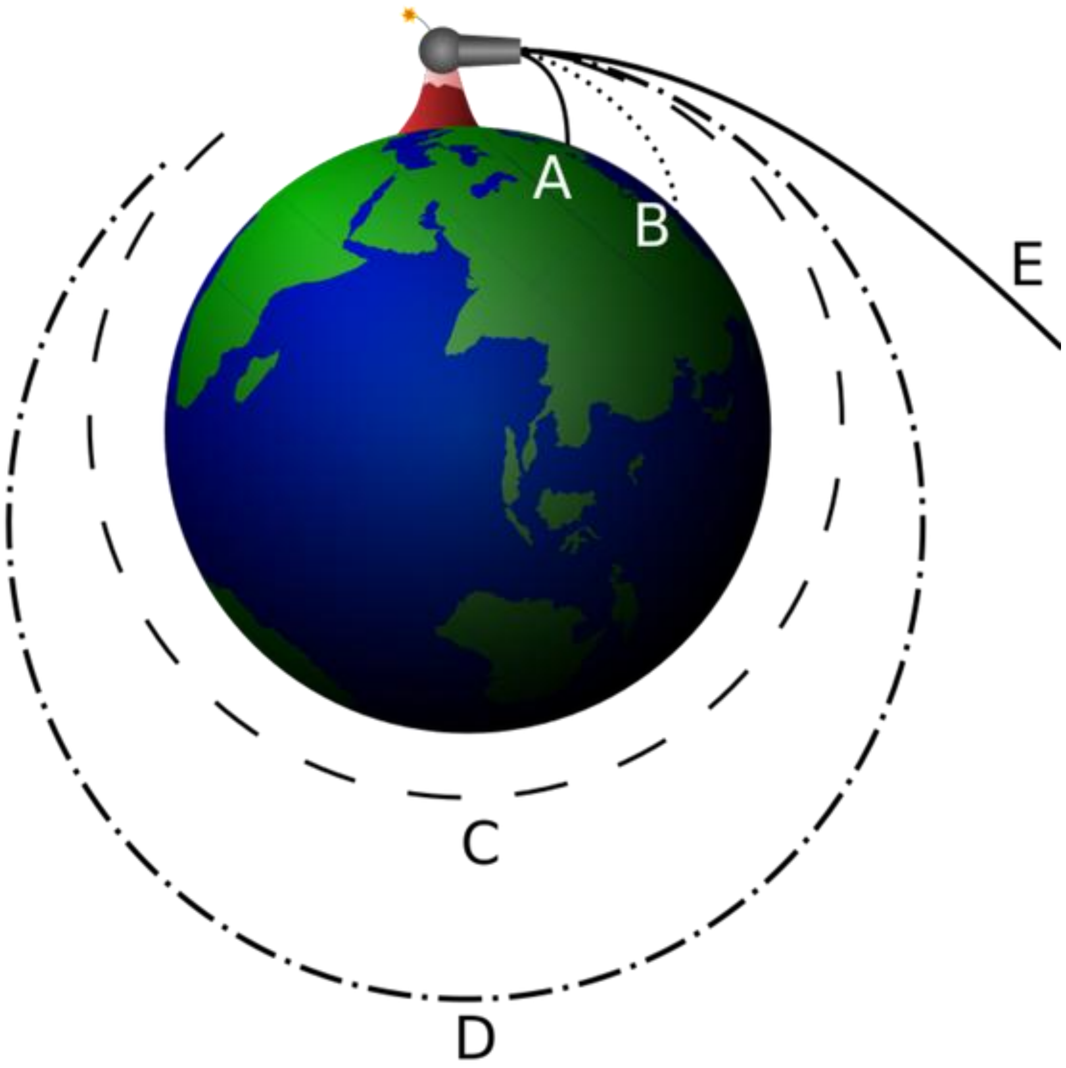
Gravity Constraints

Source: https://indianexpress.com/article/sports/cricket/dean-elgars-drs-gaffe-compared-to-sachin-tendulkars-controversy-in-2011-world-cup-7722592/



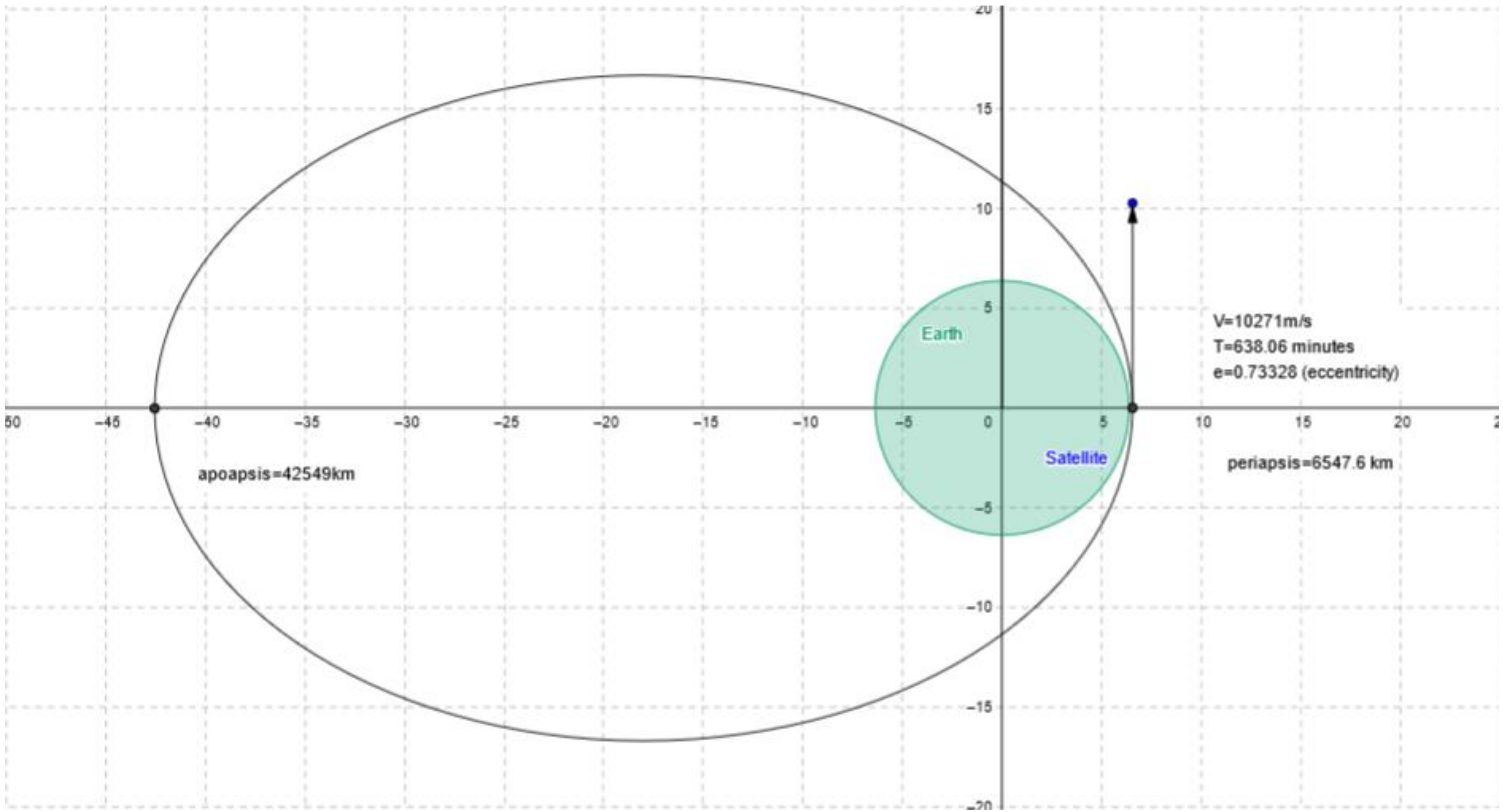
Source: https://www.mpl.live/blog/wp-content/uploads/2021/05/Longest-six-in-ODI-cricket-history.png

Firing a Cannon Ball ...



Source: https://www.quora.com/How-can-a-projectile-fall-around-the-Earth

Let’s Try …



Source: https://www.geogebra.org/classic/sqgxew9e

You Too Can Design a Simple Mission ...

Live URL: https://kvsankar.github.io/chandrayaan-mission-design/
Source Code: https://github.com/kvsankar/chandrayaan-mission-design

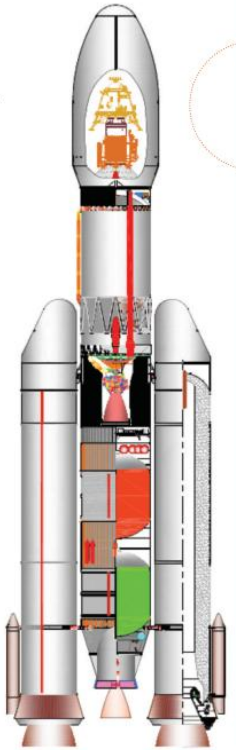
LVM3-M4/ Chandrayaan-3 Mission

LVM3 is the operational heavy lift launch vehicle of ISRO and has a spectacular pedigree of completing 6 consecutive successful missions. This is the 4th operational flight of LVM3, aims to launch the Chandrayaan-3 spacecraft to Geo Transfer Orbit (GTO).

LVM3 has proved its versatility to undertake most complex missions like:

- Injecting multi-satellites
- Mission planning to ensure safe relative distance among separated satellites through re-orientation and velocity addition maneuvers.
- Multi orbit (LEO, MEO, GEO) and execute interplanetary missions.
- India's largest and heaviest launch vehicle ferrying indian and international customer satellites.

