The Interplanetary Transport Network: Space Transportation Architecture for the 21st Century

Shane Ross

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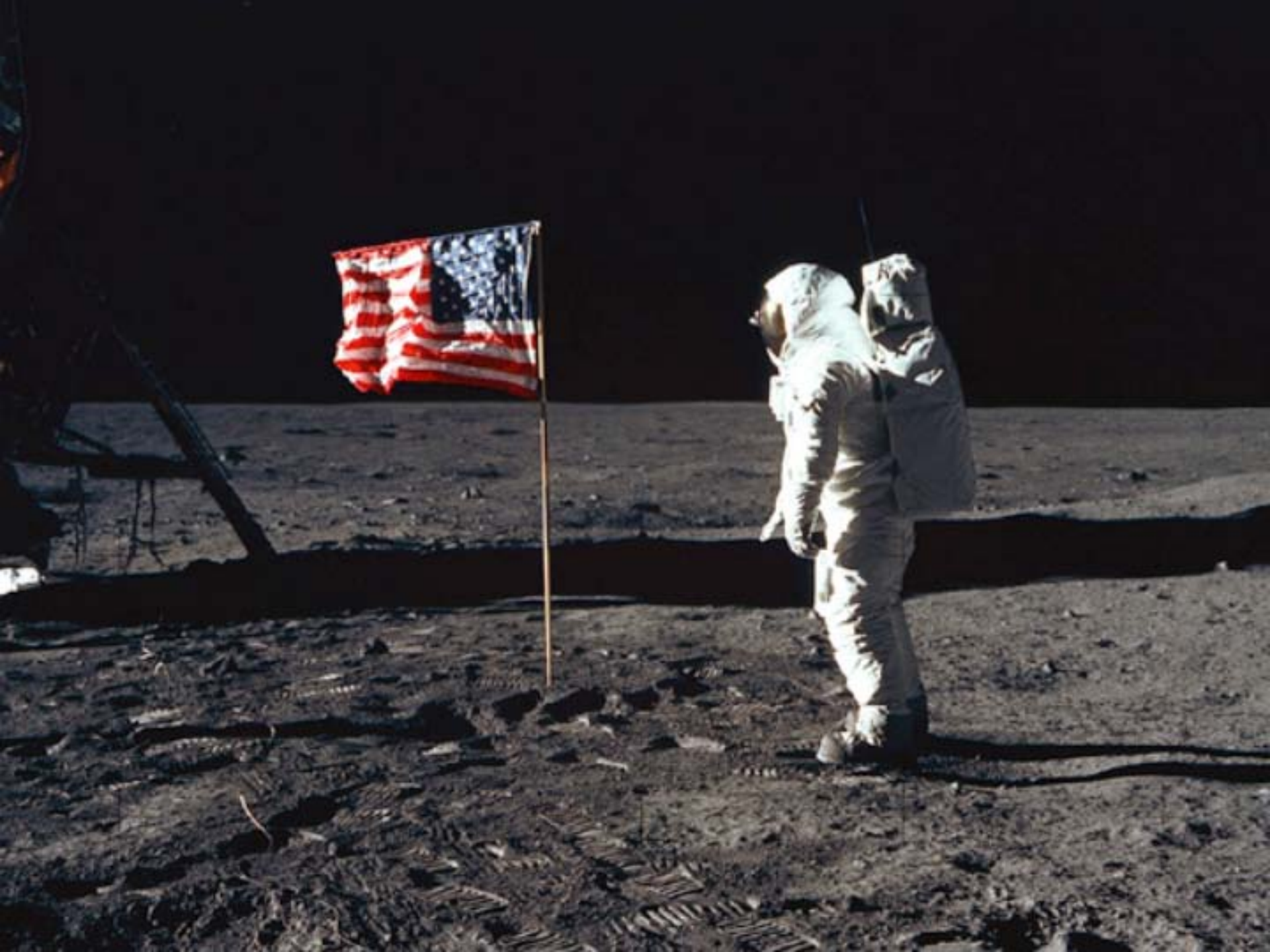
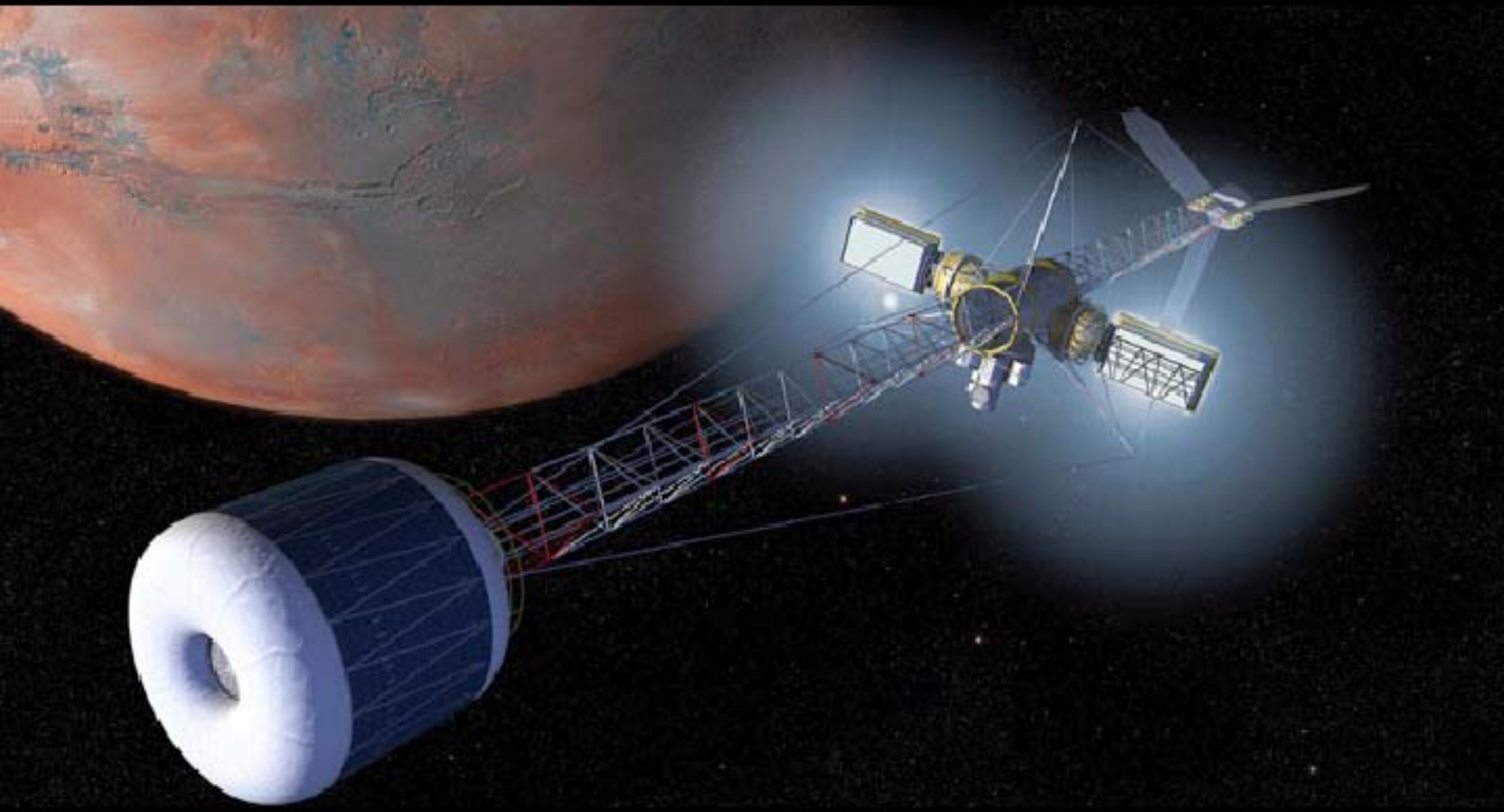
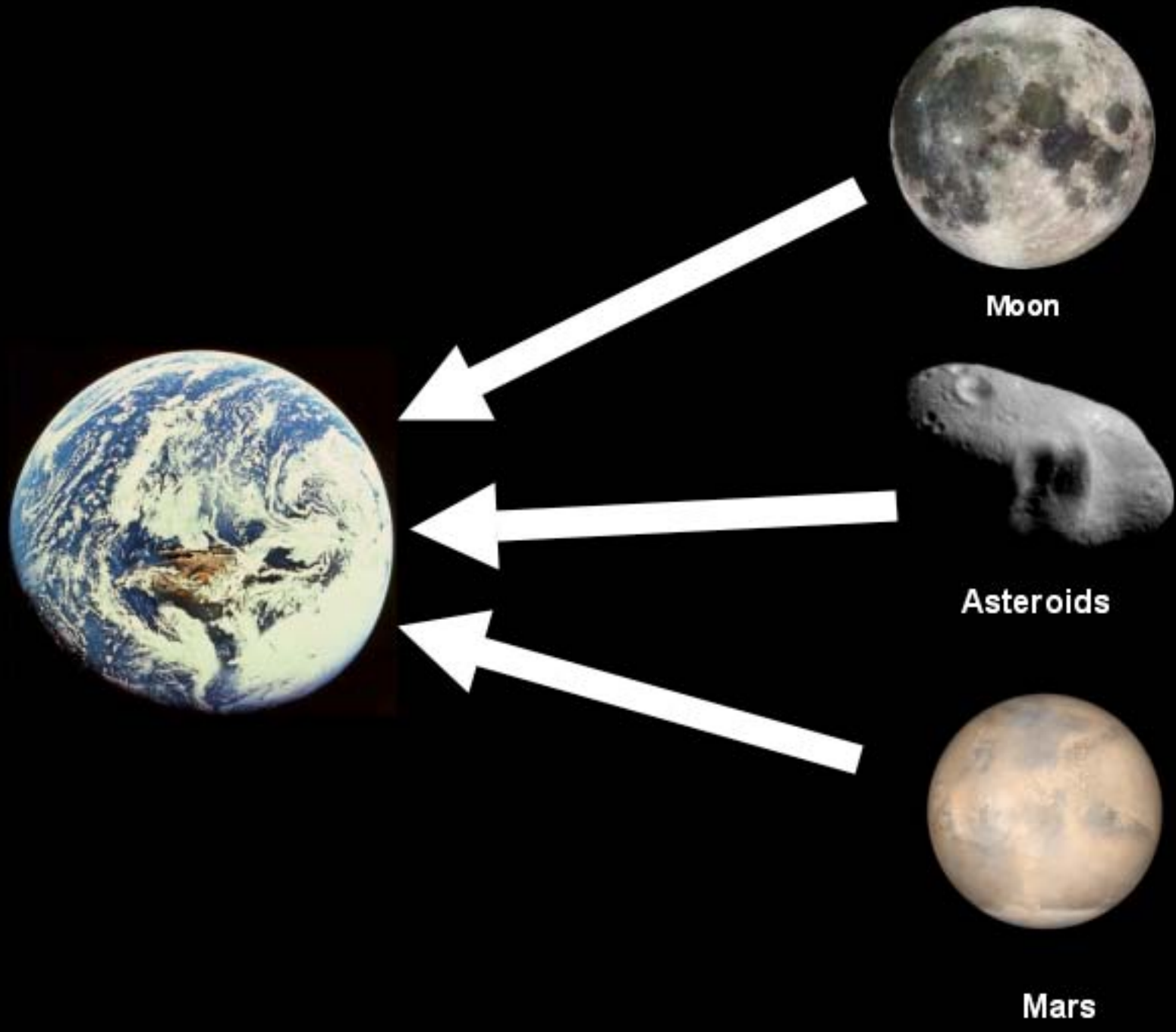
Collaborators: M.W. Lo (JPL/NASA), J.E. Marsden & W.S. Koon (CDS)

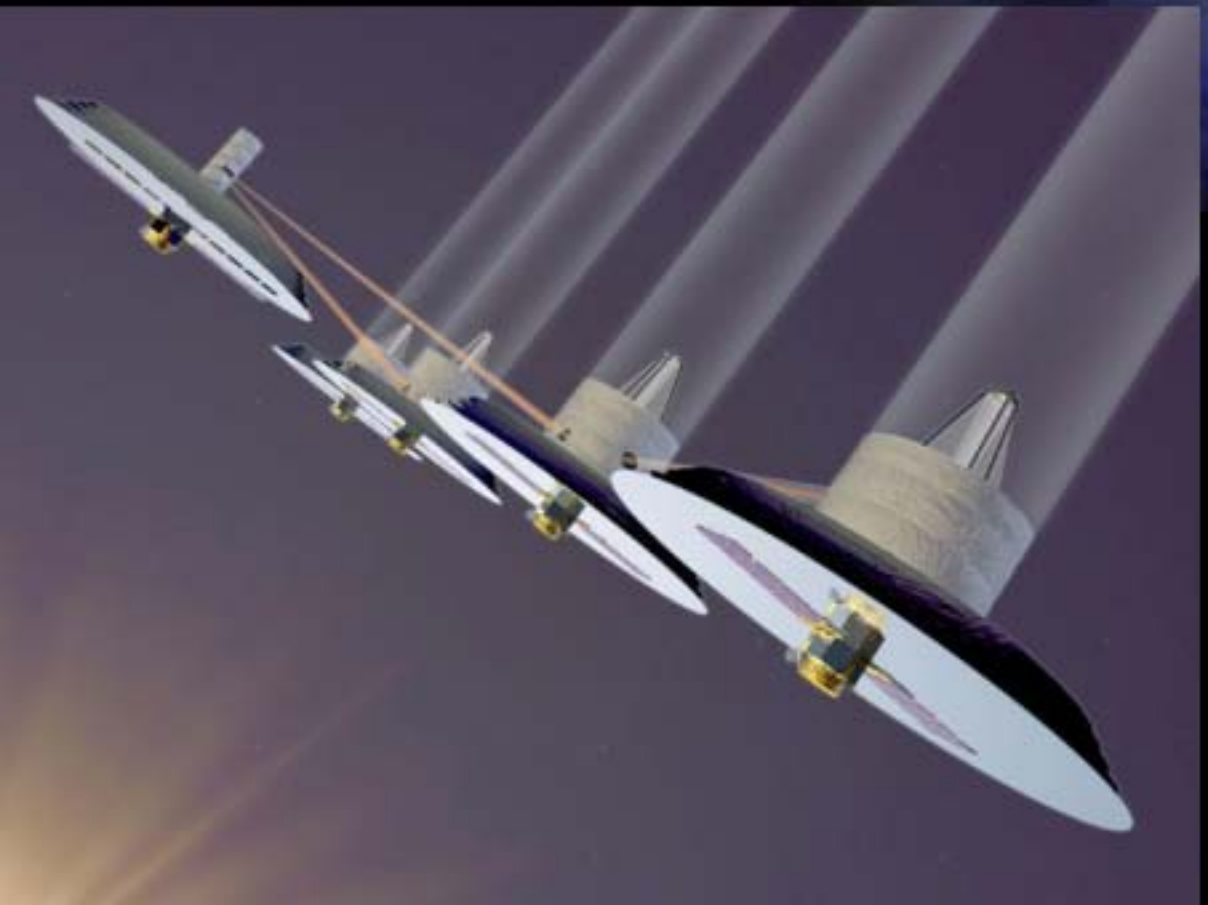




Source: John Frassanito & Associates


Moon
Asteroids
Mars

Terrestrial Planet Finder (TPF)

