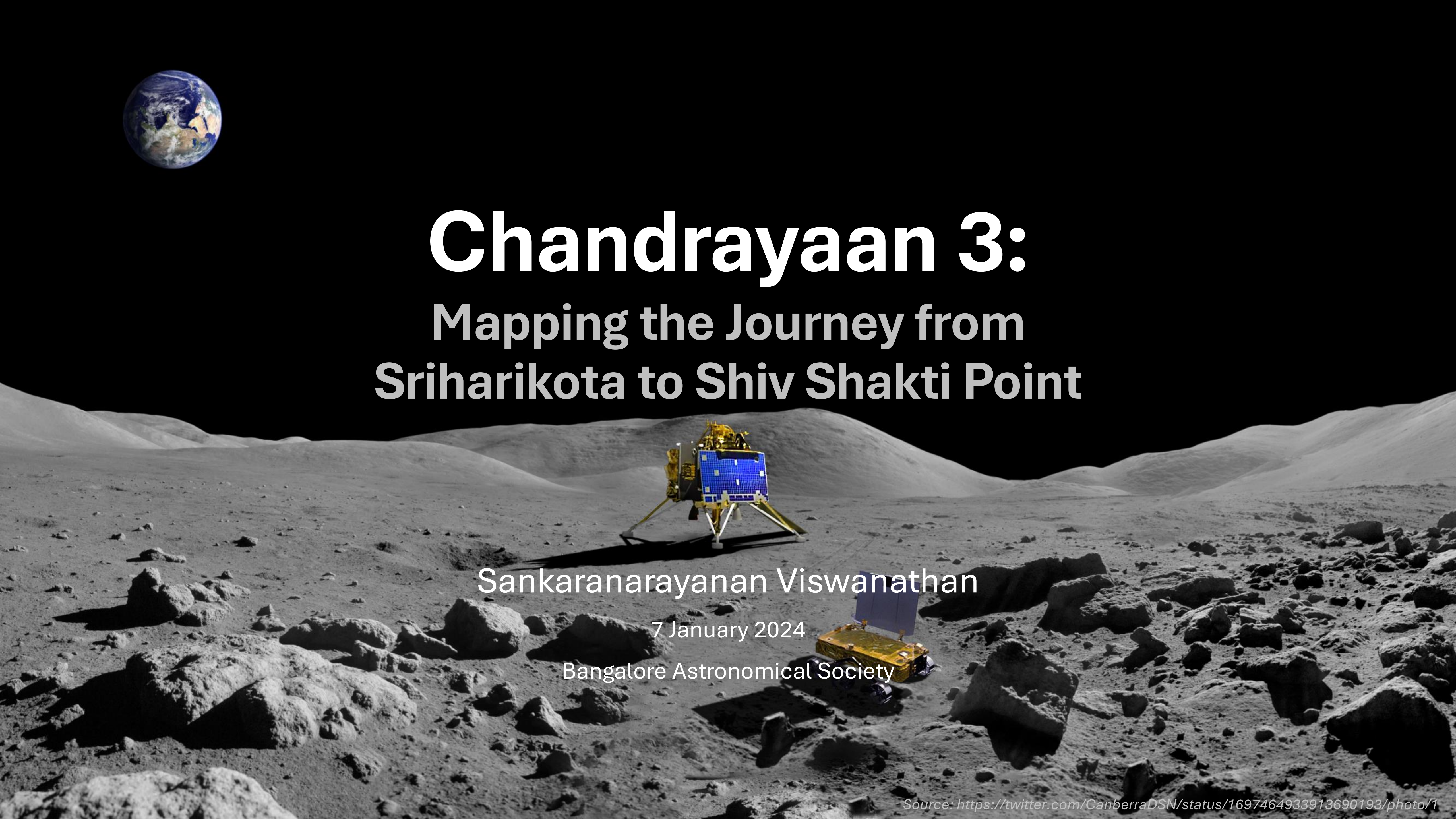


Chandrayaan 3:

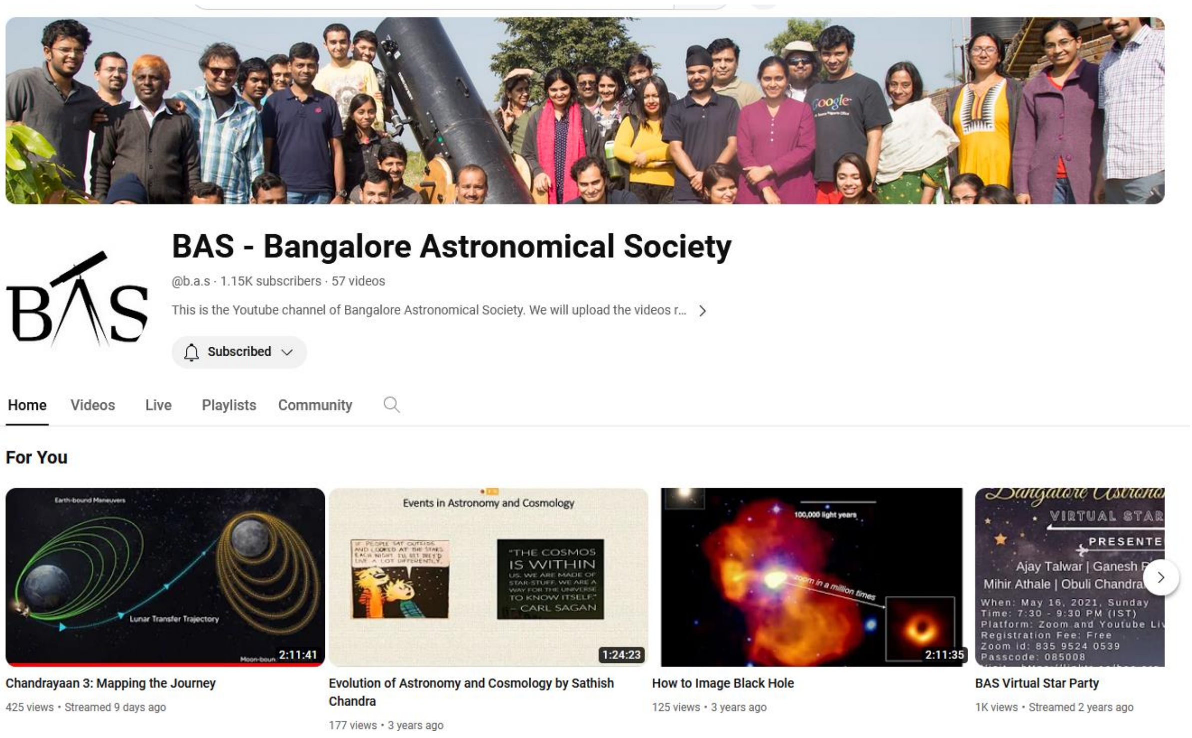
Mapping the Journey from Sriharikota to Shiv Shakti Point

Sankaranarayanan Viswanathan

7 January 2024

Bangalore Astronomical Society

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



Talk: https://www.youtube.com/watch?v=hl5MWLWvqjU

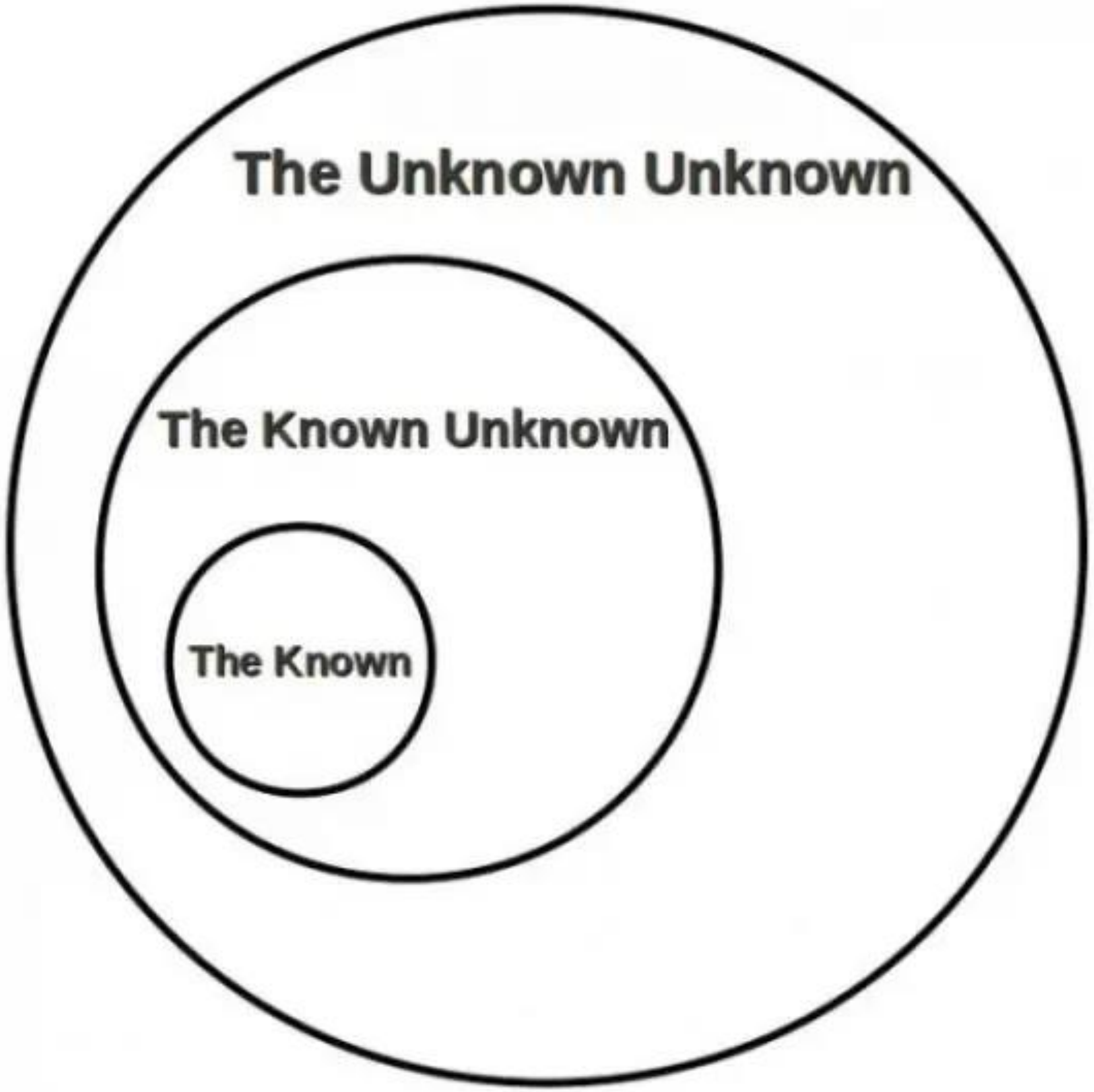
Slides: https://github.com/kvsankar/talks/blob/main/Chandrayaan3-Sankar-Viswanathan-BAS-v6.pdf

What this Talk is About

- Mission trajectory of Chandrayaan 3
- Answers common questions
  - What was the path taken by CY3?
  - Why 40 days?
  - What are those spirals?
  - And many others ...
- Gain a better understanding through
  - Foundational principles
  - High school physics at most
  - Use of interactive visual aids
- Appreciate the constraints and challenges involved
- Ignite curiosity and kindle a new perspective

What this Talk is *not*

- 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



Source: PhD Scam - https://phdscam.wordpress.com/2013/06/16/phd-unknown-knowns/

Etiquette and Expectations

- Keep your mics muted unless you are asking a question

- Interactive session
  - Respond to online quizzes via mobile

- Questions
  - Use chat to raise questions
  - Clarifications – any time
  - Others – at the end of each segment

http://etc.ch/Hcw4

Quiz #1

Outline

Foundations

1. Scale
2. Coordinate systems
3. Mapping the Moon
4. CY3 trajectory
5. Orbits
6. Orbital maneuvers

Mission Design

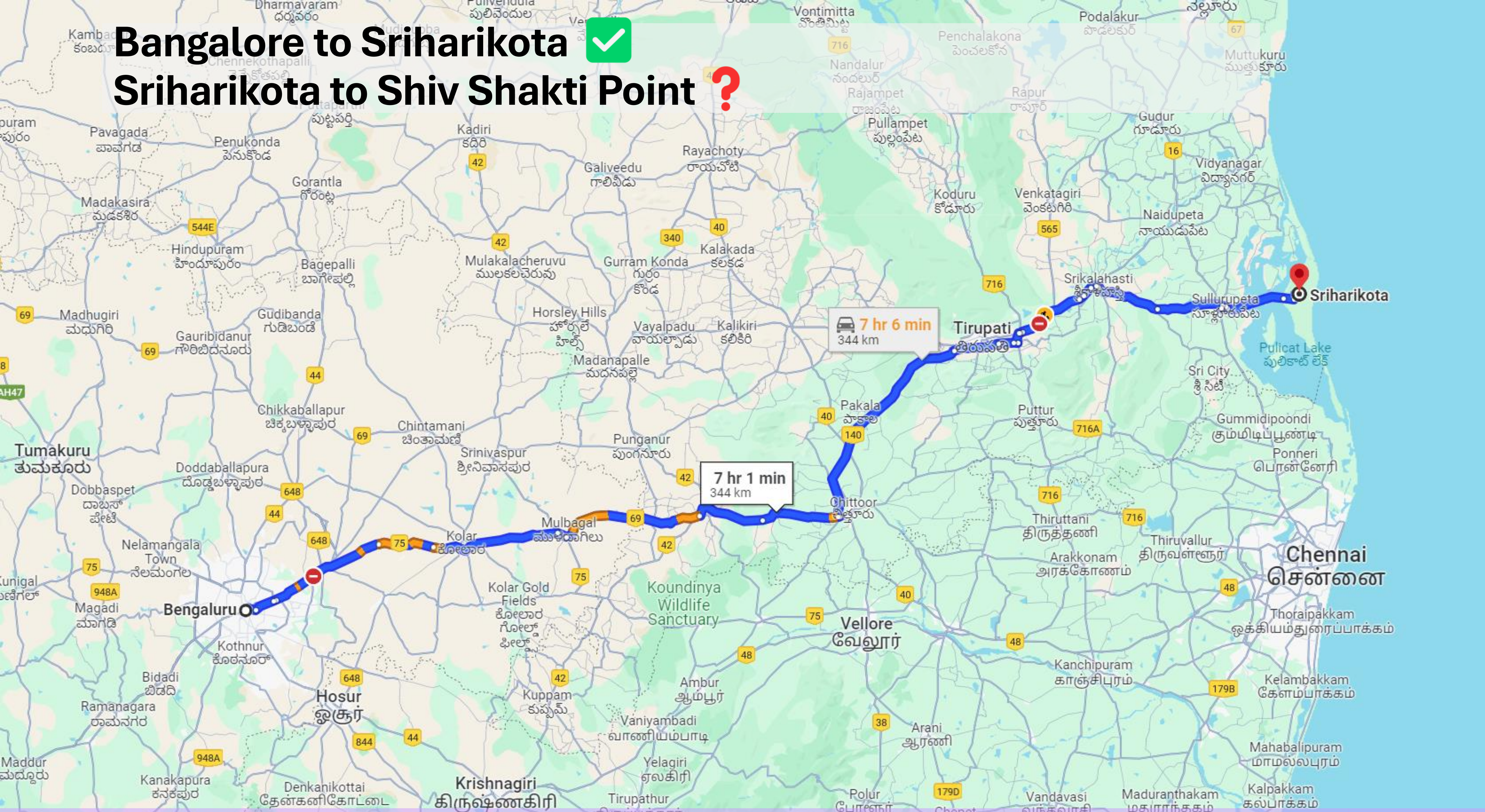
7. CY3 Lunar orbits
8. Transfer orbit
9. Launch orbit
10. Mission design

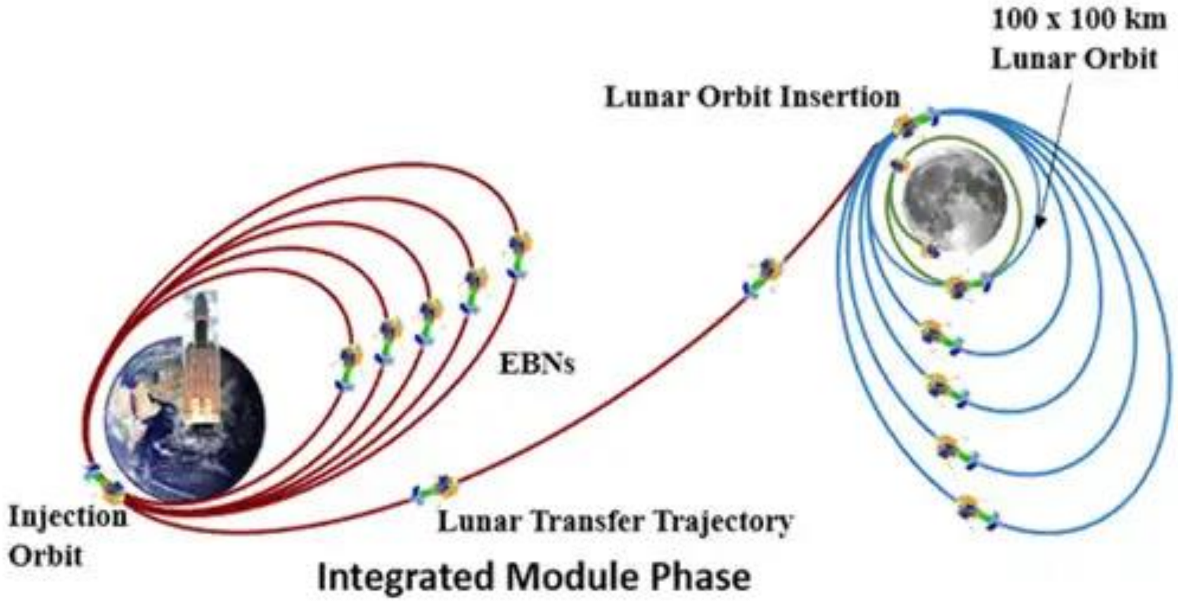
Foundations

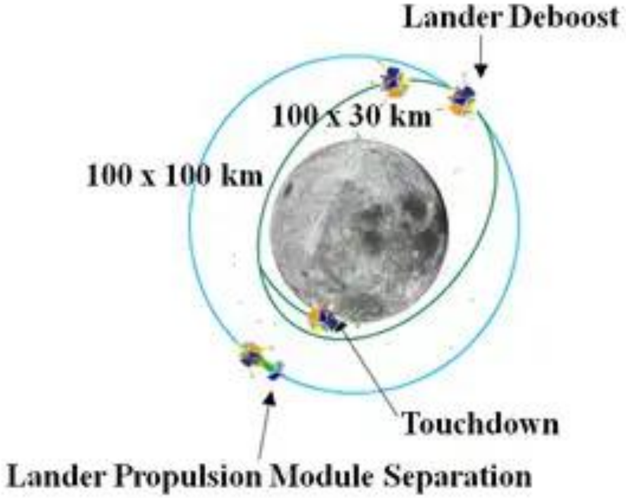
1. Scale

Foundations > Space > Scale

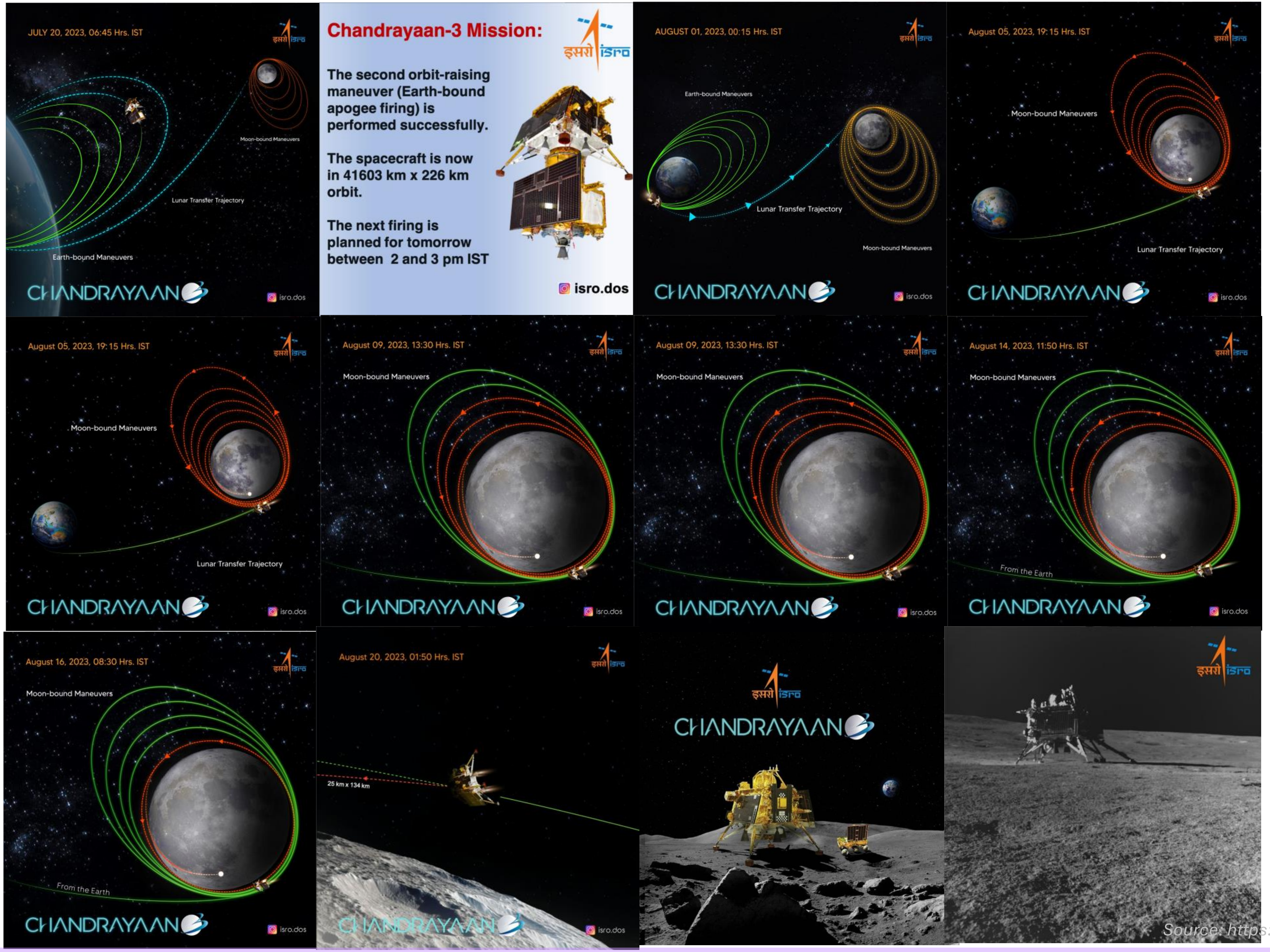
Bangalore to Sriharikota ✅
Sriharikota to Shiv Shakti Point ❓



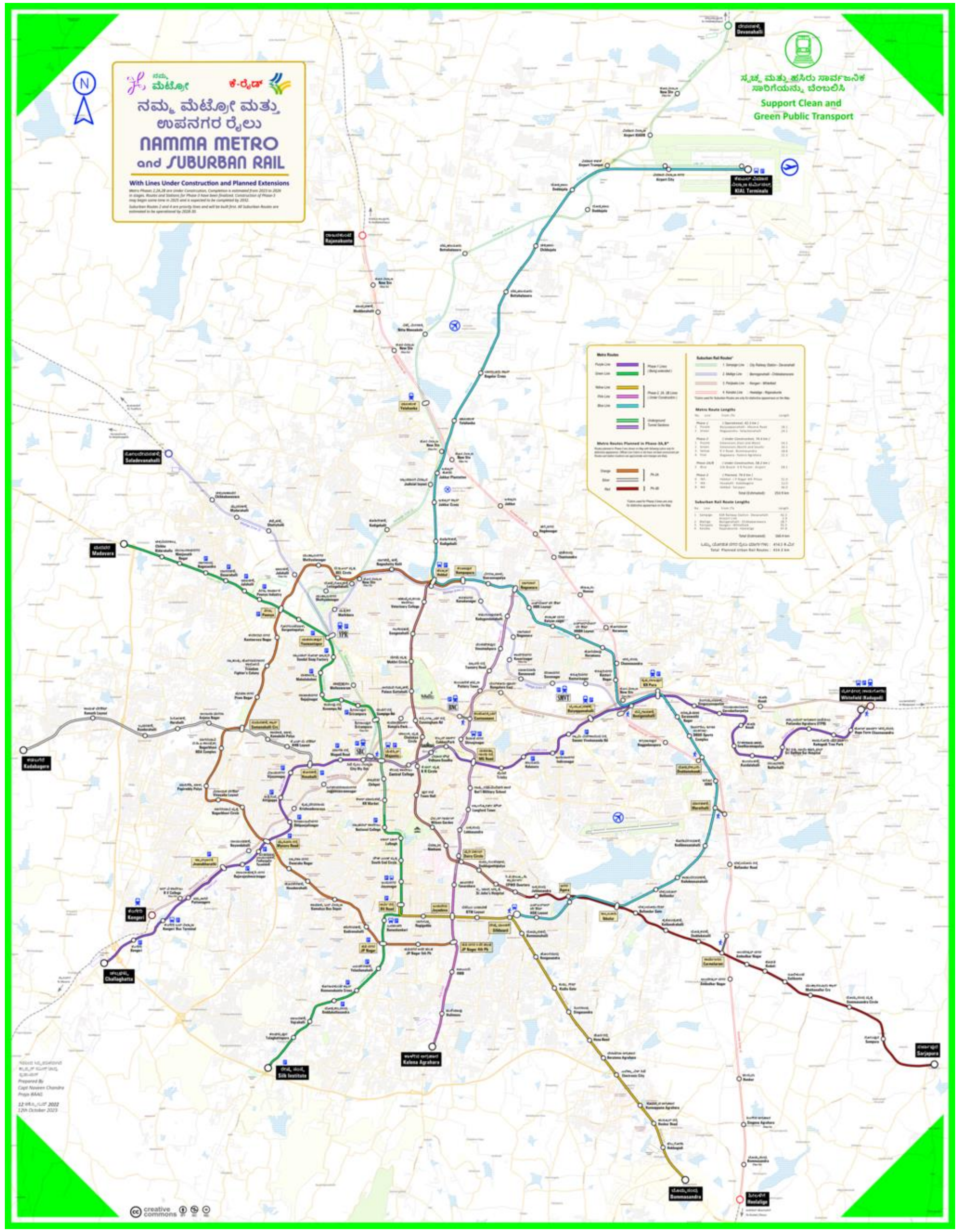


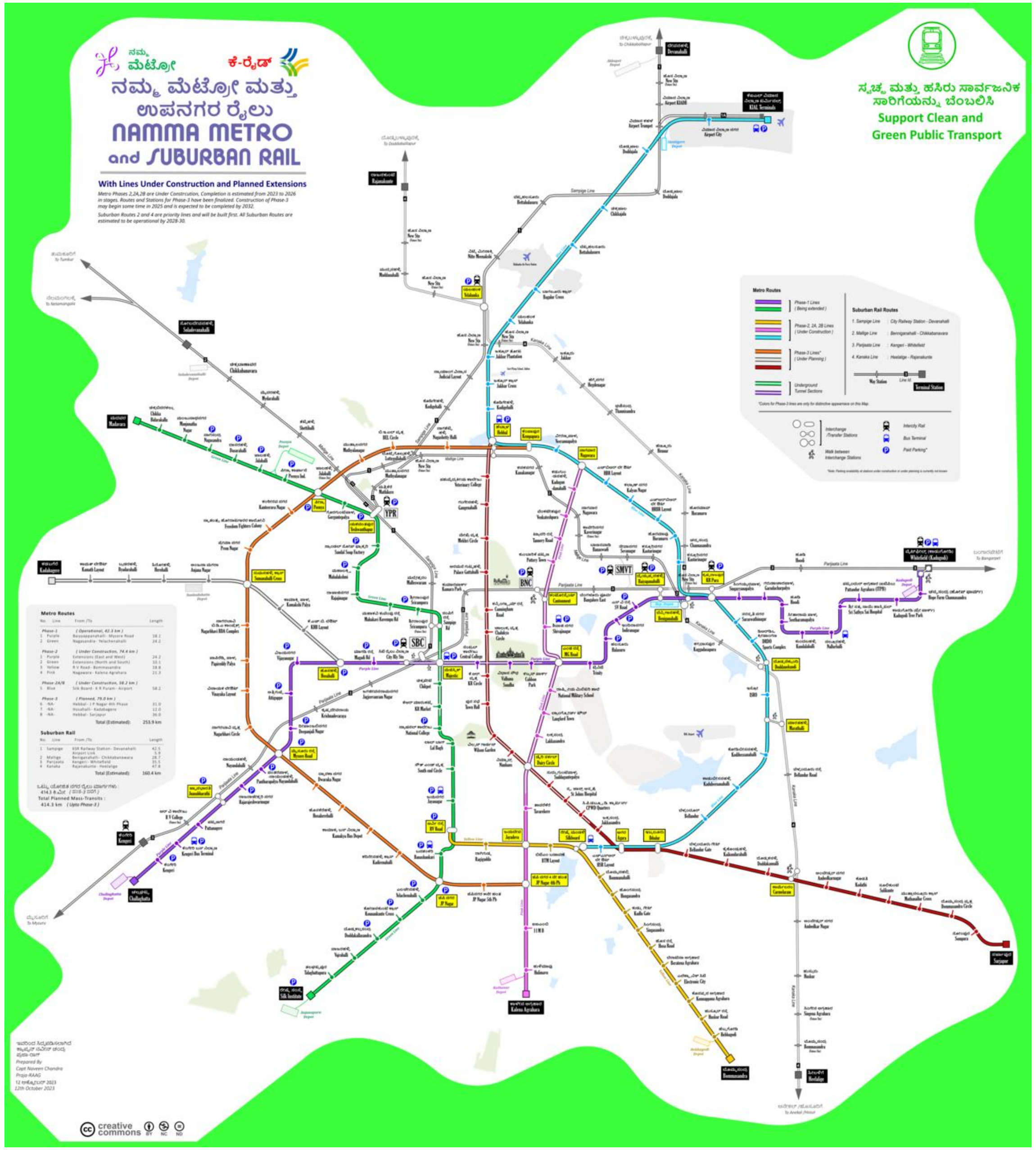


Source: https://www.isro.gov.in/Chandrayaan3_Details.html



Source: https://www.instagram.com/isro.dos/





Source: https://en.wikipedia.org/wiki/Namma_Metro#/media/File:NammaMetroUptoPh-3withKannada.png

Source: https://en.wikipedia.org/wiki/Namma_Metro#/media/File:NammaMetroSchematicwithKannada.png