LVM3-M4 will be launched from the Second Launch Pad (SLP), SDSC, SHAR.



LVM3-M4 Vehicle Configuration (2S200+L110+C25+PLF)

Payload Mass: 3895 kg

LVM3-M4 Vehicle Characteristics

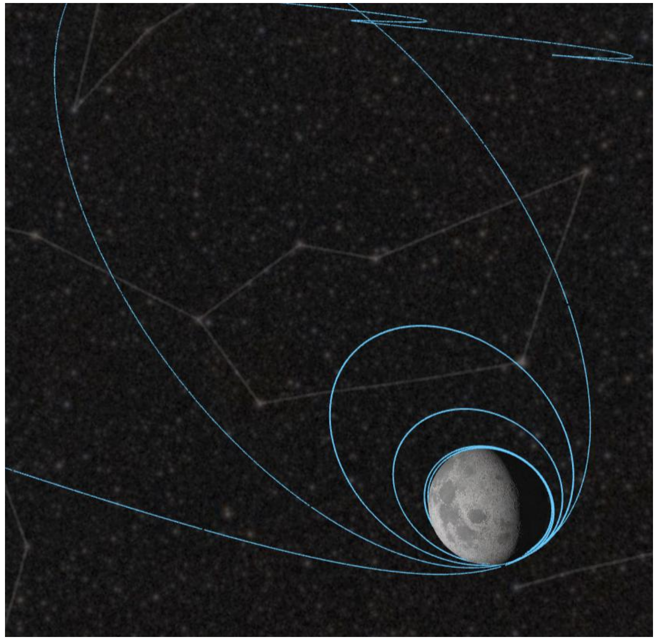
Height	43.5 m
Lift-off Mass	642 t
Propulsion Stages	
Strap-on Motors	2 x S200 (Solid)
Core Stage	L110 (Liquid)
Upper Stage	C25 (Cryo)
Payload Fairing	5 m OPLF

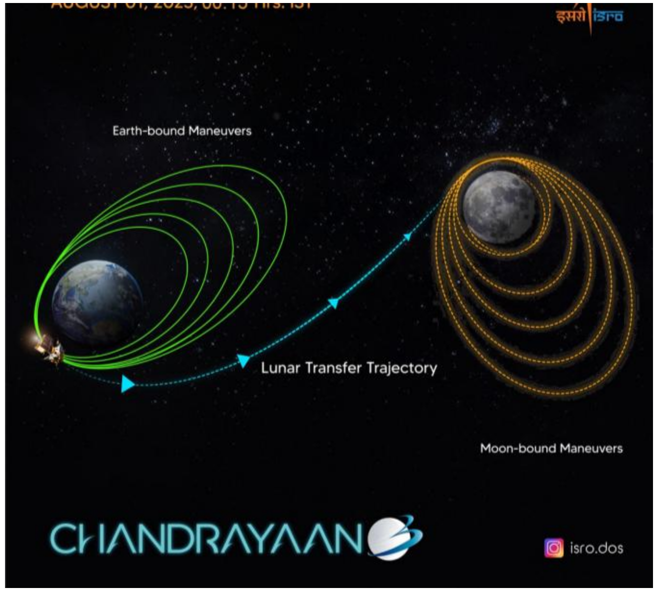
Upper Stage Delta-V Constraints

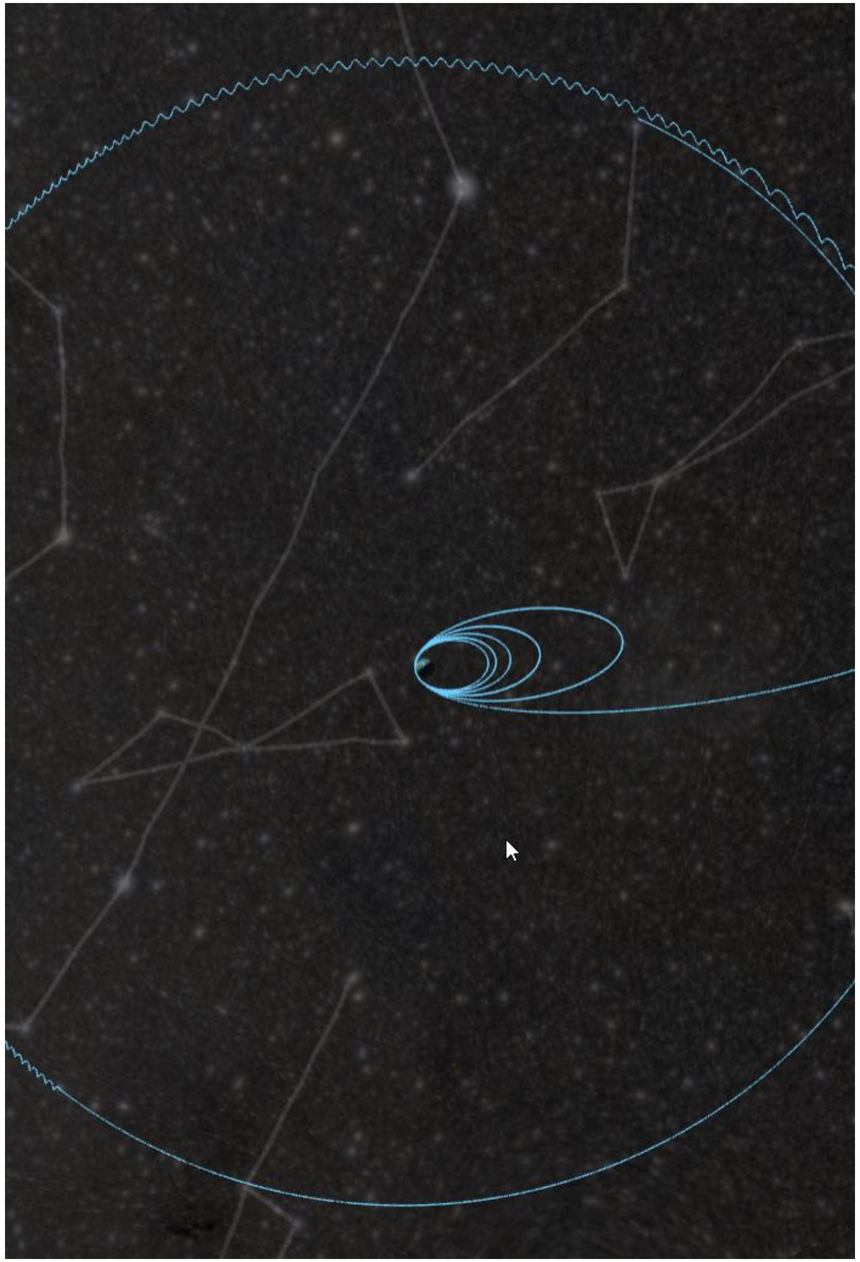
Gravity Constraints

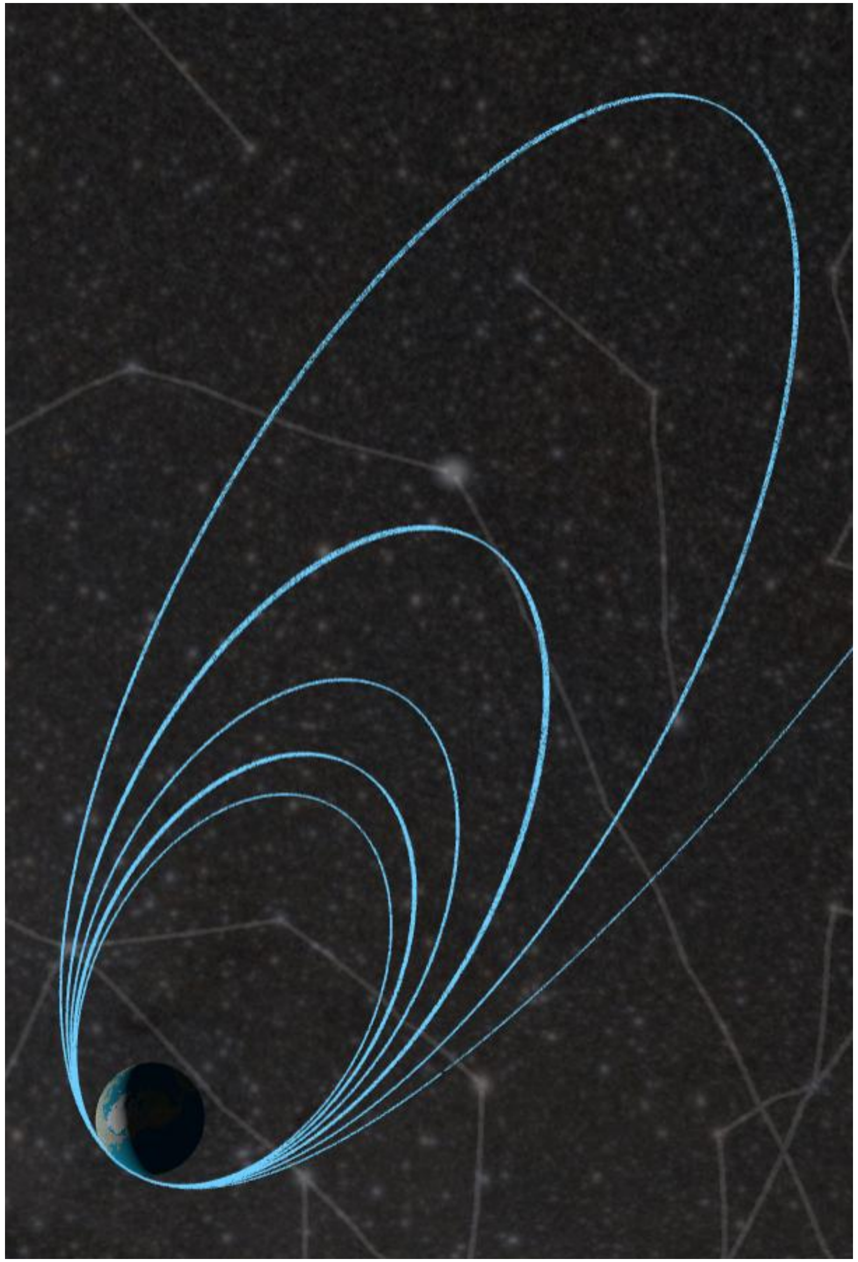
Point A to Point B | No Gravity

Upper Stage Delta-V Constraints




Earth-bound Maneuvers
Lunar Transfer Trajectory
Moon-bound Maneuvers
CHANDRAYAAN
isro.dos