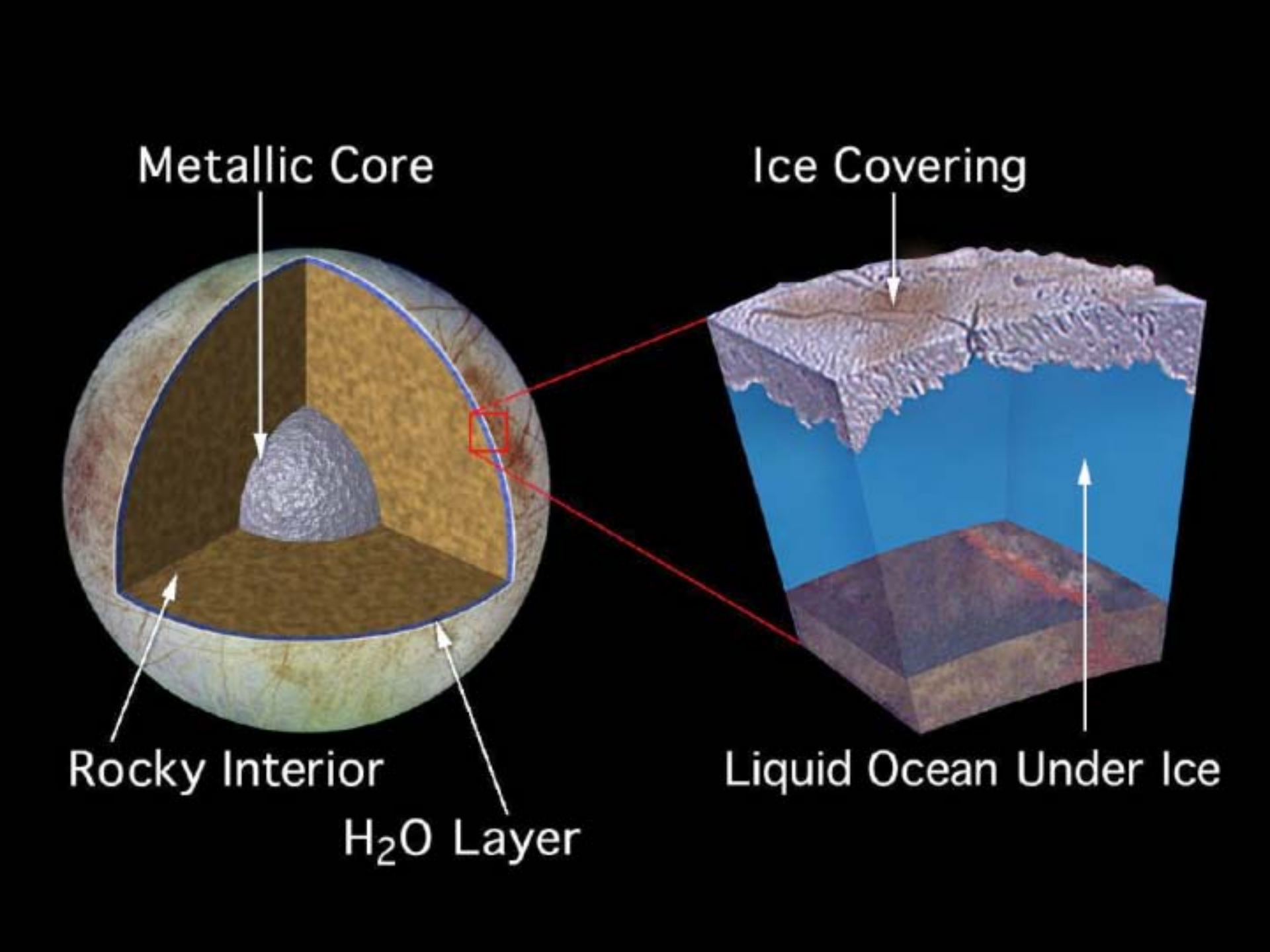


Source: Greg Harris

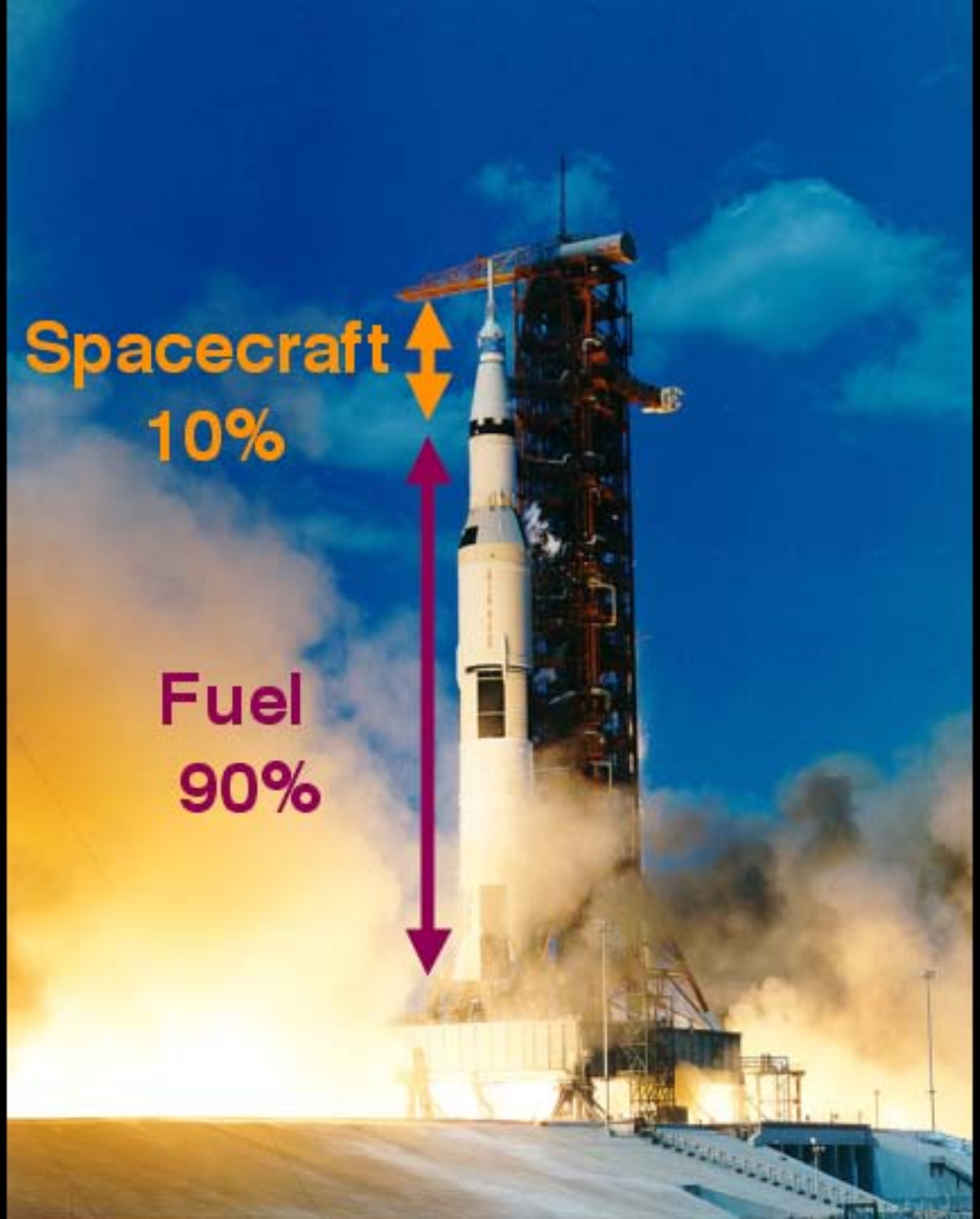
Jupiter's Moons

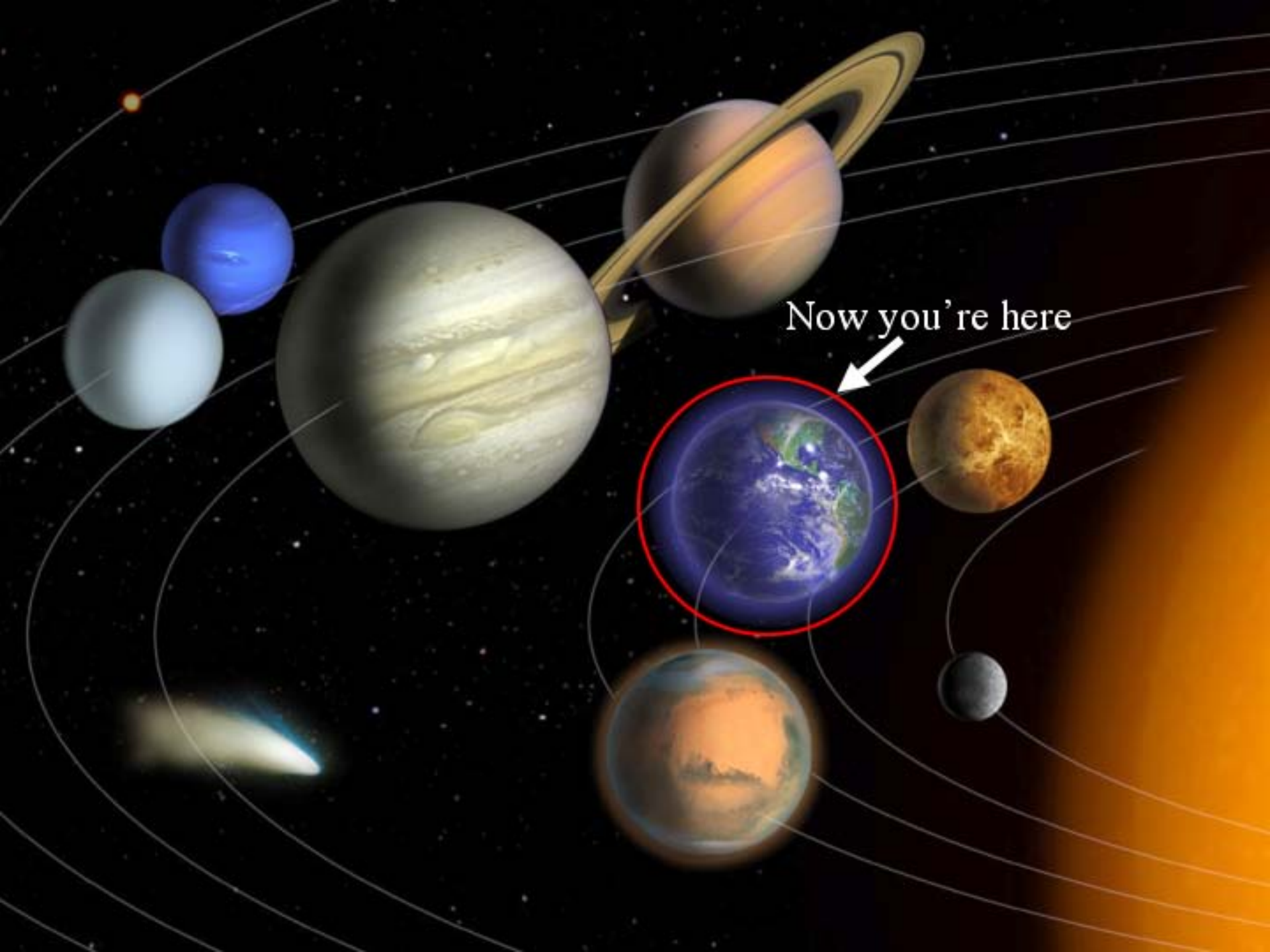

Io
Europa
Ganymede
Callisto
Earth
Moon

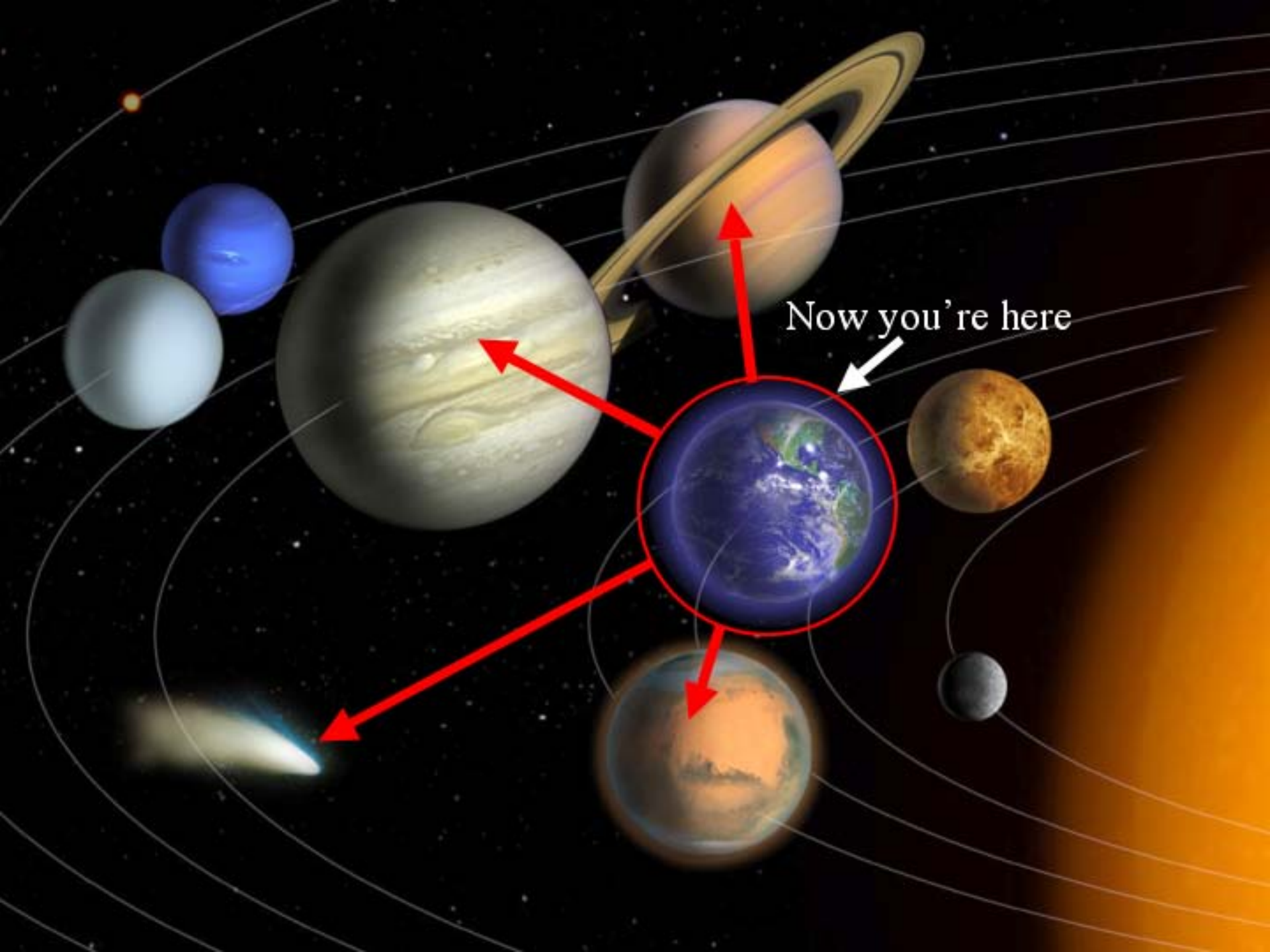
Icy Moons

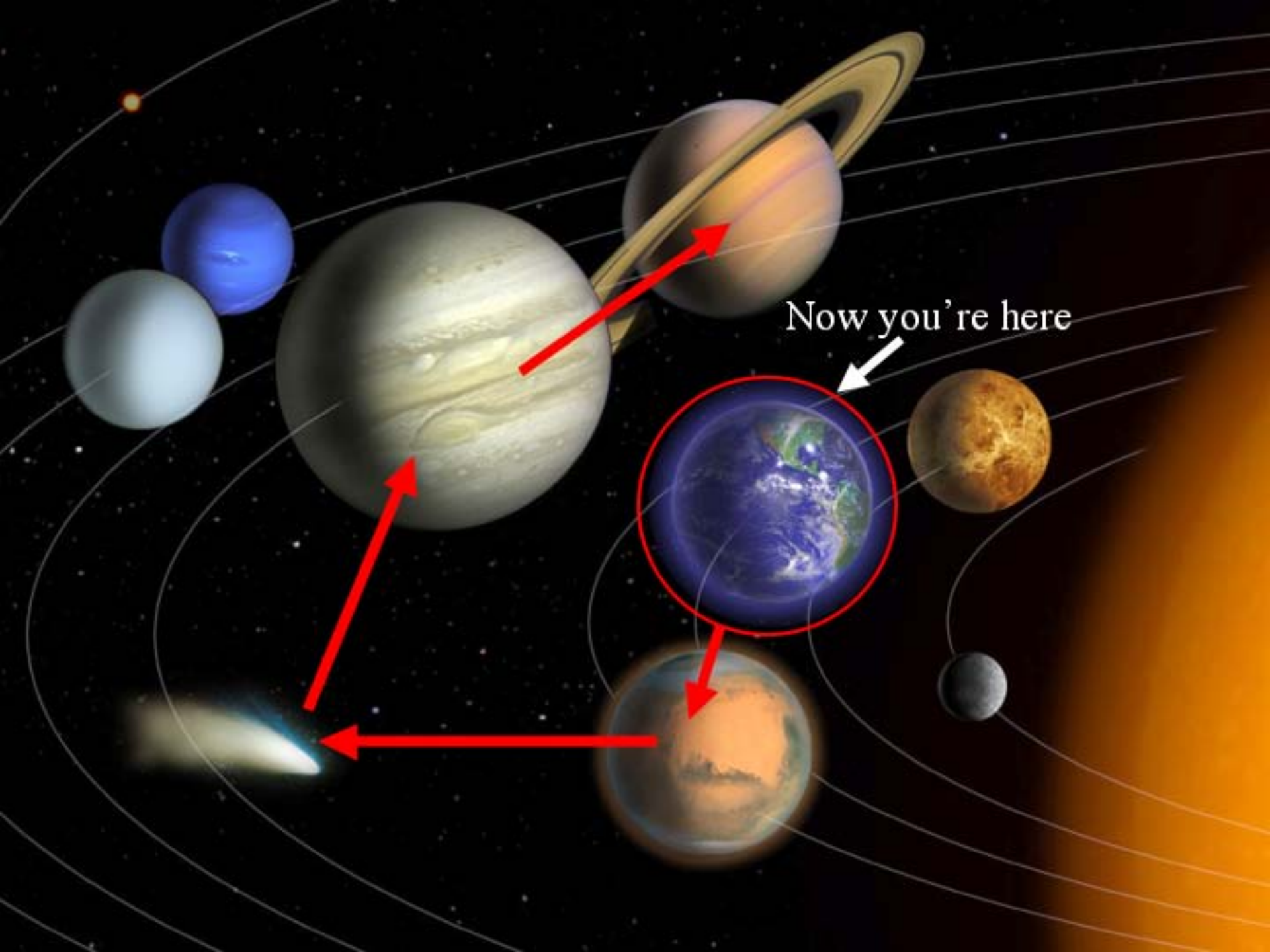

Metallic Core
Ice Covering
Rocky Interior