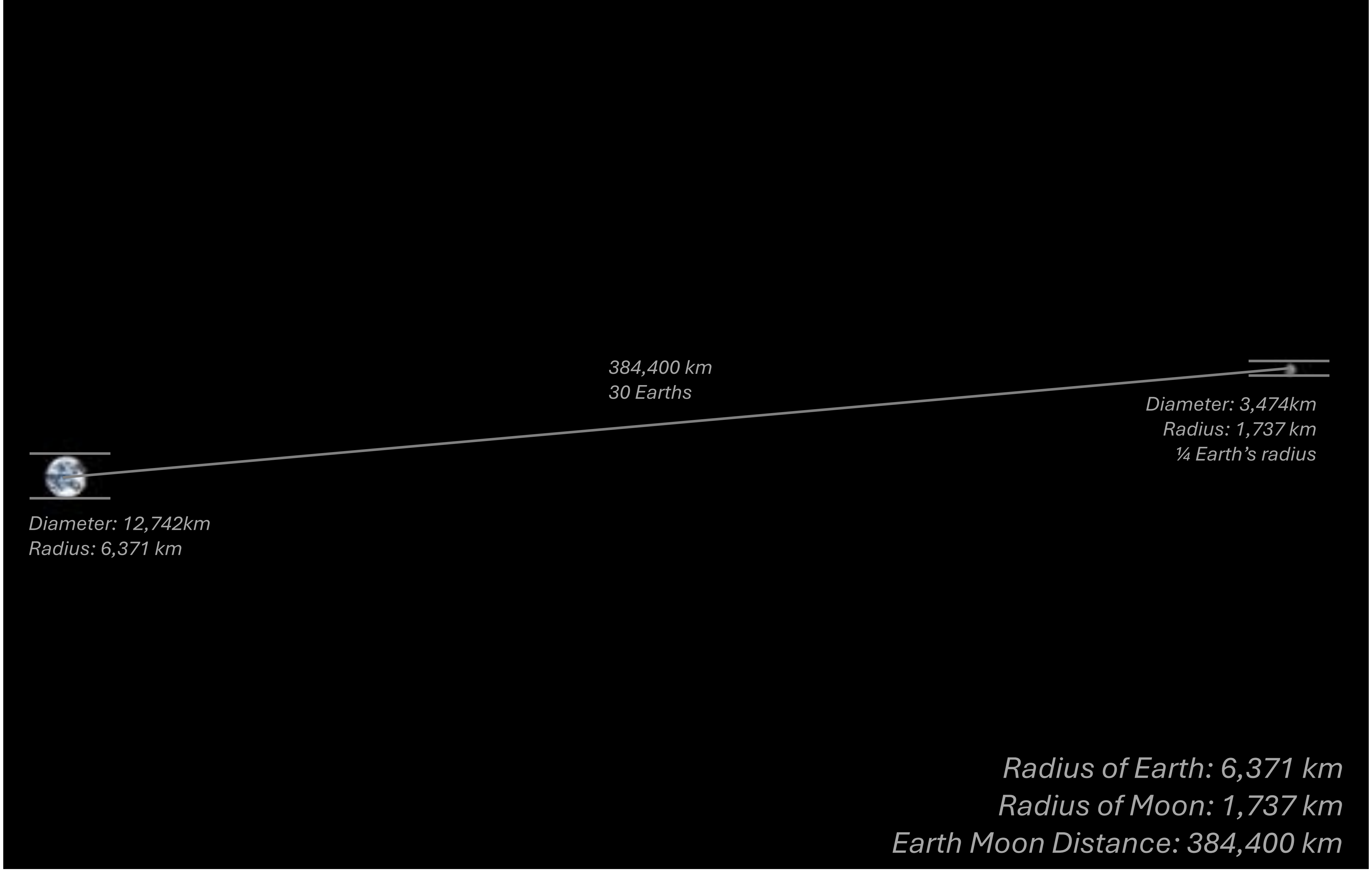
Source: https://c1.peakpx.com/wallpaper/427/549/95/plastic-balls-color-colorful-balls-wallpaper.jpg

Let’s Find Out …

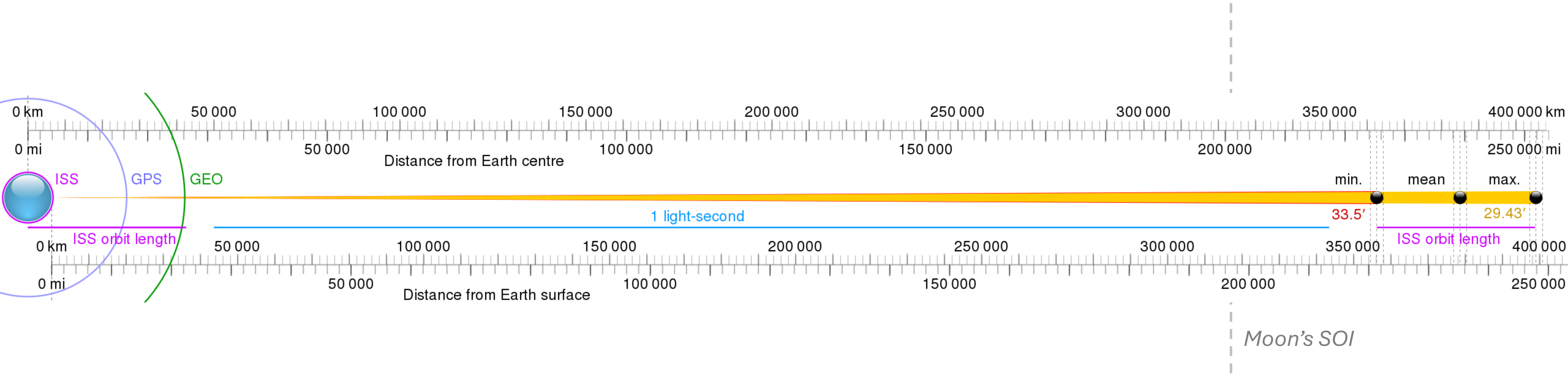
Answers

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

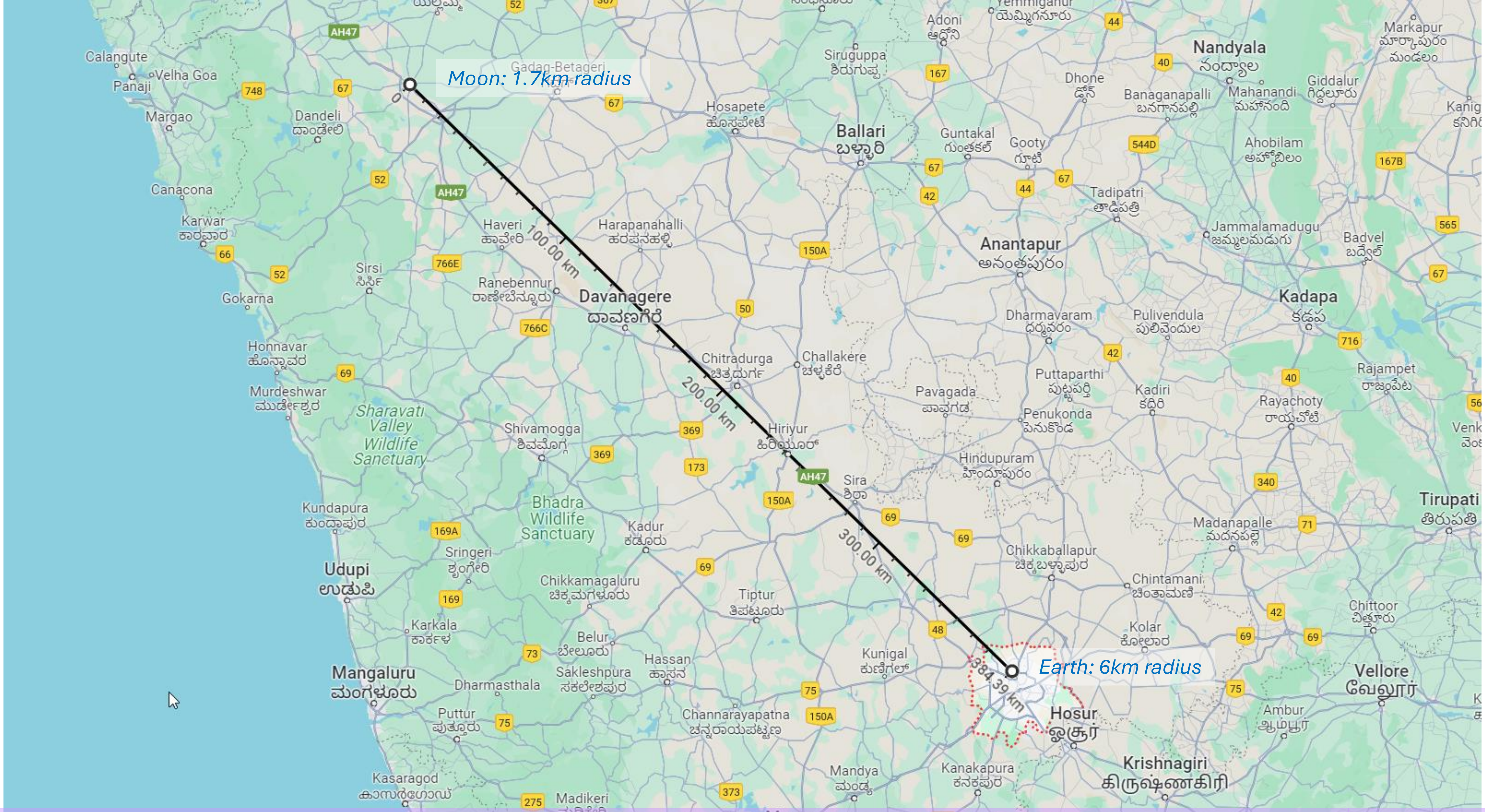
White thermocol ball – 6 cm diameter
Smaller marble – 1.5 cm diameter



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



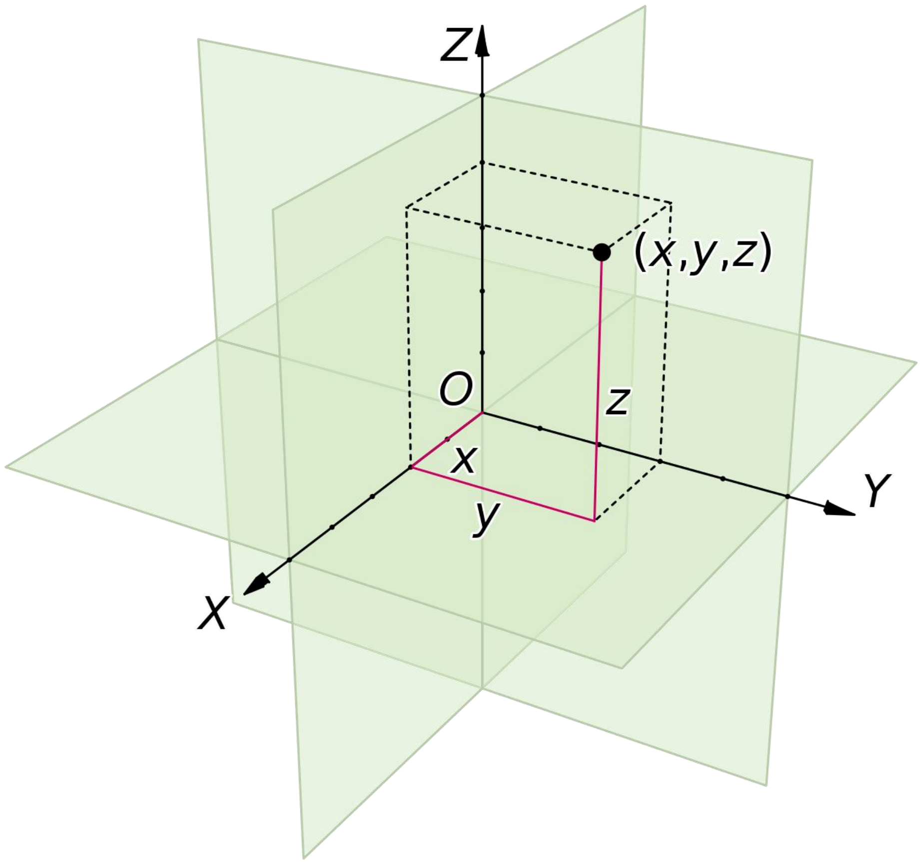
Source: https://en.wikipedia.org/wiki/Orbit_of_the_Moon#/media/File:Moon_distance_range_to_scale.svg

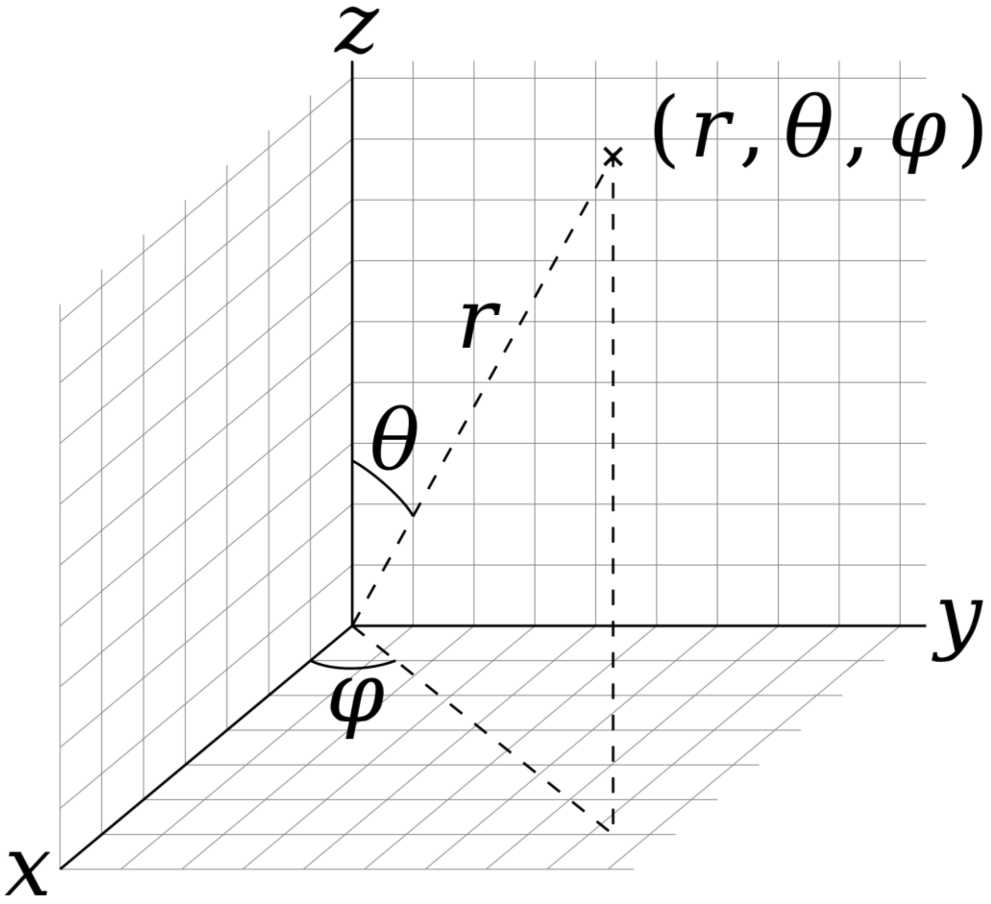


Moon: 1.7km radius
Earth: 6km radius
0
100.00 km
200.00 km
300.00 km
384.39 km
Calangute
Panaji
Velha Goa
Margao
Dandeli
Canacona
Karwar
Gokarna
Sirsi
Honnavar
Murdeshwar
Sharavati Valley Wildlife Sanctuary
Haveri
Ranebennur
Harapanahalli
Davanagere
Hosapete
Ballari
Siruguppa
Adoni
Chitradurga
Challakere
Hiriyur
Shivamogga
Bhadra Wildlife Sanctuary
Kundapura
Udupi
Sringeri
Kadur
Chikkamagaluru
Tiptur
Karkala
Belur
Hassan
Sakleshpura
Mangaluru
Dharmasthala
Puttur
Kasaragod
Madikeri
Channarayapatna
Kunigal
Mandya
Kanakapura
Hosur
Krishnagiri
Kolar
Chintamani
Chikkaballapur
Sira
Pavagada
Hindupuram
Penukonda
Puttaparthi
Dharmavaram
Anantapur
Guntakal
Gooty
Tadipatri
Dhone
Banaganapalli
Nandyala
Mahanandi
Giddalur
Ahobilam
Jammalamadugu
Badvel
Kadapa
Pulivendula
Kadiri
Rajampet
Rayachoty
Madanapalle
Tirupati
Chittoor
Vellore
Ambur
Markapur
Yemmiganur

2. Coordinate Systems

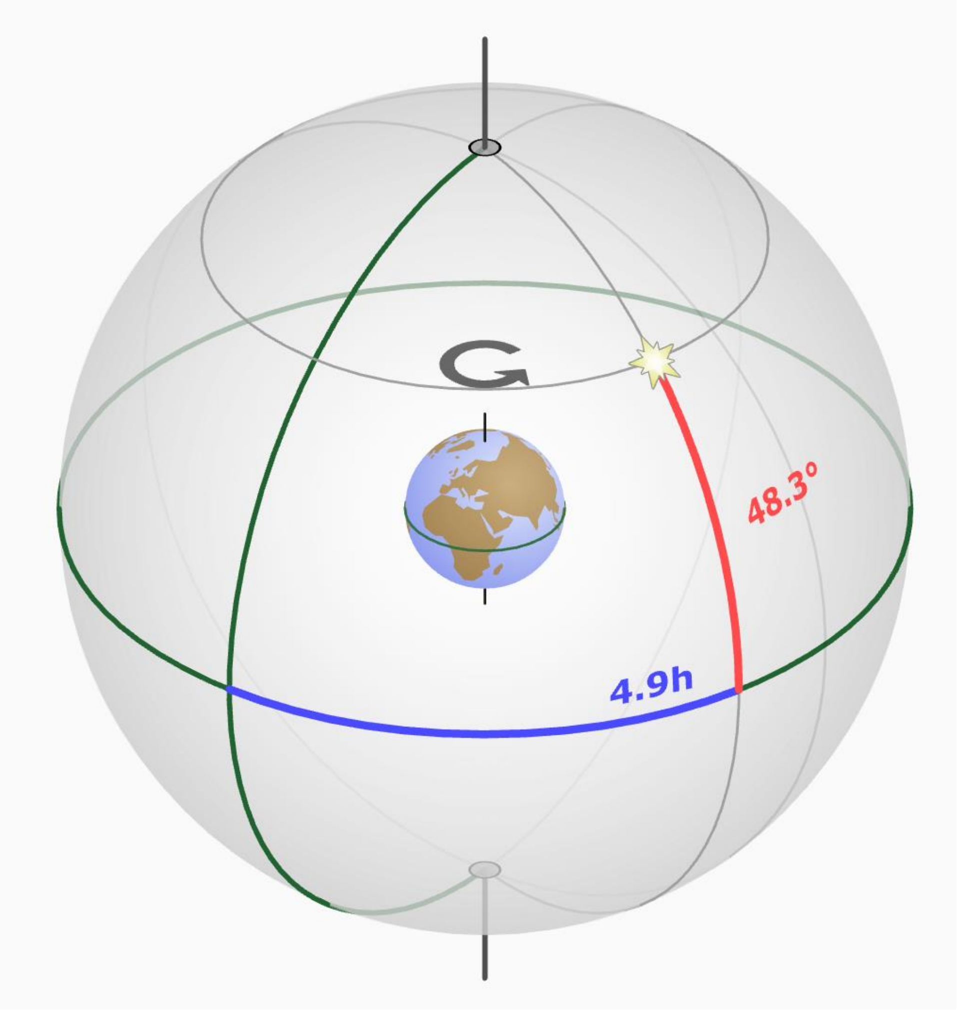
Foundations > Space > Coordinate Systems



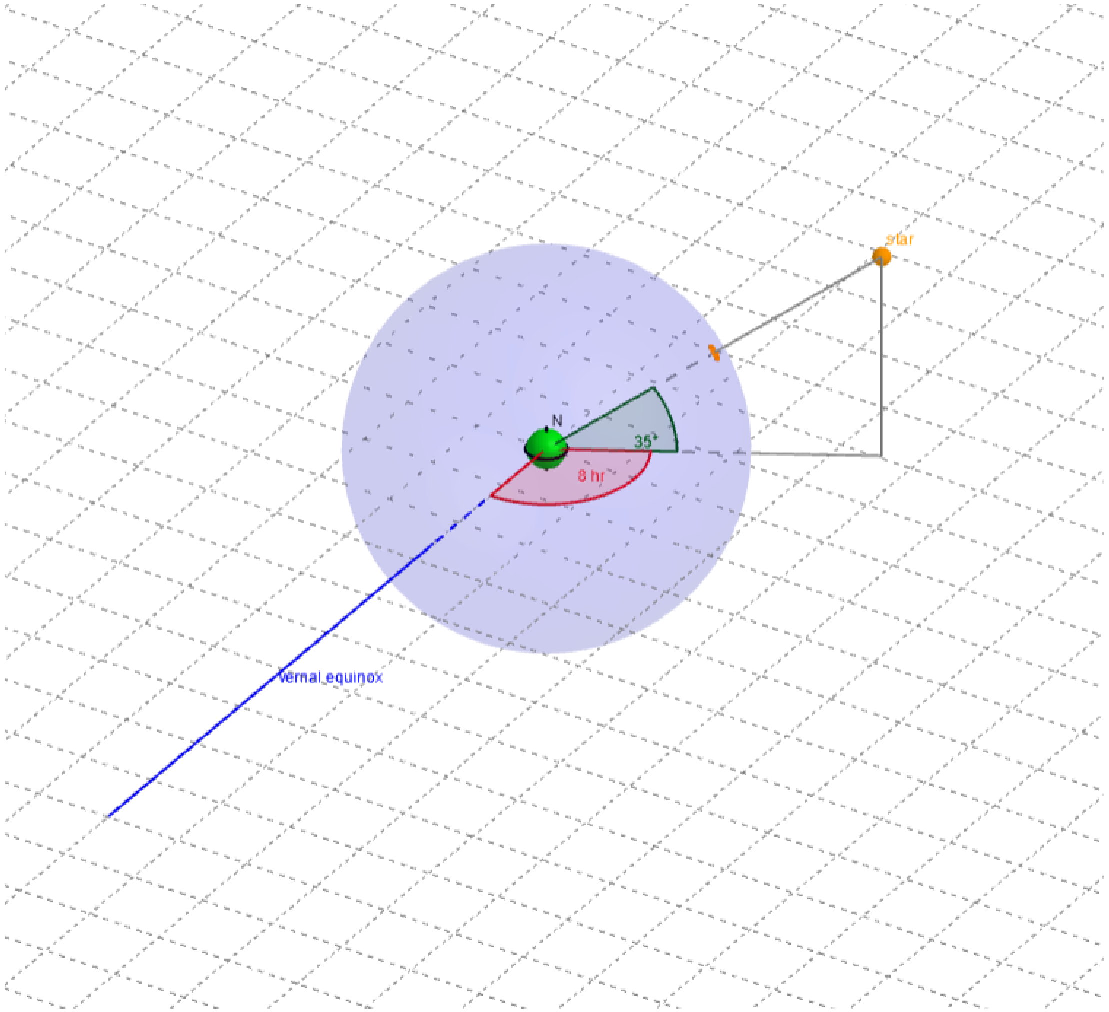


Source: https://en.wikipedia.org/wiki/Cartesian_coordinate_system#/media/File:Coord_system_CA_0.svg
Source: https://en.wikipedia.org/wiki/Spherical_coordinate_system#/media/File:3D_Spherical.svg

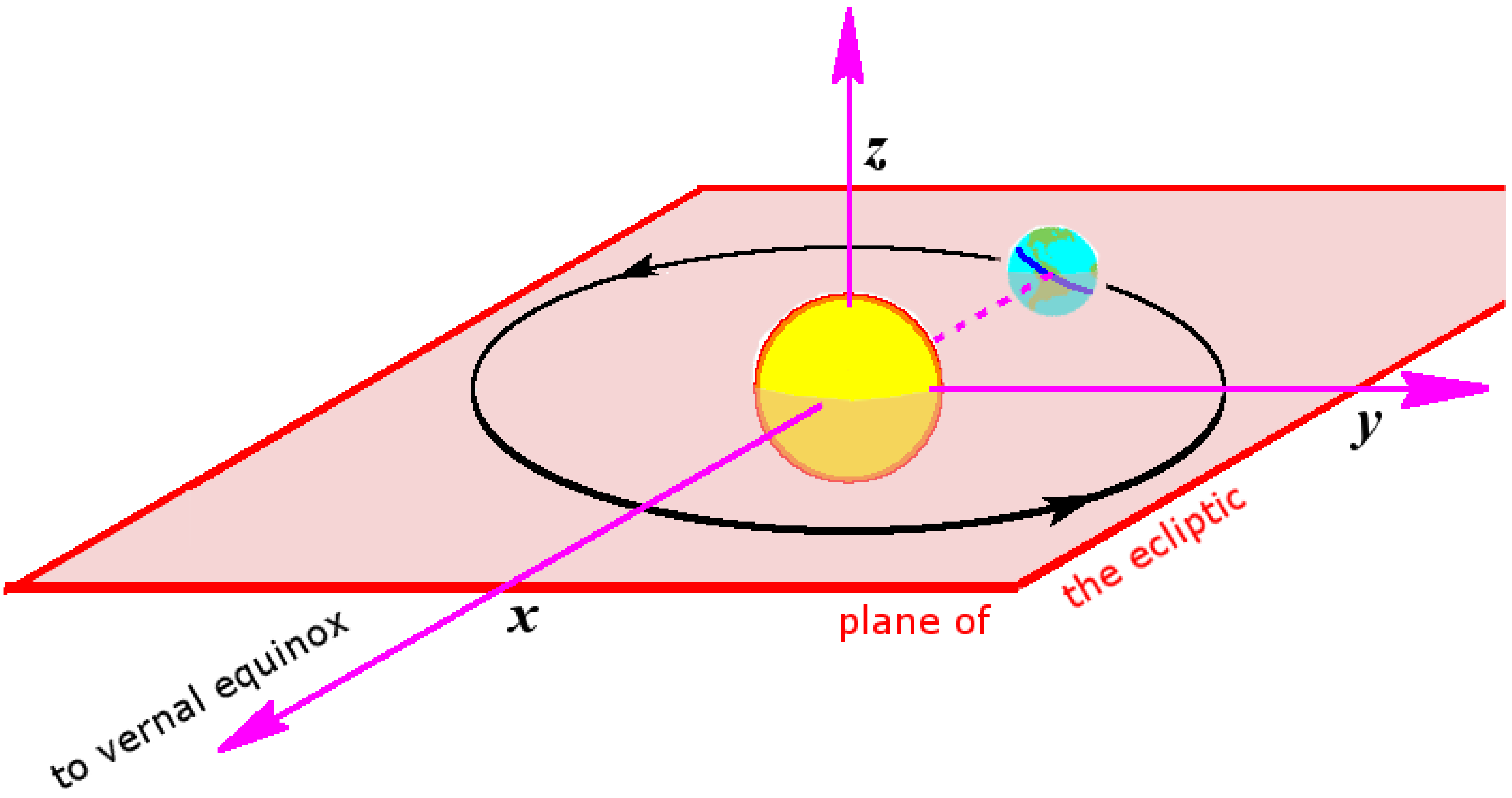
Let's Try …



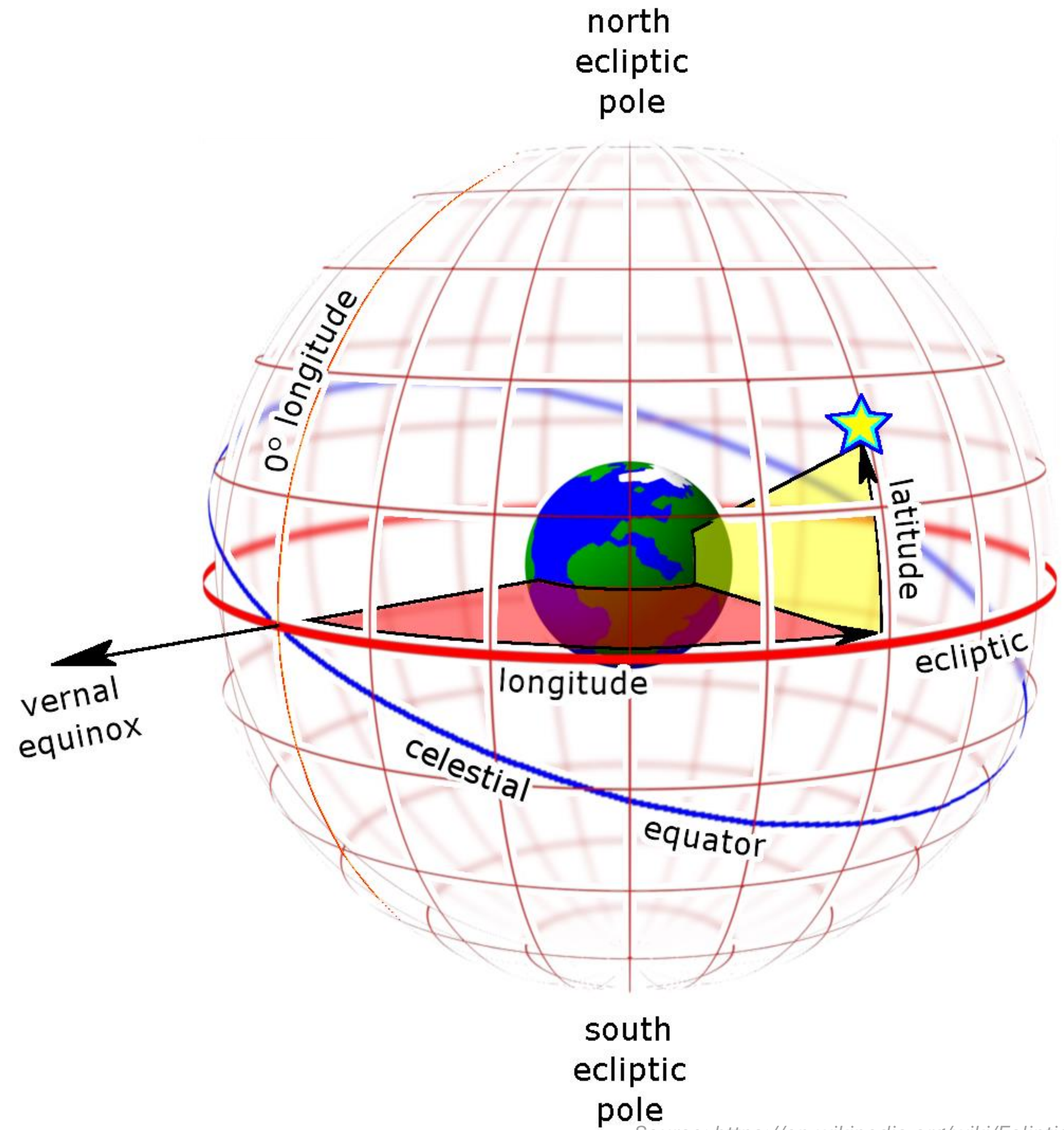
Source: https://astro.unl.edu/classaction/animations/coordsmotion/radecdemo.html