Chandrayaan 3 Orbit Events and Maneuvers

Date (UTC)	Time (UTC)	Event	Primary	Burn Point	Orbit (km)
14-Jul-2023	9:05:00 AM	Launch			
14-Jul-2023	9:23:00 AM	Orbit insertion	Earth		36500x170
15-Jul-2023	6:41:00 AM	EBN1	Earth	Perigee/Pro	41762x173
17-Jul-2023	2:15:00 AM	EBN2	Earth	Apogee/Pro	41603x226
18-Jul-2023	9:24:00 AM	EBN3	Earth	Perigee/Pro	51400x228
20-Jul-2023	9:16:00 AM	EBN4	Earth	Perigee/Pro	71351x233
25-Jul-2023	9:00:00 AM	EBN5	Earth	Perigee/Pro	127603x236
31-Jul-2023	6:43:00 PM	TLI	Earth	Perigee/Pro	369328x288
5-Aug-2023	2:00:00 PM	LOI	Moon	Perilune/Retro	18074x164
6-Aug-2023	5:49:00 PM	LBN1	Moon	Perilune/Retro	4313x170
9-Aug-2023	8:21:00 AM	LBN2	Moon	Perilune/Retro	1437x174
14-Aug-2023	6:38:00 AM	LBN3	Moon	Perilune/Retro	177x150
16-Aug-2023	3:00:00 AM	LBN4	Moon	Perilune/Retro	163x153
17-Aug-2023	7:45:00 AM	PM separation	Moon		163x153
18-Aug-2023	10:20:00 AM	Deboost 1	Moon	Perilune/Retro	157x113
19-Aug-2023	8:20:00 PM	Deboost 2	Moon	Perilune/Retro	134x25
23-Aug-2023	12:33:00 PM	Landing!	Moon		

Orbit Maneuvers with Period and Velocities Computed

Event	Apogee Alt (km)	Perigee Alt (km)	Orbits	Duration (Days)	Relative Time (Days)	Period (hours)	Perigee Velocity (km/s)	Apogee Velocity (km/s)	Delta V (m/s)
Launch									
Orbit insertion	36500	170	2	0.013	0.01	10.740	10.2769	1.5694	
EBN1	41762	173	3.5	0.887	0.90	12.501	10.3495	1.4084	72.57
EBN2*	41603	226	2.5	1.815	2.72	12.465	10.3008	1.4178	-48.66
EBN3	51400	228	3	1.298	4.01	15.967	10.4064	1.1898	105.58
EBN4	71351	233	5	1.994	6.01	23.940	10.5419	0.8966	135.50
EBN5	127603	236	3	4.989	11.00	51.526	10.7172	0.5291	175.32
TLI	369328	288	0.5	6.405	17.40	231.099	10.8399	0.1923	122.70
LOI	18074	164	1	4.803	22.20	28.191	2.1697	0.2082	
LBN1	4313	170	10	1.159	23.36	6.254	1.9775	0.6233	-192.21
LBN2	1437	174	37	2.606	25.97	3.195	1.7899	1.0776	-187.65
LBN3	177	150	21.5	4.928	30.90	2.065	1.6178	1.5950	-172.05
LBN4	163	153	14	1.849	32.75	2.056	1.6129	1.6045	-4.87
PM separation	163	153	13	1.198	33.94	2.056	1.6129	1.6045	0.00
Deboost 1	157	113	17	1.108	35.05	2.019	1.6377	1.5996	24.74
Deboost 2	134	25	46	1.417	36.47	1.930	1.6931	1.5945	55.46
Landing!				3.676	40.14				

[Ascent Orbit and Geometry Constraints]

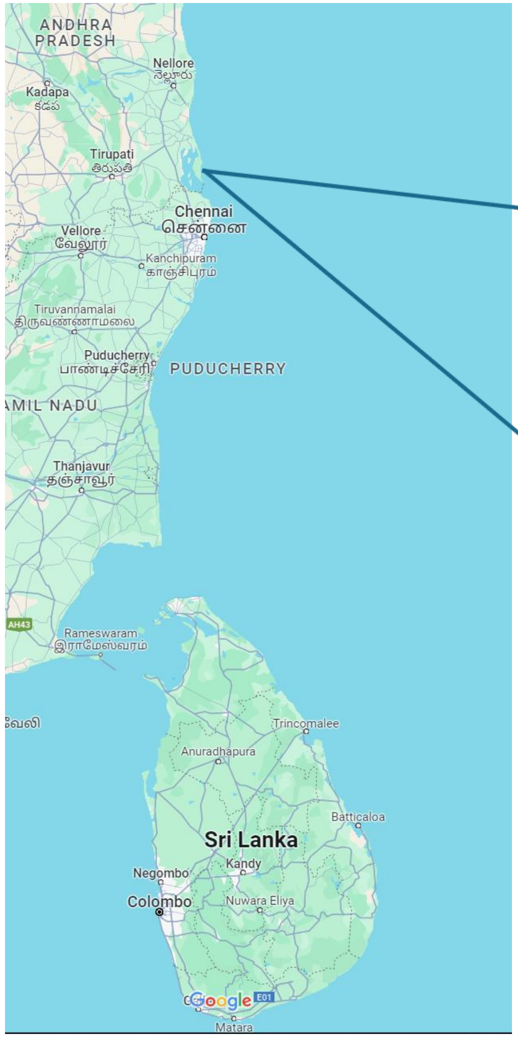
[Upper Stage Delta-V Constraints]

[Gravity Constraints]

Point A to Point B | No Gravity

Ascent Orbit & Geometry Constraints

Launch Constraints



Azimuth 106.7°
Inclination 21.5°
AoP 178°
Max apogee 39,350km

Azimuth 129.9°
Inclination 41.8°
AoP 198° through 203°
Max apogee 35,770km through 33,925km
Low apogee due to less gains from earth's rotation

$$\cos(inclination) = \cos(lat) * \sin(azimuth)$$

Launch Window Constraints

Ascent Orbit and Geometry Constraints

Upper Stage Delta-V Constraints

Gravity Constraints

Point A to Point B | No Gravity

Launch Window Constraints

Launch Window

- LOI timing determined by Moon's crossing equatorial plane
  - Two opportunities per month
- TLI timing implicitly determined by LOI timing
- Line of apsides determined by LOI intercept
  - Not just for the lunar transfer trajectory
  - But for all parking orbits including the launch orbit
- Launch orbit
  - Needs to align with the LTT line of apsides
  - Weeklong window – buffers to fine tune orbit raising strategy
  - Instantaneous launch window on a day to match $\Omega + \omega$