H_2O Layer
Liquid Ocean Under Ice


You are here


Spacecraft
10%
Fuel
90%


Now you're here


Now you're here


Now you're here

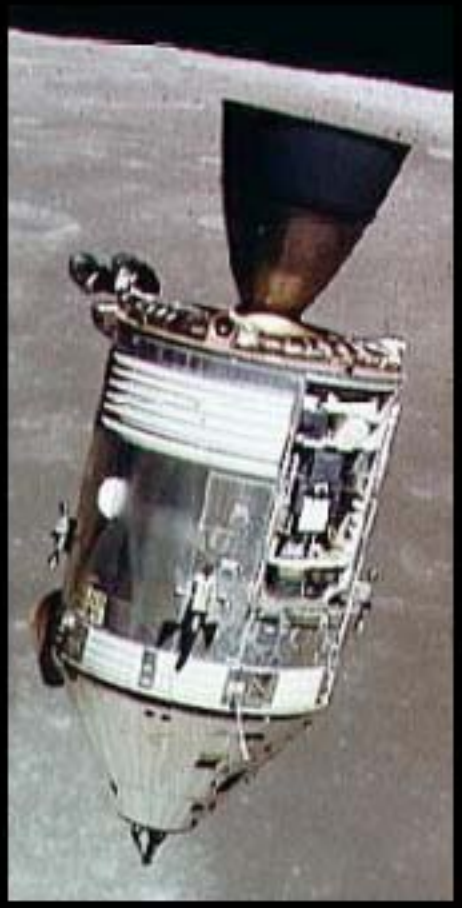
Destinations, stay time =>

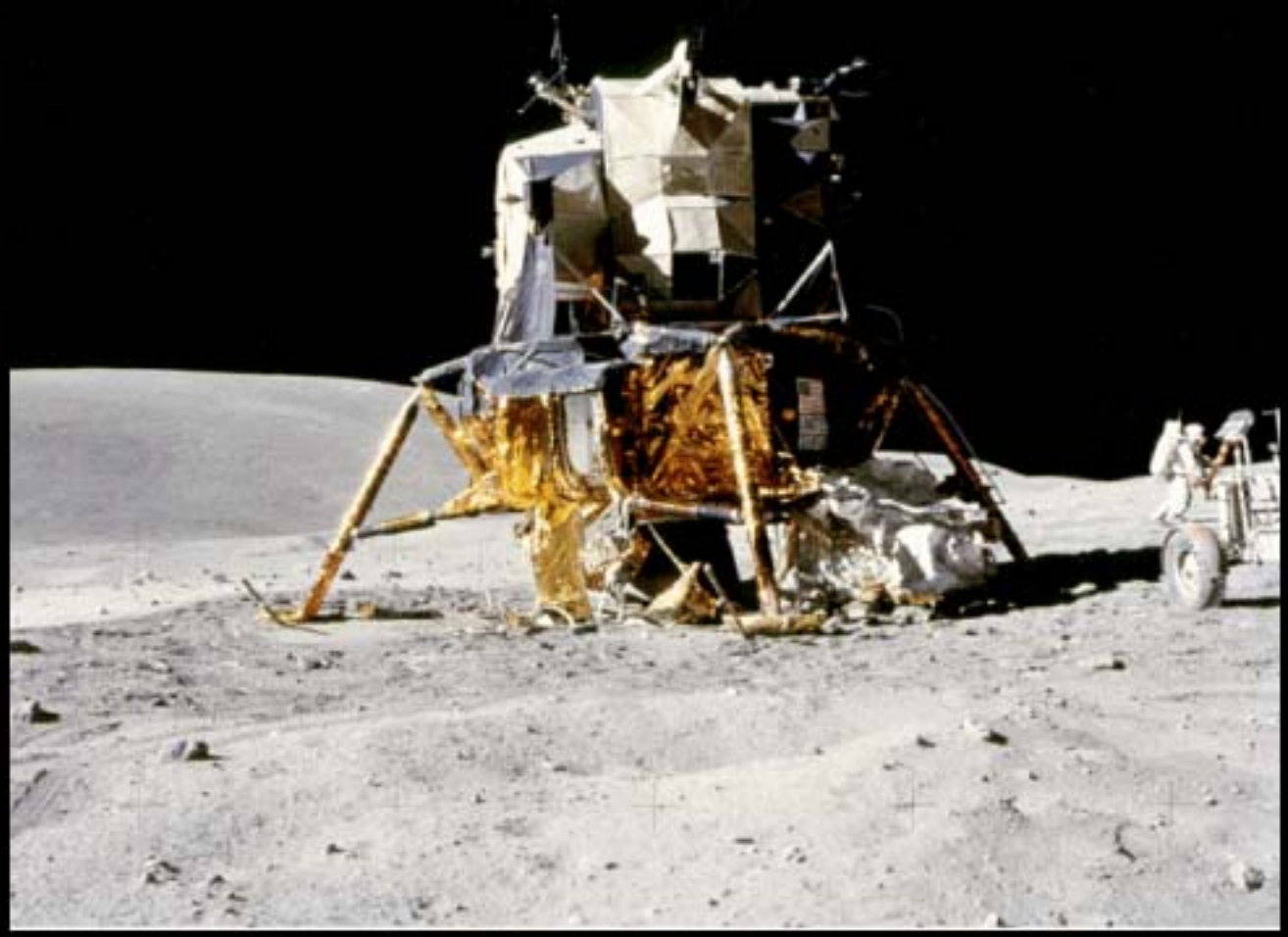
on-board fuel mass %

Rockets =>

limited spacecraft mass

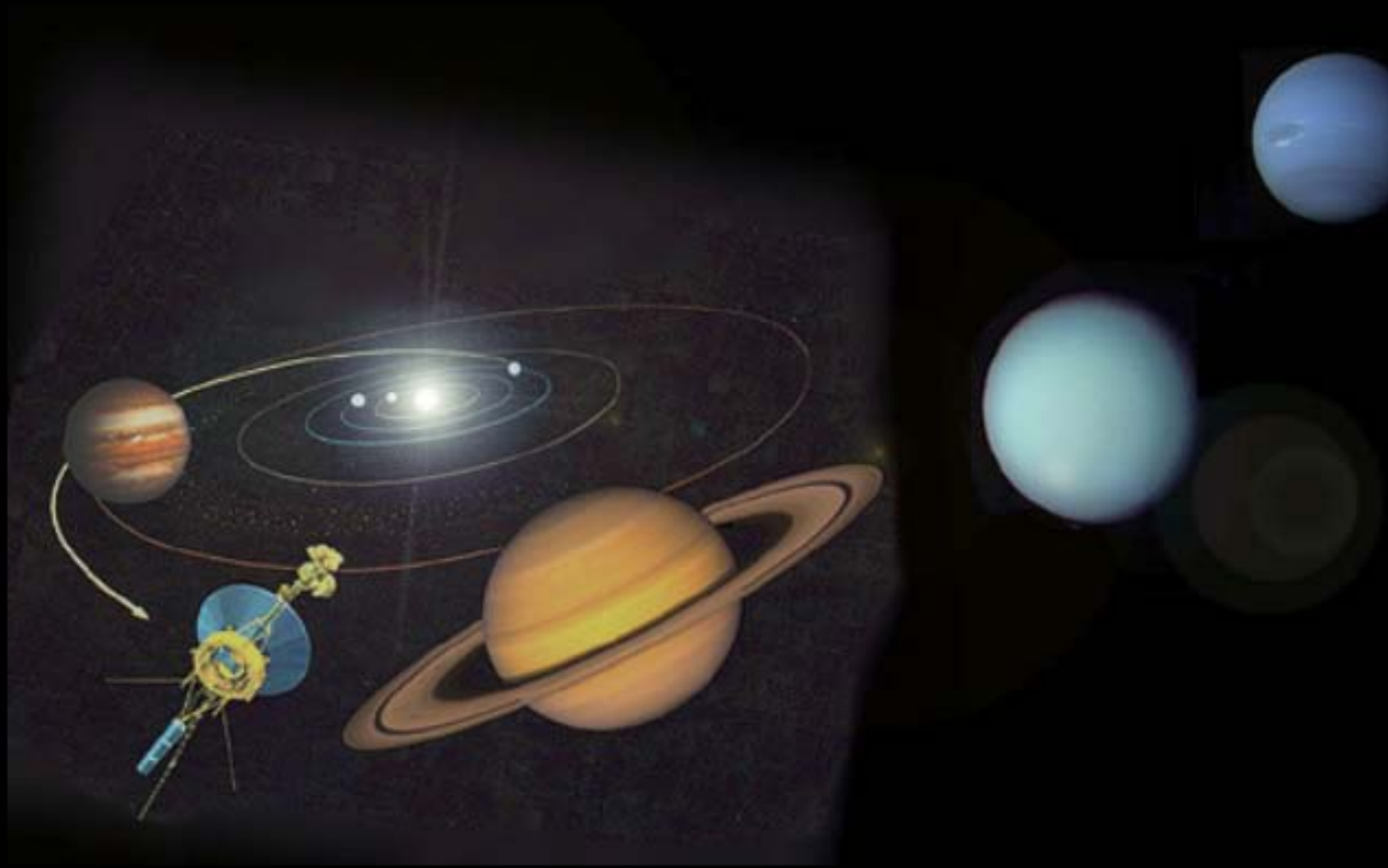