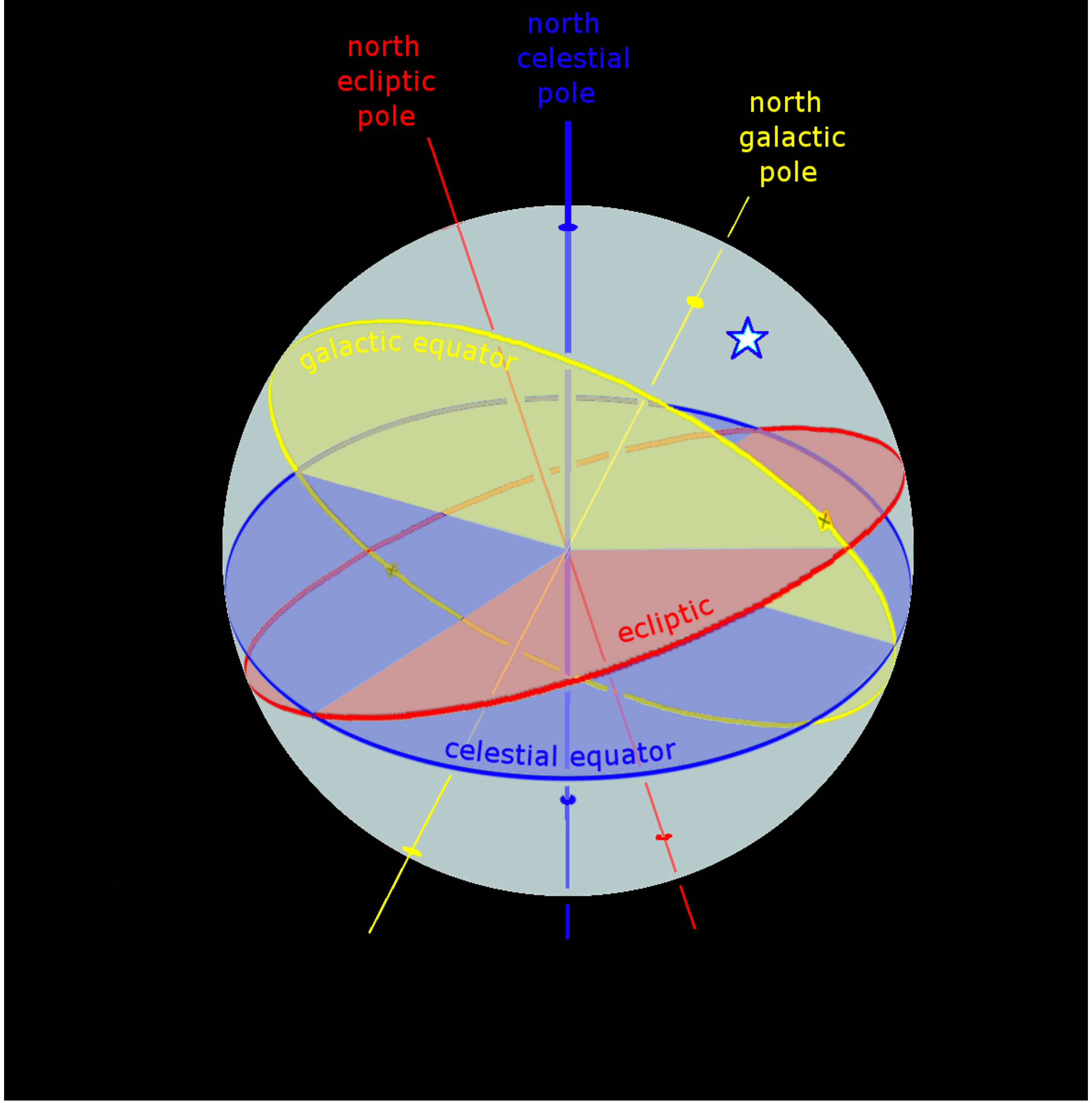
Source: https://www.geogebra.org/classic/GRrAn2tF



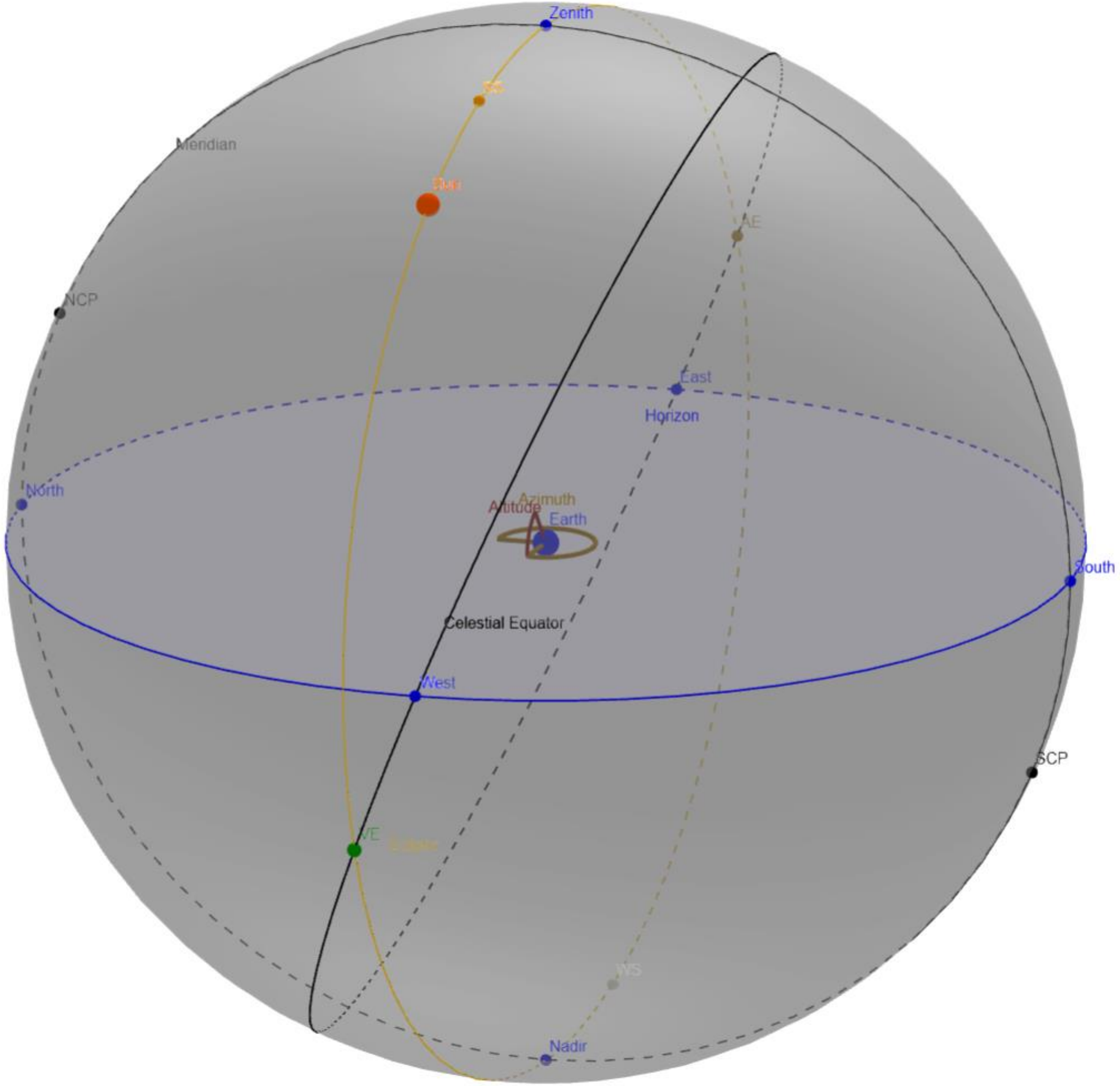
Source: https://en.wikipedia.org/wiki/Ecliptic_coordinate_system#/media/File:Heliocentric_rectangular_ecliptic.png



Source: https://en.wikipedia.org/wiki/Ecliptic_coordinate_system#/media/File:Ecliptic_grid_globe.png



Source: https://en.wikipedia.org/wiki/Astronomical_coordinate_systems#/media/File:Ecliptic_equator_galactic_anim.gif

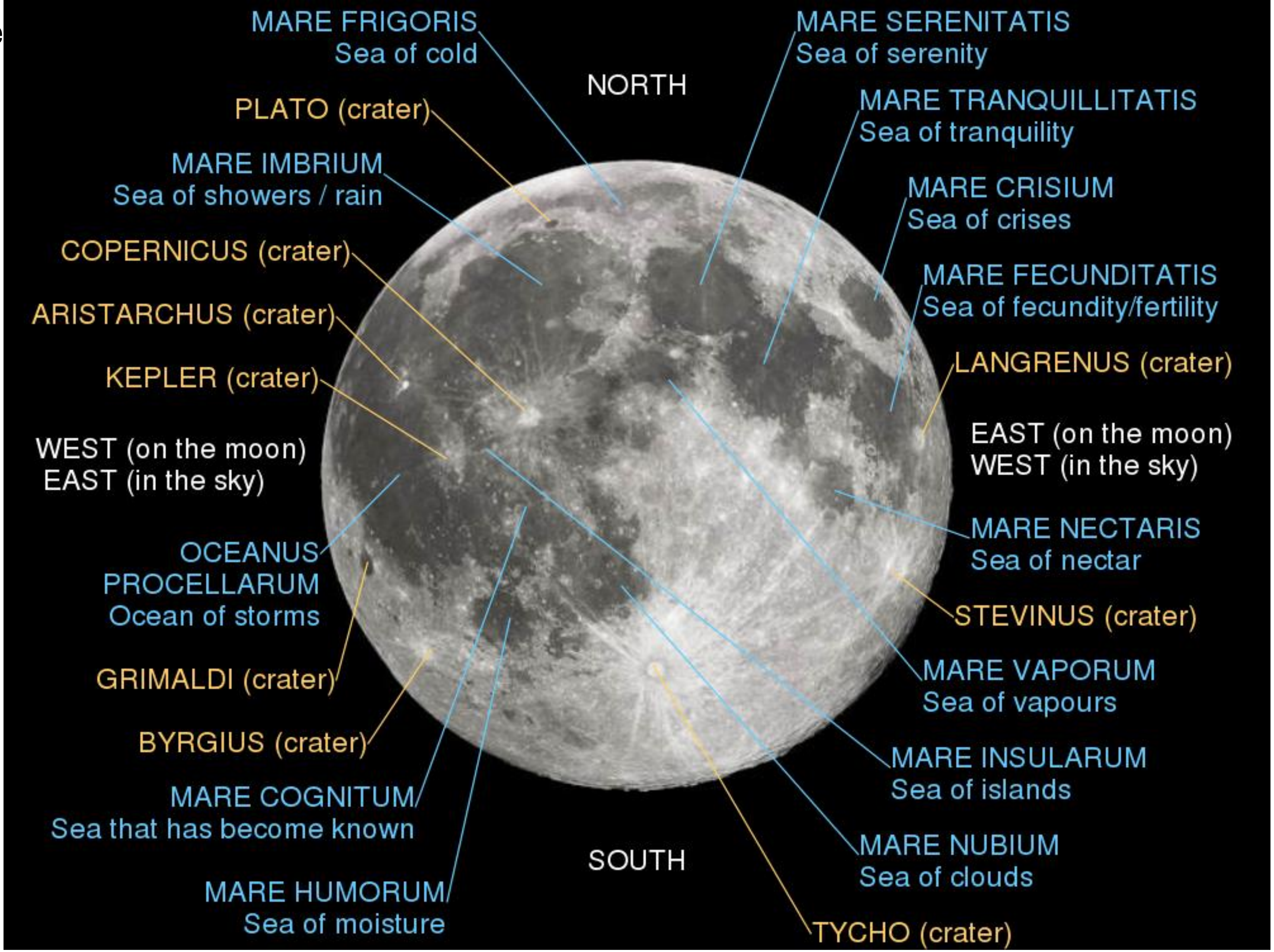


Source: [*https://www.geogebra.org/classic/f5vf2jga*](https://www.geogebra.org/classic/f5vf2jga)

3. Mapping the Moon

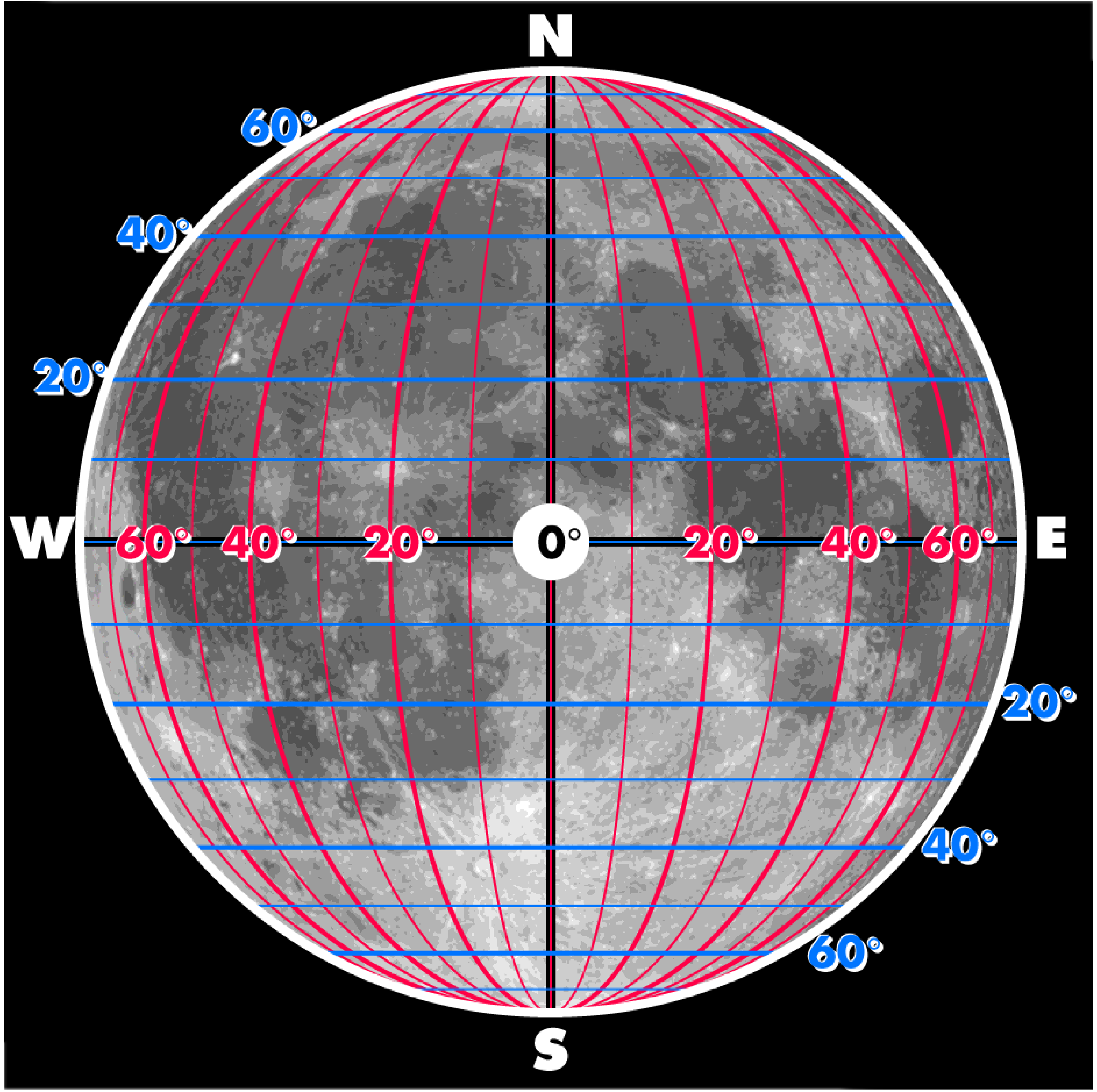
Foundations > Mapping the Moon

Near Side of the Moon



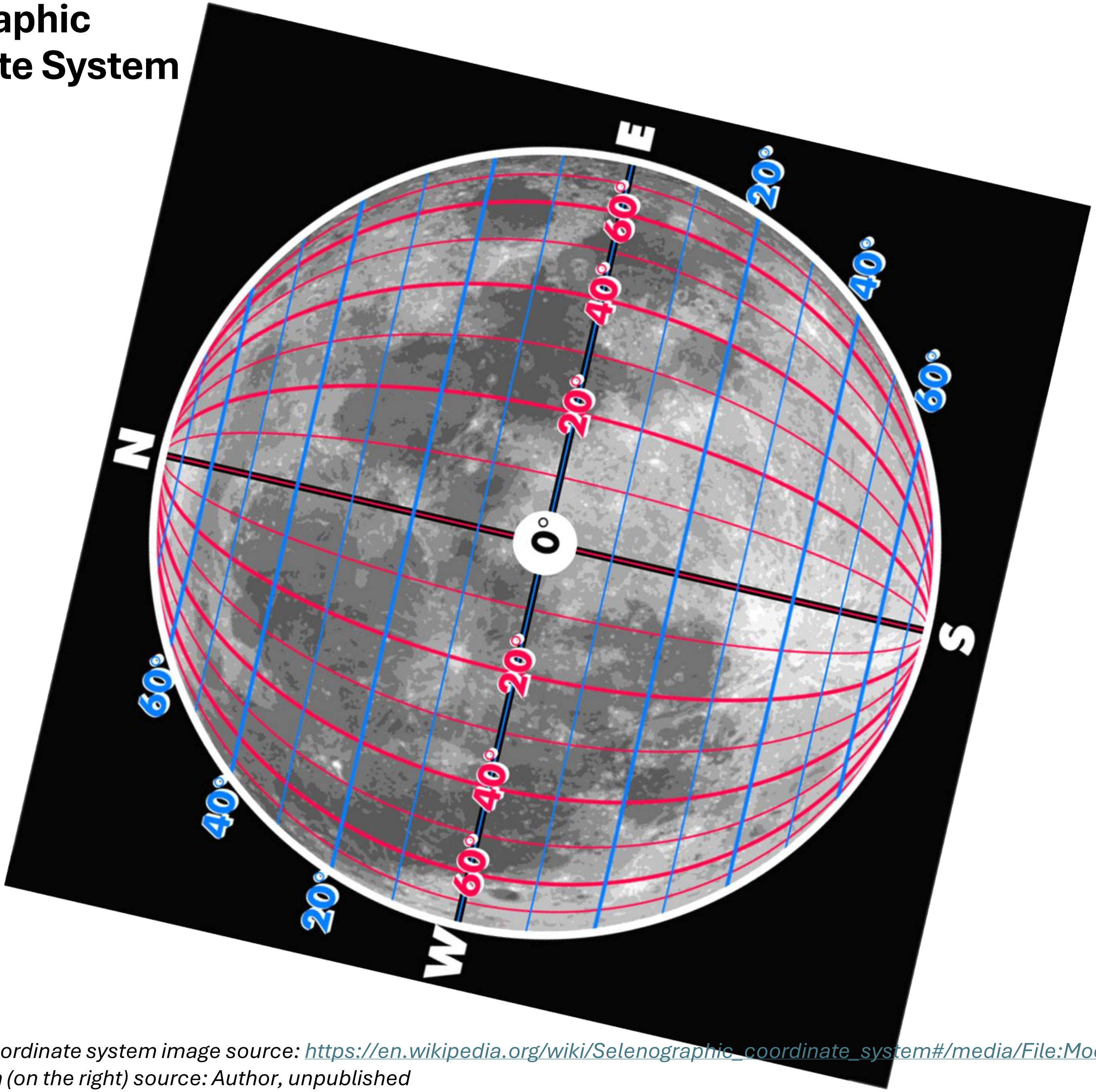
Source: *https://en.wikipedia.org/wiki/Moon#/media/File:Moon_names.svg*

Selenographic Coordinate System



Source: https://en.wikipedia.org/wiki/Selenographic_coordinate_system#/media/File:Moon-map.png

Selenographic Coordinate System



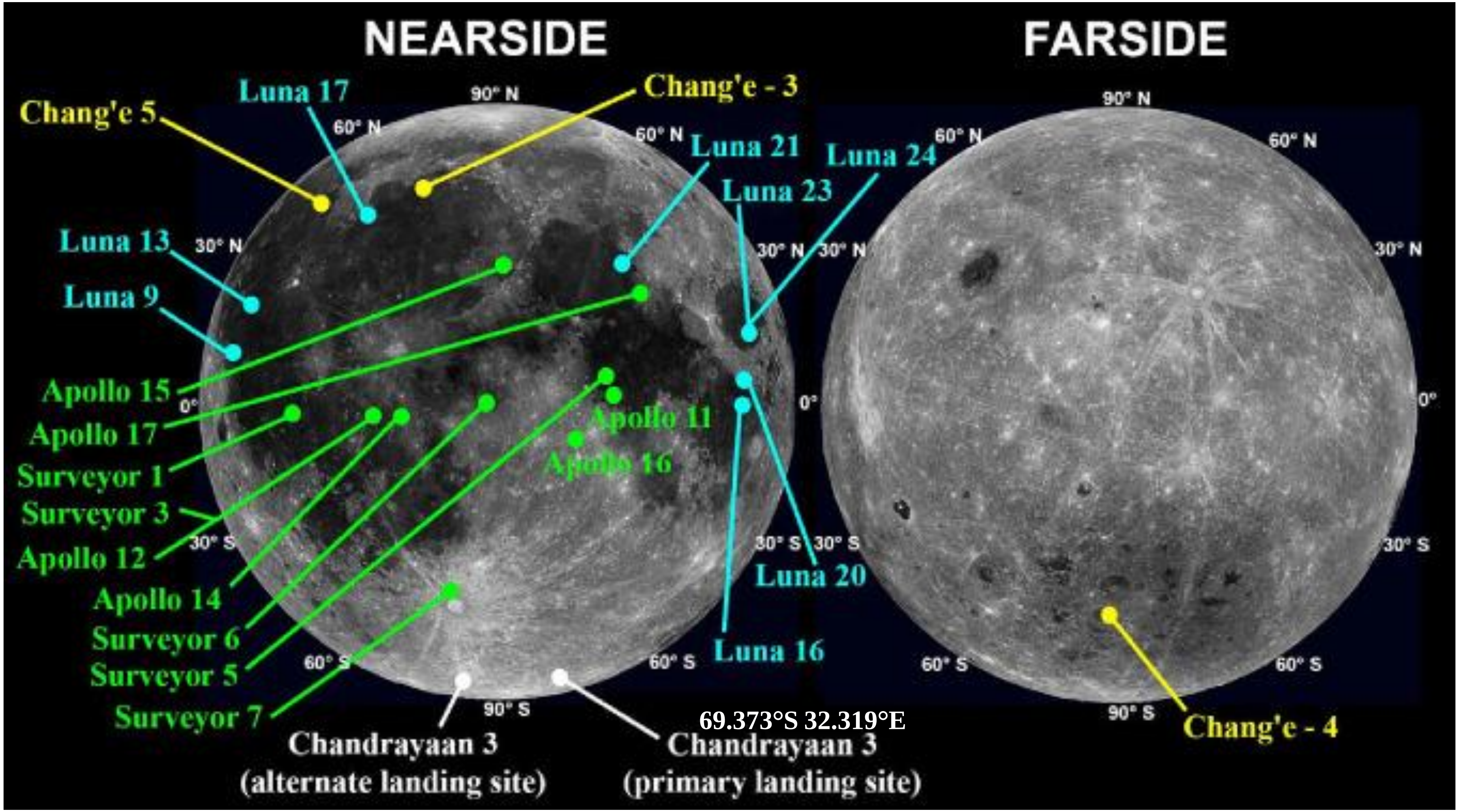
Typical view from Bangalore (13° N) looking towards east on a full-moon evening

Selenographic coordinate system image source: https://en.wikipedia.org/wiki/Selenographic_coordinate_system#/media/File:Moon-map.png
Moon photograph (on the right) source: Author, unpublished

Equirectangular Map of the Moon

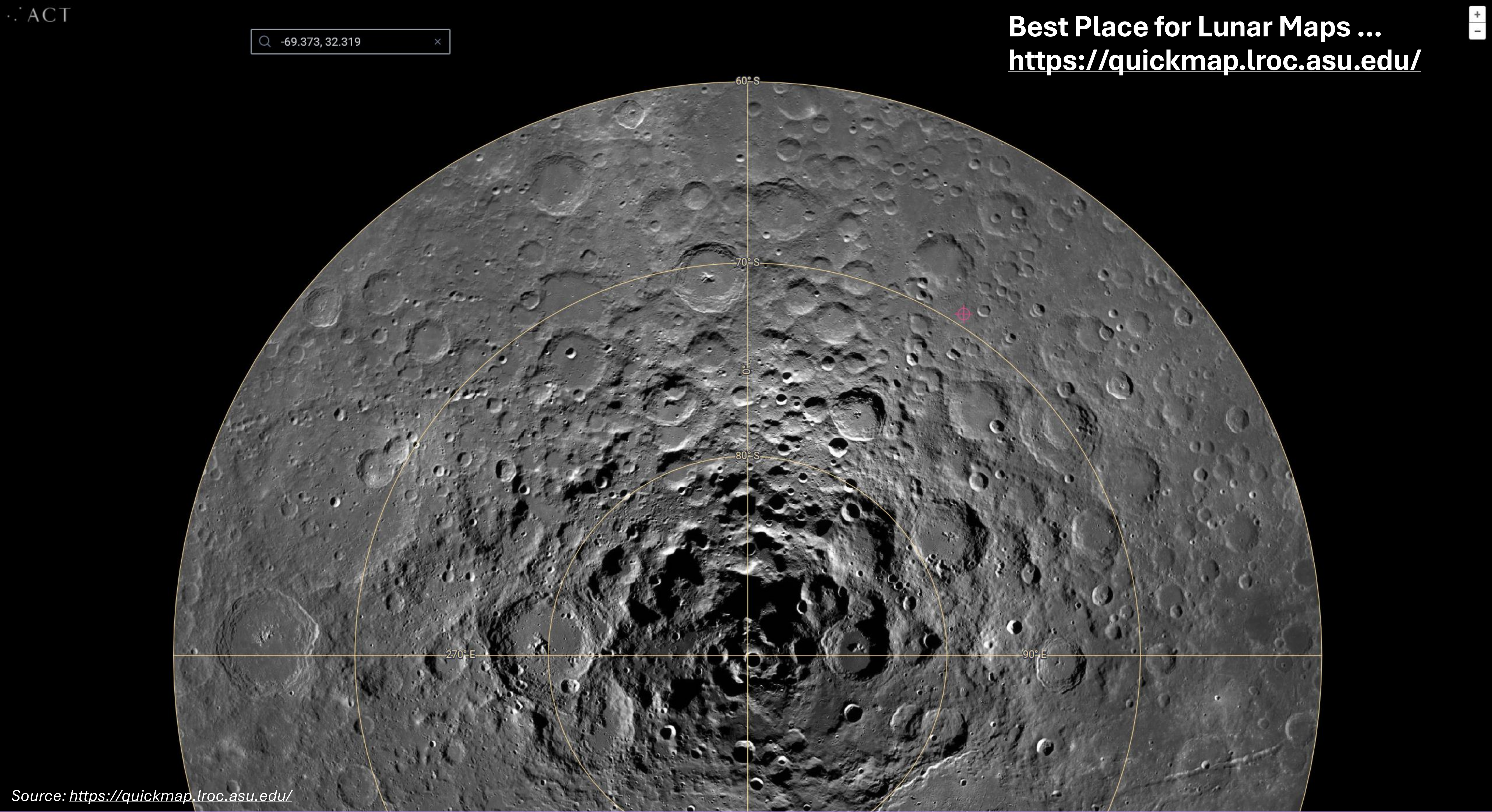
Source: *https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=4720*

Landing Sites on the Moon



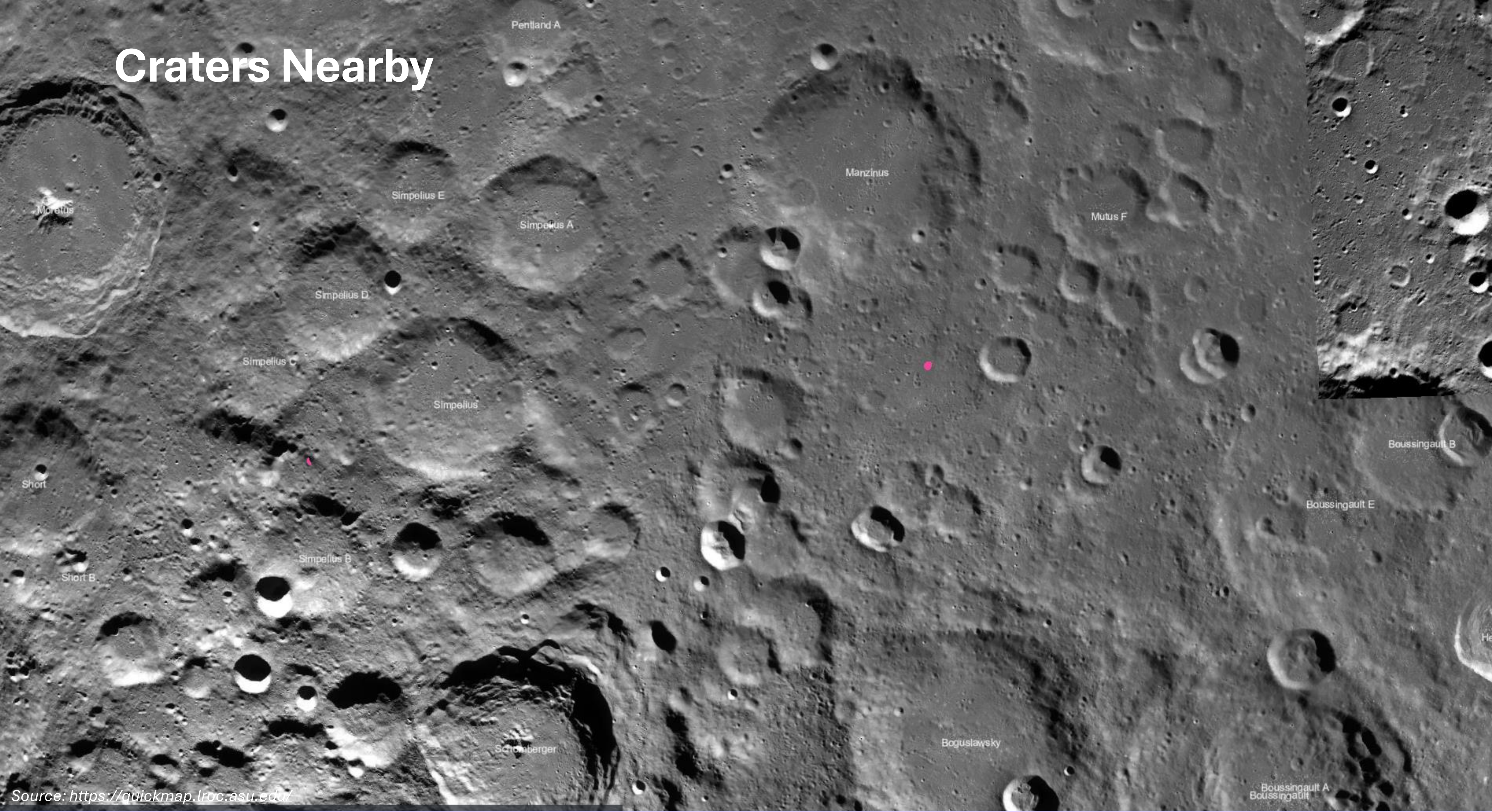
Source: *https://upload.wikimedia.org/wikipedia/commons/3/34/Moon_landing_sites.svg*