Lunar Orbit Constraints

Launch Window Constraints

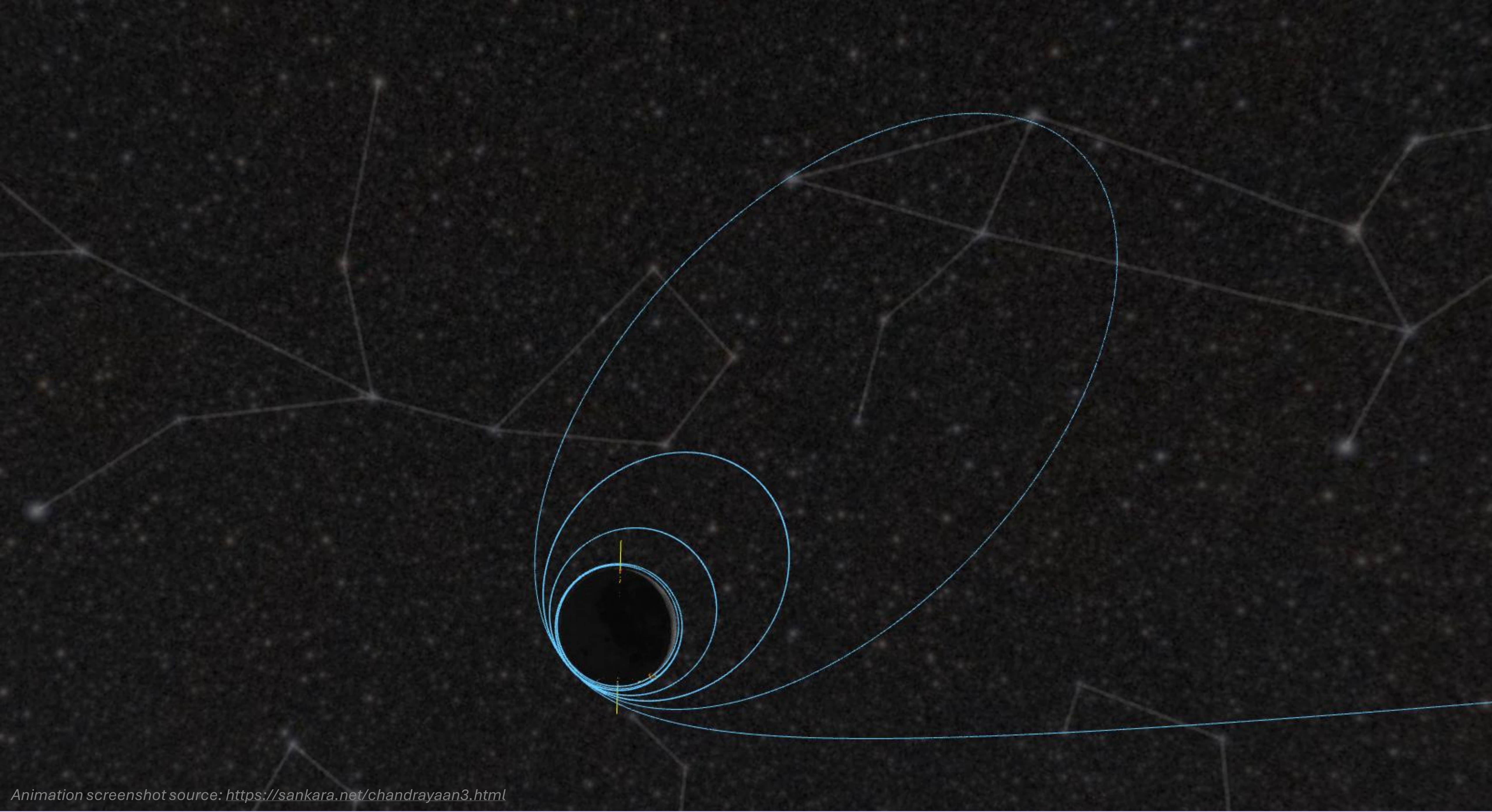
Ascent Orbit and Geometry Constraints

Upper Stage Delta-V Constraints

Gravity Constraints

Point A to Point B | No Gravity

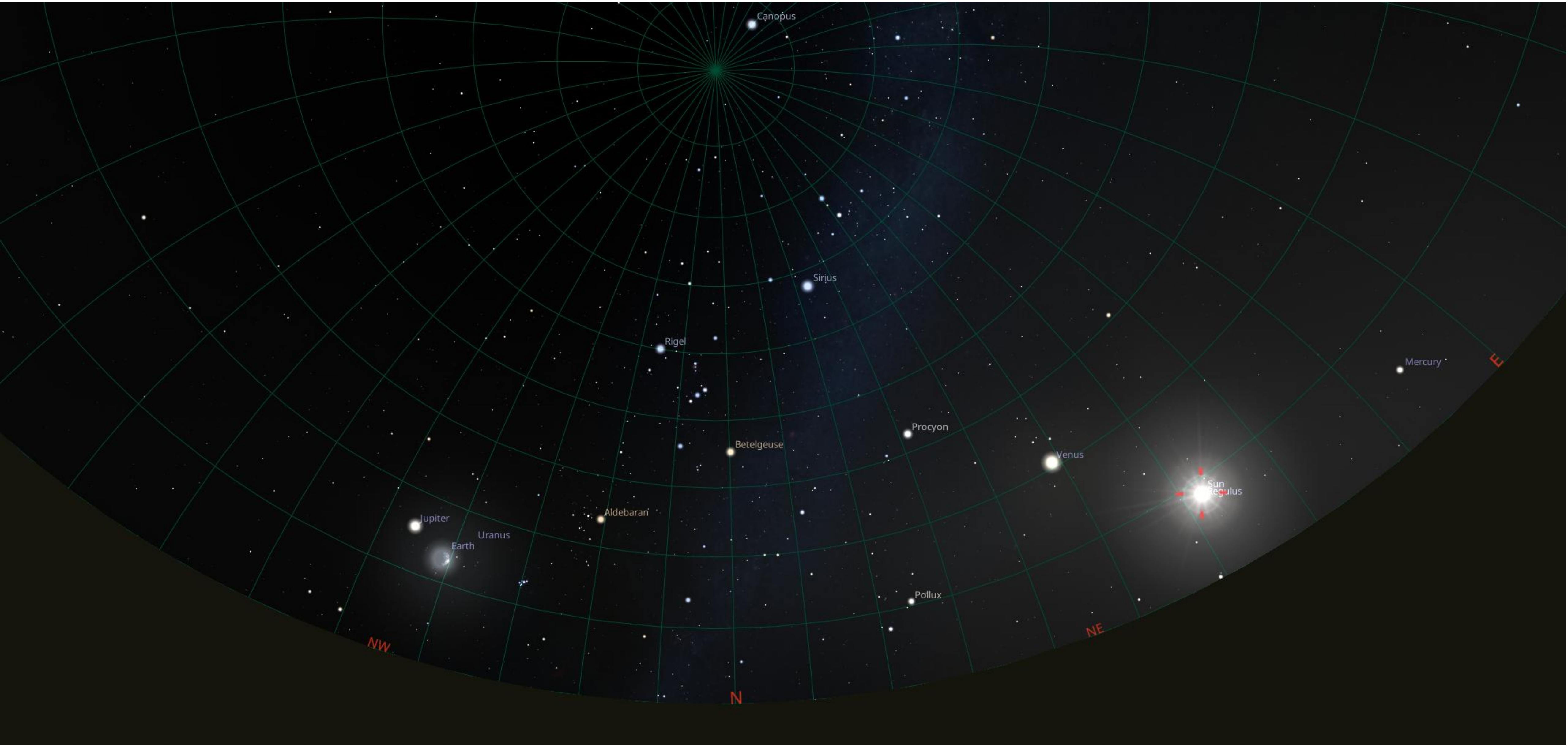
Lunar Orbit Constraints



Animation screenshot source: https://sankara.net/chandrayaan3.html

Lunar Orbits

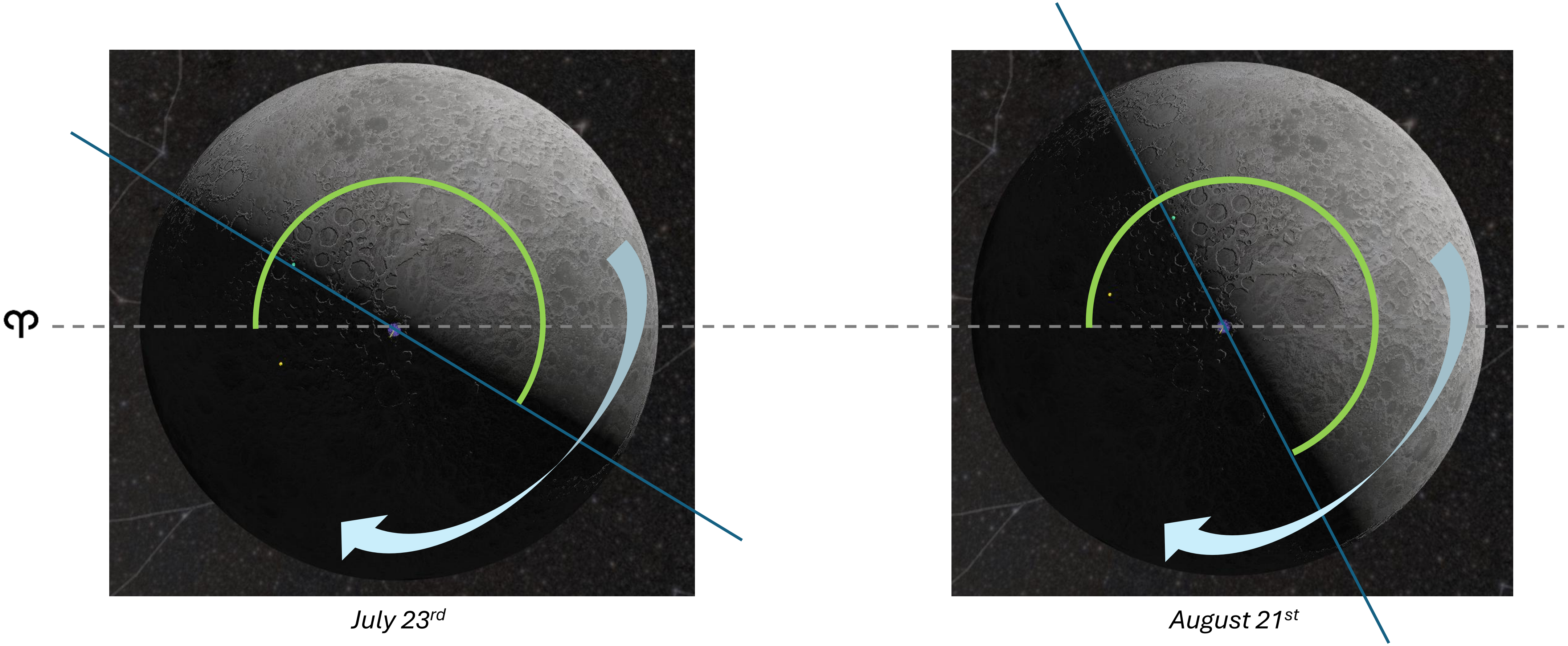
- Polar orbits
  - Reachability to PLS and ALS
    PLS: 69.367621° S, 32.348126° E
    ALS: 69.497764° S, 17.330409° W
  - Lunar imaging coverage (at least for CY2)
  - Negligible cross axis ground track shift
- Sun altitude 6–9° at landing
  - Determines the landing window in a synodic month
  - Implies the RAAN of the lunar orbit
  - No orbit inclination maneuvers ⇒ RAAN remains the same