- Apollo (Lunar Lander): 61%






NATIONAL AERONAUTICS & SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER

- Pioneer / Voyager (Planetary Flybys): 46%

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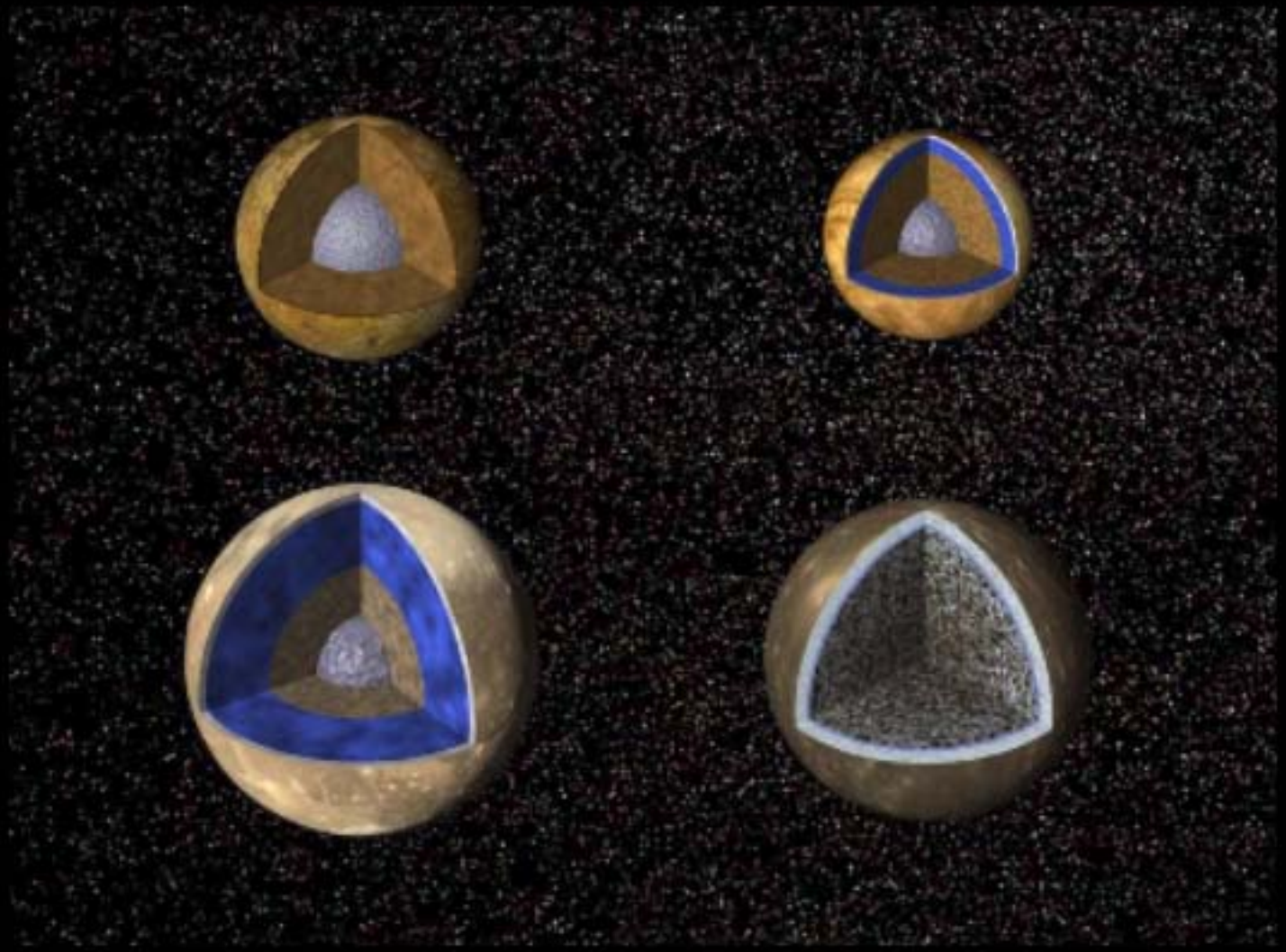
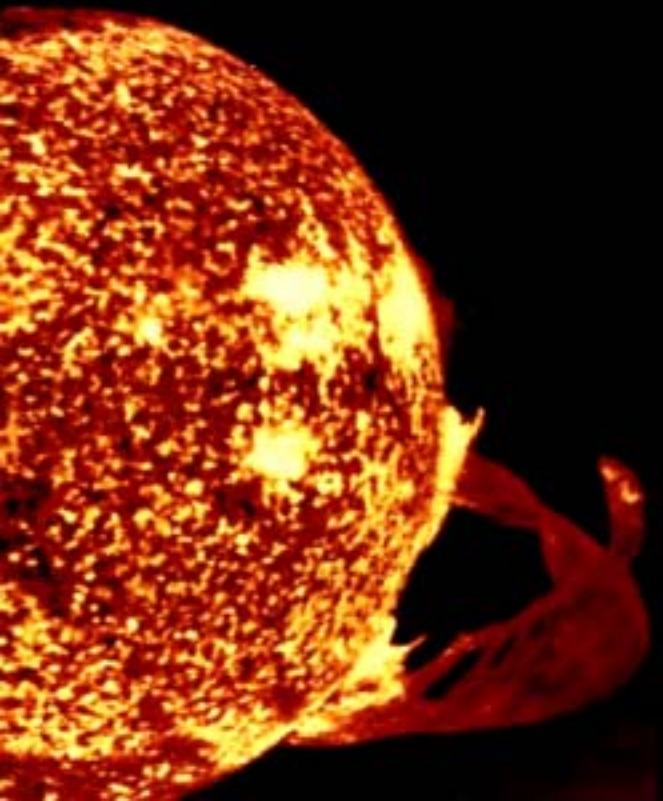
- Galileo (Jupiter Orbiter): 42%