Best Place for Lunar Maps …
https://quickmap.lroc.asu.edu/



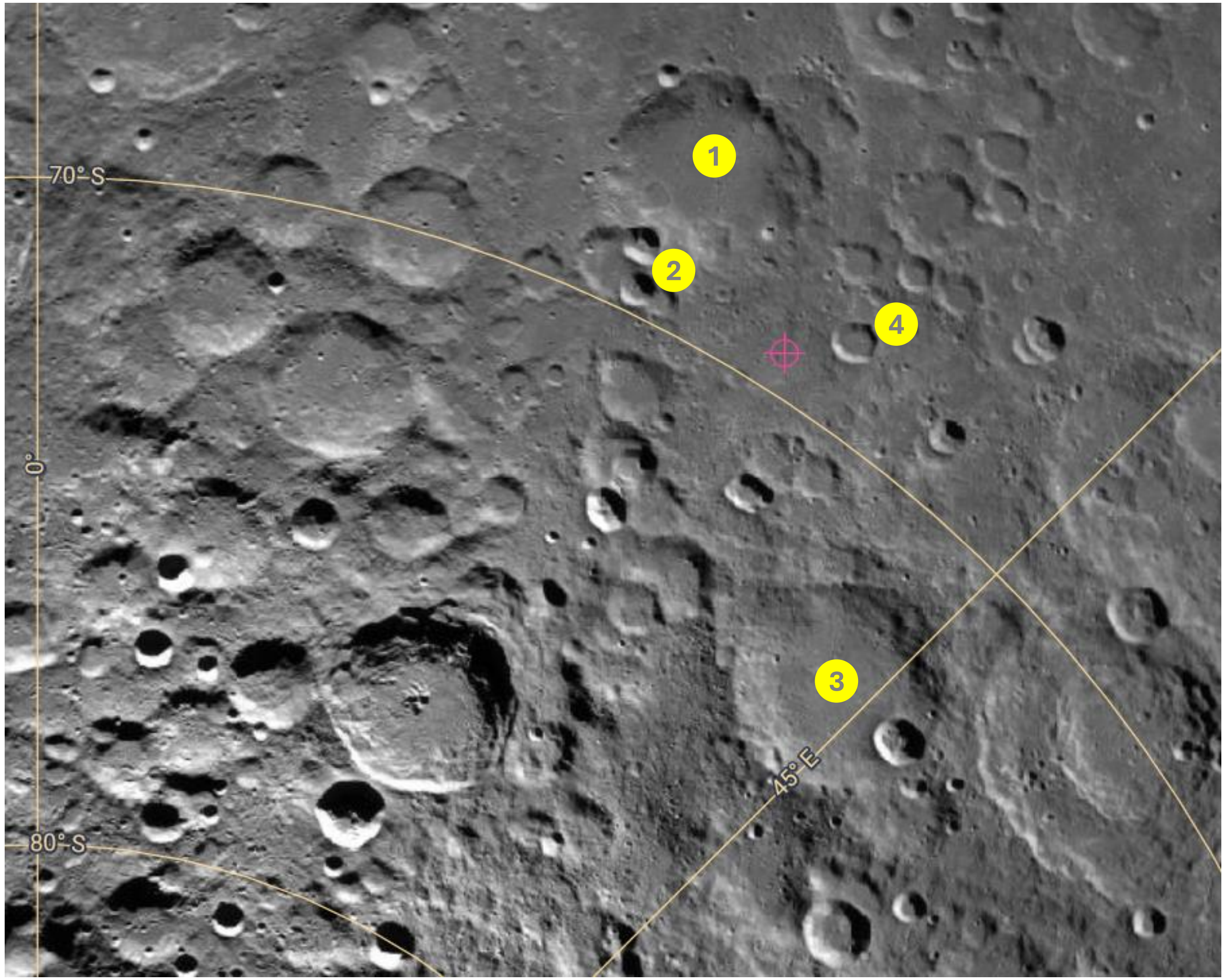
Source: https://quickmap.lroc.asu.edu/

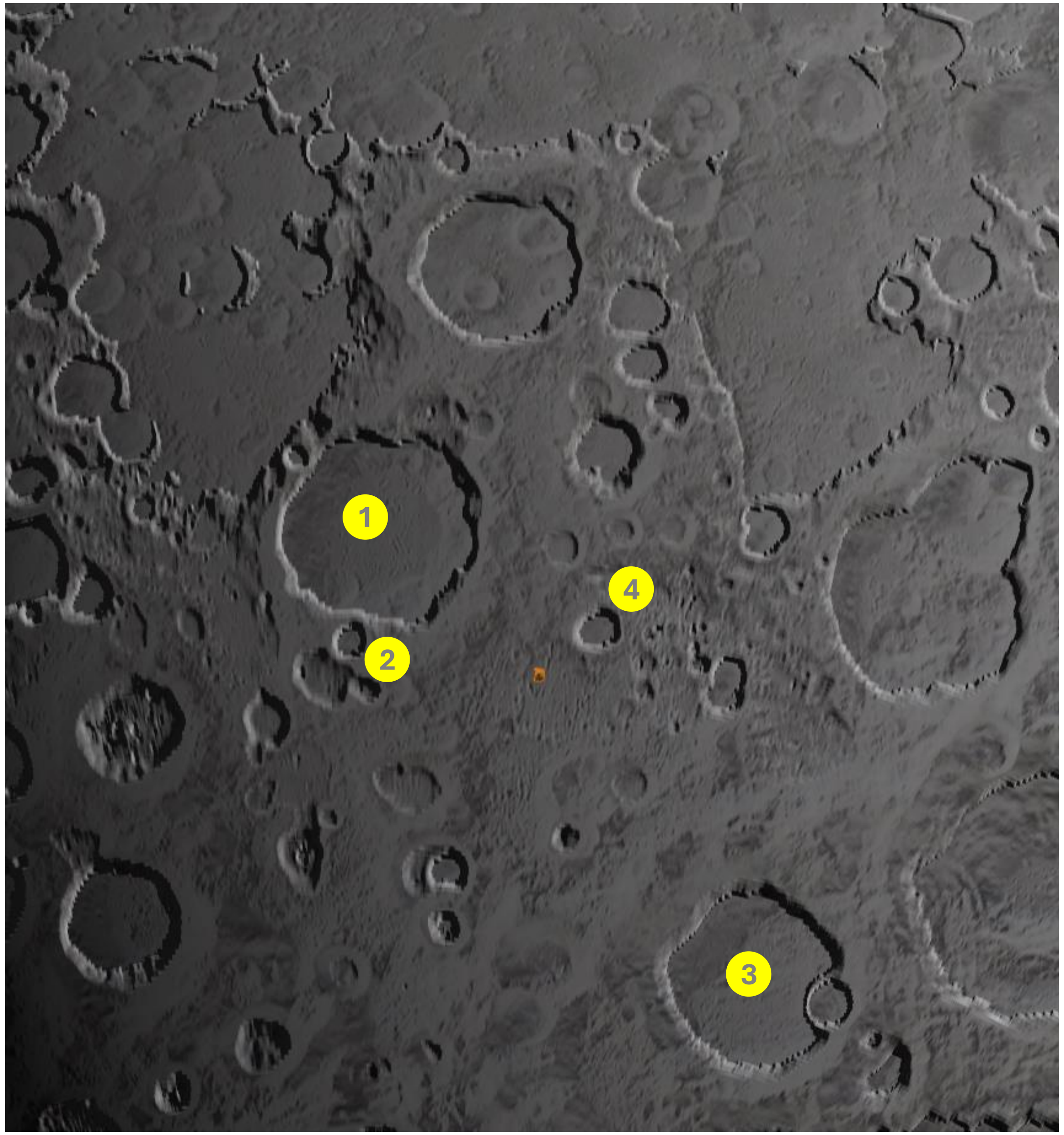
Craters Nearby



Source: https://quickmap.lroc.asu.edu/

LRO Image vs. Animation





LRO image source: Source: https://quickmap.lroc.asu.edu/
Animation screenshot source: https://sankara.net/chandrayaan3.html

Quiz #2

4. CY3 Trajectory

Foundations > CY3 Trajectory

How to Plot Chandrayaan 3 Trajectory?

- Get location coordinates at periodic time intervals
- Plot the points

NASA JPL Horizons

Jet Propulsion Laboratory
California Institute of Technology

Solar System Dynamics

Home | About | Orbits & Ephemerides | Planets | Planetary Satellites | Small Bodies | Tools | Extras

Home / Tools / Horizons System

Horizons System

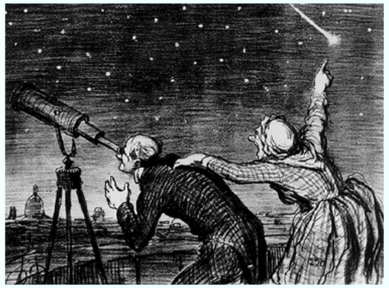
About | App | Manual | Tutorial | Time Spans | News

About Horizons

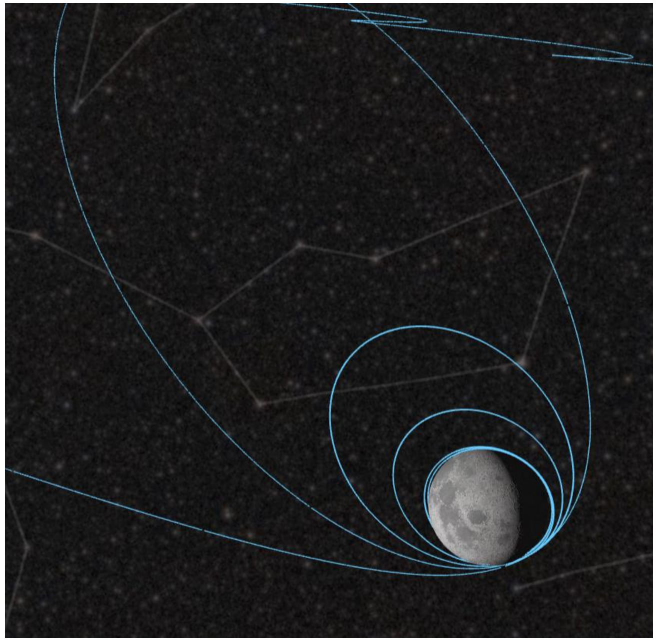
The JPL Horizons on-line solar system data and ephemeris computation service provides access to key solar system data and flexible production of highly accurate ephemerides for solar system objects (1,330,535 asteroids, 3,904 comets, 290 planetary satellites {includes satellites of Earth and dwarf planet Pluto}, 8 planets, the Sun, L1, L2, select spacecraft, and system barycenters). Horizons is provided by the Solar System Dynamics Group of the Jet Propulsion Laboratory.

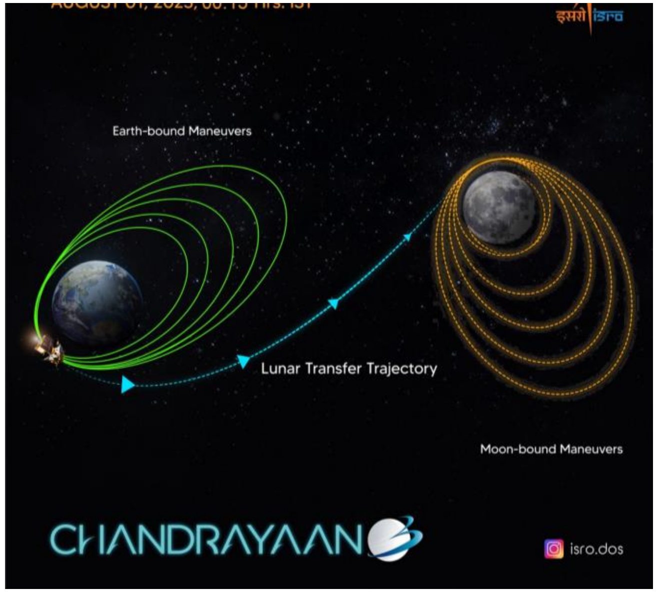
Documentation is available via the "Manual" tab above. Available time-spans for objects provided by Horizons can be viewed via the "Time Spans" tab above. When requesting an ephemeris for a specific object, you should ensure the requested time(s) are within the available time-span for that object.

> The Horizons system can be accessed via a variety of interfaces: web, command-line, email, and an API. Each interface is described below.

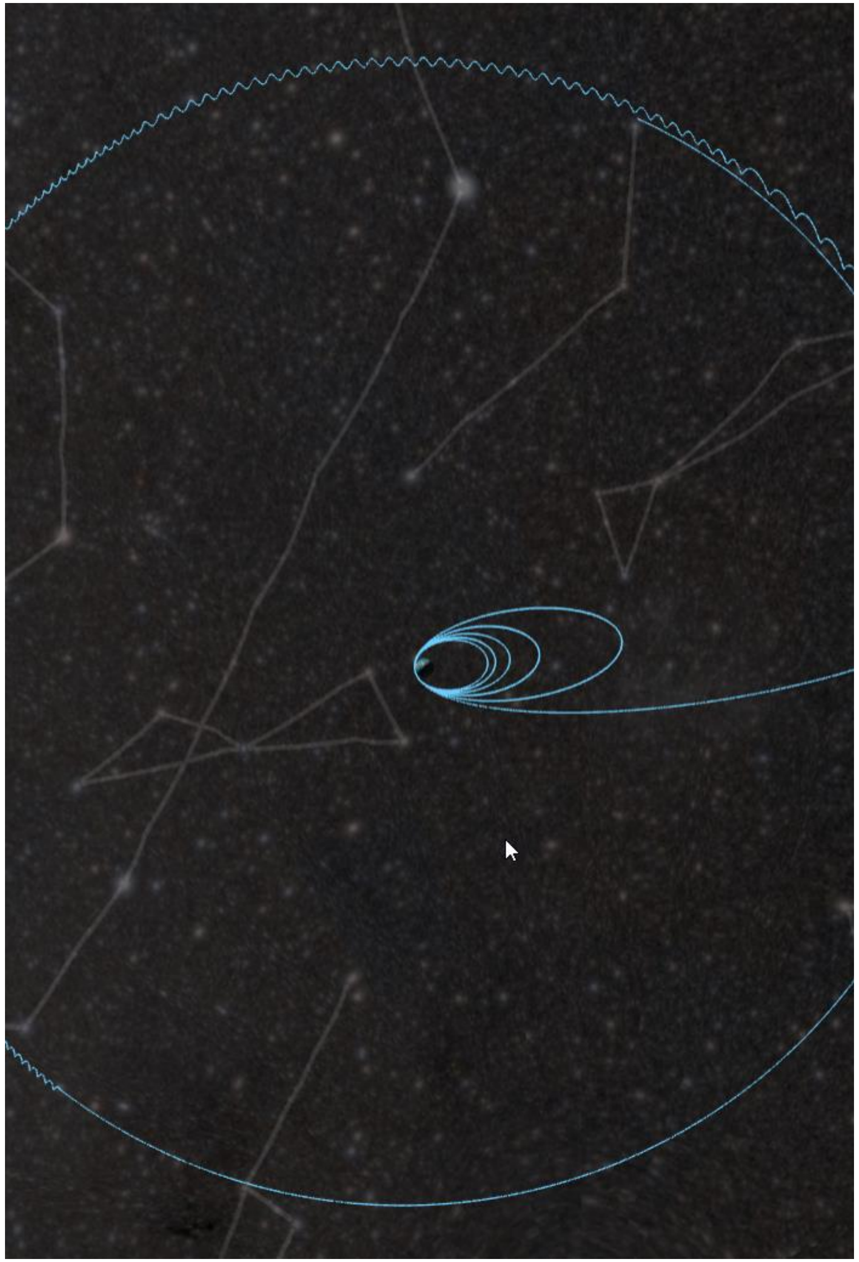


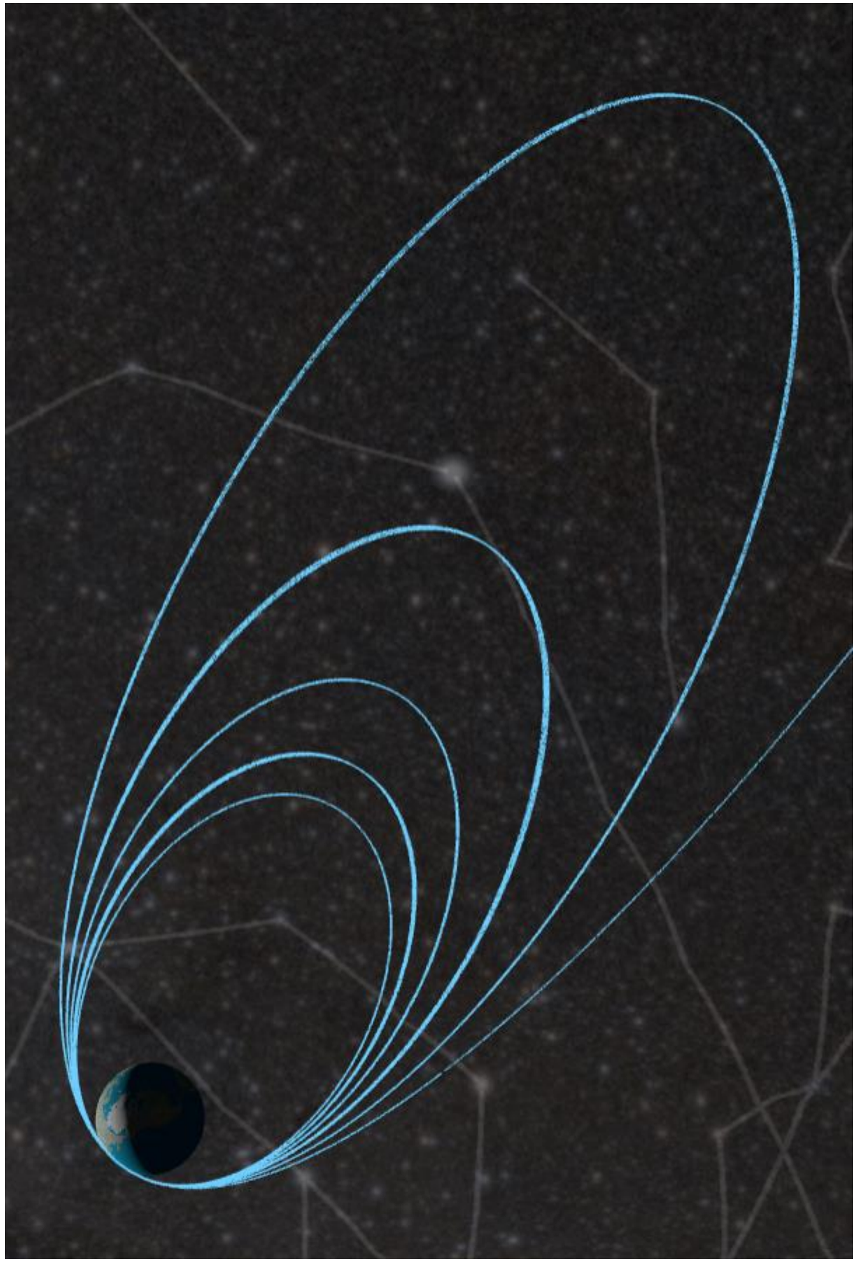
Pierre! Next time, use the Horizons Ephemeris Service...





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

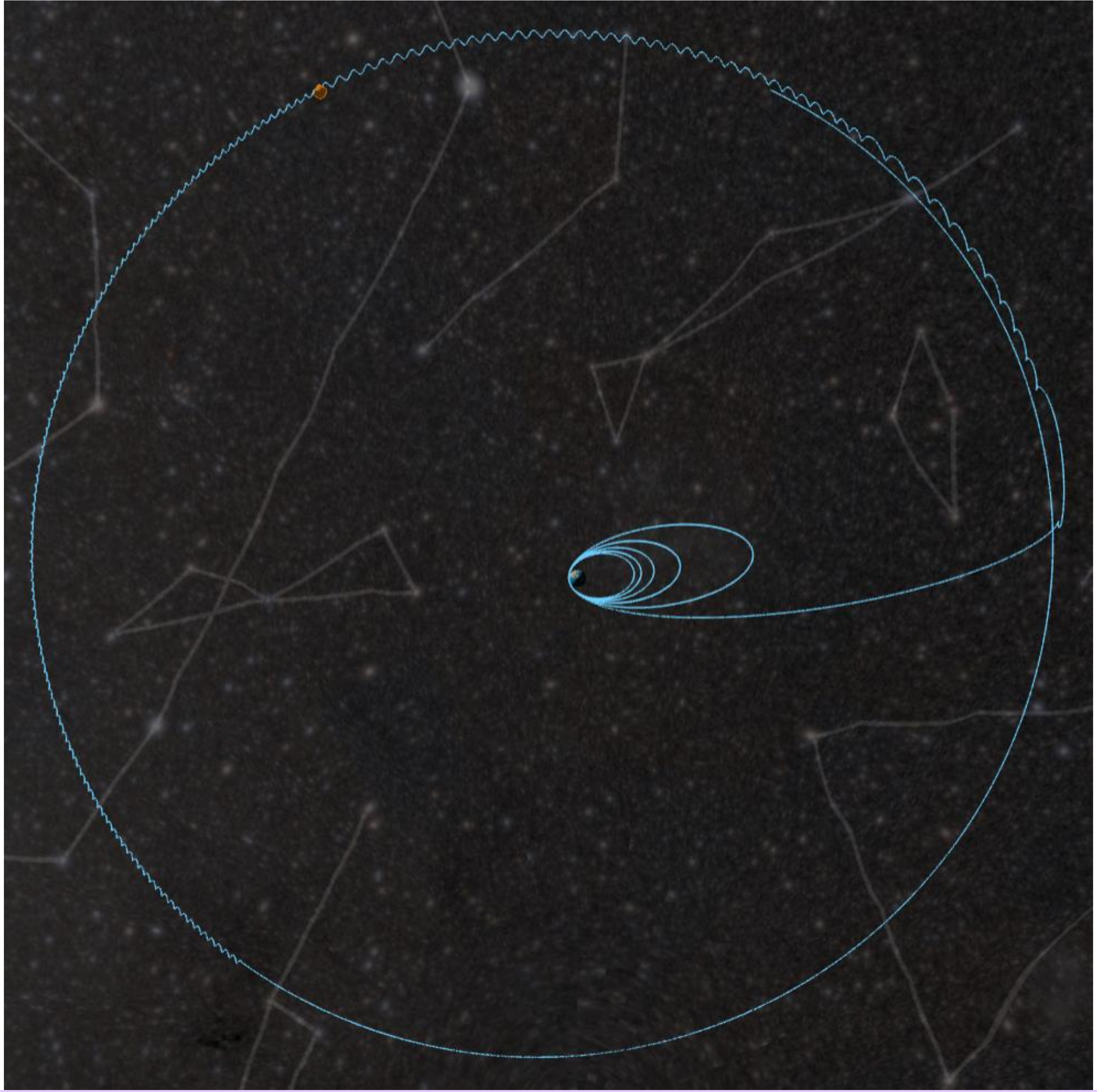




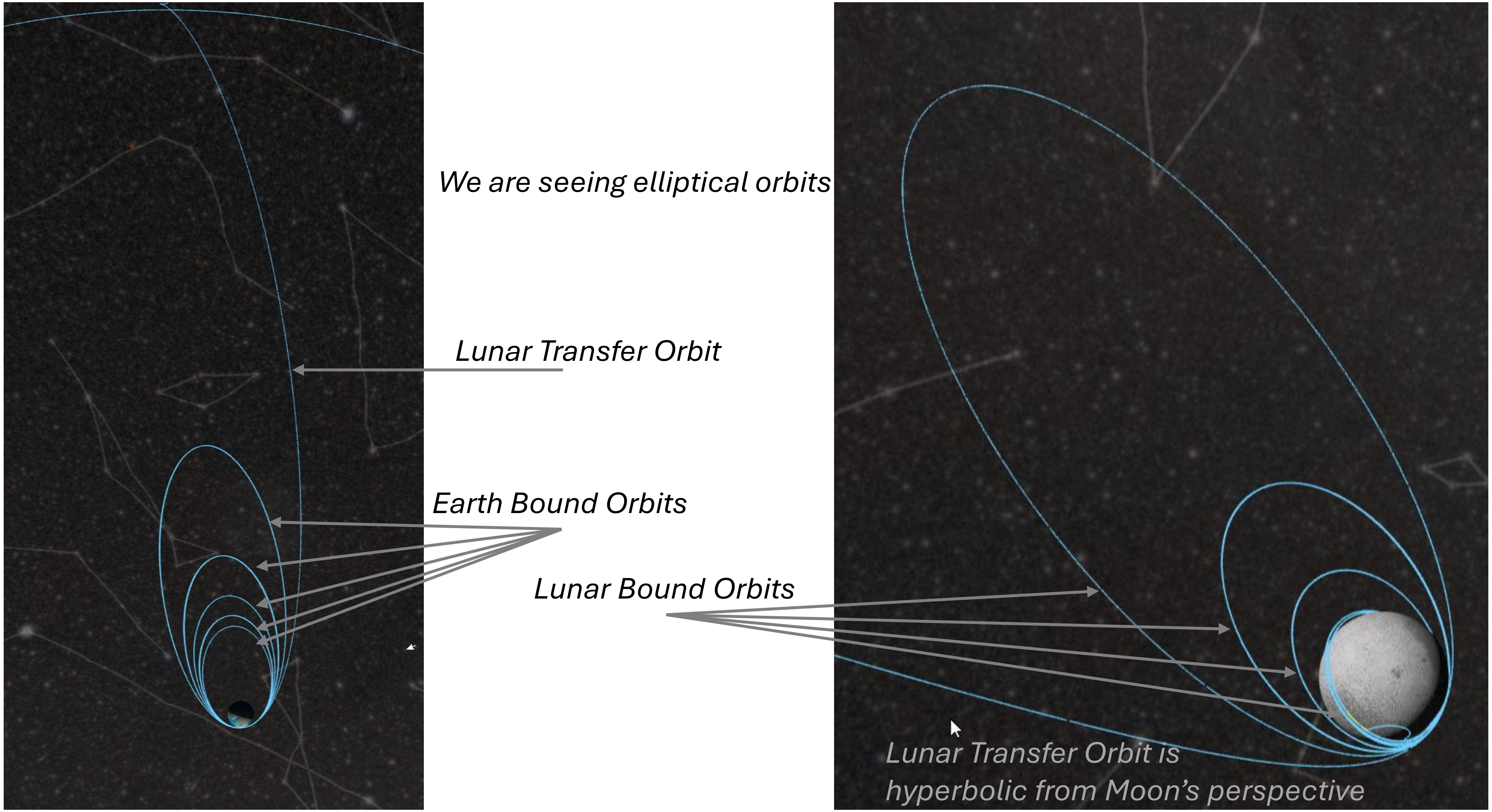
Trajectory

- As a sequence of points over time
- As a structure, as a composition of orbits

Mission Sequence



Elliptical Orbits in Chandrayaan 3 Trajectory



Quiz #3

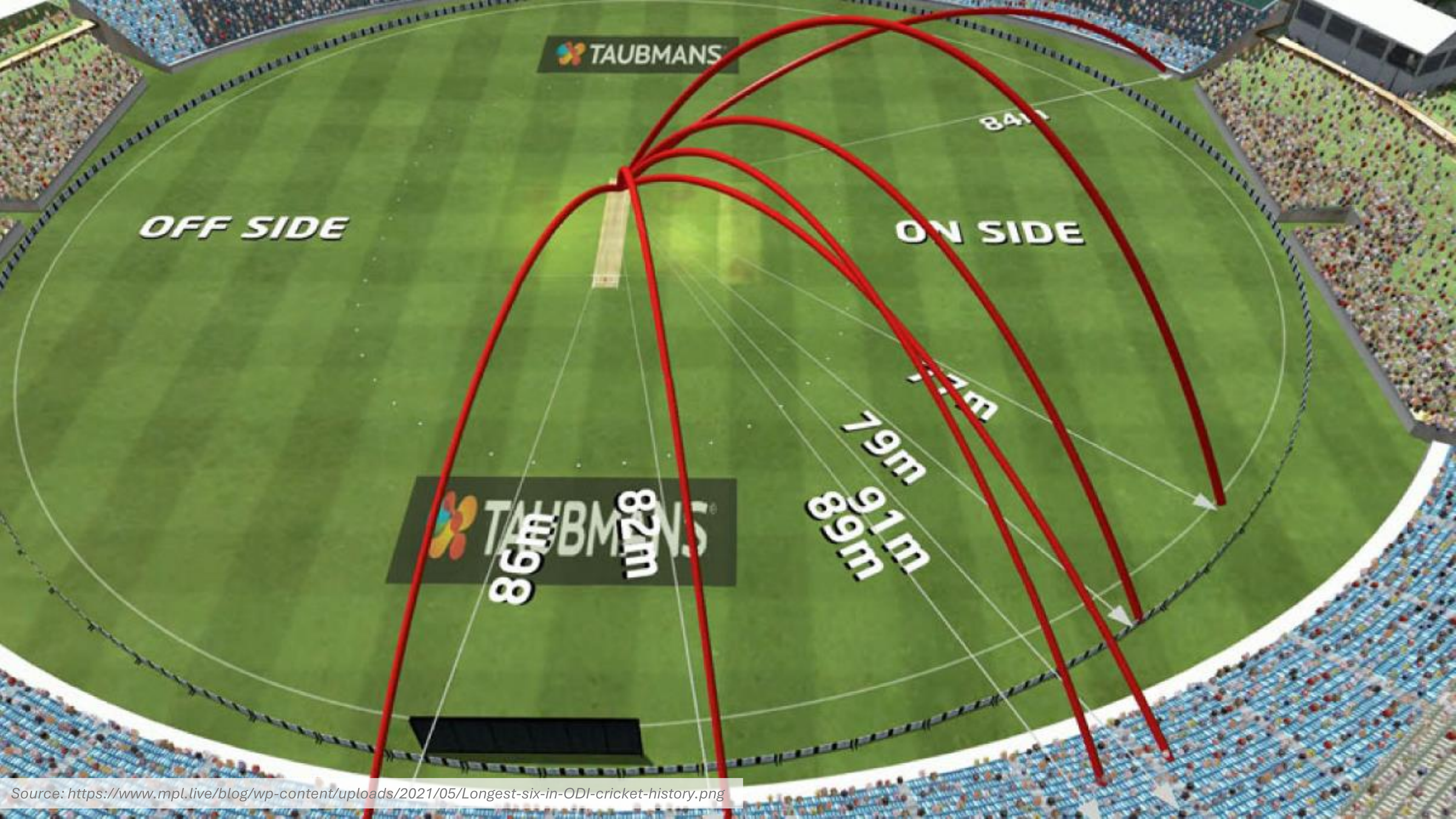
5. Orbits

Foundations > Orbits

Maneuvers in space are elegant, to say the least. There are no roads and routes — only geometry, gravity, and a lot of math.