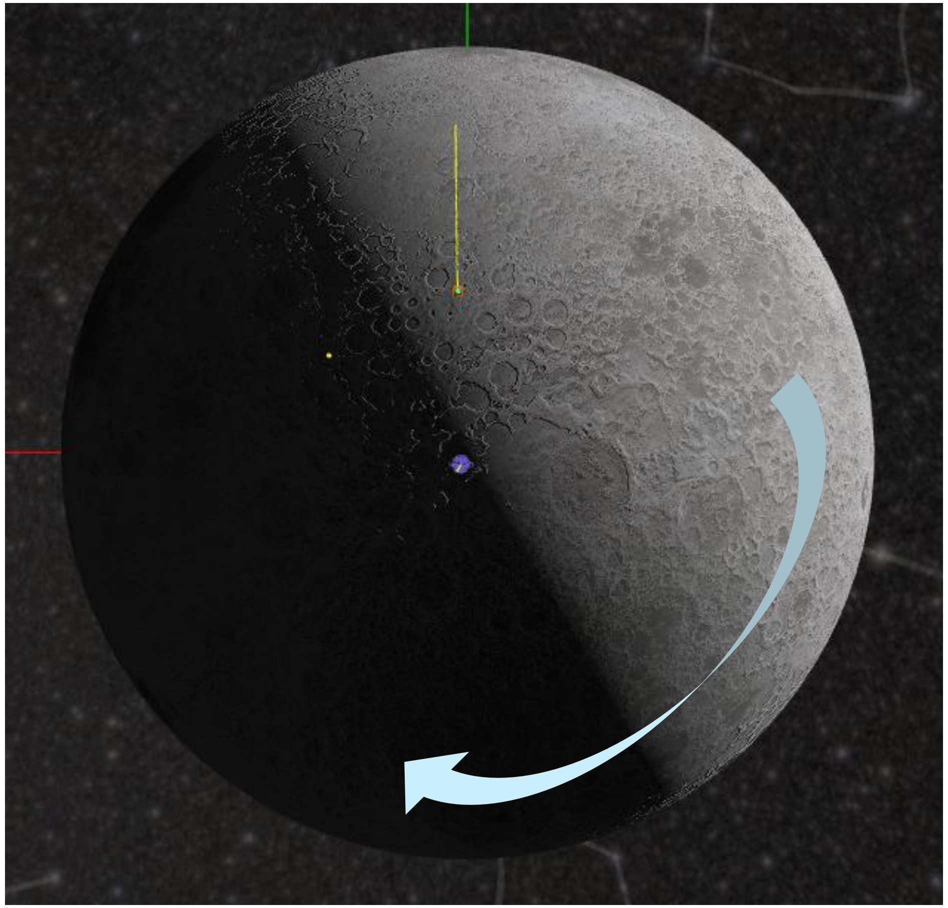
Sunrise at the PLS 69.367621˚S, 32.348126˚E: Aug 21st 10:21 UTC – Sun altitude 0 degrees
At CY3 landing time Aug 23rd 12:34 UTC – Sun altitude 8.5 degrees
Local Sidereal Time 6h 2m (91 degrees)

Source: Stellarium screenshot

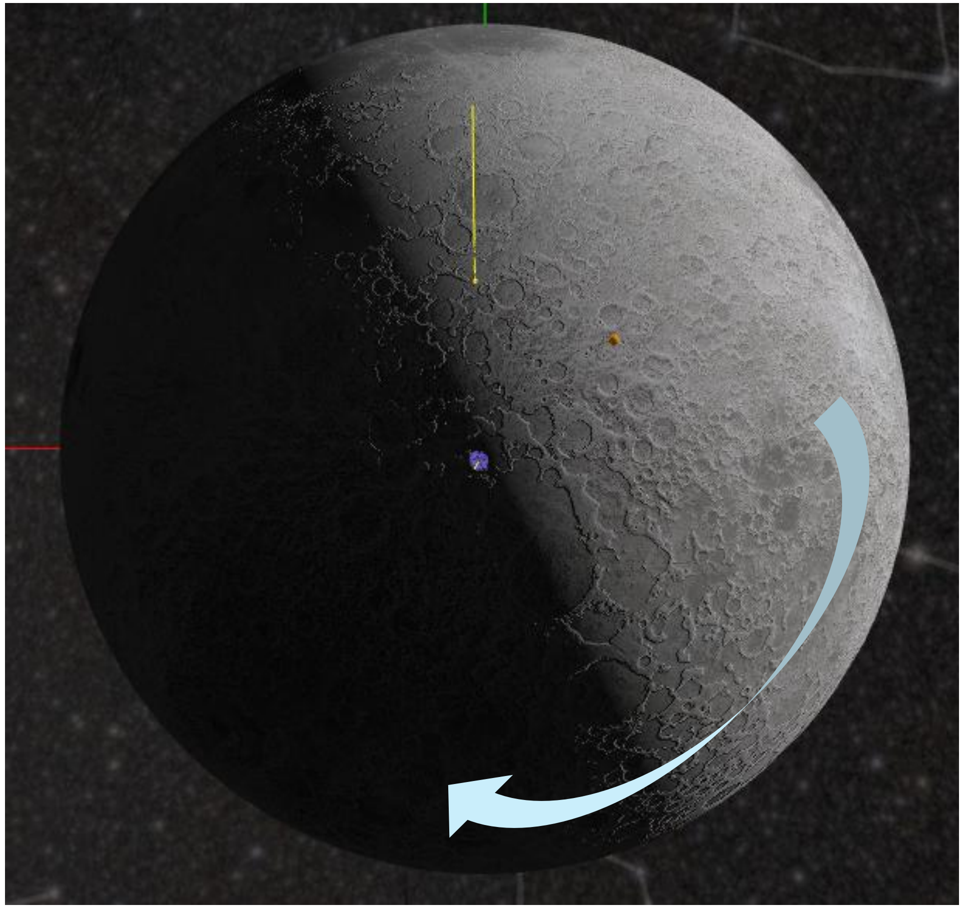
RAAN Aligning with Terminator Lines



Animation screenshots source: https://sankara.net/chandrayaan3.html



PLS: Aug 23rd
32.3 East

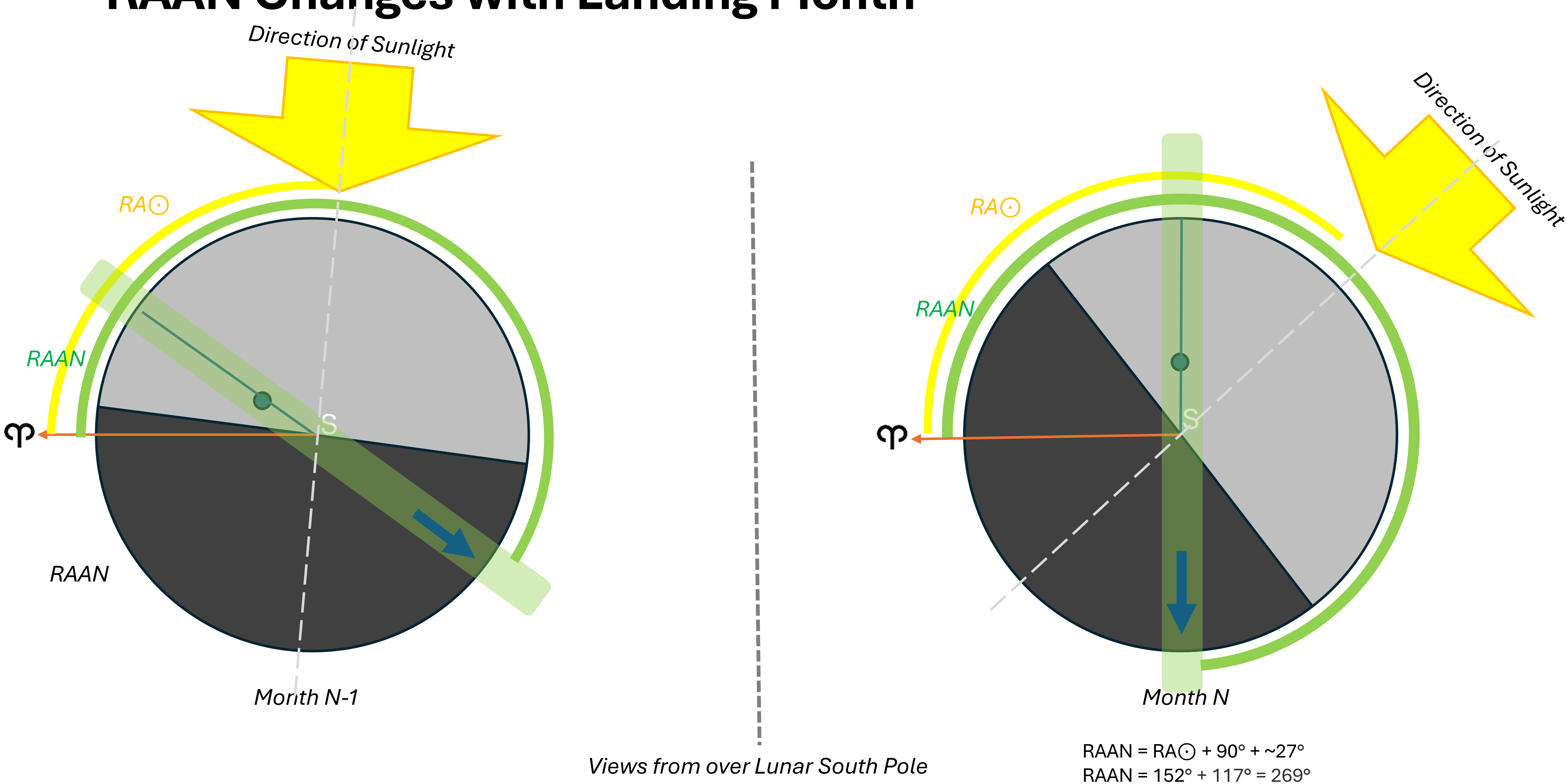


ALS: Aug 27th
17.3 West

40 degrees in longitude ~ 4 days
360 degrees in longitude ~ 27.3 days
13.3 degrees in longitude ~ 1 day