- Galileo (Jupiter Orbiter): **42%**



- NEAR (Asteroid Orbiter / Lander): 40%

- Genesis (Solar Wind Sample Return): 4%



- Your car (San Francisco): 5%

- Your car (Bakersfield, maybe?): 5%

Less fuel =>
more payload
more science

Less fuel =>
more payload
more science
more bang per buck


You
are here

Pick your destinations

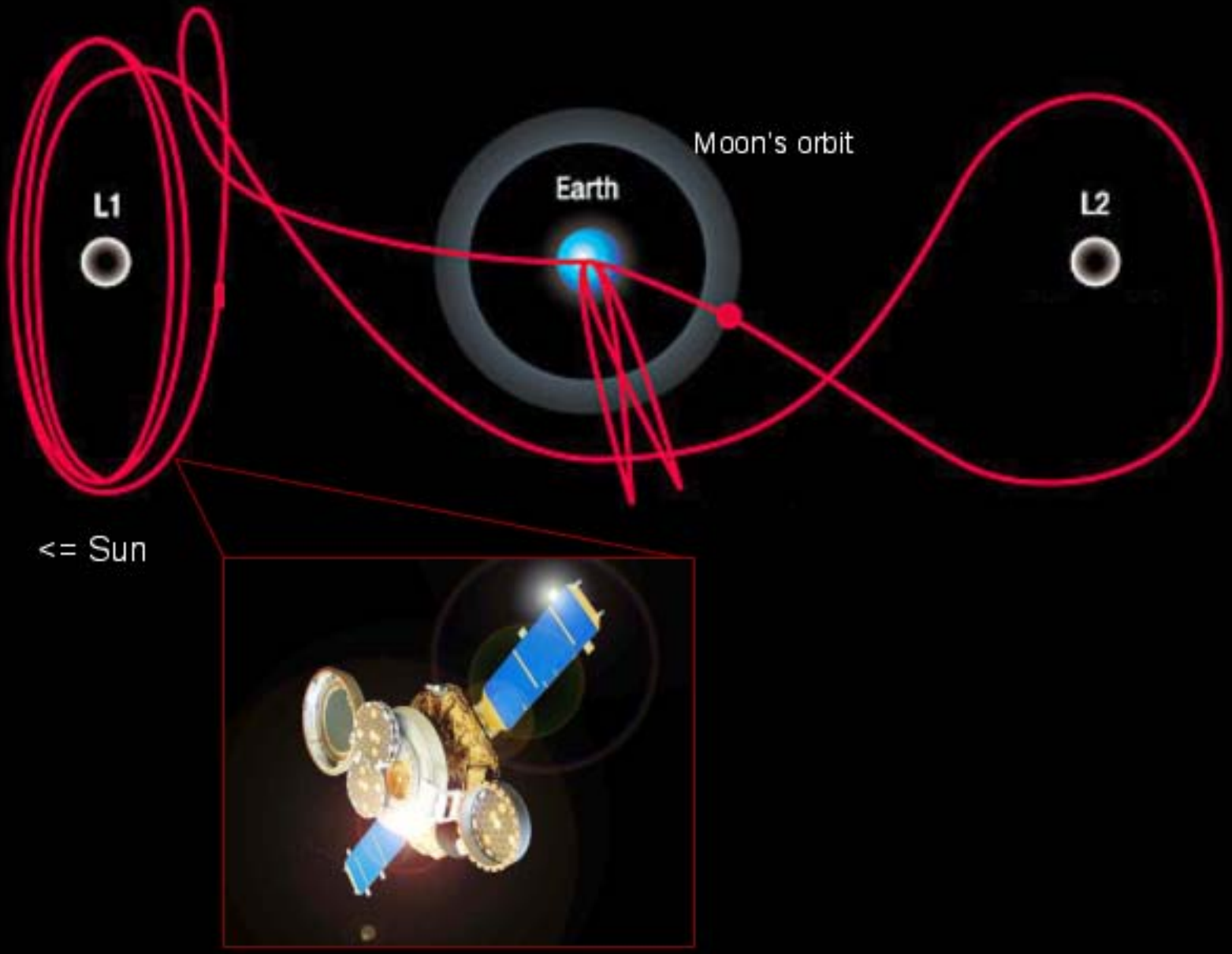
Flybys

Pioneer and Voyager Probes

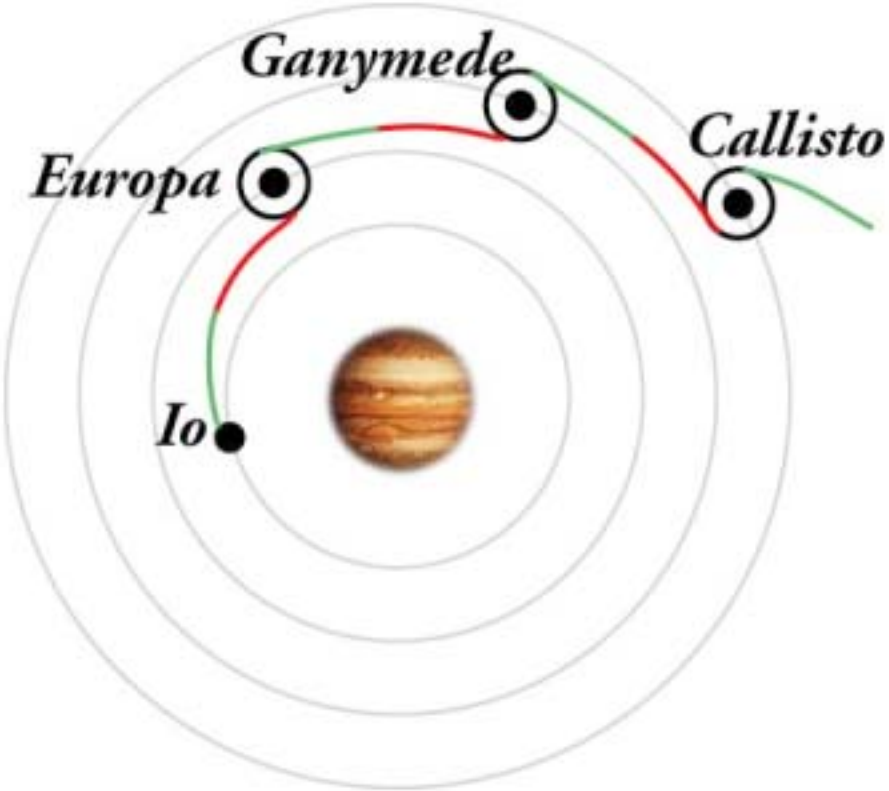
Clever path choice

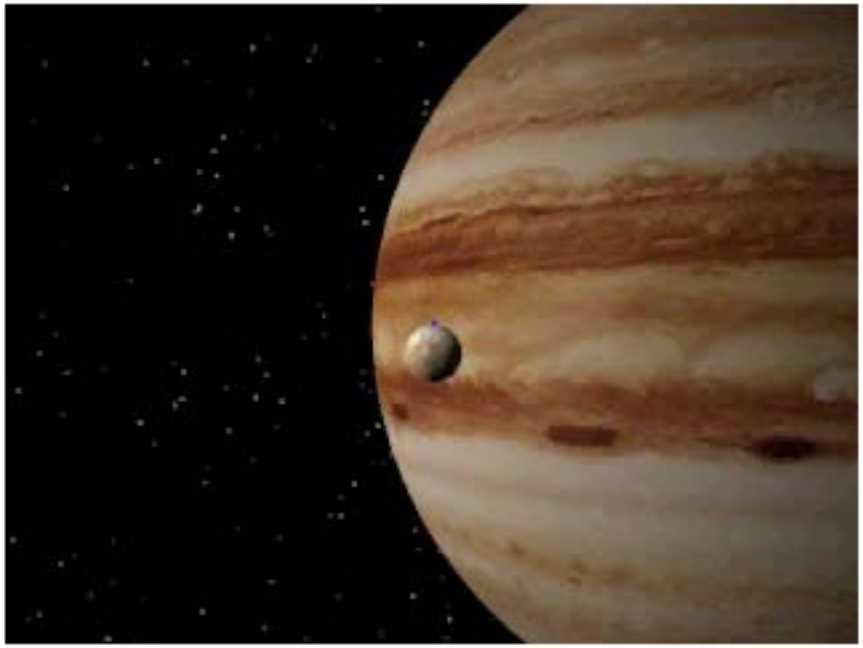
Clever path choice

Genesis and other future missions

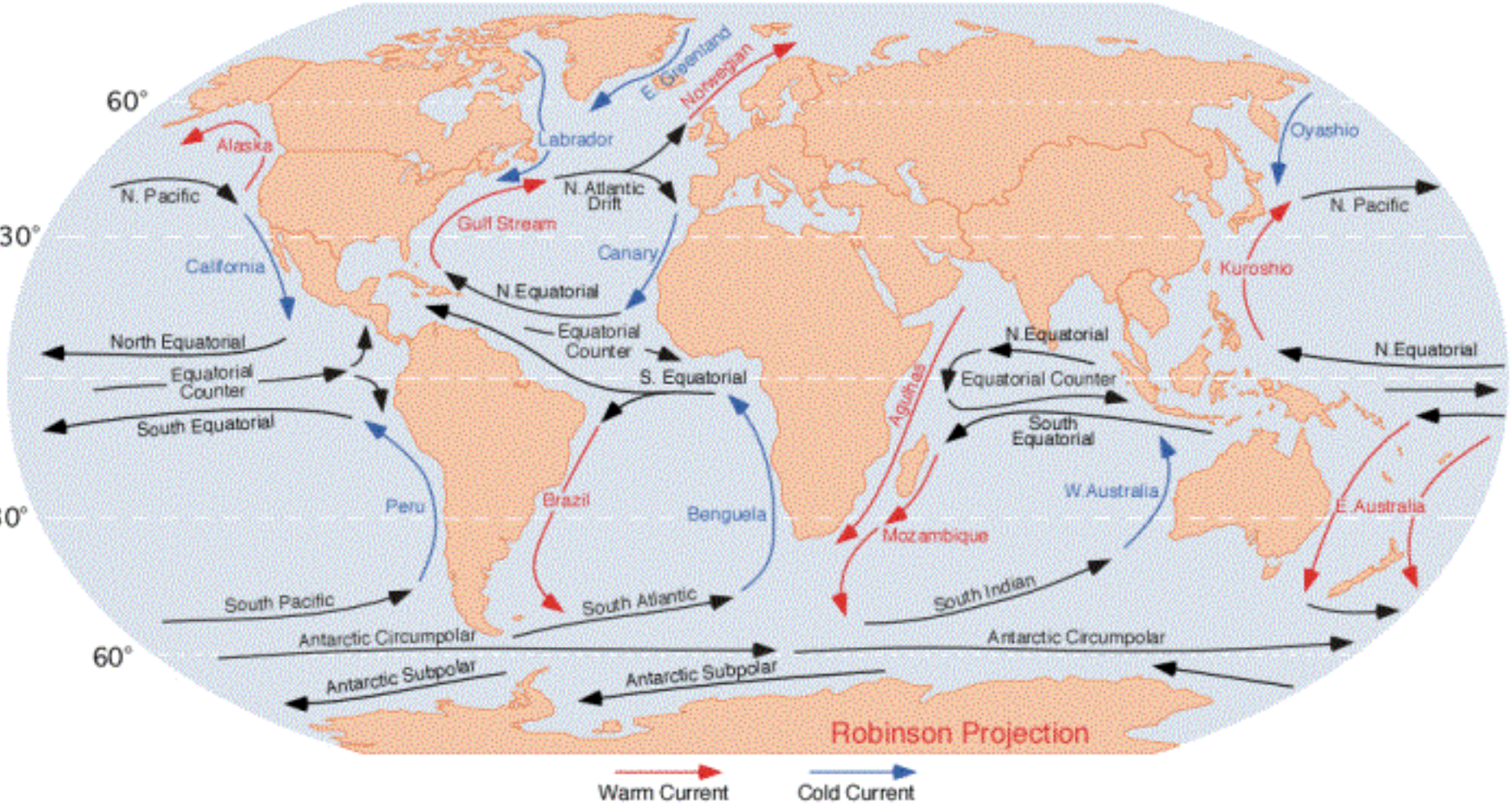


Multi-Moon Orbiter

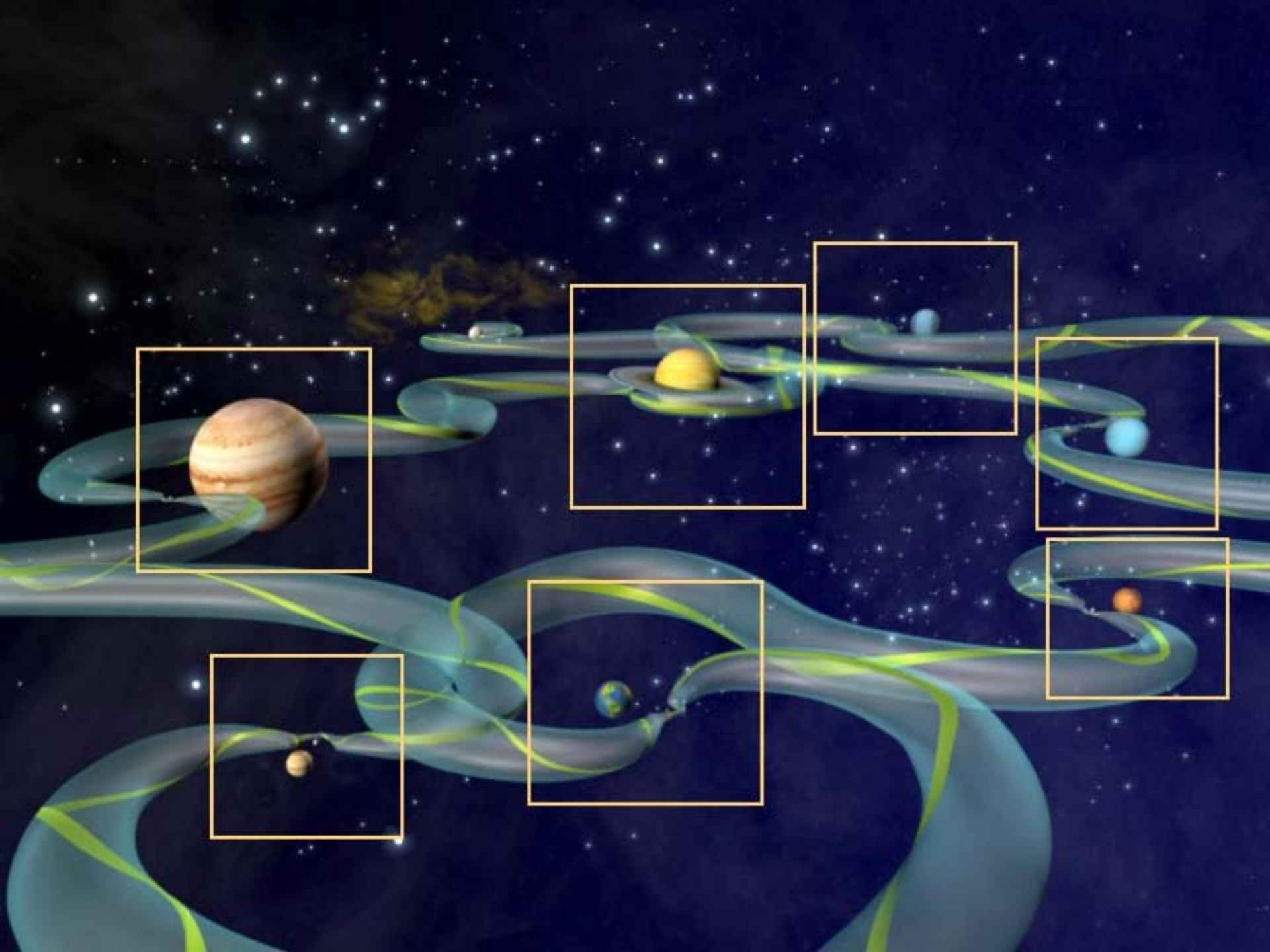




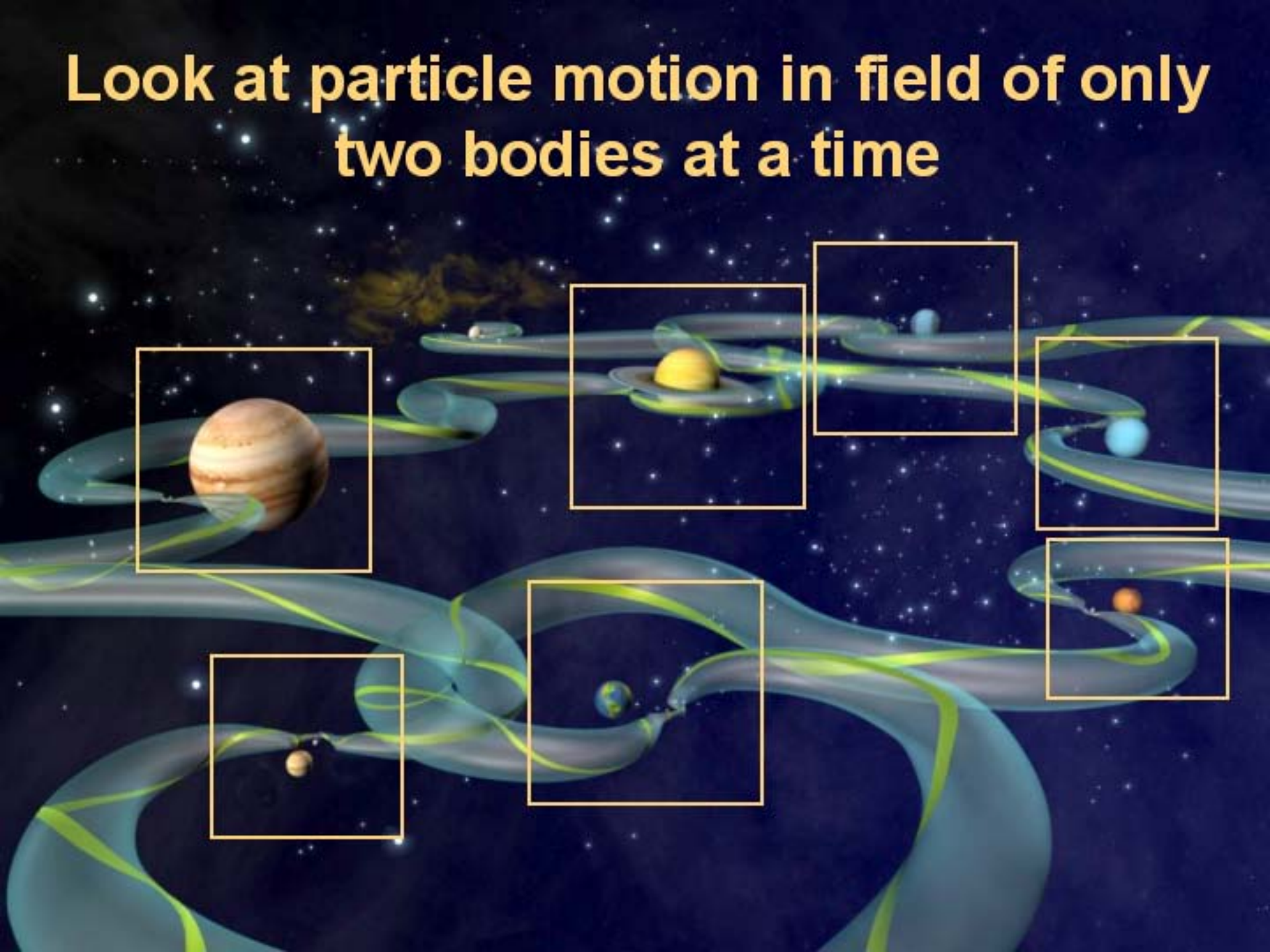
Map of all the clever paths: Low energy passageways