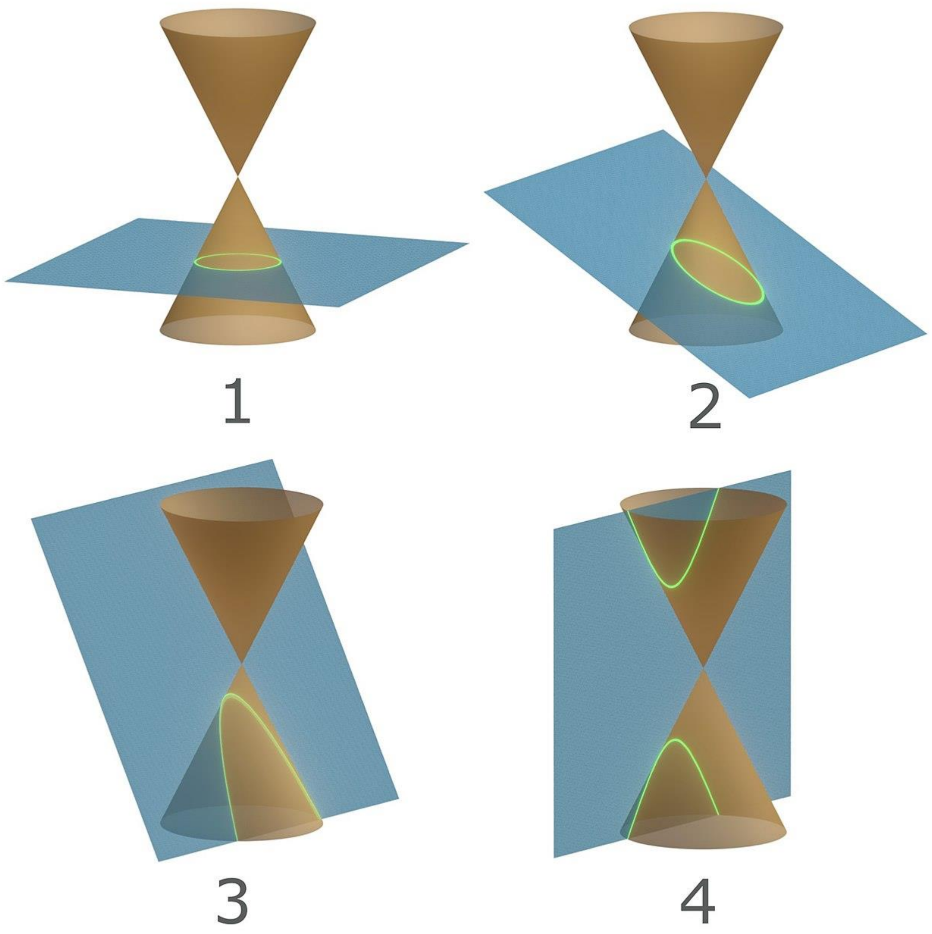
David Borchia, Delta-V Calculator; https://www.omnicalculator.com/physics/delta-v

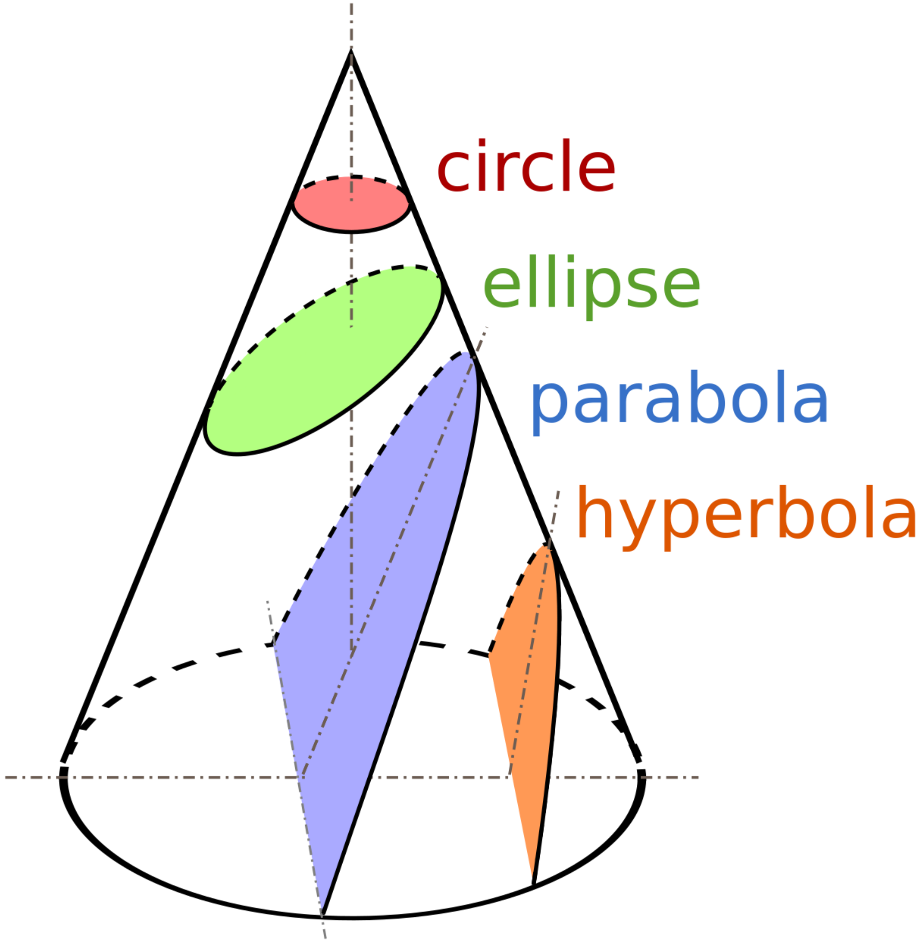
Source: https://indianexpress.com/article/sports/cricket/dean-elgars-drs-gaffe-compared-to-sachin-tendulkars-controversy-in-2011-world-cup-7722592/



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

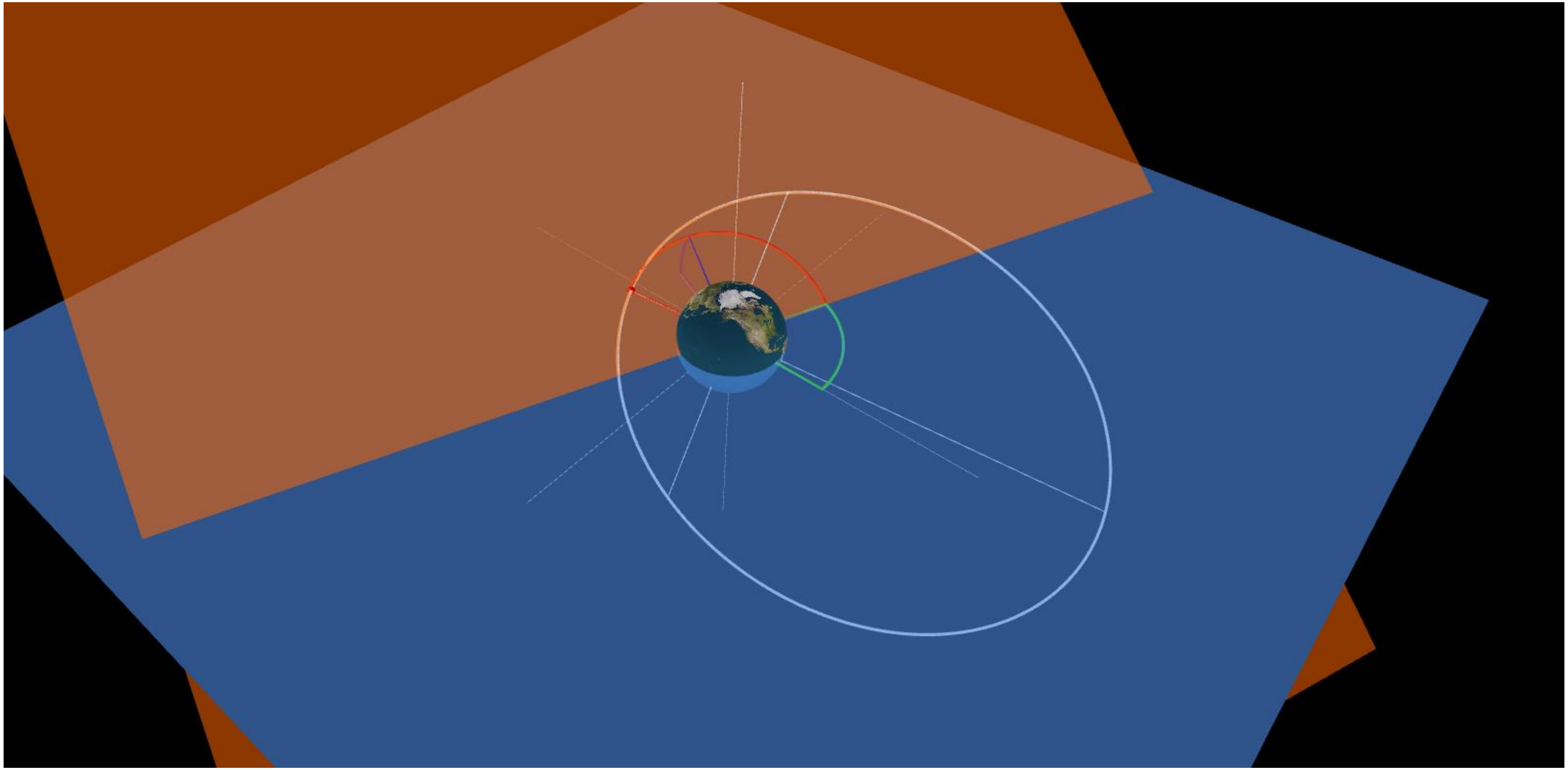
Conic Sections





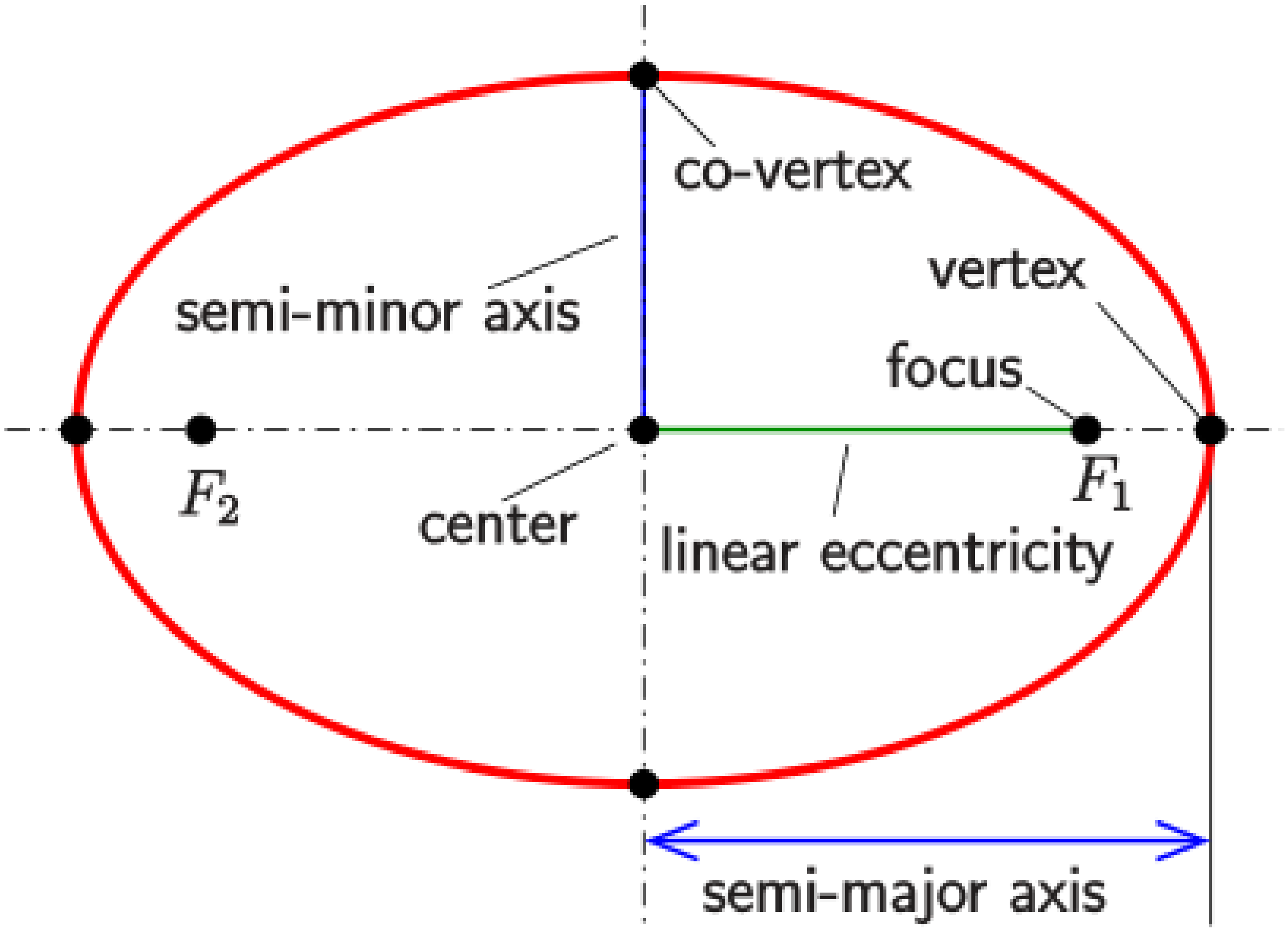
Source: https://en.wikipedia.org/wiki/Conic_section#/media/File:TypesOfConicSections.jpg
Source: https://en.wikipedia.org/wiki/Conic_section#/media/File:Conic_Sections.svg

Let’s Try …



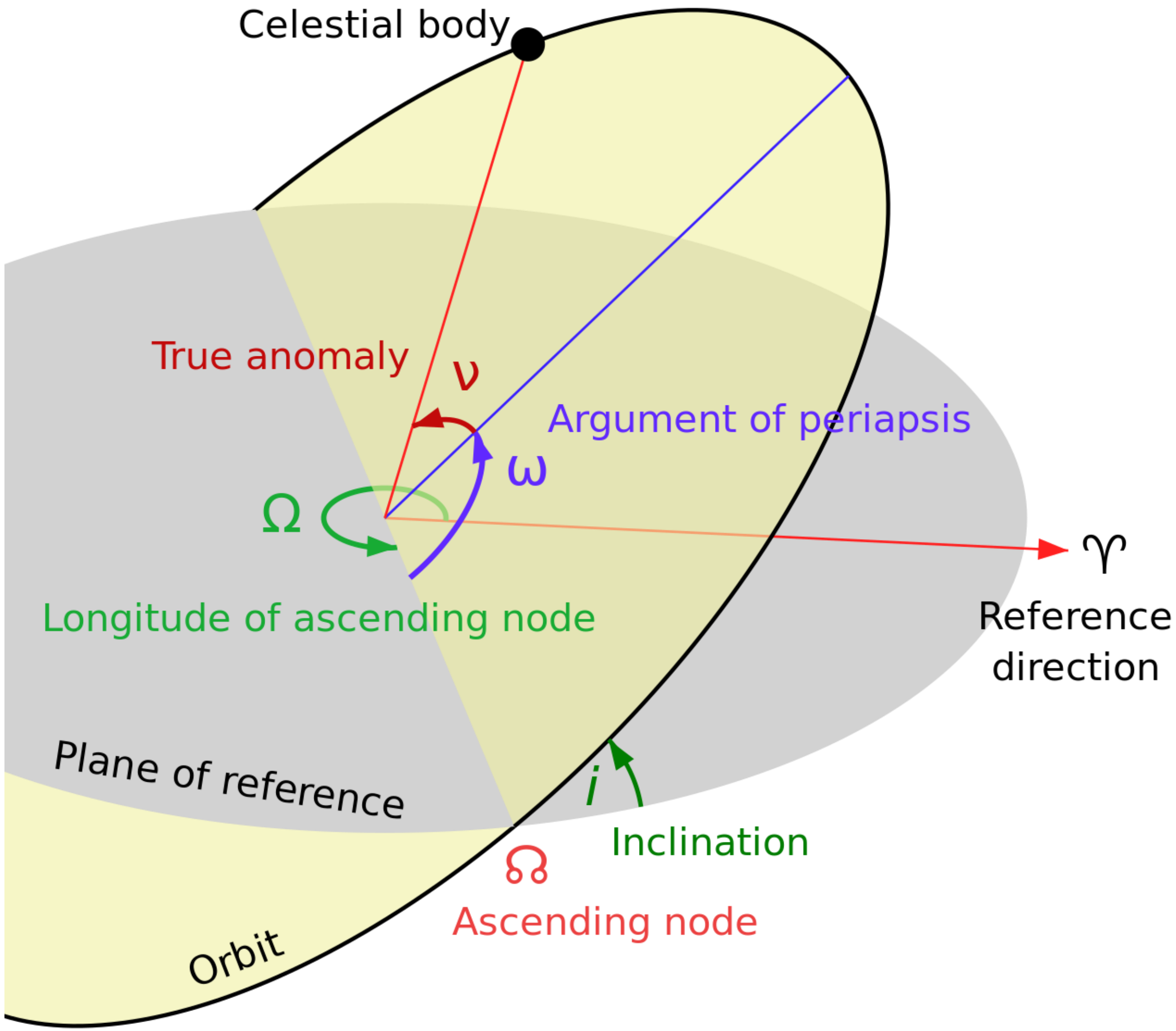
Source: https://orbitalmechanics.info/

Ellipse Notations



Source: https://en.wikipedia.org/wiki/Ellipse#/media/File:Ellipse-def0.svg

Keplerian Orbital Elements

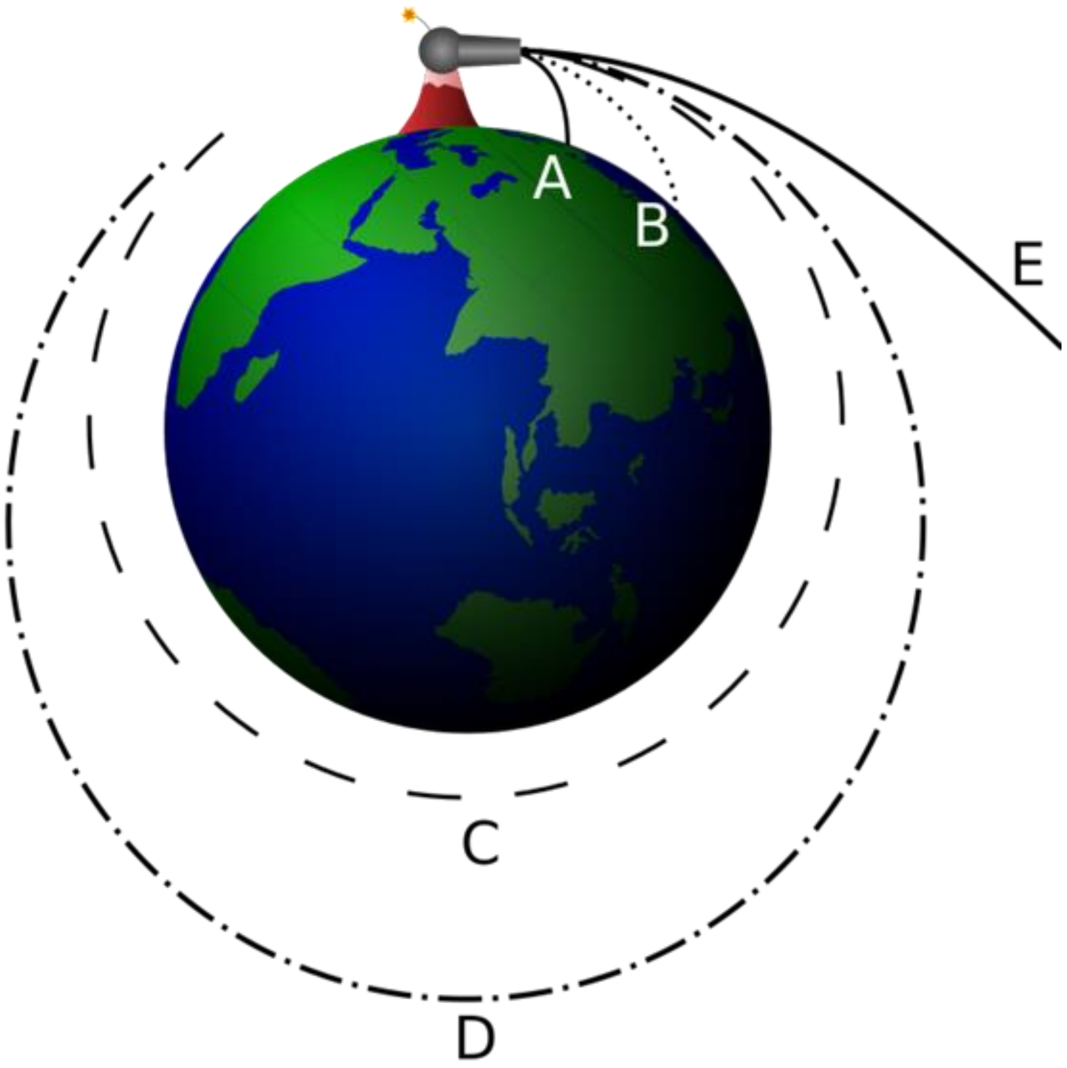


Source: https://en.wikipedia.org/wiki/Orbital_elements#/media/File:Orbit1.svg

Chandrayaan 3 Orbit Events and Maneuvers

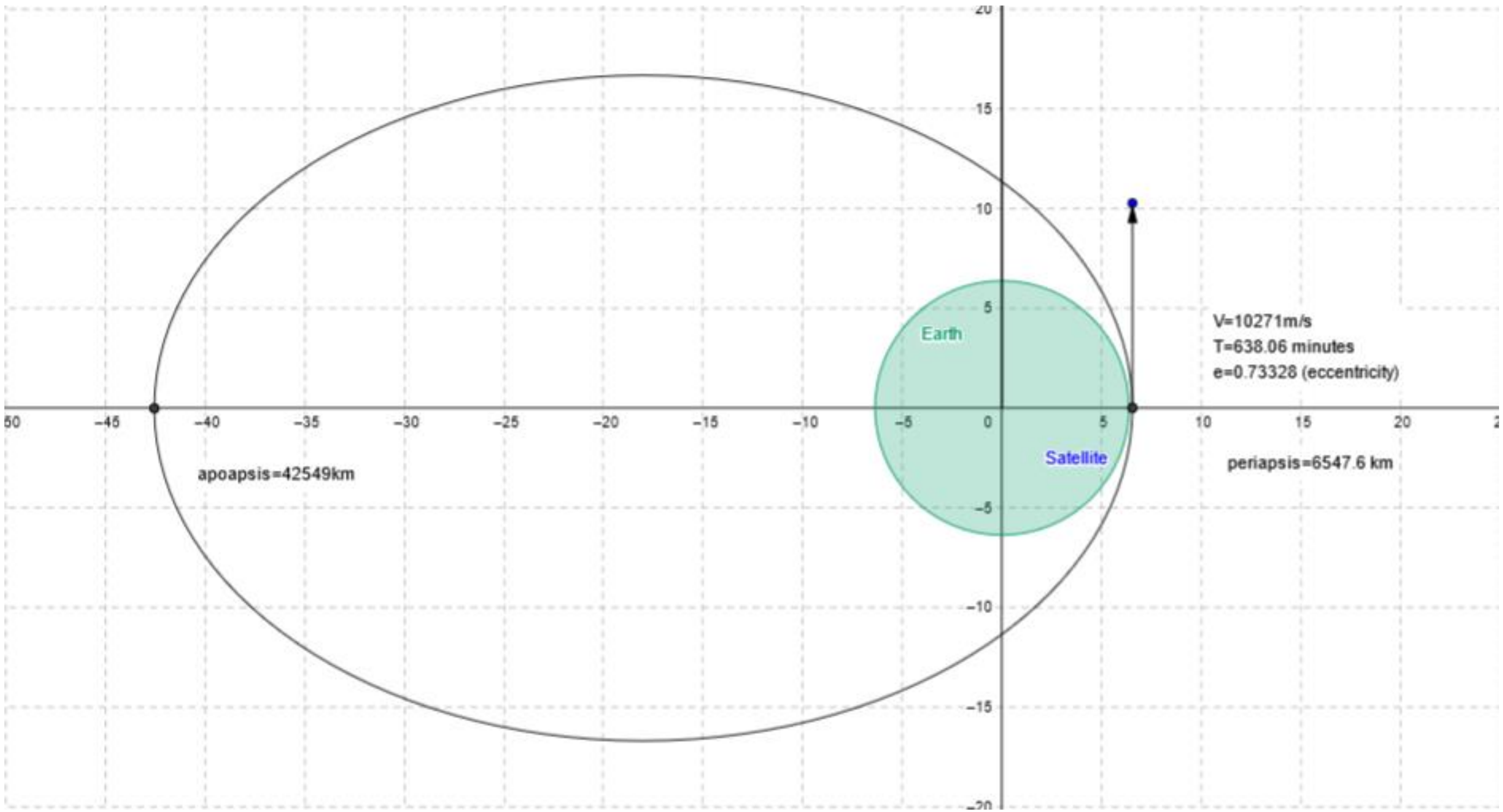
Date (UTC)	Time (UTC)	Event	Primary	Burn Point	Orbit (km)
14-Jul-2023	9:05:00 AM	Launch			
14-Jul-2023	9:23:00 AM	Orbit insertion	Earth		36500x170
15-Jul-2023	6:41:00 AM	EBN1	Earth	Perigee/Pro	41762x173
17-Jul-2023	2:15:00 AM	EBN2	Earth	Apogee/Pro	41603x226
18-Jul-2023	9:24:00 AM	EBN3	Earth	Perigee/Pro	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		

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

Principles

- Newton’s laws of motion
- Newton’s law of gravity
- Calculus
- Kepler’s laws can be derived from the above
- Real-world trajectory designs use classical mechanics
  - Often modeled as two-body problems
  - Effect of other bodies modeled as perturbations

Elliptic Orbits: Key Equations

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

Vis-viva equation in two forms

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

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

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

Orbit Maneuvers with Period and Velocities Computed

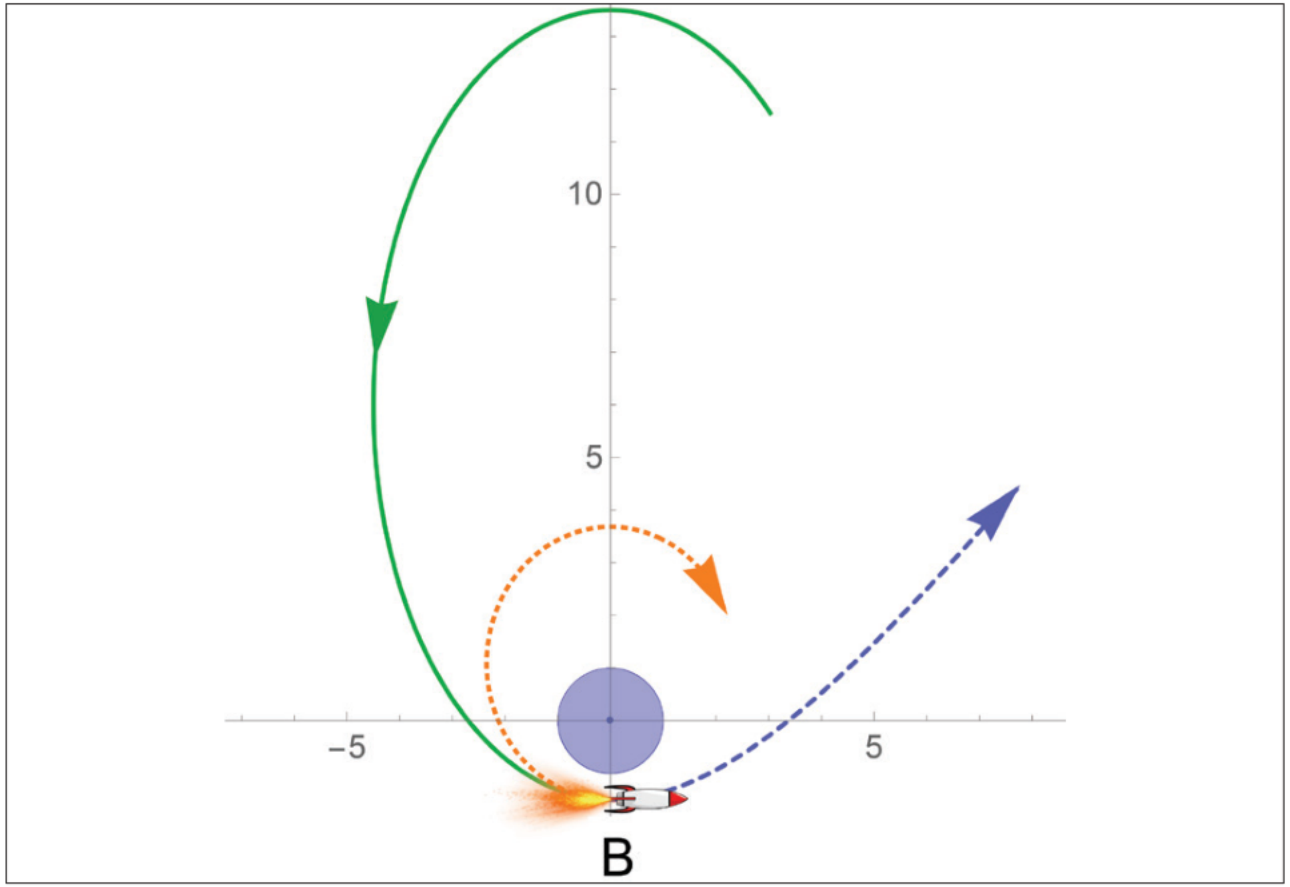
Event	Apogee Alt (km)	Perigee Alt (km)	Orbits	Duration (Days)	Relative Time (Days)	Period (hours)	Perigee Velocity (km/s)	Apogee Velocity (km/s)	Delta V (m/s)
Launch									
Orbit insertion	36500	170	2	0.013	0.01	10.740	10.2769	1.5694	
EBN1	41762	173	3.5	0.887	0.90	12.501	10.3495	1.4084	72.57
EBN2*	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				