Animation screenshots source: https://sankara.net/chandrayaan3.html

RAAN Changes with Landing Month



RAAN = RA☉ + 90° + ~27°
RAAN = 152° + 117° = 269°

Operational Constraints

Lunar Orbit Constraints

Launch Window Constraints

Ascent Orbit and Geometry Constraints

Upper Stage Delta-V Constraints

Gravity Constraints

Point A to Point B | No Gravity

Operational Constraints

Mission Design

Mission Design

Science Goals

Sites suitable for soft landing

PLS
69.367621˚S, 32.348126˚E

Reachable after 3 to 4 days from the same orbit

ALS
69.497764 ˚S, 17.330409 ˚W

Altitude of Sun at PLS/ALS about 6° while landing
Polar orbit for lander during landing
Polar orbit for orbiter
Minimal eclipse time

Lunar Day = 29.5 Earth Days →
Daytime = Nighttime = 14.75 earth days
~ One landing opportunity every month

Candidate Landing Day *Month N*	Candidate Landing Day *Month N+1*	Candidate Landing Day *Month N+x*
RAAN	RAAN	RAAN

RAAN = Right Ascension of Ascending Node
AOP = Argument of Perigee

Moon close to nodes to reduce orbit plane changes
AOP suitable for RAAN/Inclination
Higher apogees at EPO insertion to reduce fuel
Constraints due to launch site, rocket designs, etc.

LVM3 can vary AOP a bit though
nominal value is close to 180 degrees;
Some candidate landing days can be dropped here

Candidate LOI Epoch	Candidate LOI Epoch	Candidate LOI Epoch
TLI Epoch	TLI Epoch	TLI Epoch

One or two opportunities prior to landing
aligned with the nodal crossing

4 to 5 days

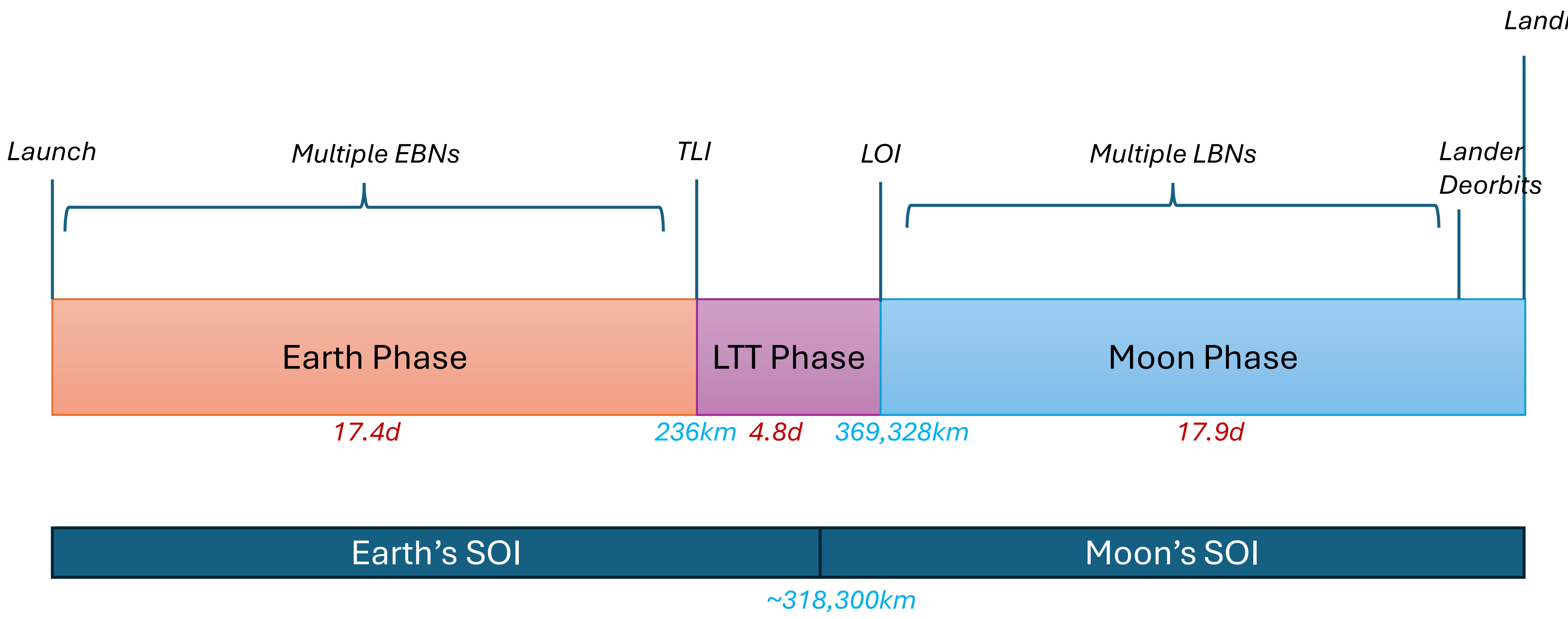
Time window for successive EBNs
Visibility from tracking stations during burns

Flexibility via EBNs to meet the same TLI epoch
from different launch days

Launch Week & Time	Launch Week & Time	Launch Week & Time

Based on "ISRO's Unprecedented Journey to the Moon" by Mathavaraj S et al.
Source: https://ui.adsabs.harvard.edu/abs/2020AcAau.177..286S/abstract

Timeline



EBN = Earth Bound Maneuver – usually, perigee burns making use of Oberth effect to raise apogee
LTT = Lunar Transfer Trajectory
TLI = Trans Lunar Injection
LBN = Lunar Bound Maneuver – usually perilune burns making use of Oberth effect to drop apolune
LOI = Lunar Orbit Insertion