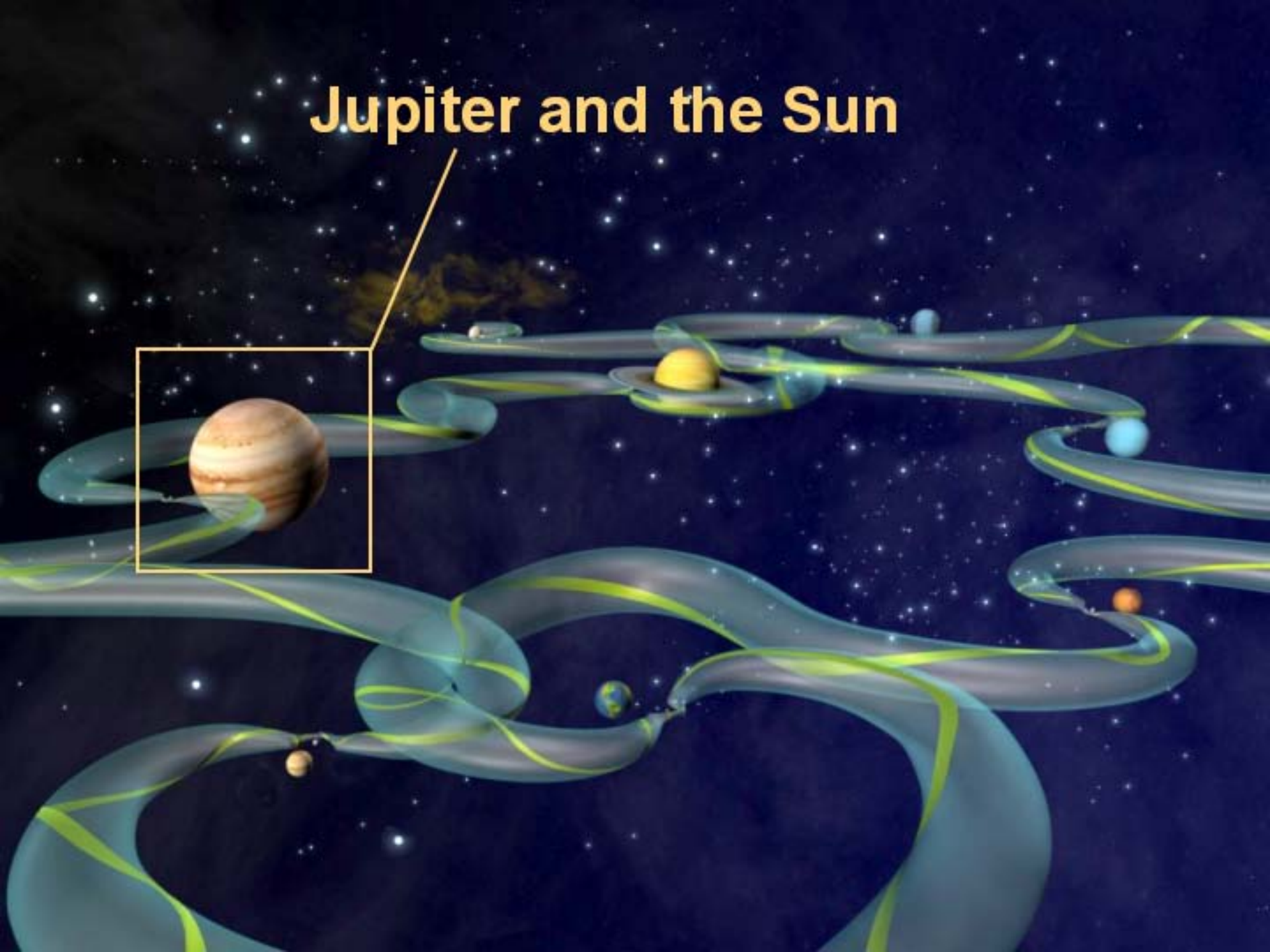

60°
30°
0°
30°
60°
Alaska
N. Pacific
California
North Equatorial
Equatorial Counter
South Equatorial
Peru
South Pacific
Antarctic Circumpolar
Antarctic Subpolar
Labrador
E. Greenland
Norwegian
N. Atlantic Drift
Gulf Stream
Canary
N.Equatorial
Equatorial Counter
S. Equatorial
Brazil
Benguela
South Atlantic
Antarctic Subpolar
Oyashio
N. Pacific
Kuroshio
N.Equatorial
Equatorial Counter
South Equatorial
Agulhas
Mozambique
W.Australia
South Indian
Antarctic Circumpolar
N.Equatorial
E.Australia
Robinson Projection
Warm Current
Cold Current

What makes a comet or spacecraft move along strange paths?



Look at particle motion in field of only two bodies at a time



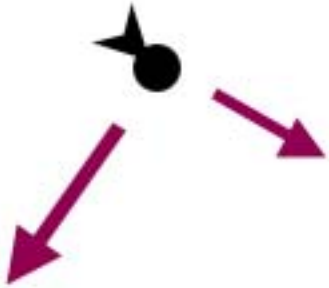

Jupiter and the Sun

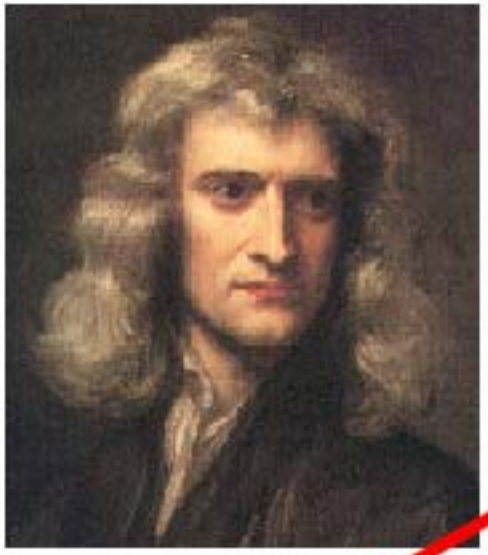
Kepler

Image source: http://www.[illegible]/famousKepler.jpg

Newton

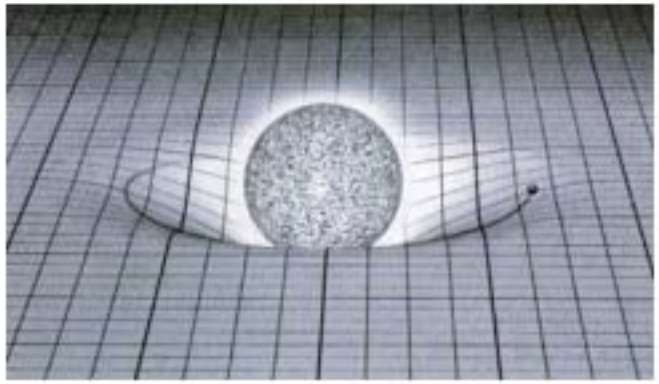
Newton





Newton

UNSOLVABLE




All Forces
Balance


Park At Your
Own Risk
All Forces
Balance

Euler

Image source: http://ods.schule.de/schule/arbeiten/aktuelles/euler.jpg

Lagrange

Lagrange Points

Lagrange

L4

L2

L1

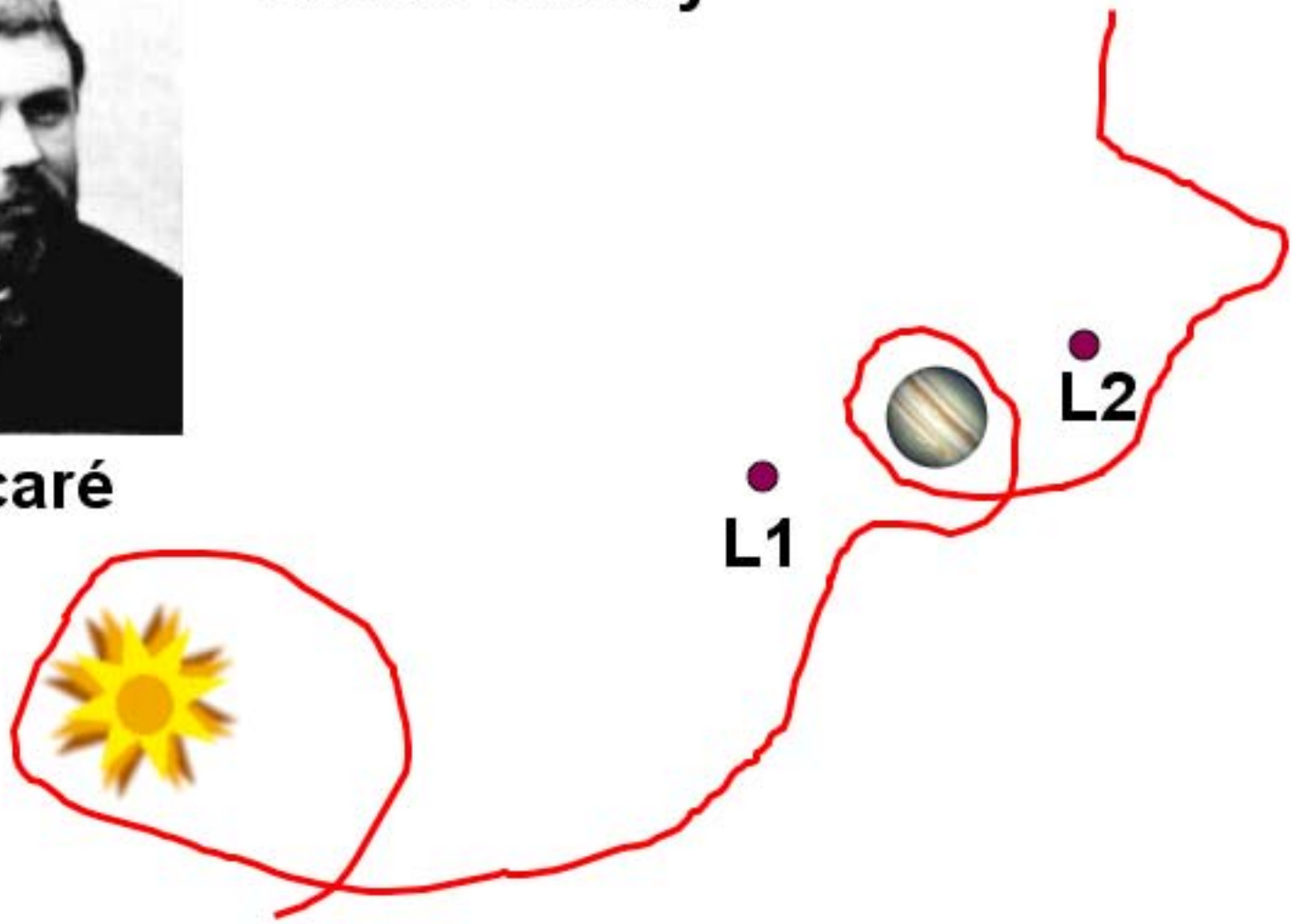
L3

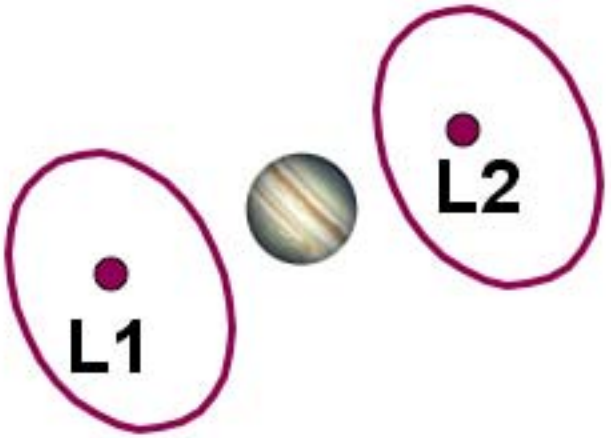
L5


L2
L1

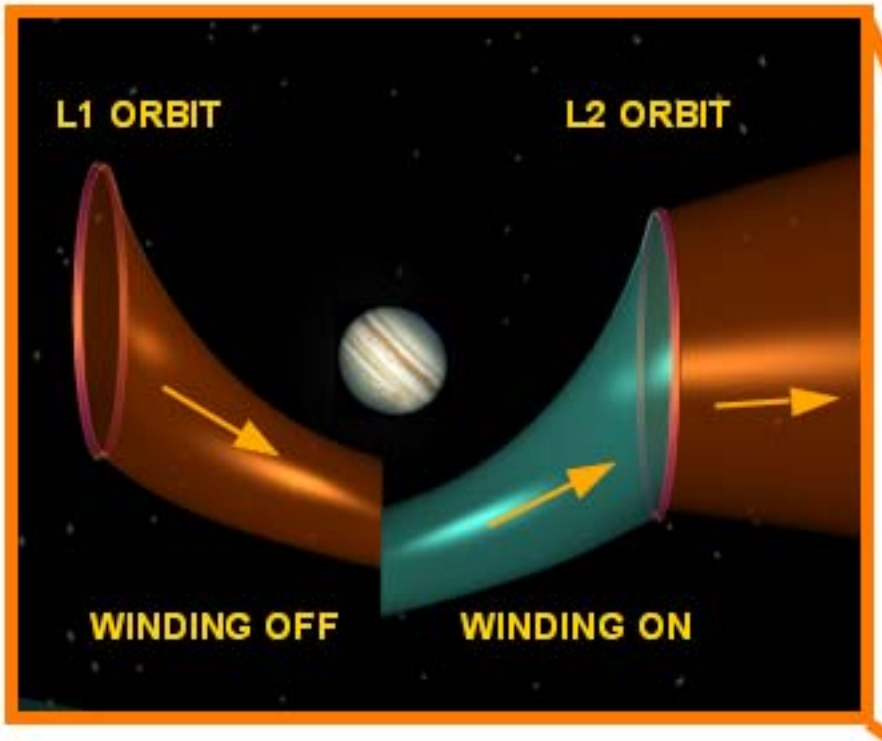
“Chaos Theory”