Quiz #4

6. Orbital Maneuvers

Foundations > Orbital Maneuvers

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

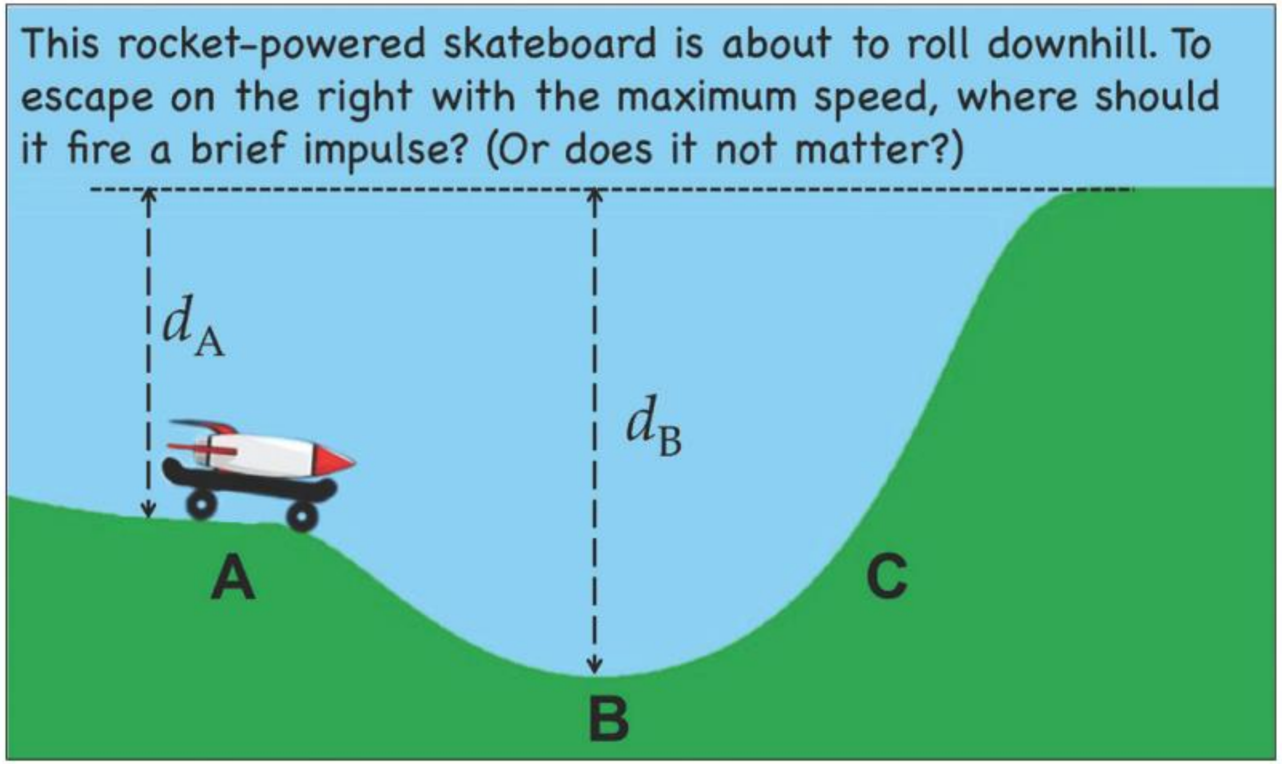
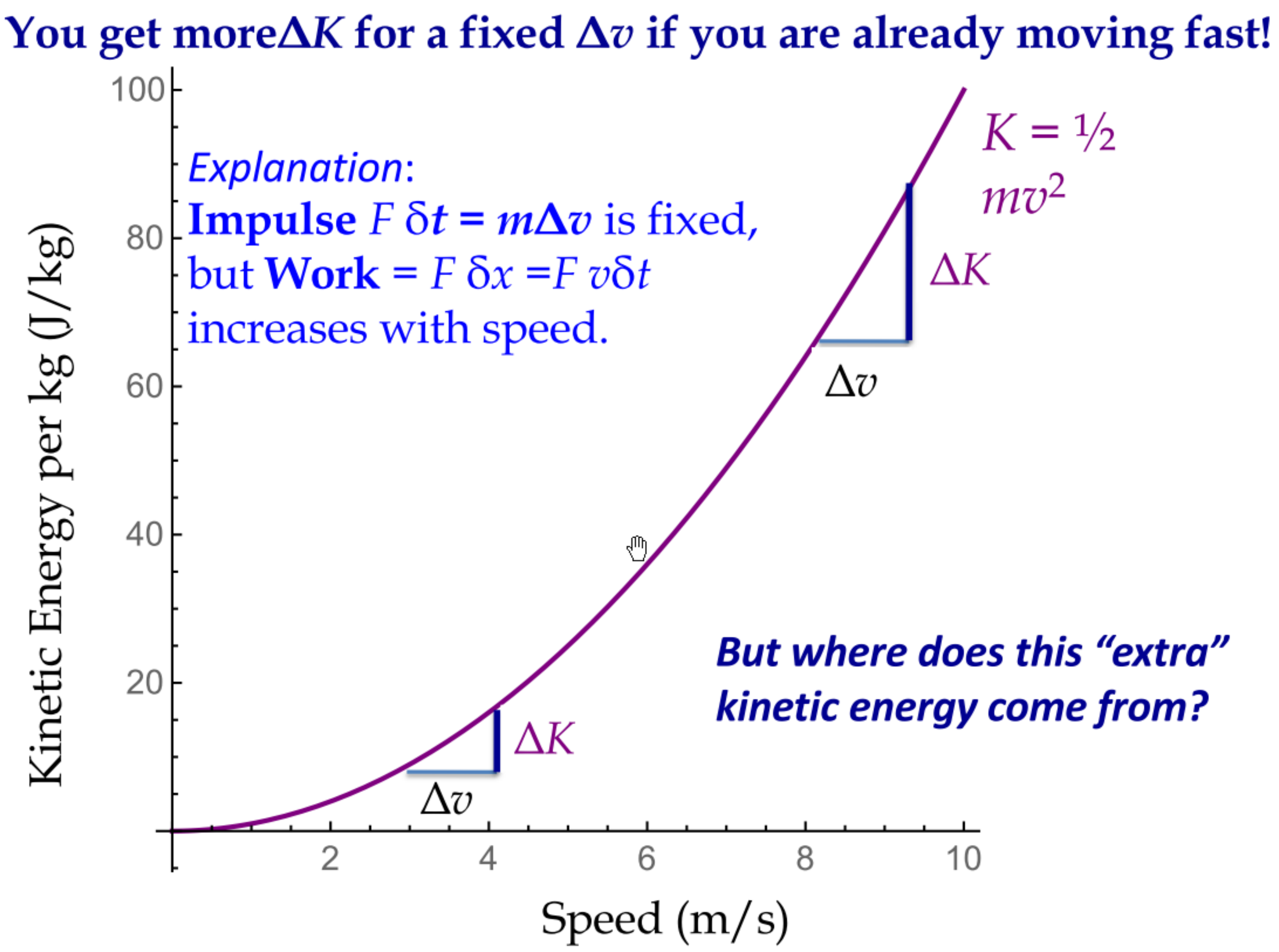


Fig. 1. Statement of the problem. A version without annotations is provided in the online supplement.[16]

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

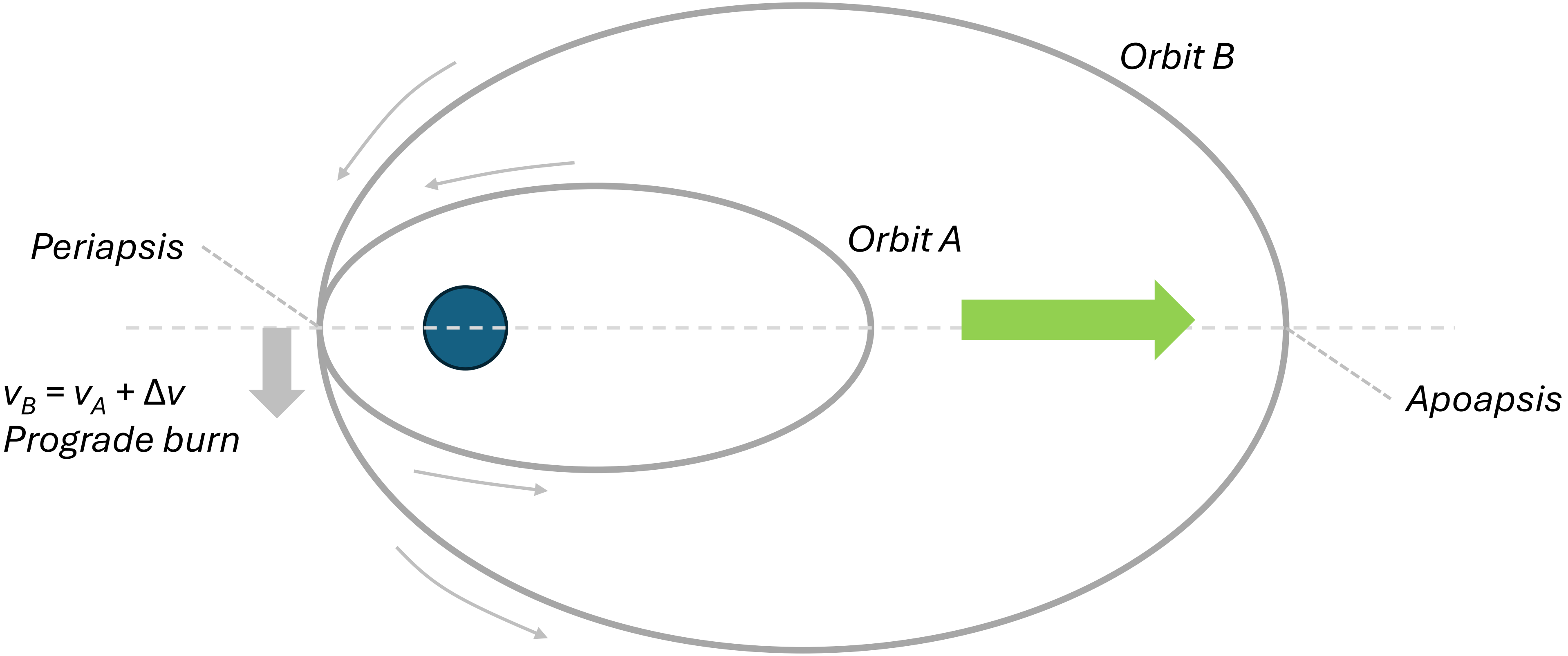
Source: https://www.researchgate.net/publication/336060638_Rocket_propulsion_classical_relativity_and_the_Oberth_effect

Oberth Effect Explained

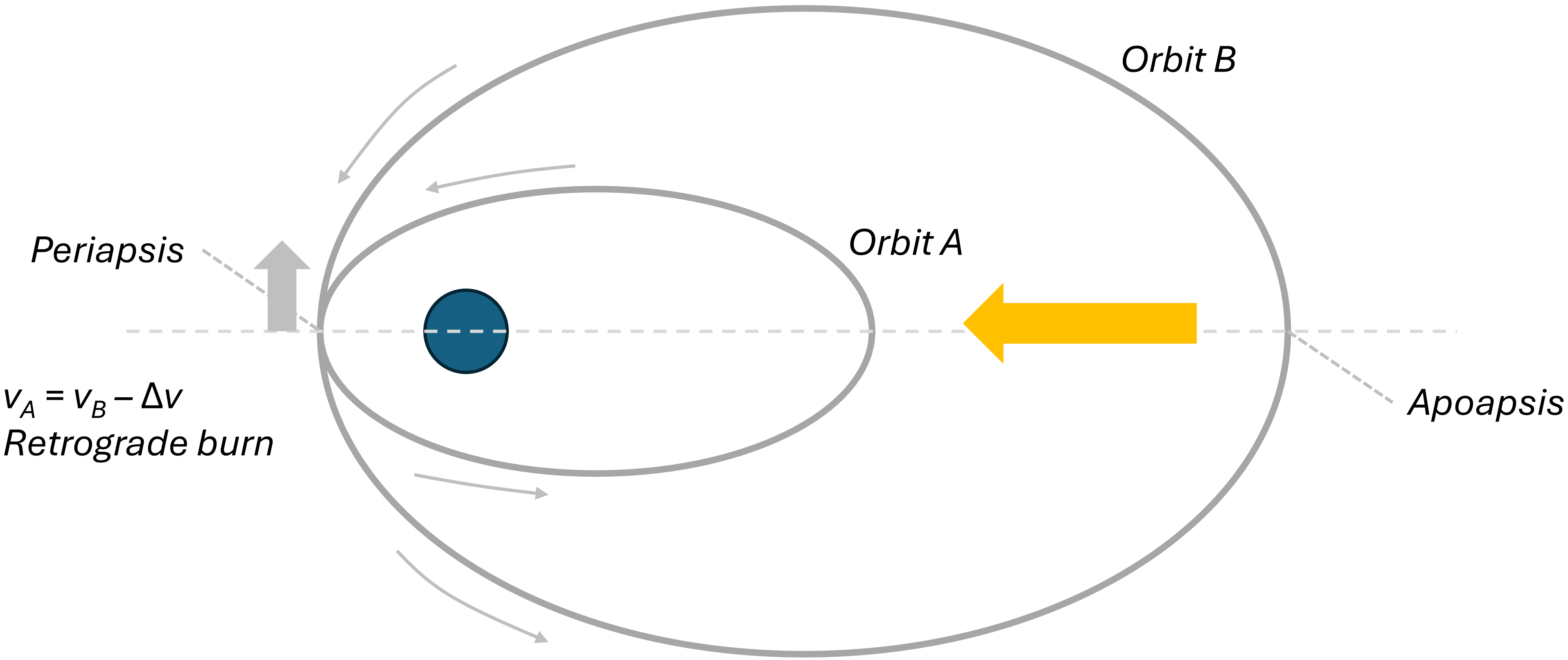


Source: https://www.researchgate.net/publication/336060638_Rocket_propulsion_classical_relativity_and_the_Oberth_effect

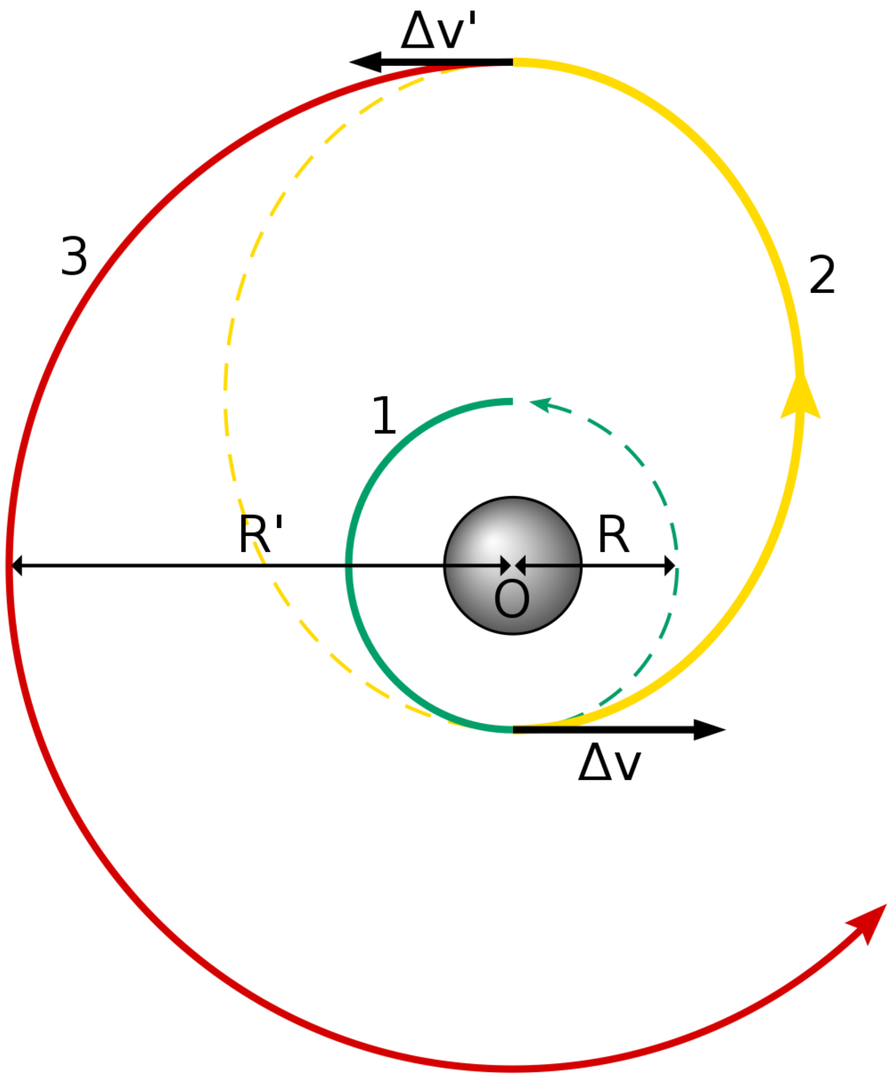
Orbital Maneuver to Raise an Orbit



Orbital Maneuver to Lower an Orbit

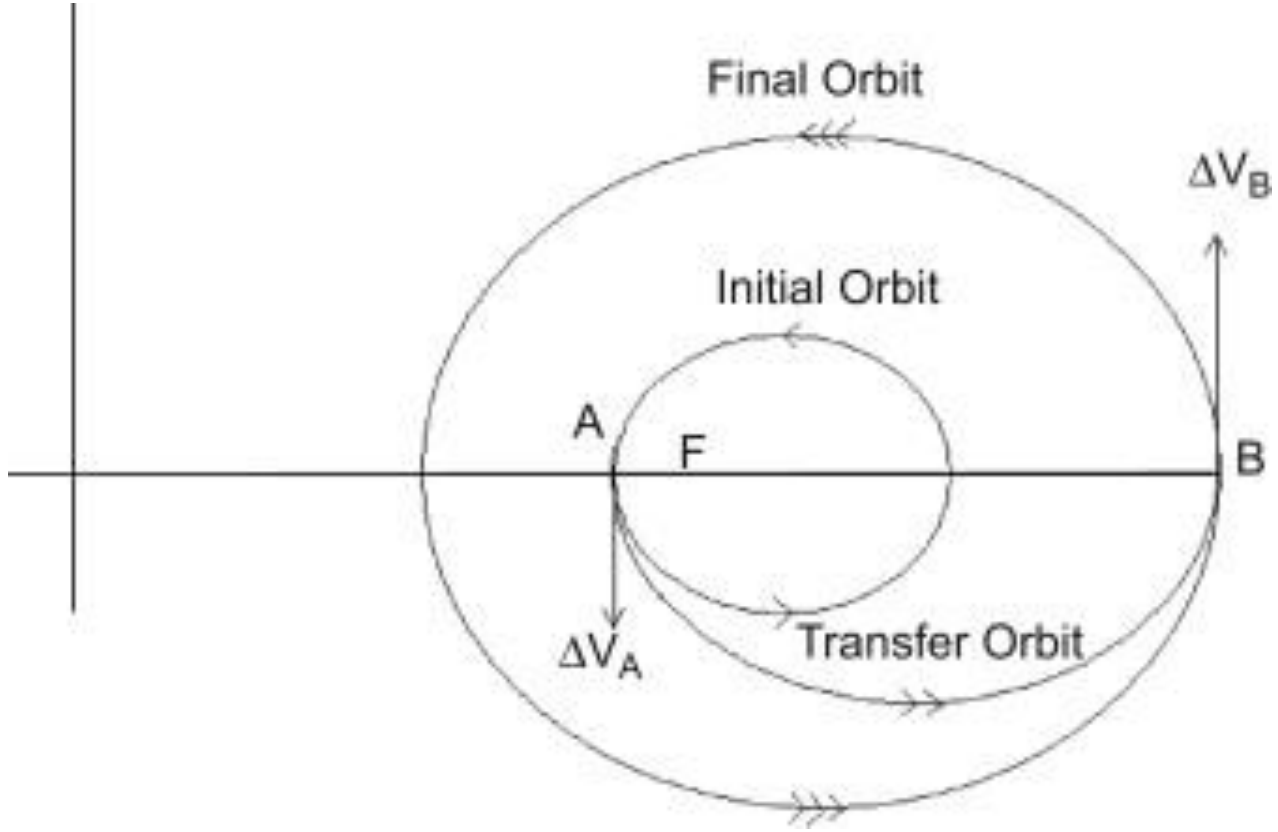


Hohmann Transfer

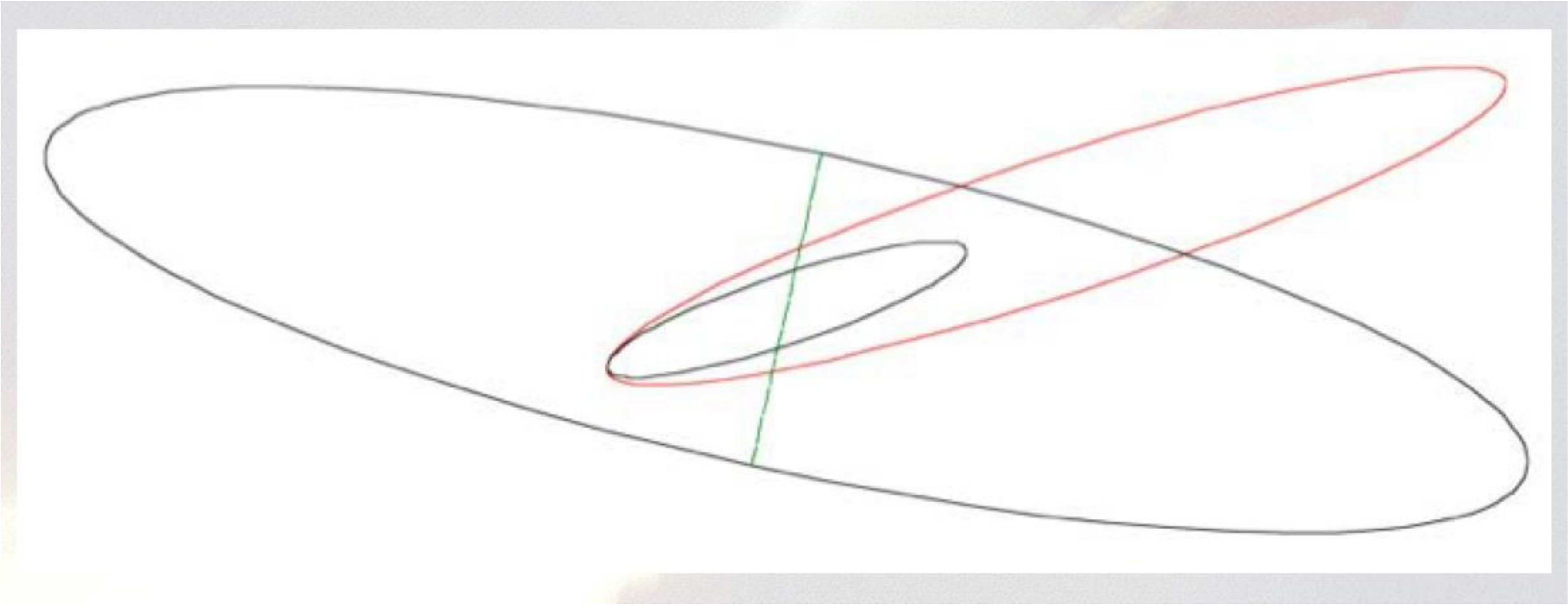


Source: https://en.wikipedia.org/wiki/Hohmann_transfer_orbit#/media/File:Hohmann_transfer_orbit.svg

Hohmann Transfer Across Elliptic Orbits

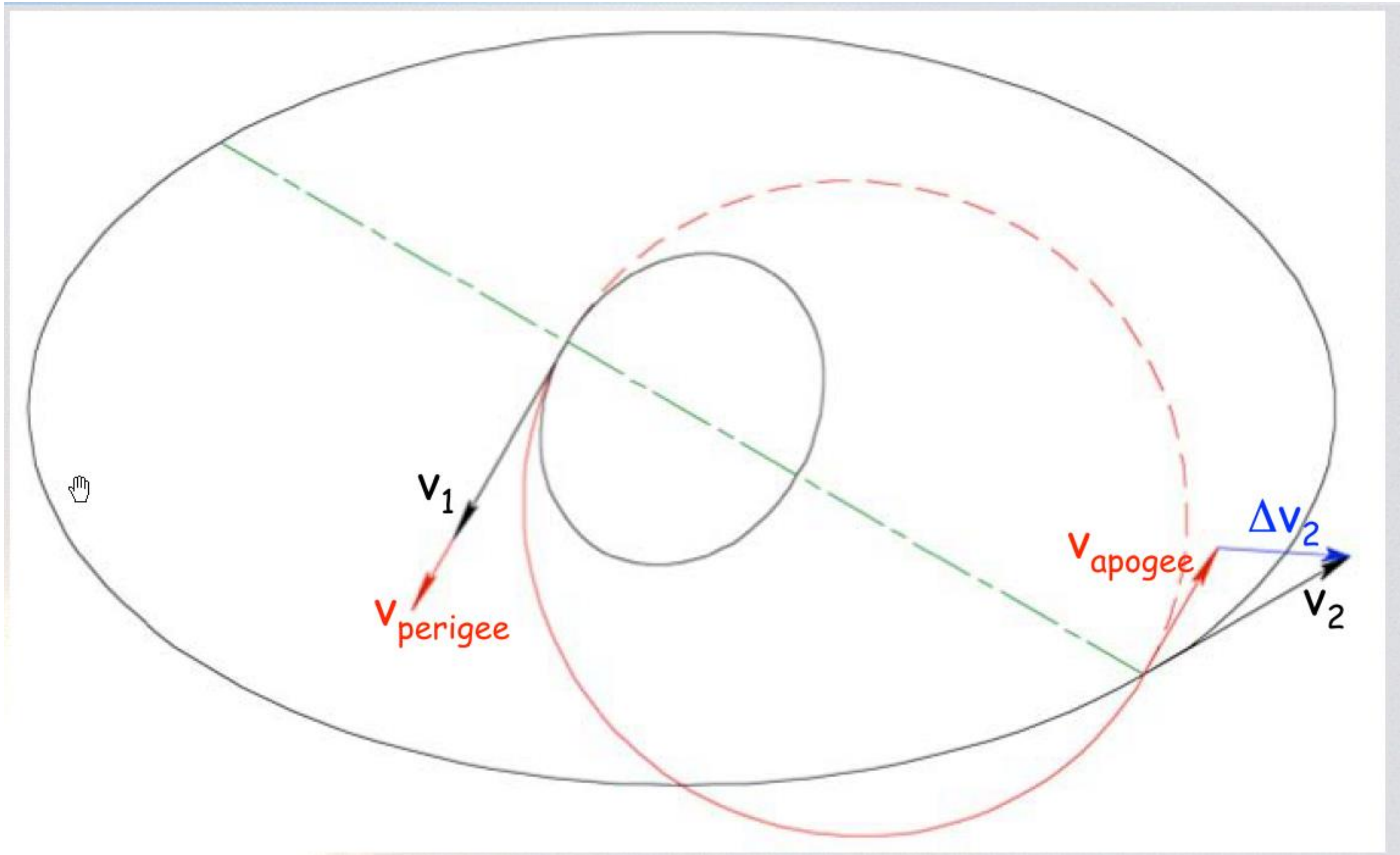


What if the Target Orbit is in a Different Plane?



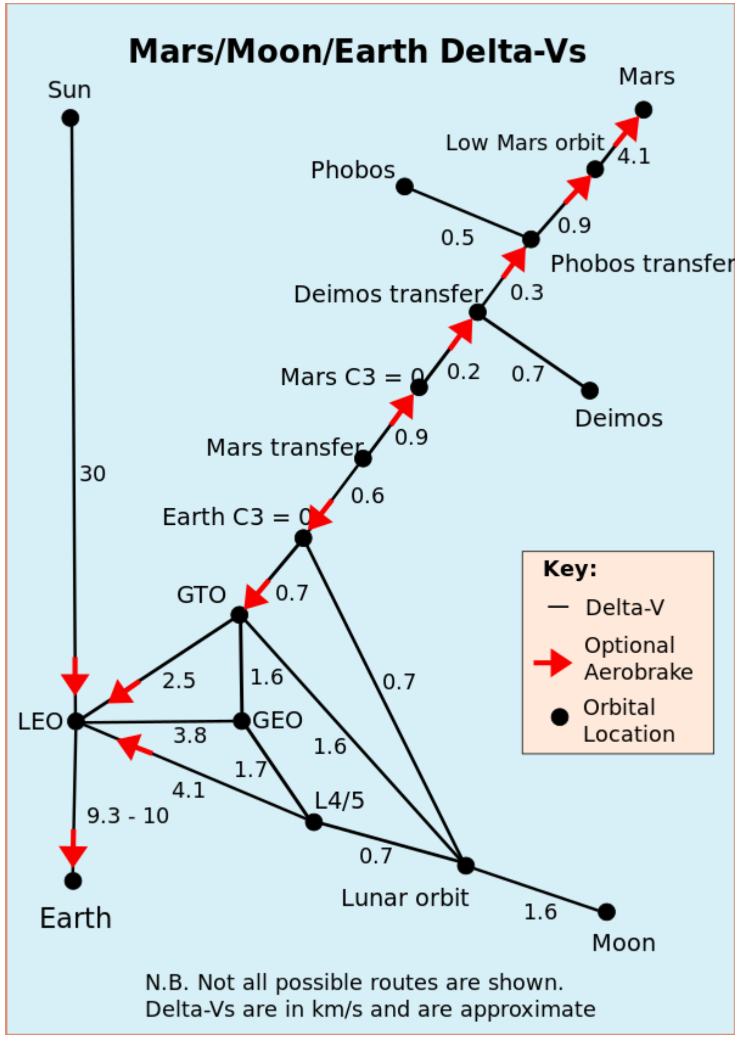
Source: https://spacecraft.ssl.umd.edu/academics/791S16/791S16L02.orbmechx.pdf

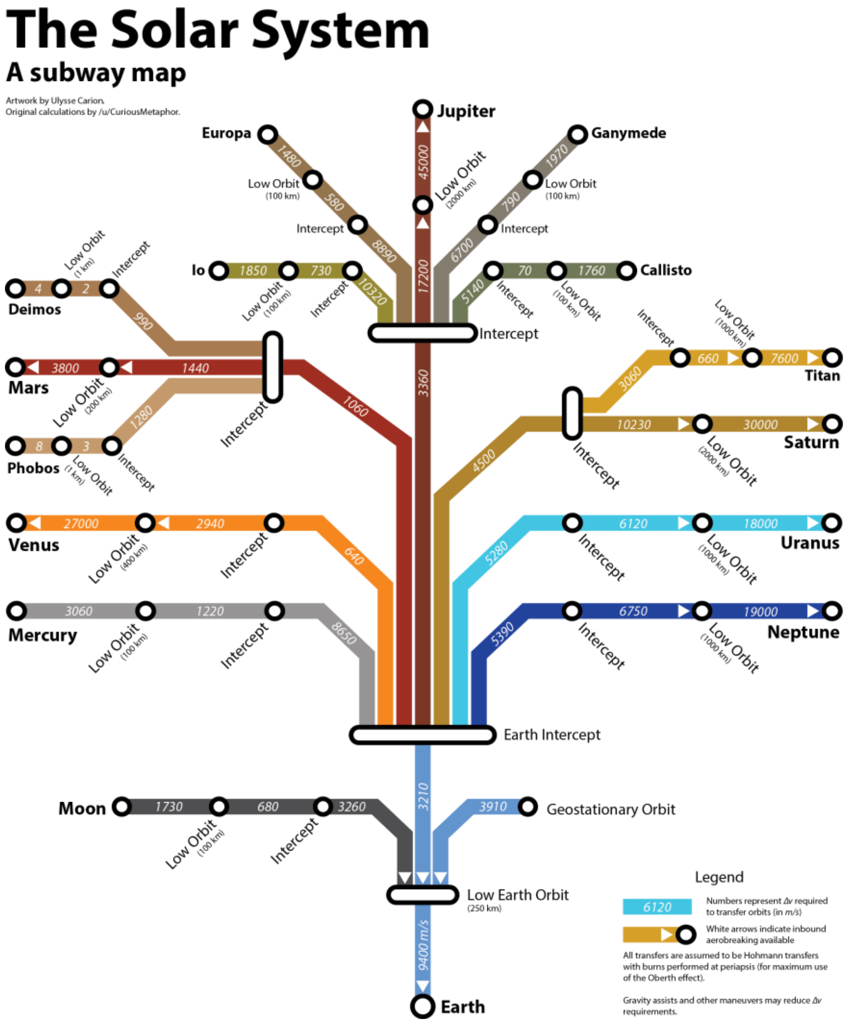
Simple Plane Change



Source: https://spacecraft.ssl.umd.edu/academics/791S16/791S16L02.orbmechx.pdf

Delta-V Map





Source: https://www.quora.com/How-much-Delta-V-does-it-take-to-get-to-the-moon

Source: https://en.wikipedia.org/wiki/Delta-v_budget#/media/File:Delta-Vs_for_inner_Solar_System.svg