Takeaways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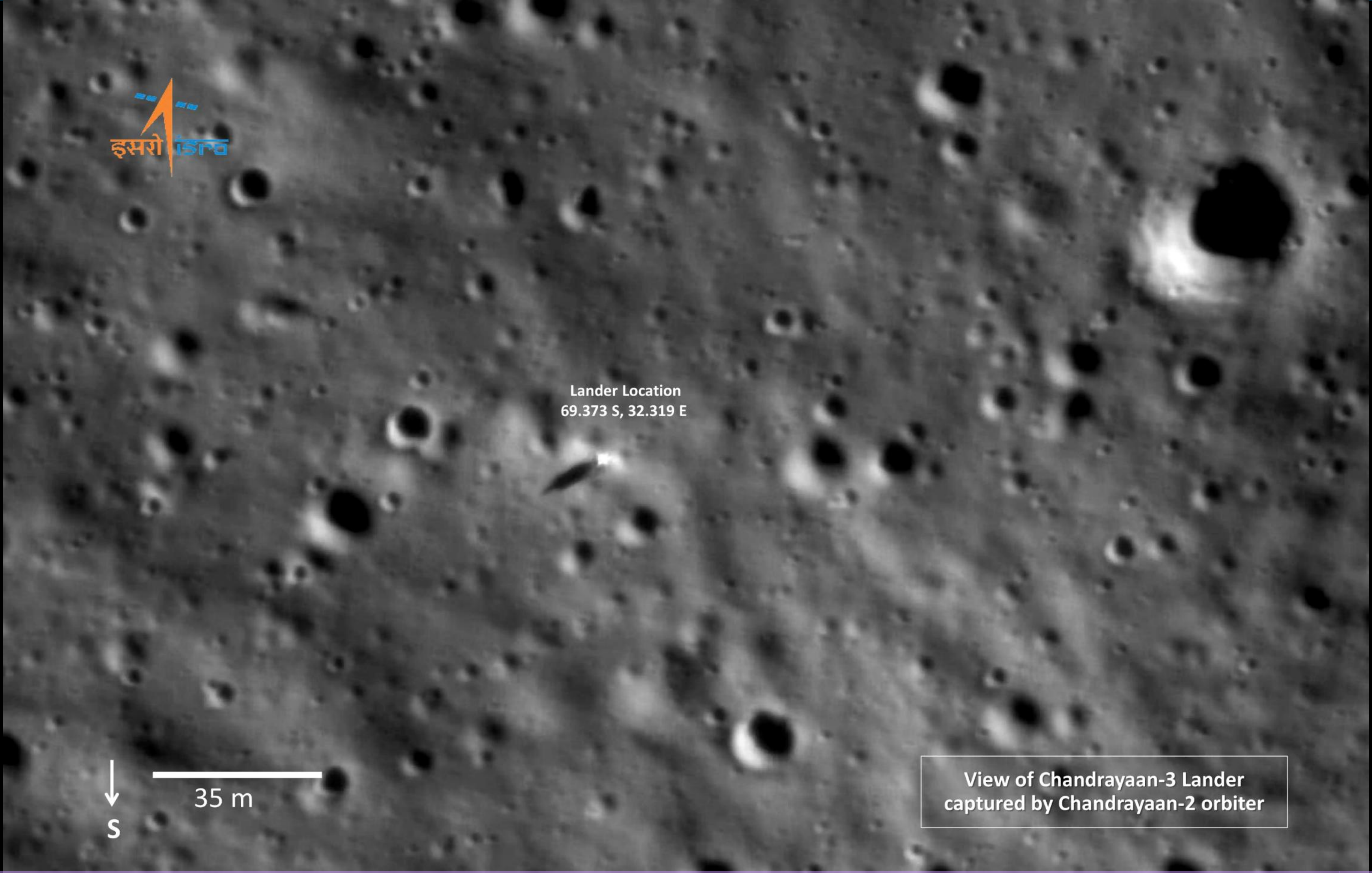
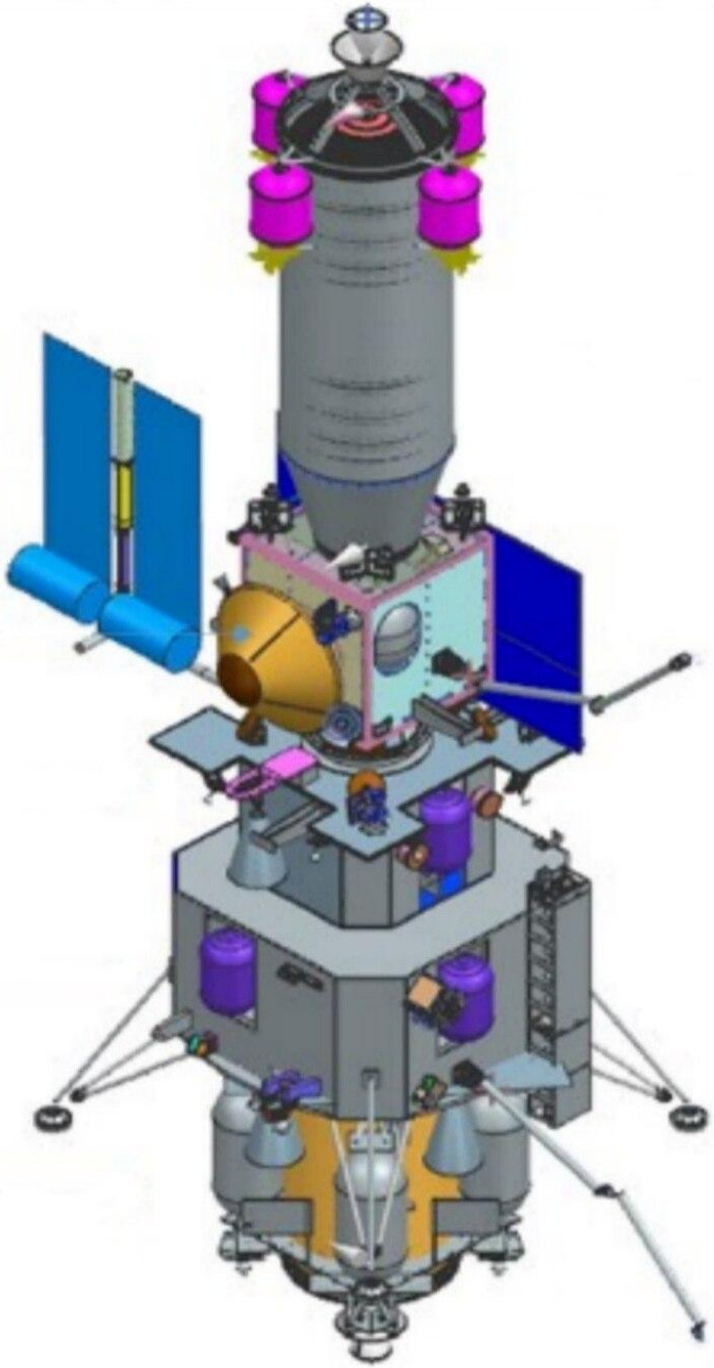


इसरो isro
Lander Location
69.373 S, 32.319 E
S
35 m
View of Chandrayaan-3 Lander
captured by Chandrayaan-2 orbiter



Supplementary Material

Elliptic Orbits: Key Equations

$$v = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)}$$

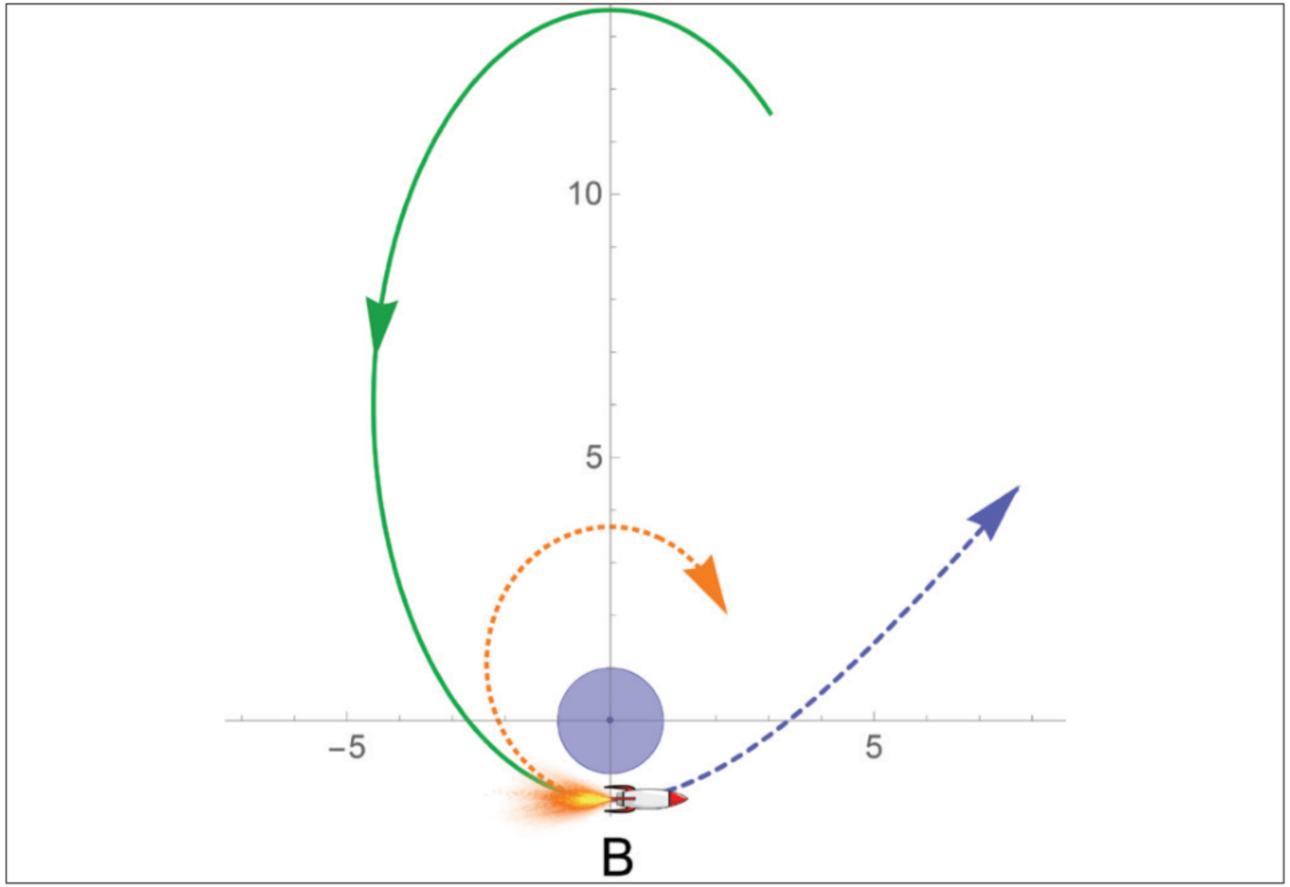
Vis-viva equation in two forms

$$\frac{v^2}{2} - \frac{\mu}{r} = -\frac{\mu}{2a} = \epsilon < 0$$

v = orbital velocity
$\mu = G(m_1+m_2)$
r = distance between orbiting body and center of mass
a = semi major axis
T = orbital period

$$T = 2\pi\sqrt{\frac{a^3}{\mu}}$$

Oberth Effect



The greatest boost to the rocket's orbital energy is produced by a prograde (forward-acting) impulse made near periapsis.