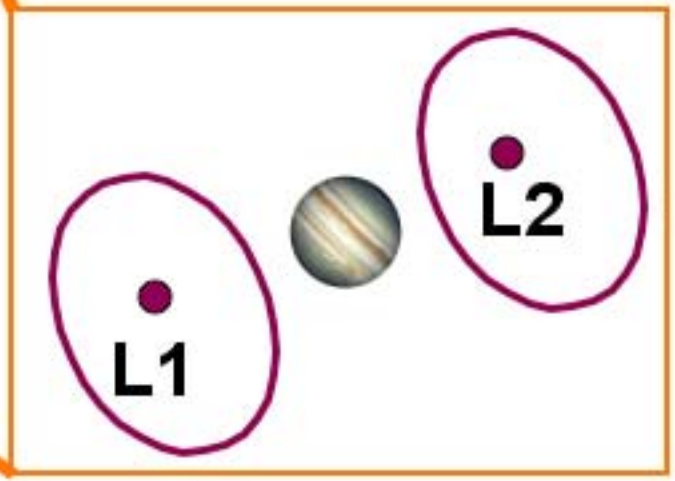
Poincaré

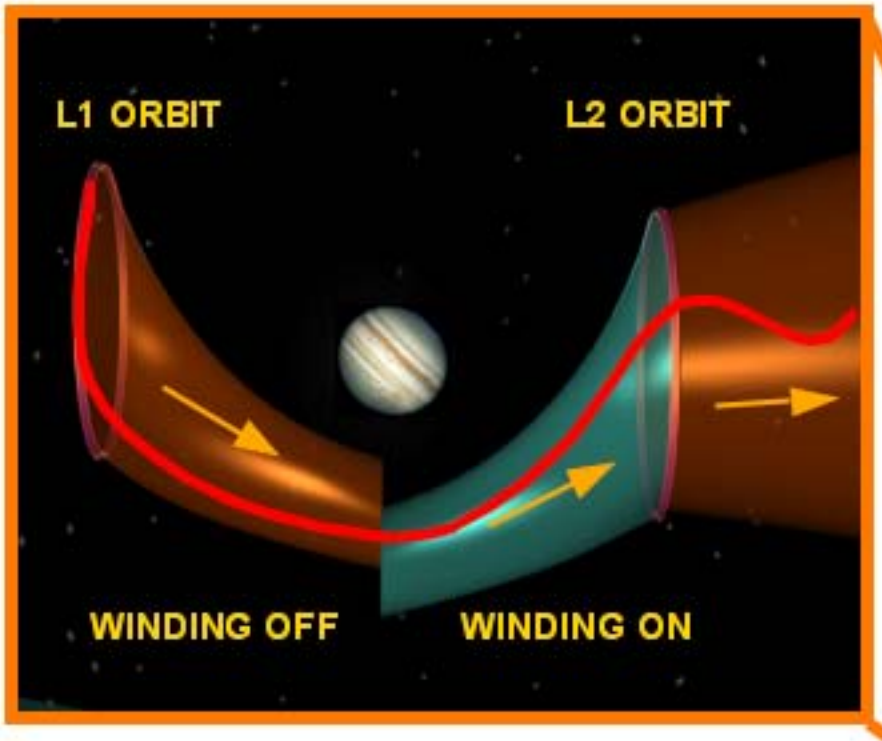



L2
L1

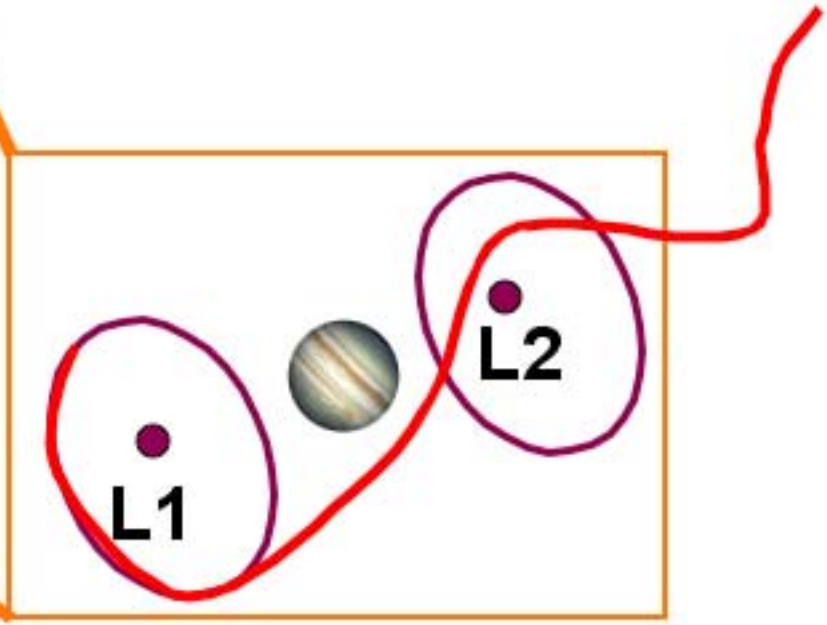
Tubes

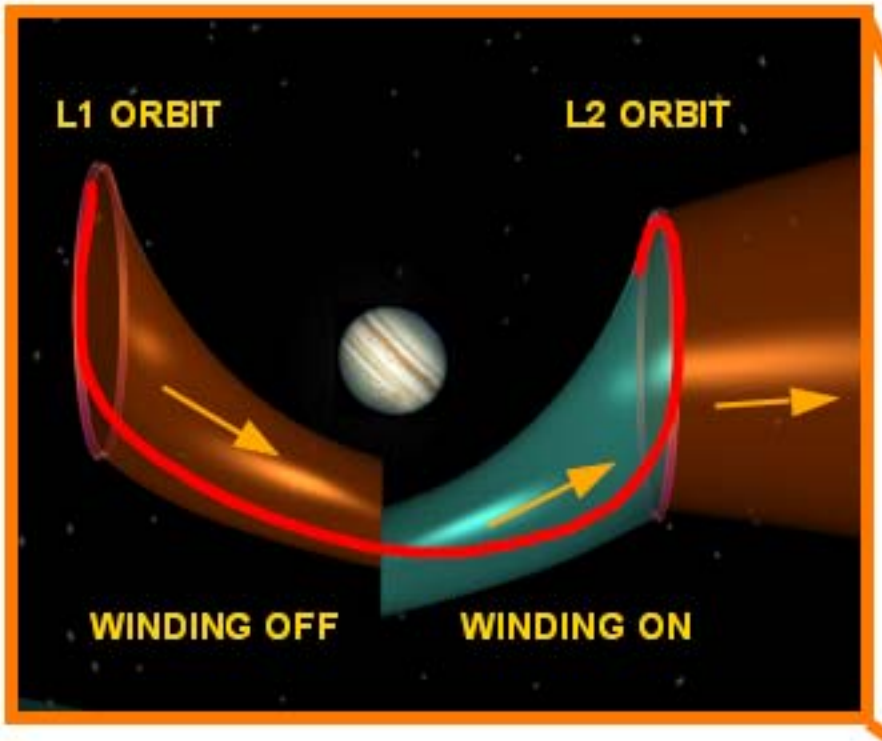




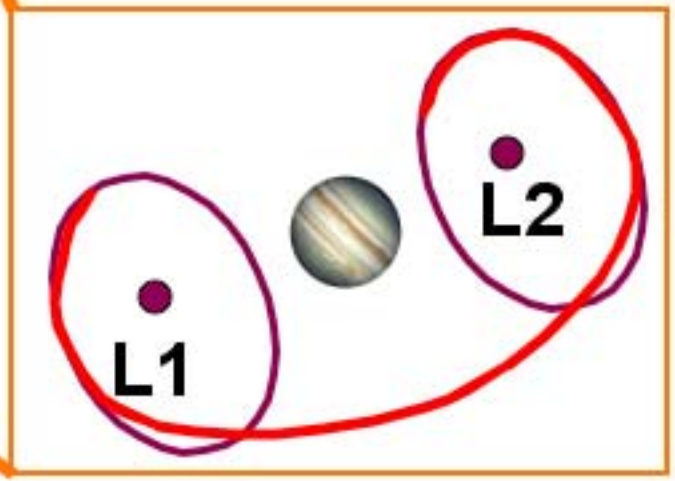


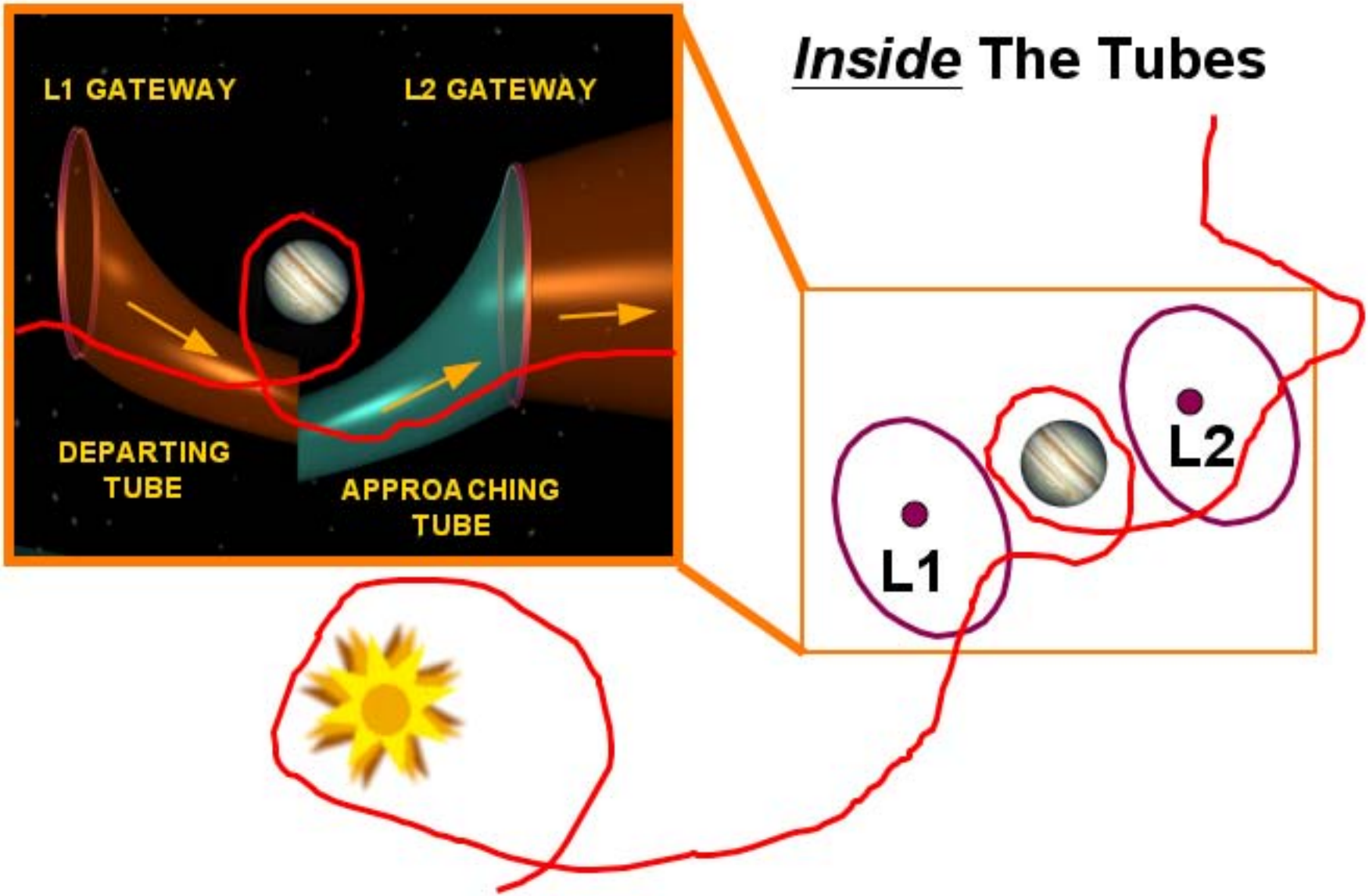
On One Tube

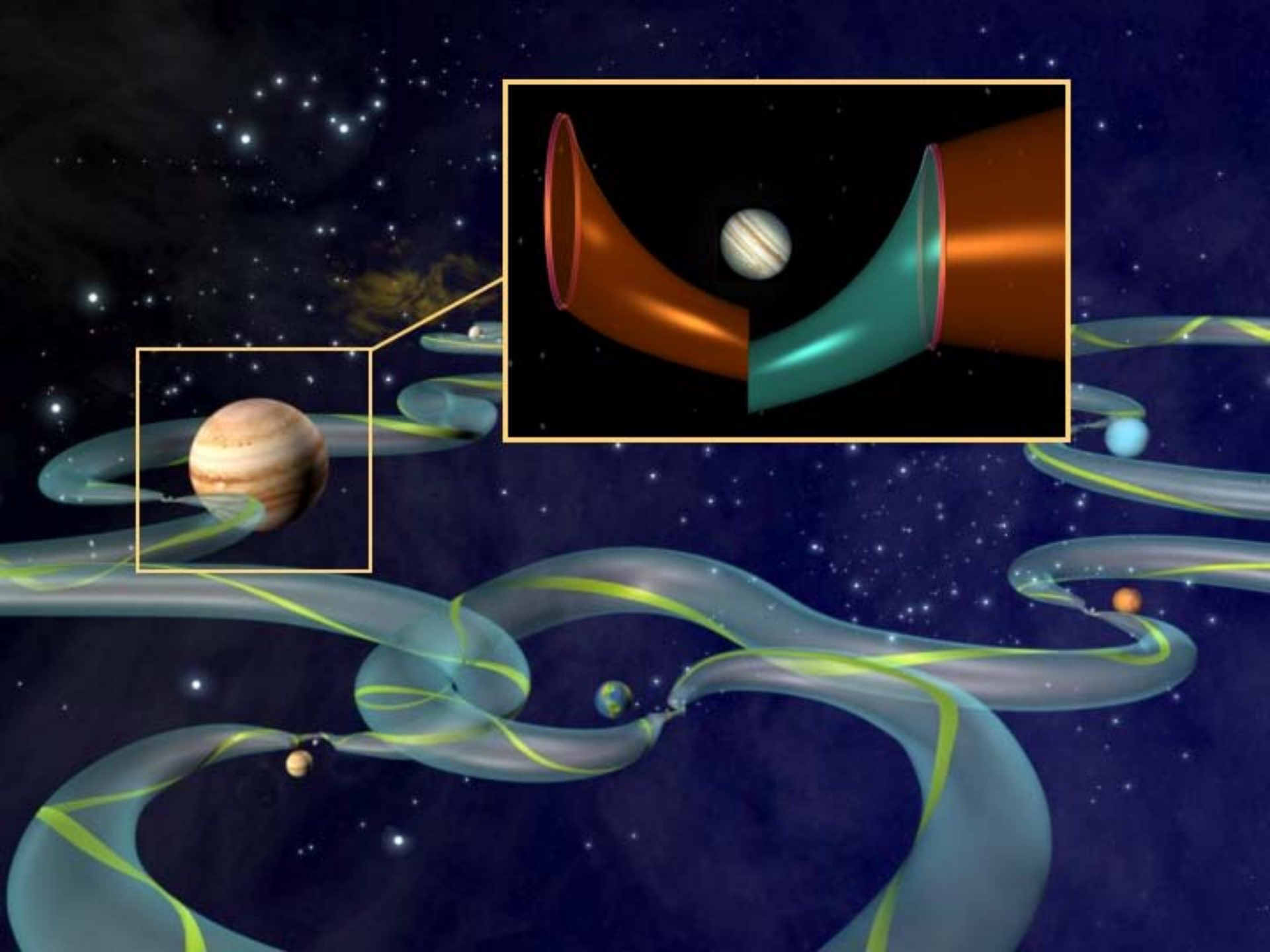