Rocket Equation

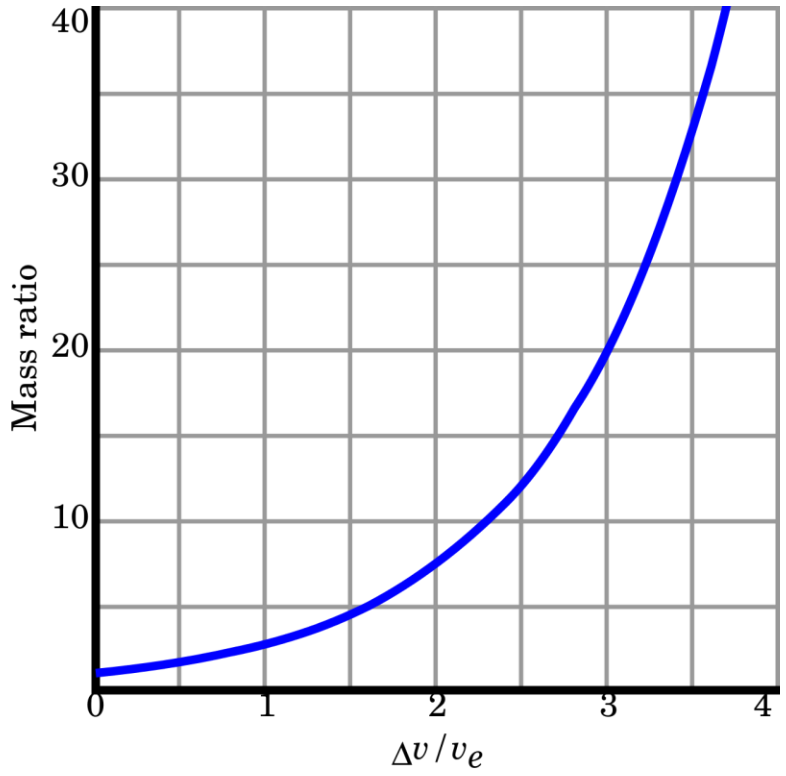
$$\Delta v = v_e \ln \frac{m_0}{m_1}$$

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

Propulsion and Fuel Needs

- Delta-V + Mass + Other Variables ➔ Fuel needs

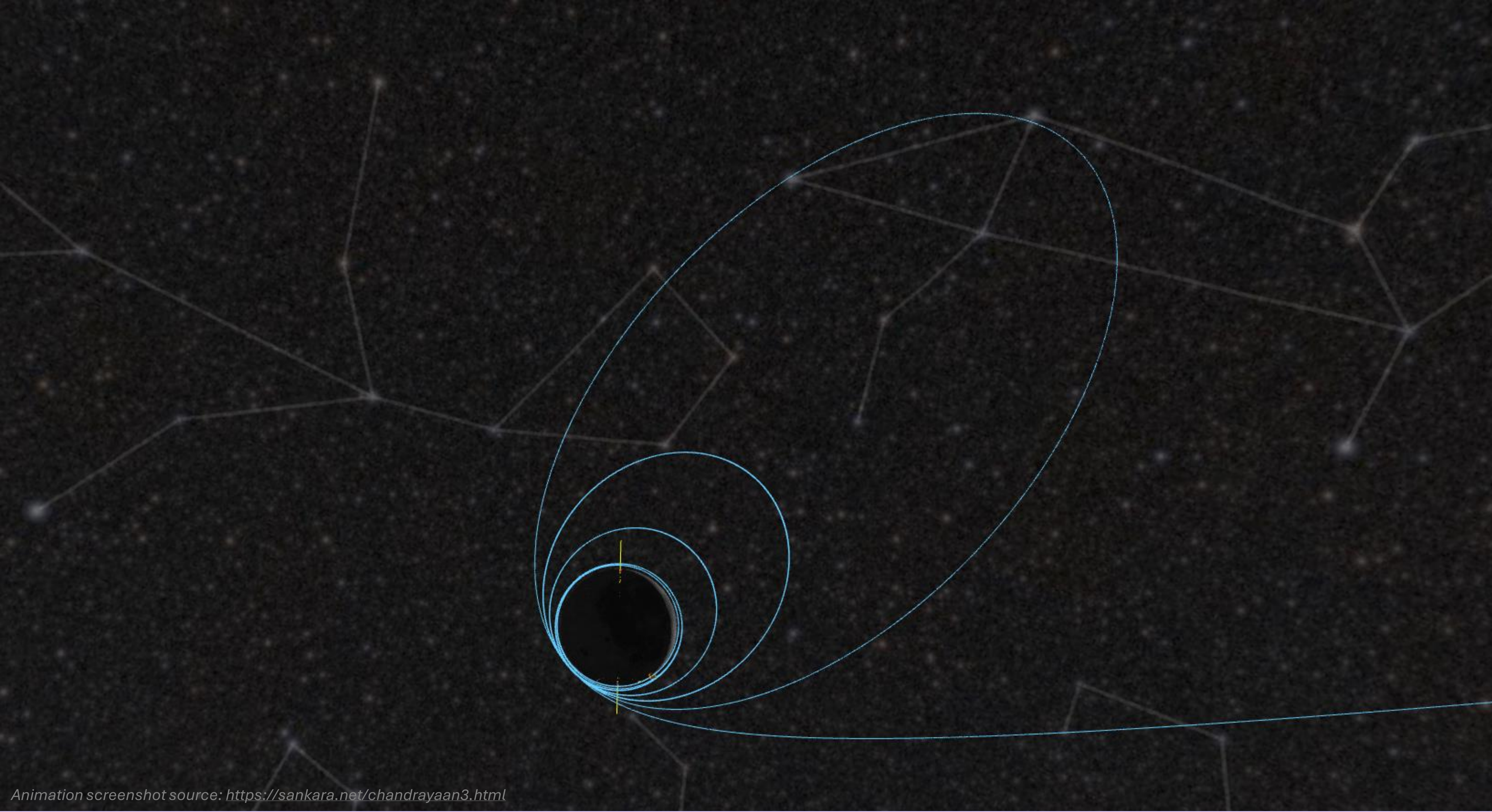
- Not covered in this lecture

Quiz #5

Mission Design

7. CY3 Lunar Orbits

Mission Design > Lunar Orbits

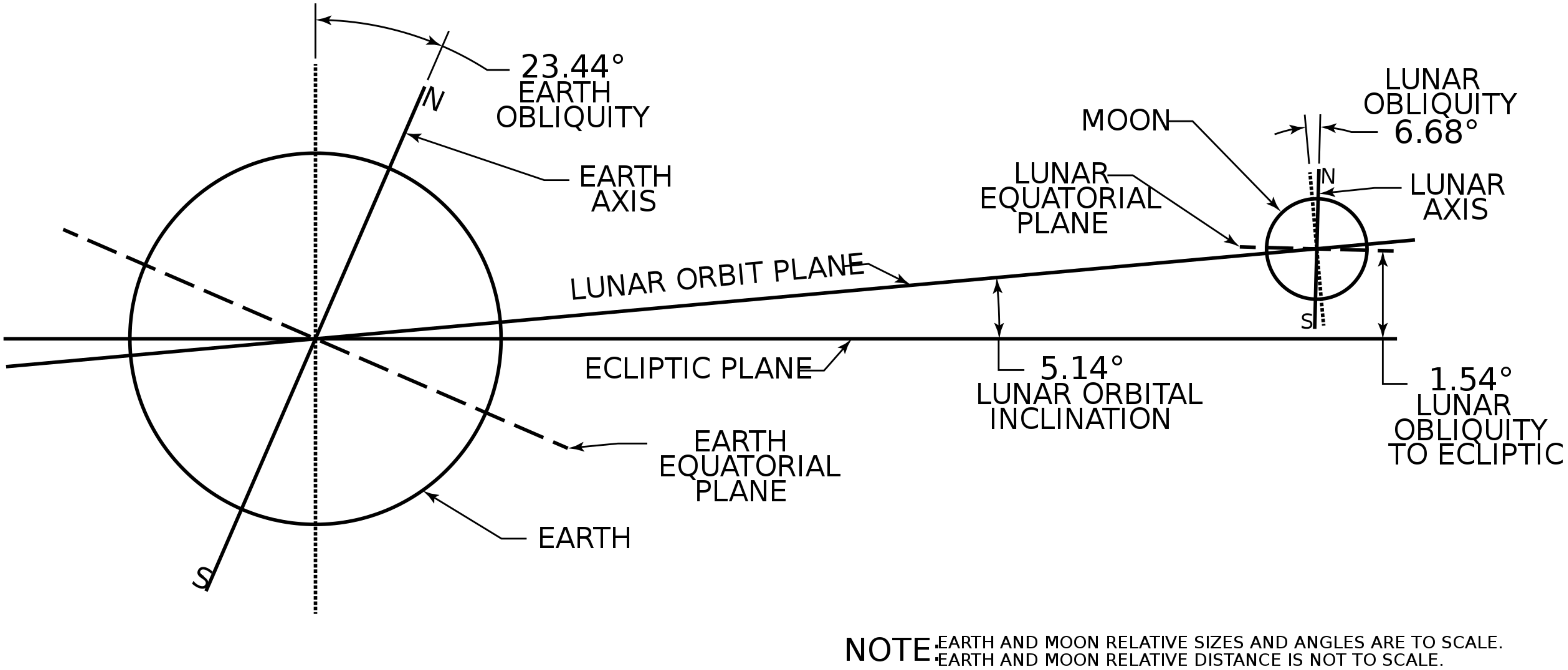


Animation screenshot source: https://sankara.net/chandrayaan3.html

Lunar Orbits

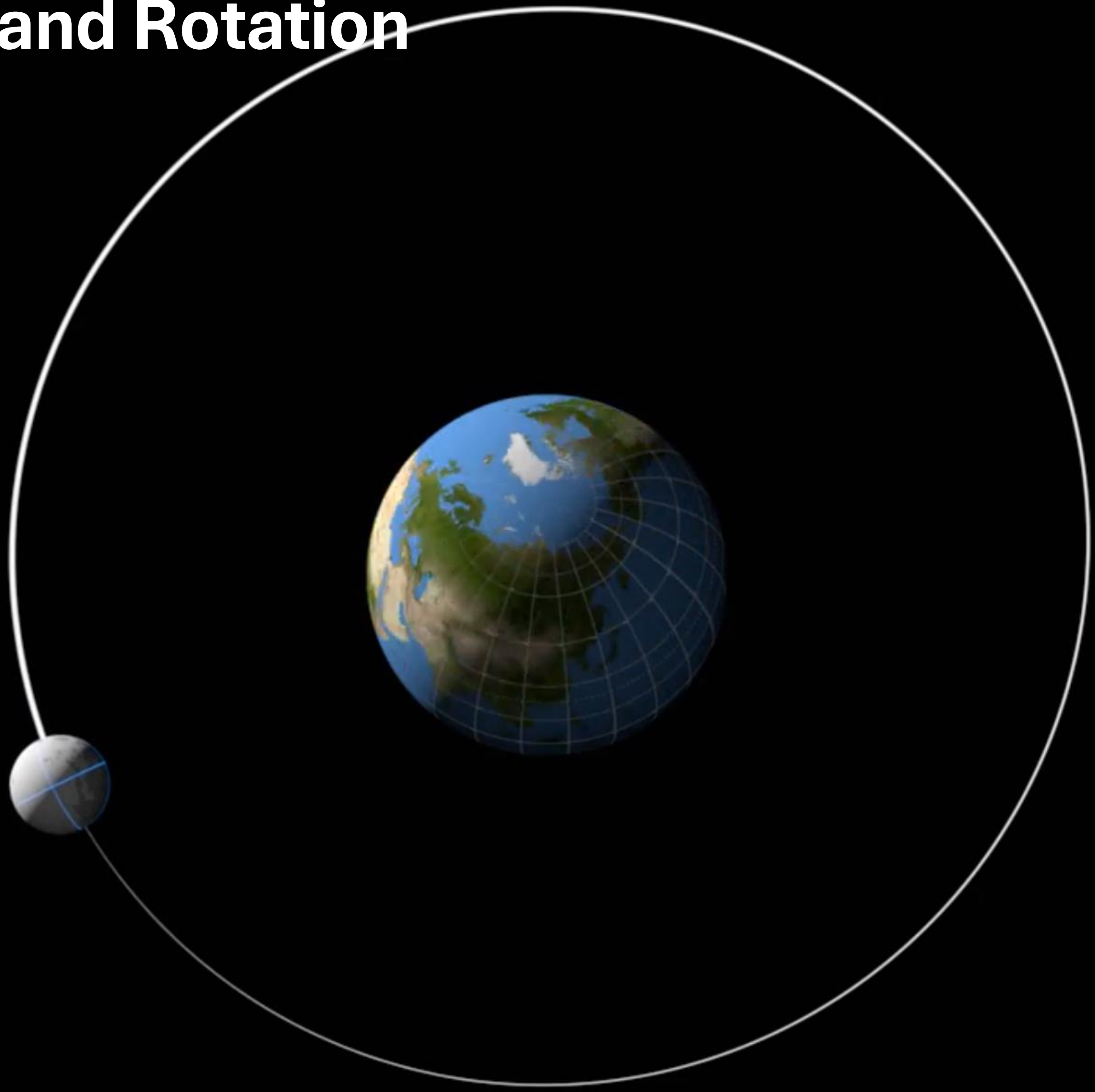
- Polar orbits
  - Reachability to PLS and ALS
    PLS: 69.367621˚S, 32.348126˚E
    ALS: 69.497764˚S, 17.330409˚W
  - Lunar imaging coverage (at least for CY2)
  - Negligible cross axis ground track shift
- Sun altitude 6–9˚ at landing
  - Determines the landing window in a synodic month
  - Implies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

Lunar Orbit and Orientation

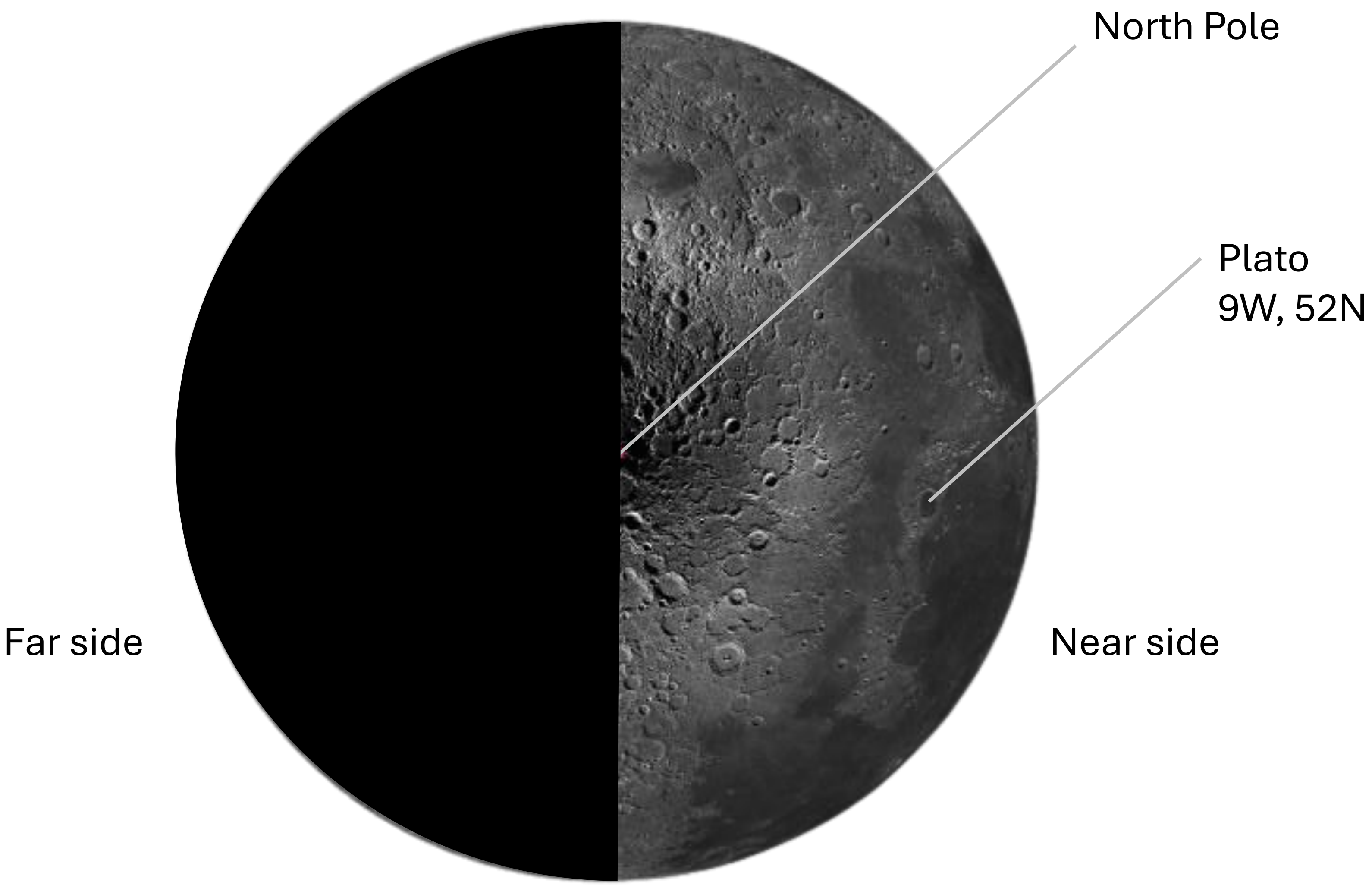


Source: https://en.wikipedia.org/wiki/Orbit_of_the_Moon#/media/File:Lunar_Orbit_and_Orientation_with_respect_to_the_Ecliptic.svg

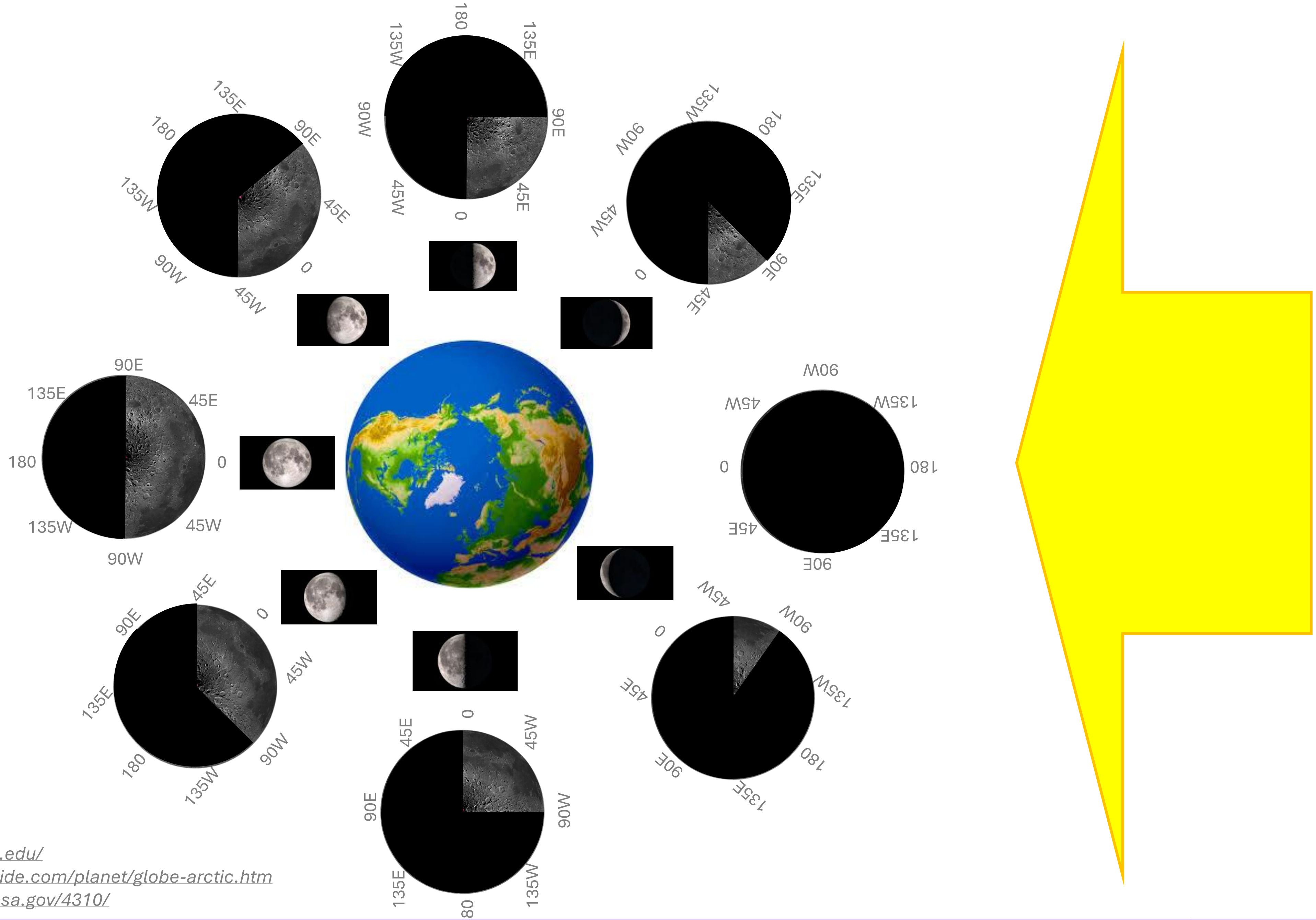
Moon's Orbit and Rotation



Source: https://moon.nasa.gov/resources/429/the-moons-orbit-and-rotation/
Source: https://svs.gsfc.nasa.gov/5048/



LRO Moon image source: https://quickmap.lroc.asu.edu/



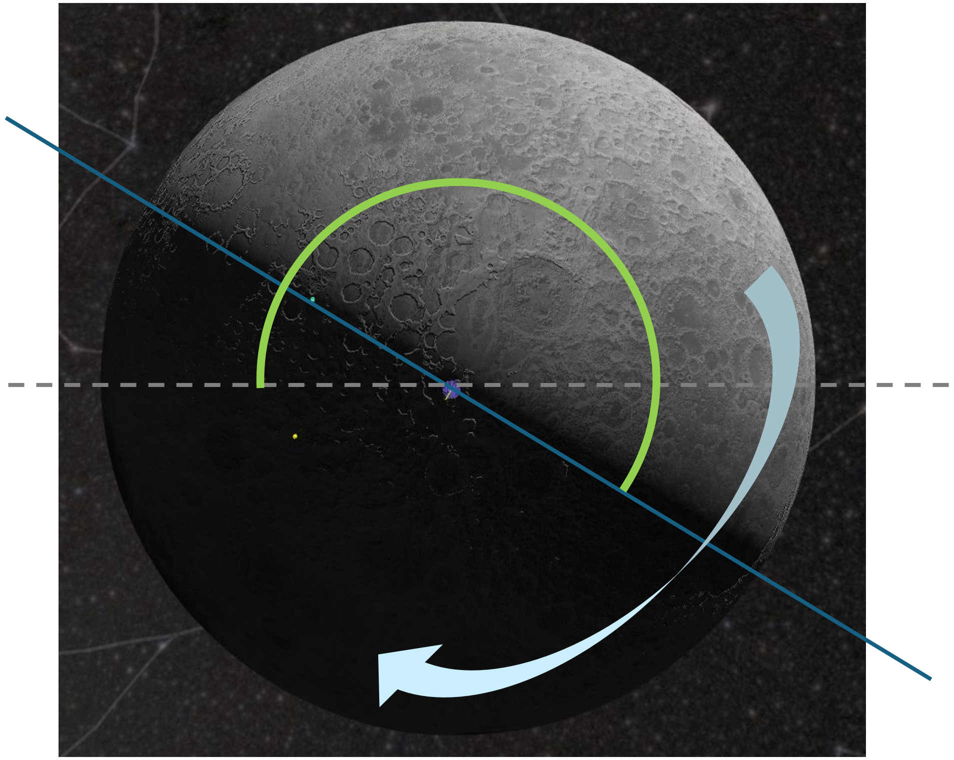
Moon image source: https://quickmap.lroc.asu.edu/
Earth image source: https://www.geographicguide.com/planet/globe-arctic.htm
Moon phase images source: https://svs.gsfc.nasa.gov/4310/

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)