Source: https://www.researchgate.net/publication/336060638_Rocket_propulsion_classical_relativity_and_the_Oberth_effect

Oberth Effect Example

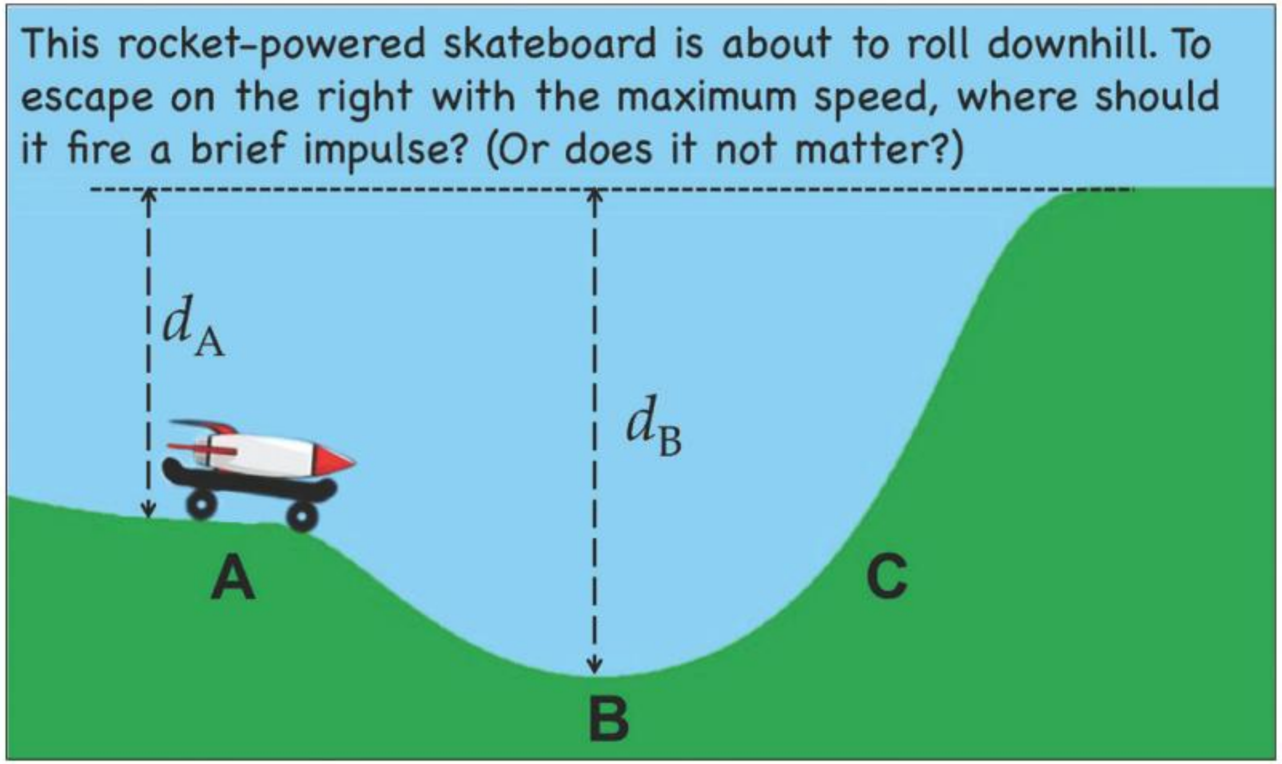
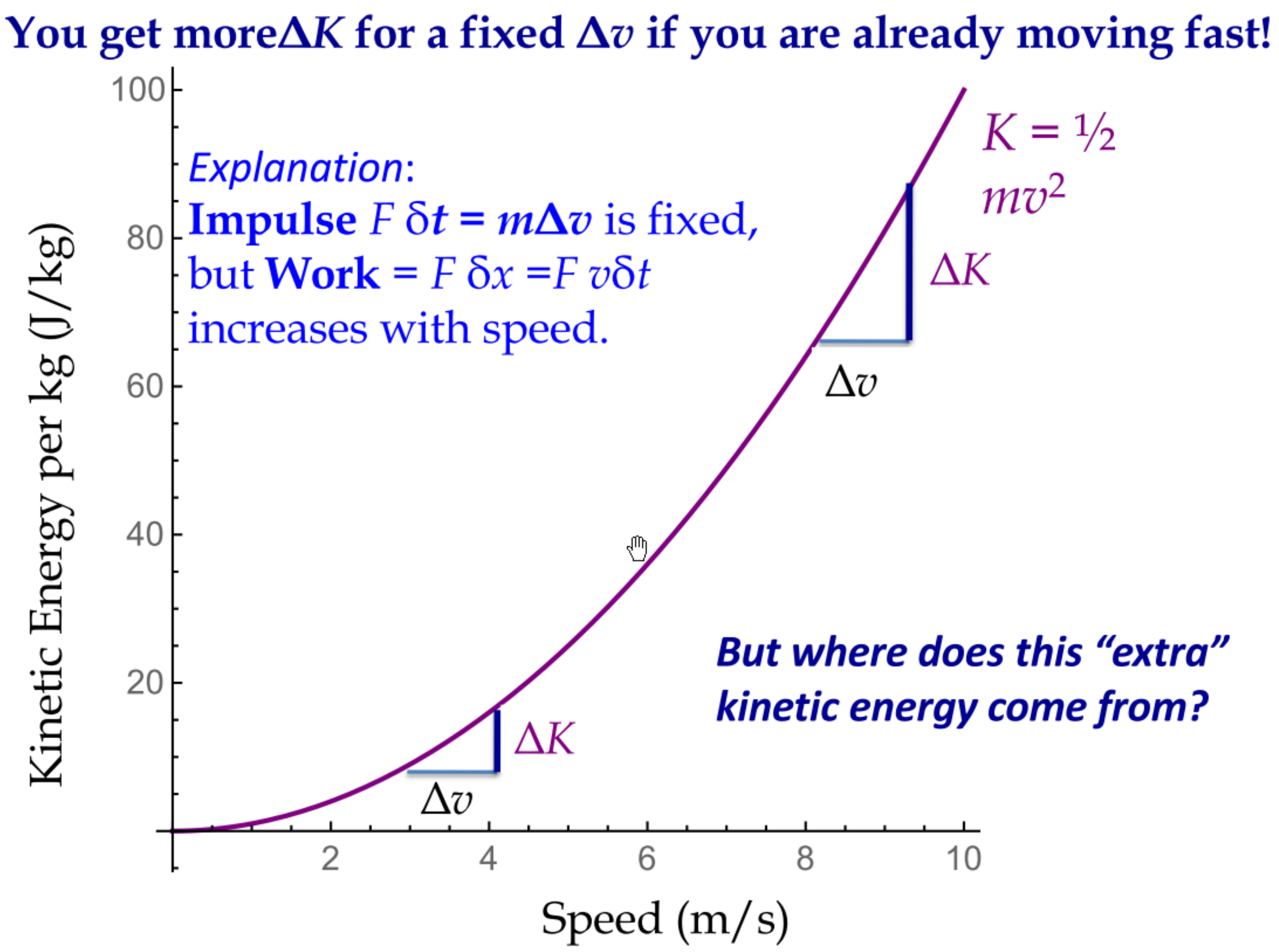


Fig. 1. Statement of the problem. A version without annotations is provided in the online supplement.[16]

$$\Delta K_R = \tfrac{1}{2} M_R (v+\Delta v)^2 - \tfrac{1}{2} M_R v^2 = \tfrac{1}{2} M_R (\Delta v)^2 + M_R v \Delta v, \quad (2)$$

Source: https://www.researchgate.net/publication/336060638_Rocket_propulsion_classical_relativity_and_the_Oberth_effect

Oberth Effect Explained



Source: https://www.researchgate.net/publication/336060638_Rocket_propulsion_classical_relativity_and_the_Oberth_effect

Rocket Equation

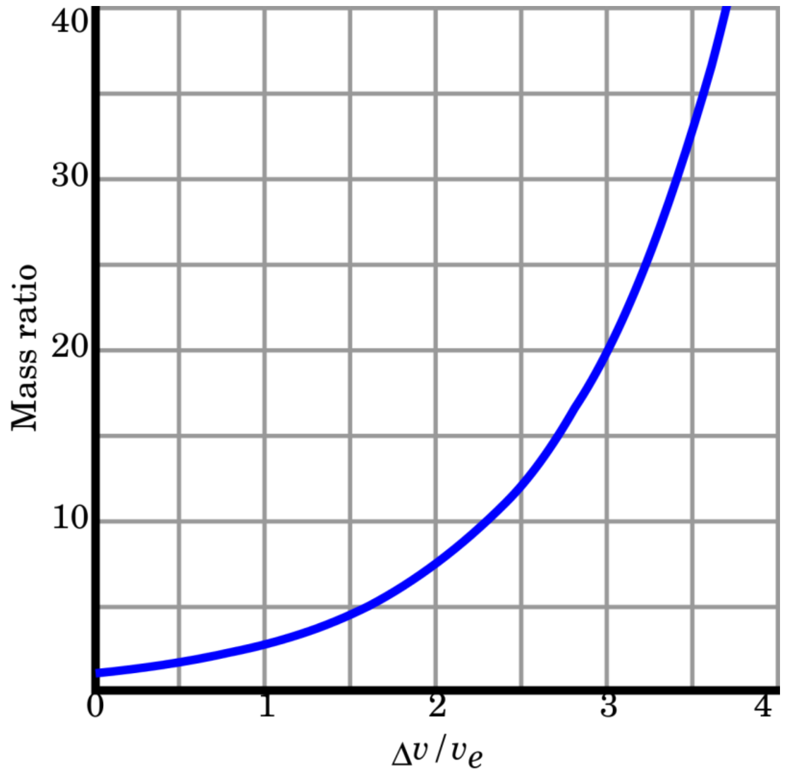
$$\Delta v = v_e \ln \frac{m_0}{m_1}$$

where

- Δv is the desired change in the rocket's velocity
- v_e is the effective exhaust velocity (see specific impulse)
- m_0 is the initial mass (rocket plus contents plus propellant)
- m_1 is the final mass (rocket plus contents)

This equation can be rewritten in the following equivalent form:

$$\frac{m_0}{m_1} = e^{\Delta v / v_e}$$



Source: https://en.wikipedia.org/wiki/Tsiolkovsky_rocket_equation