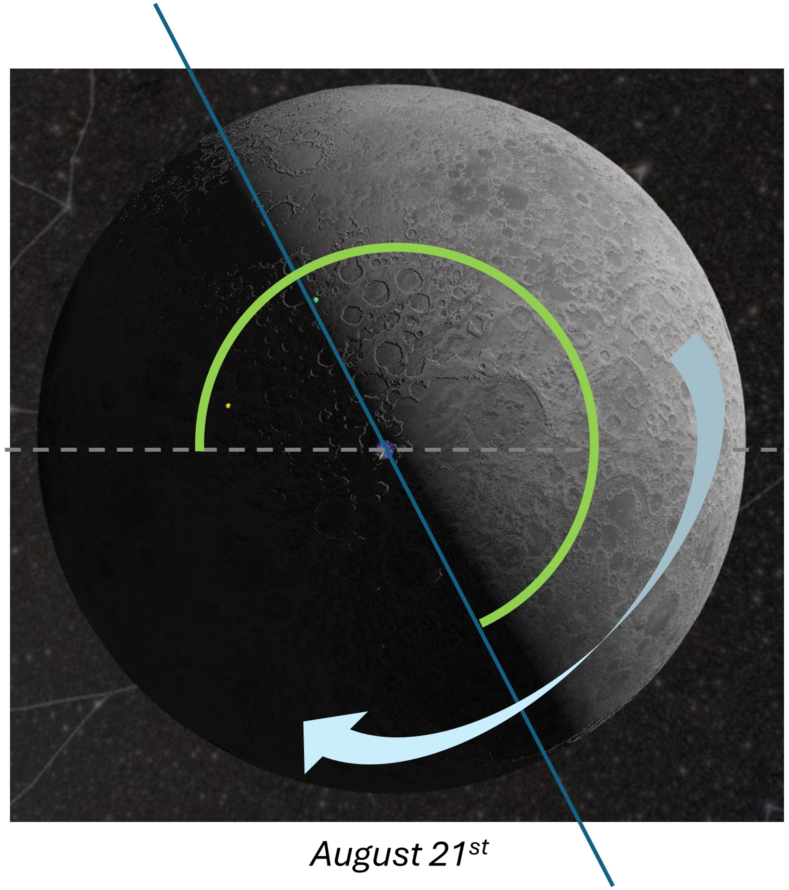
Source: Stellarium screenshot

RAAN Aligning with Terminator Lines

♈

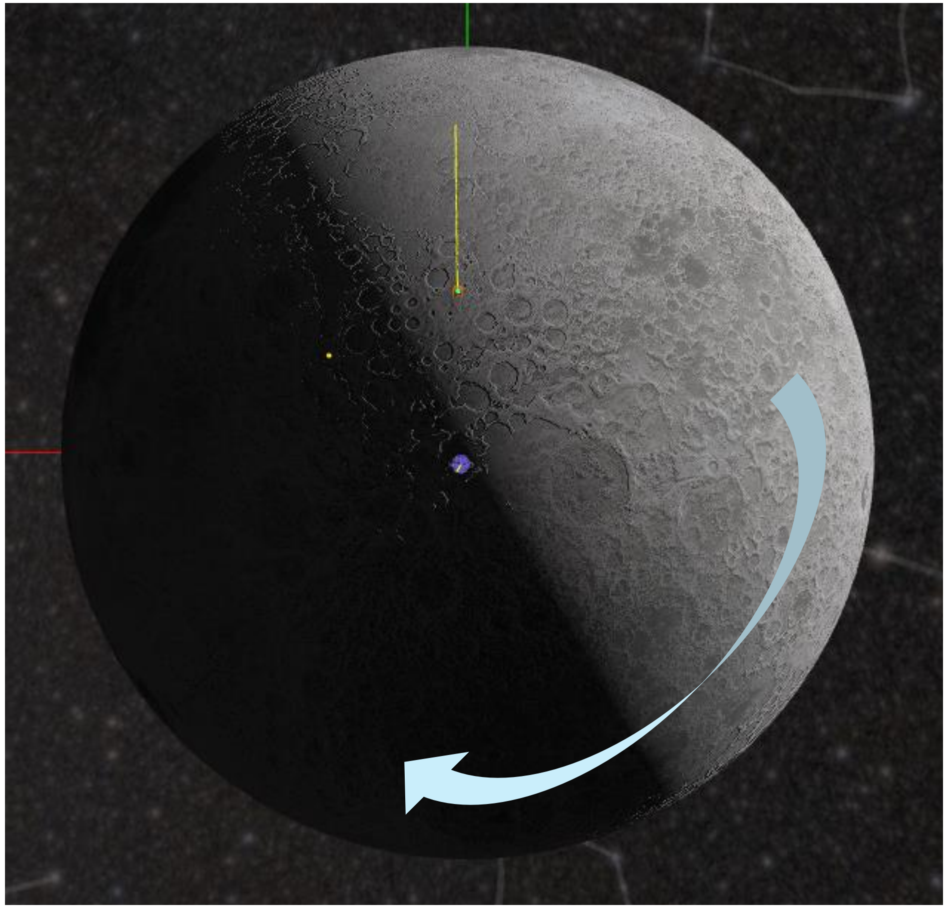


July 23rd

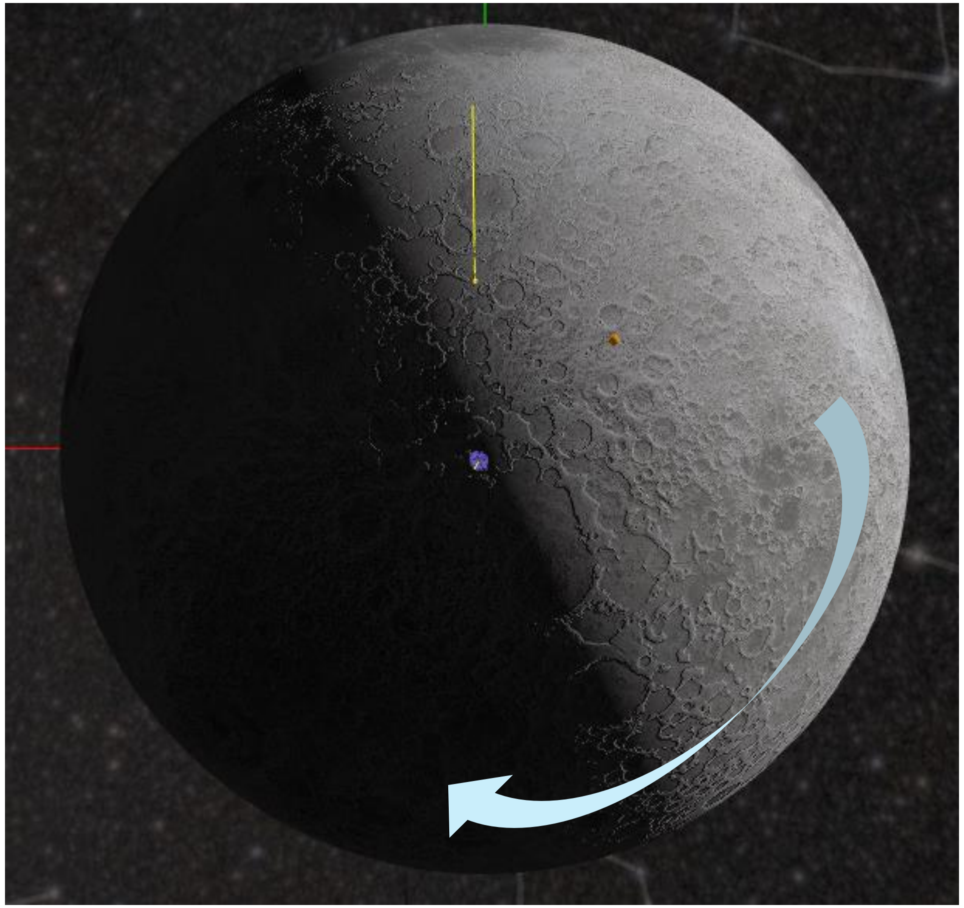


August 21st

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



PLS: Aug 23rd
32.3 East

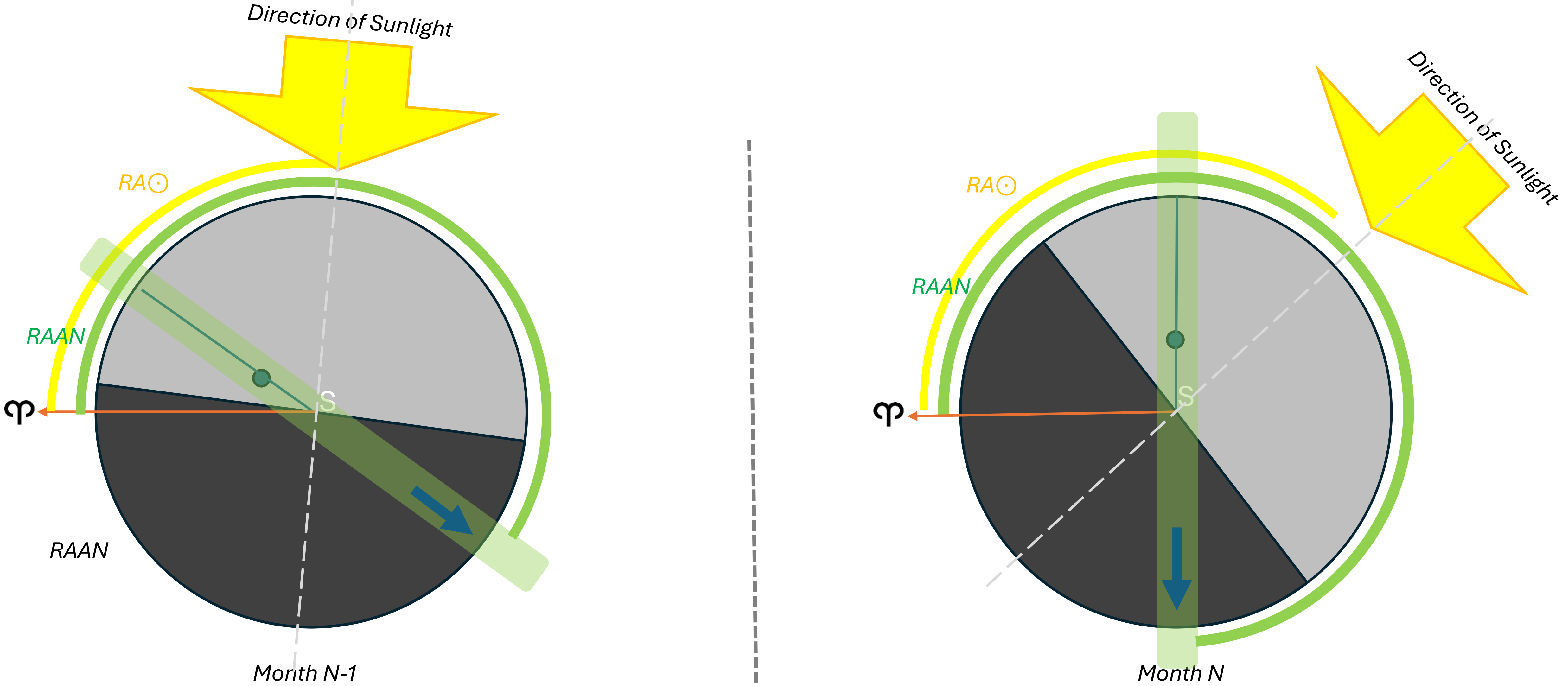


ALS: Aug 27th
17.3 West

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°

Views from over Lunar South Pole

JPL Horizons Osculating Elements for CY3

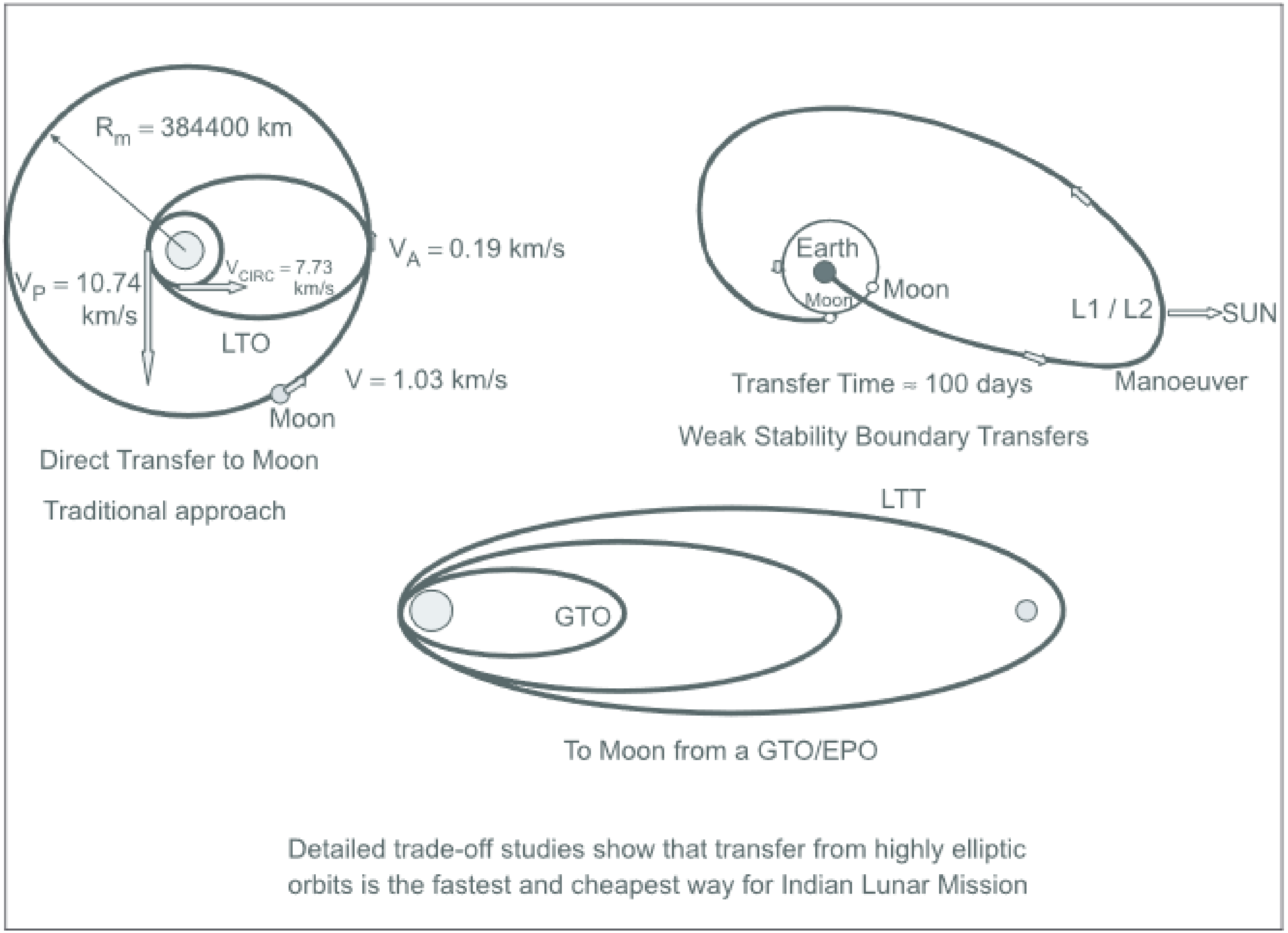
```
2460180.013888889 = A.D. 2023-Aug-23 12:20:00.0000 TDB
 EC= 5.246550080246817E-01 QR= 5.509730603008451E+02 IN= 9.019810069784361E+01
 OM= 2.685481968427781E+02 W = 3.549473780701157E+01 Tp=  2460180.034037434496
 N = 1.016629162531195E-01 MA= 1.830217031519831E+02 TA= 1.811067728449000E+02
 A = 1.159101430755062E+03 AD= 1.767229801209278E+03 PR= 3.541114235830841E+03
2460180.014583333 = A.D. 2023-Aug-23 12:21:00.0000 TDB
 EC= 6.167001304835656E-01 QR= 4.186336576176179E+02 IN= 9.020690786596550E+01
 OM= 2.685549810271034E+02 W = 3.743852901641886E+01 Tp=  2460180.032882653642
 N = 1.111479661879572E-01 MA= 1.842682547086133E+02 TA= 1.812858571818228E+02
 A = 1.092183146698589E+03 AD= 1.765732635779561E+03 PR= 3.238925662312352E+03
2460180.015277778 = A.D. 2023-Aug-23 12:22:00.0000 TDB
 EC= 7.004719223852478E-01 QR= 3.106348050612248E+02 IN= 9.020690529692149E+01
 OM= 2.685548769038173E+02 W = 3.927782067460682E+01 Tp=  2460180.032097228803
 N = 1.201229151702458E-01 MA= 1.854373125286016E+02 TA= 1.813425630129885E+02
 A = 1.037080755617034E+03 AD= 1.763526706172843E+03 PR= 2.996930265052136E+03
```

Source: https://ssd.jpl.nasa.gov/horizons/app.html#/

8. Transfer Orbit

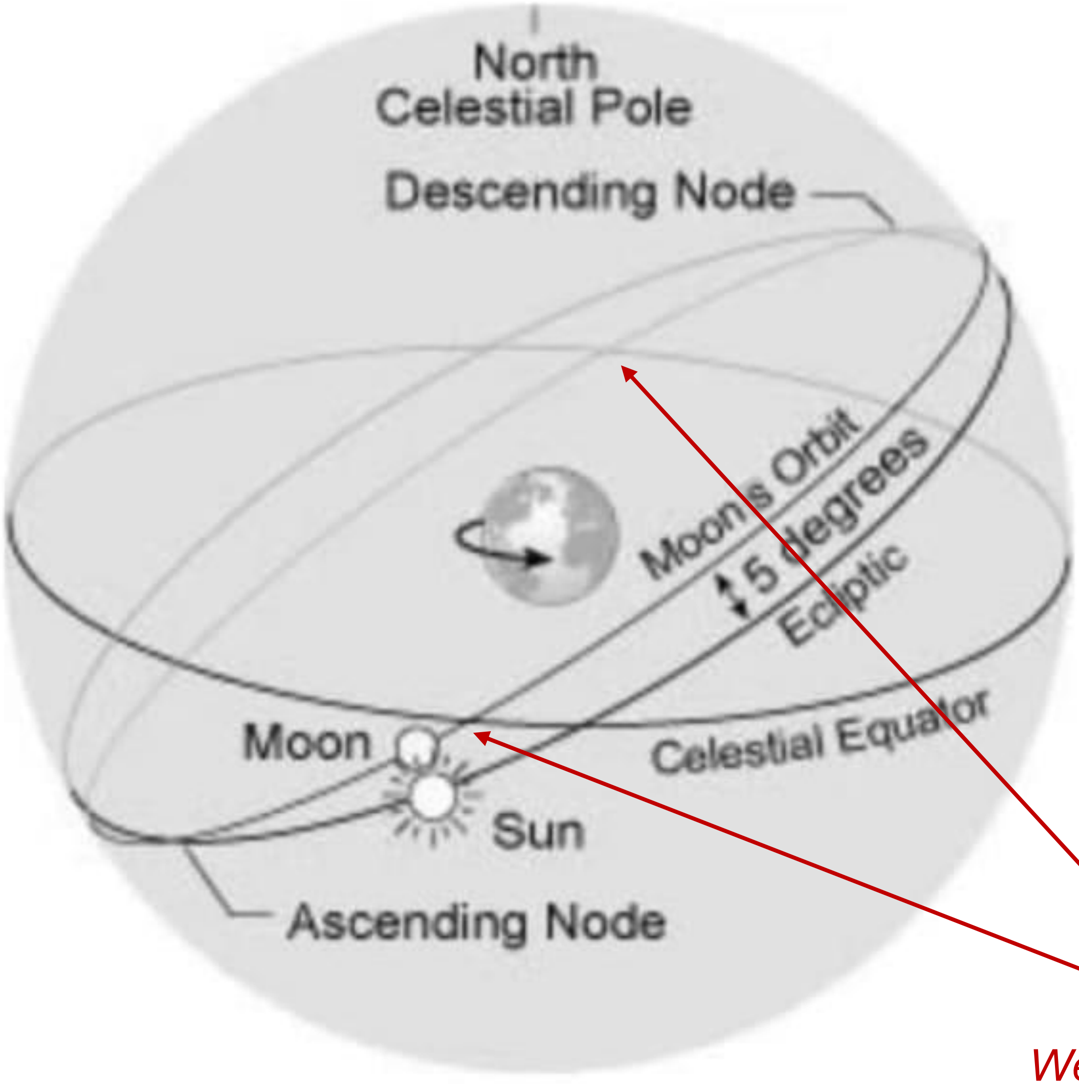
Mission Design > Transfer Orbit

Three Ways to the Moon



Source: https://www.ias.ac.in/article/fulltext/jess/114/06/0711-0716

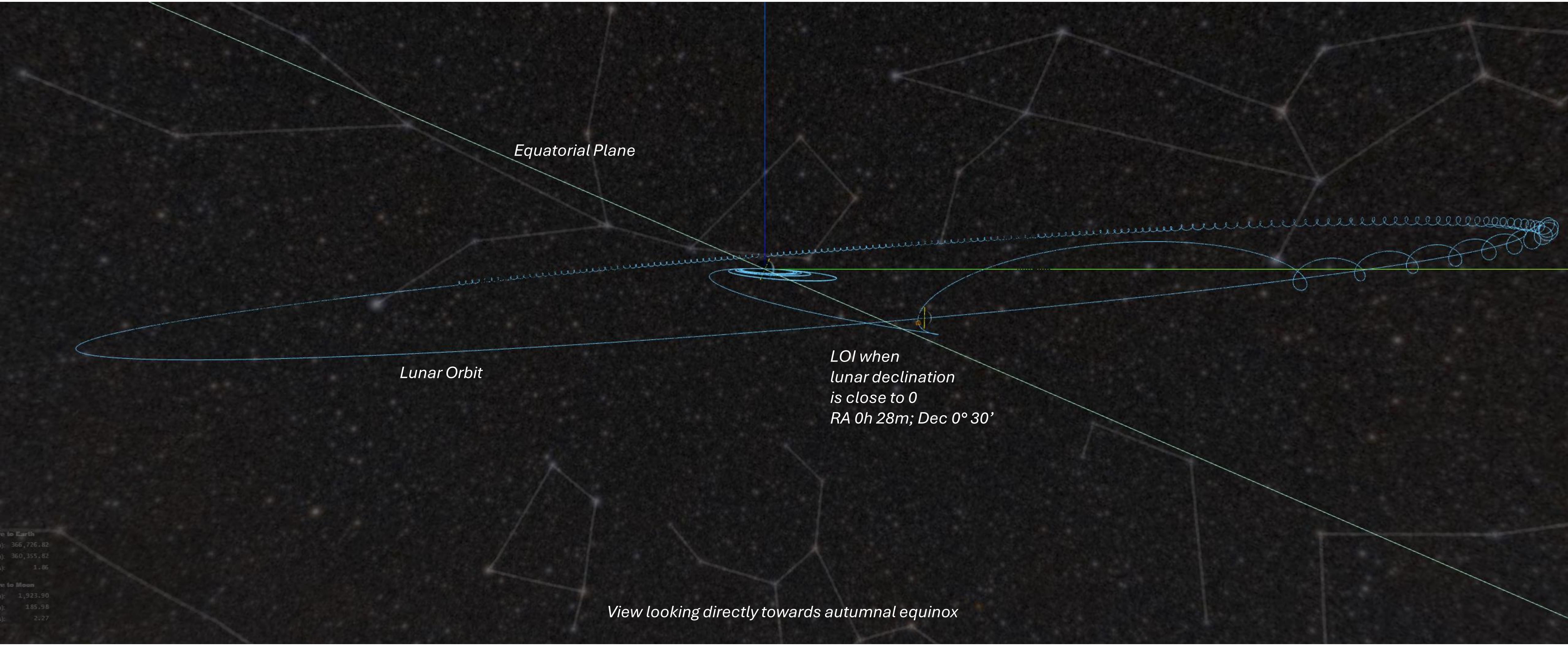
Aligning the GTO with Moon’s Orbit



We’re interested in these nodes

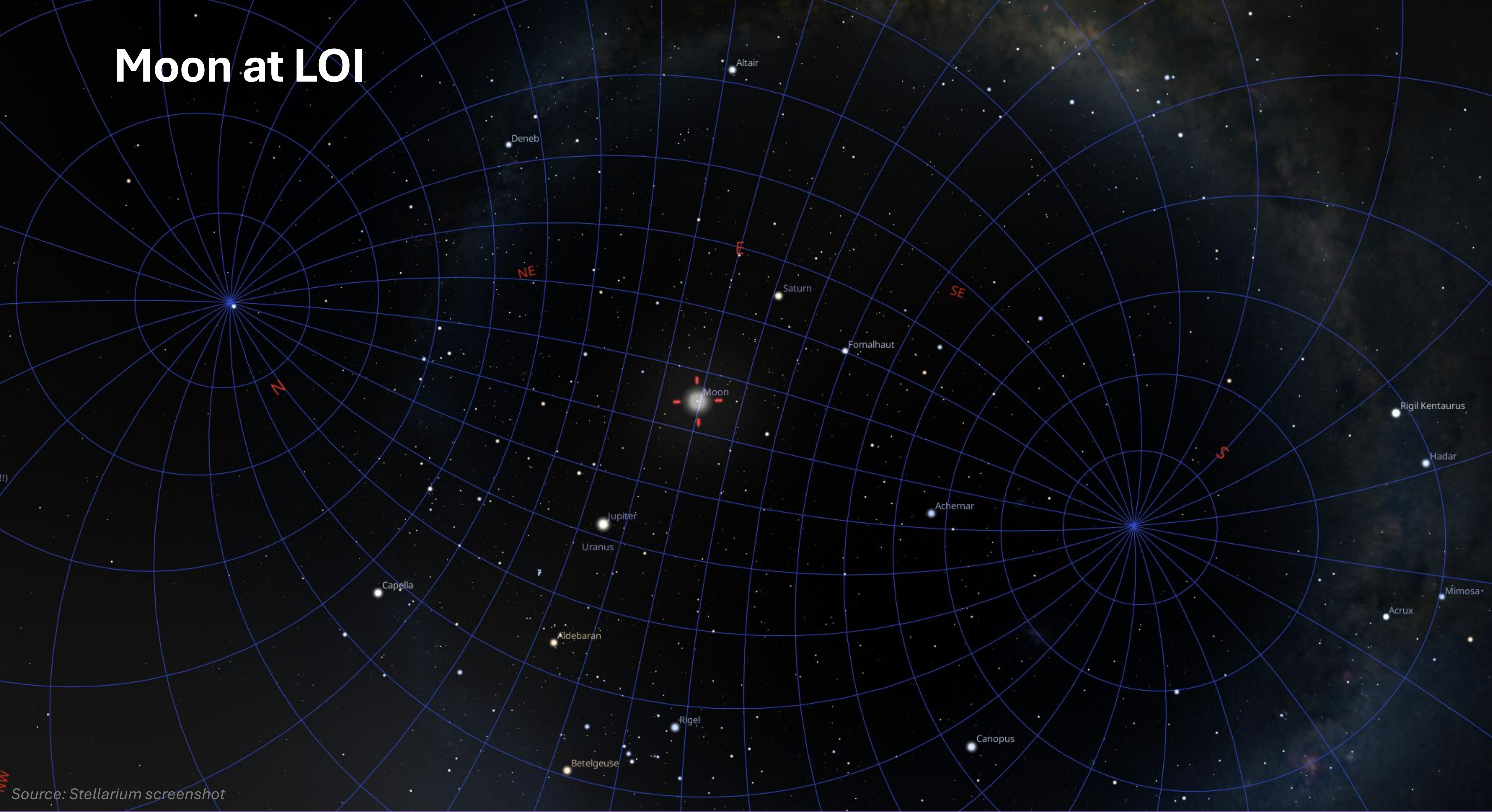
Source: [*https://vocal.media/futurism/the-lunar-nodes*](https://vocal.media/futurism/the-lunar-nodes)

LOI Timing



Source: https://sankara.net/chandrayaan3.html

Moon at LOI

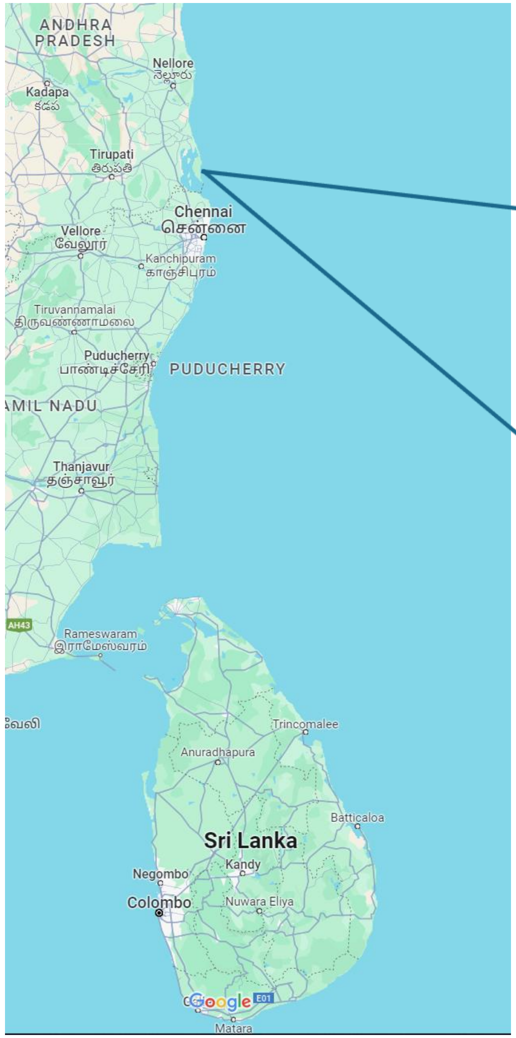


Source: Stellarium screenshot

9. Launch Orbit

Mission Design > Launch Orbit

Launch Azimuth/Inclination Constraints



Azimuth 106.7
Inclination 21.5
Argument of perigee can be tuned a bit; but it affects apogee altitude

Azimuth 129.9
Inclination 41.8
Low apogee due to less gains from earth's rotation

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

Launch Window

- LOI timing determined by Moon's crossing equatorial plane
  - Two opportunities per month

- Line of apsides determined by LOI intercept
  - Not just for the transfer orbit
  - But for all parking orbits including the launch orbit

- Launch orbit
  - Weeklong window – buffers to fine tune orbit raising strategy
  - Instantaneous launch window on a day to match $\Omega + \omega$

10. 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

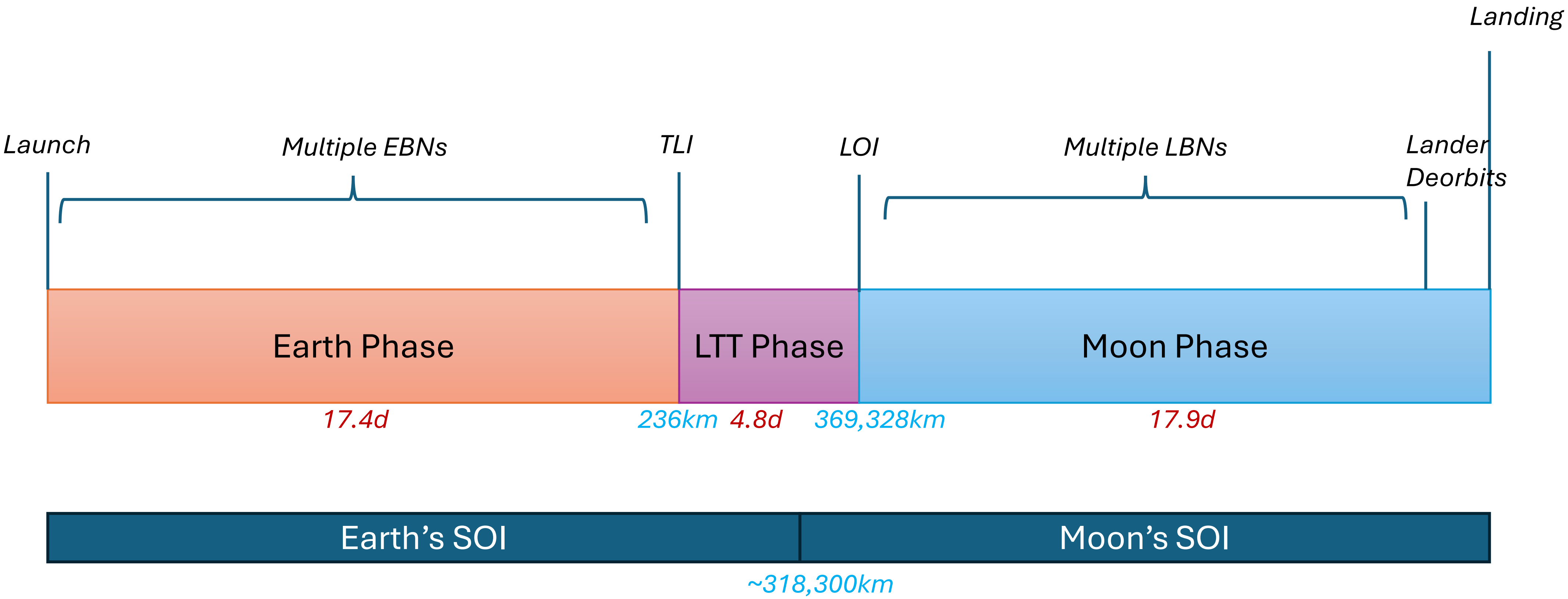
Flexibility via EBNs to meet the same TLI epoch from different launch days

↓

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

11. Takeaways

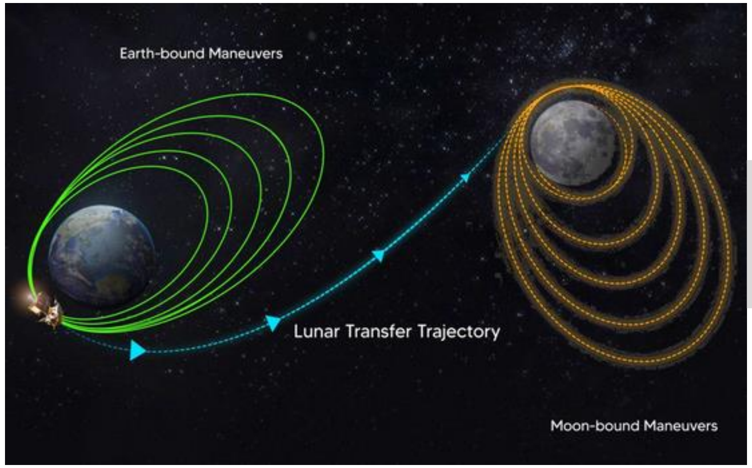
Looking Back at the Outline …

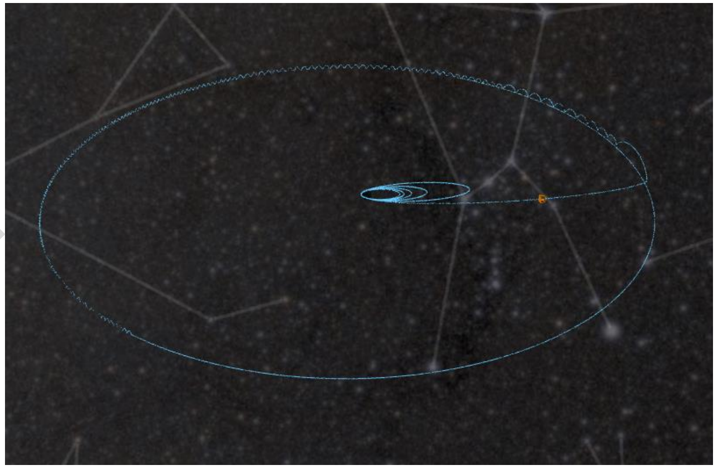
Foundations

1. Scale
2. Coordinate systems
3. Mapping the Moon
4. CY3 trajectory
5. Orbits
6. Orbital maneuvers

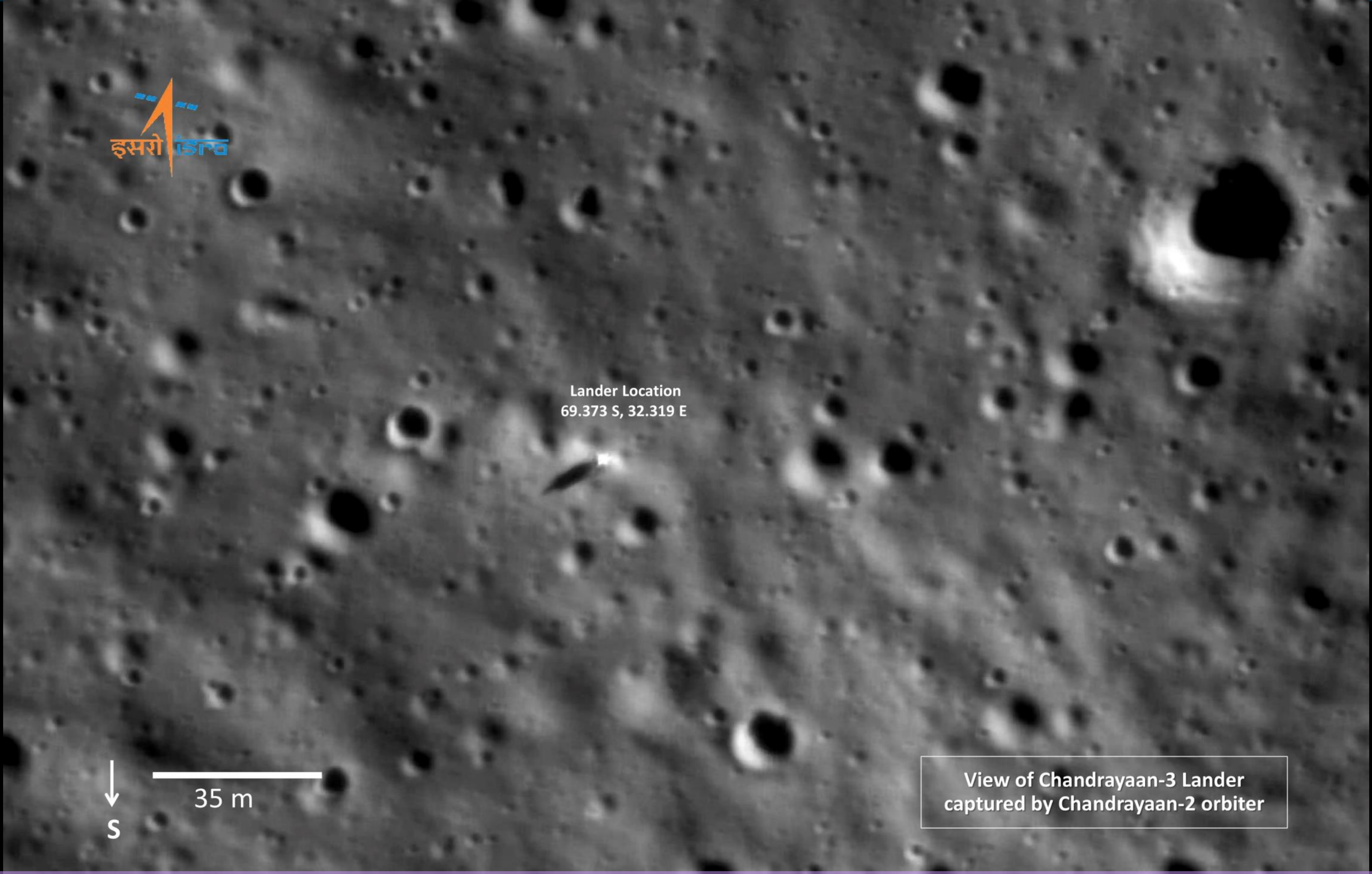
Mission Design

7. CY3 Lunar orbits
8. Transfer orbit
9. Launch orbit
10. Mission design






इसरो isro



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

Pale Blue Dot – Carl Sagan

From this distant vantage point, the Earth might not seem of any particular interest. But for us, it's different. Consider again that dot. That's here. That's home. That's us. On it everyone you love, everyone you know, everyone you ever heard of, every human being who ever was, lived out their lives. The aggregate of our joy and suffering, thousands of confident religions, ideologies, and economic doctrines, every hunter and forager, every hero and coward, every creator and destroyer of civilization, every king and peasant, every young couple in love, every mother and father, hopeful child, inventor and explorer, every teacher of morals, every corrupt politician, every "superstar," every "supreme leader," every saint and sinner in the history of our species lived there – on a mote of dust suspended in a sunbeam.

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

Be Persistently Curious!