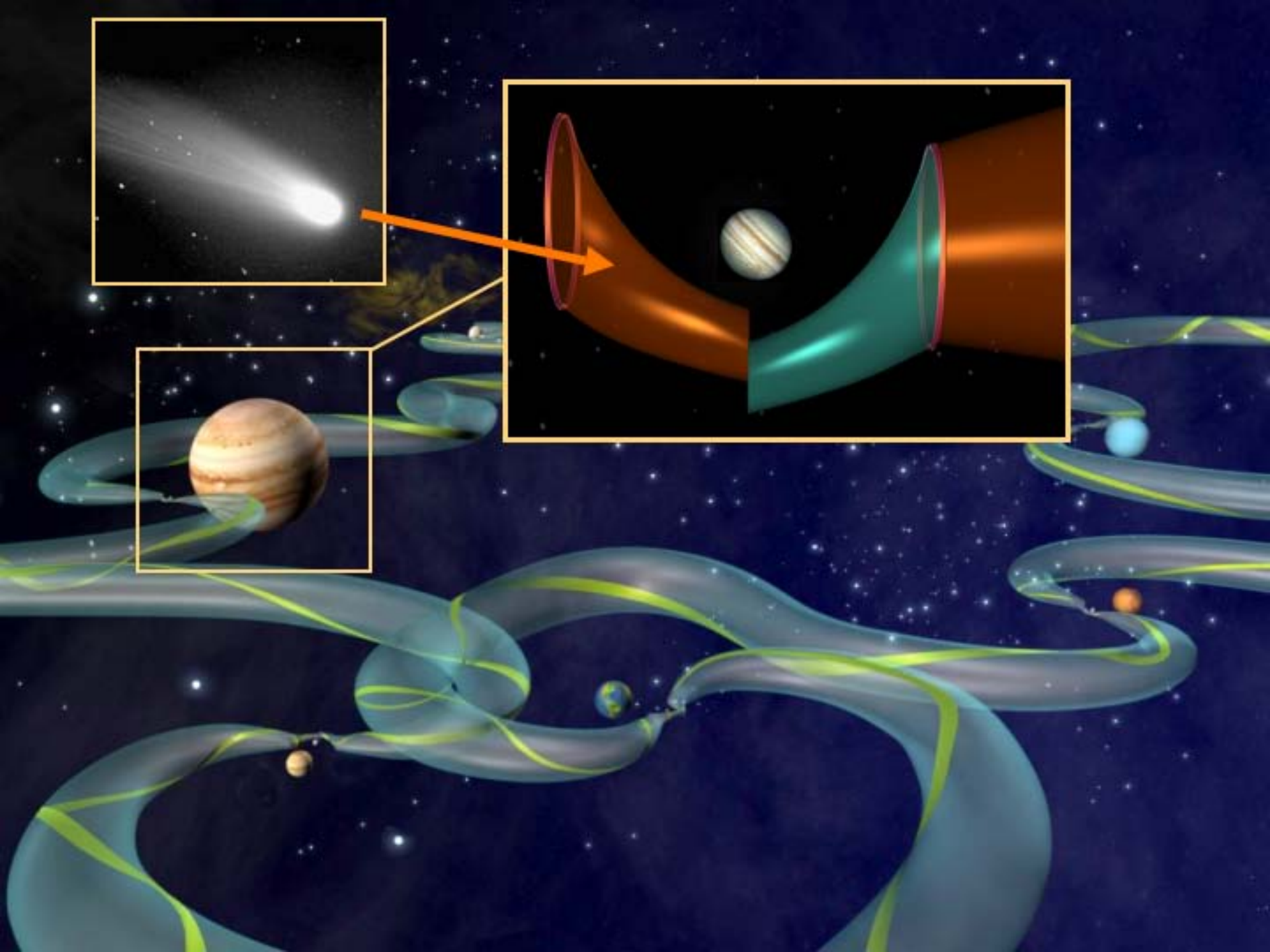


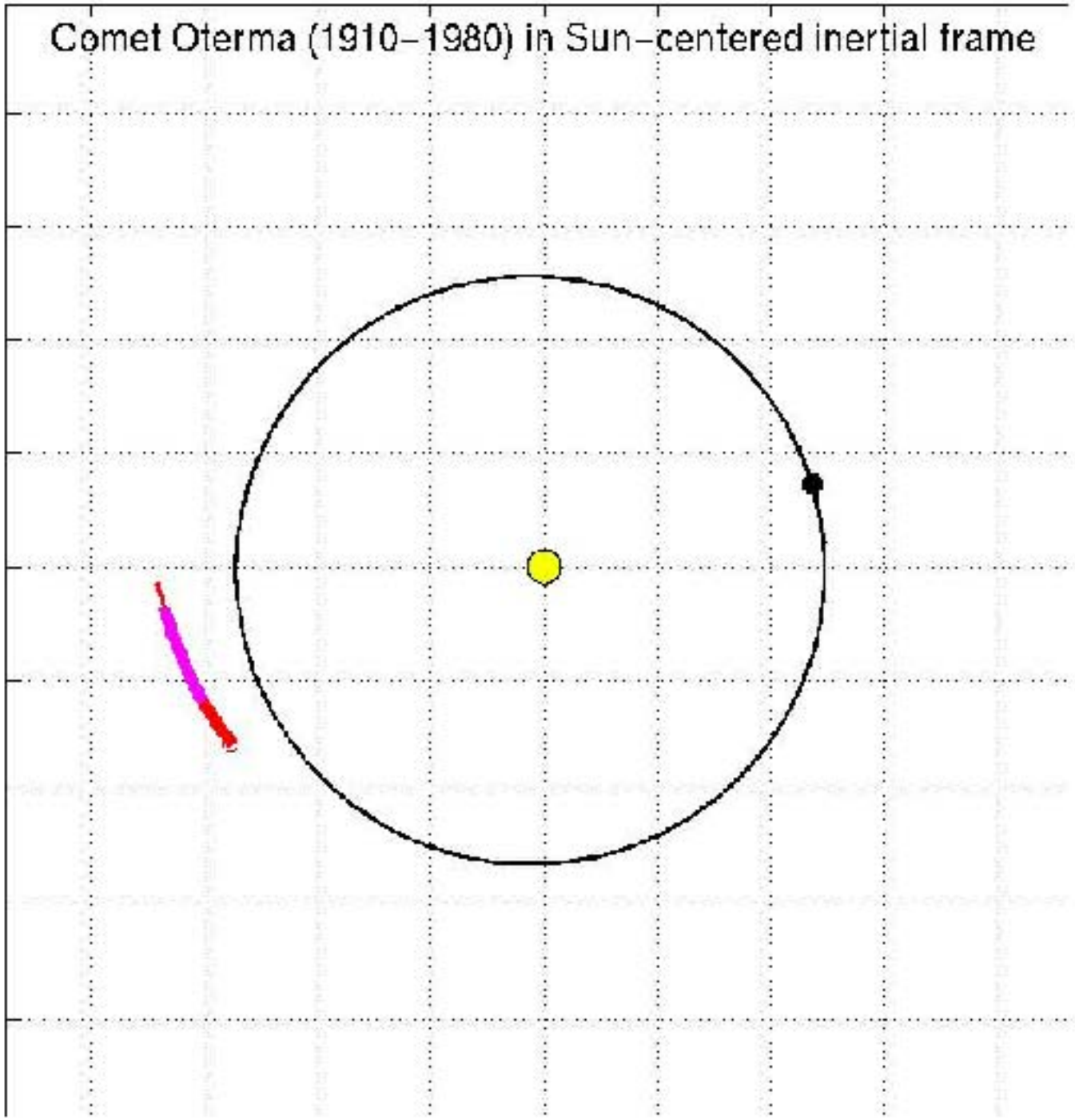
On Both Tubes

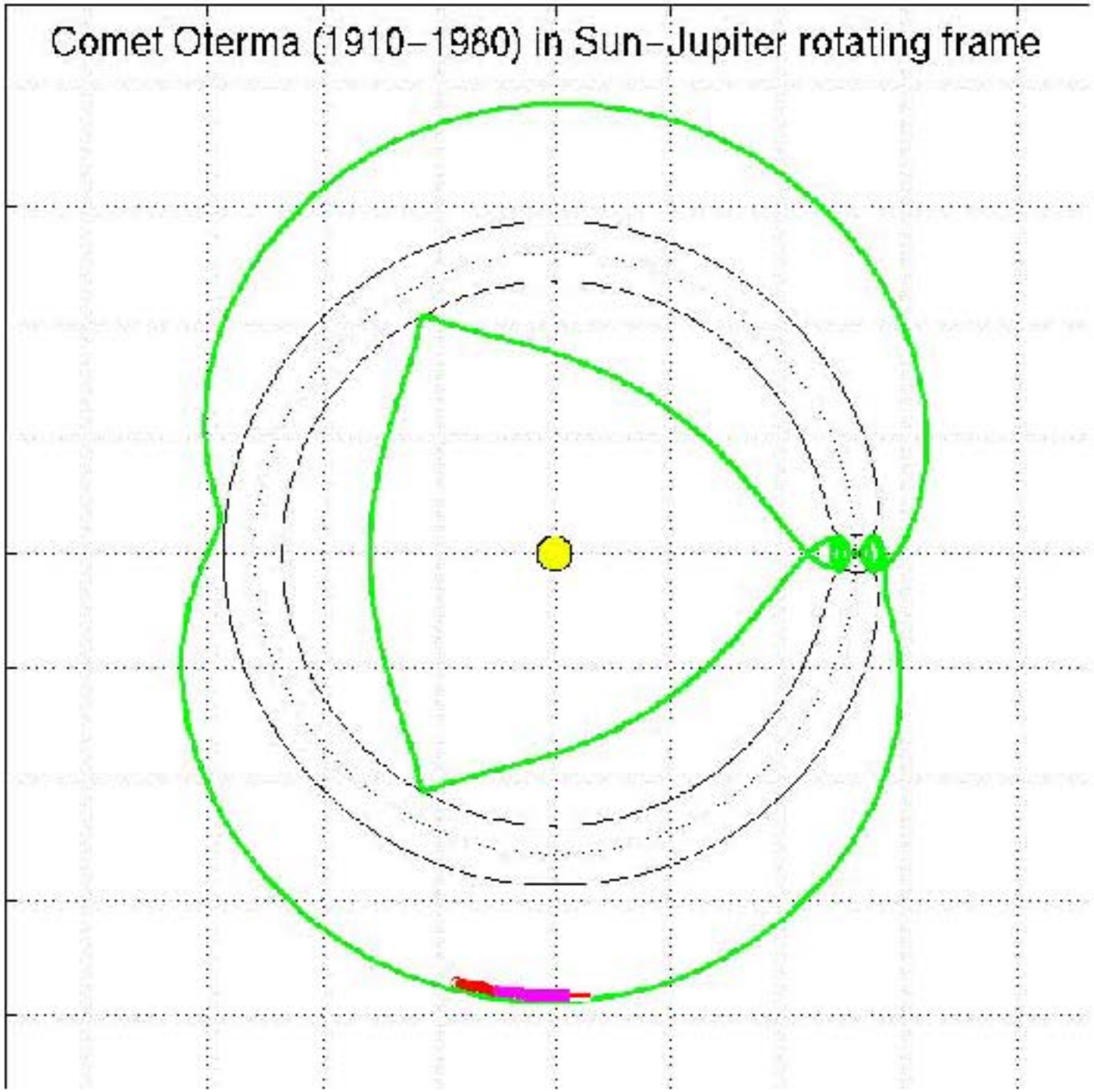



L1 GATEWAY
L2 GATEWAY
DEPARTING TUBE
APPROACHING TUBE
Inside The Tubes
L1
L2



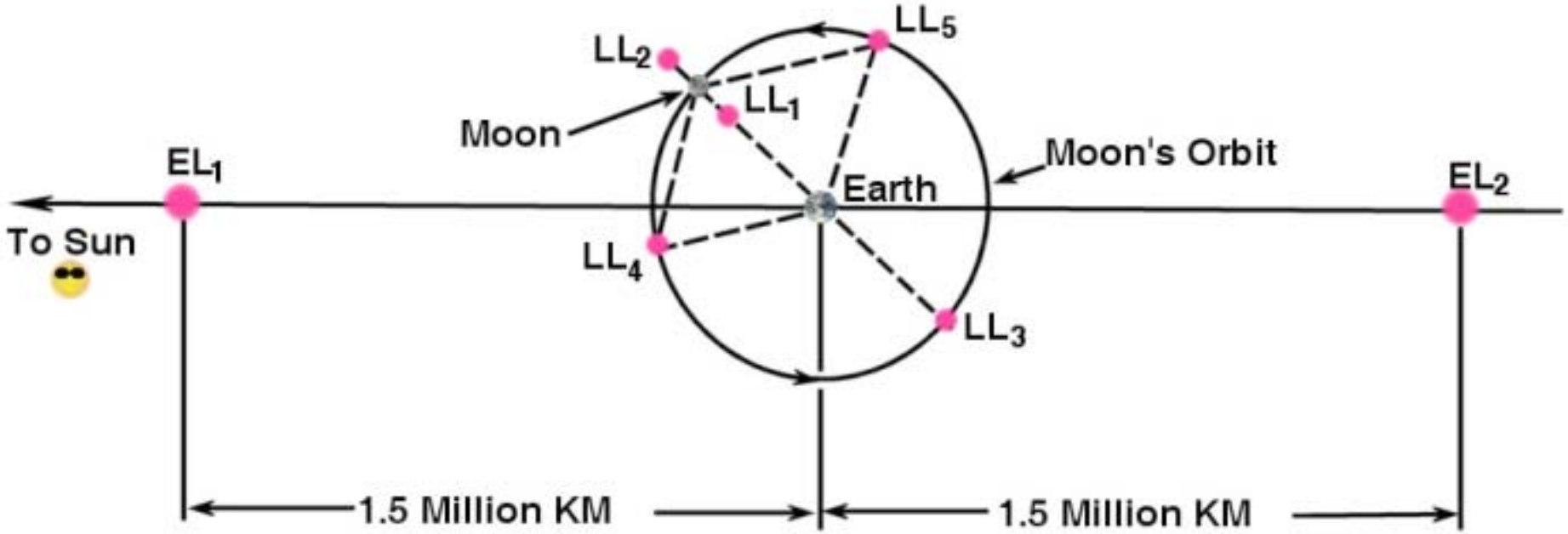



Comet Oterma (1910–1980) in Sun–centered inertial frame

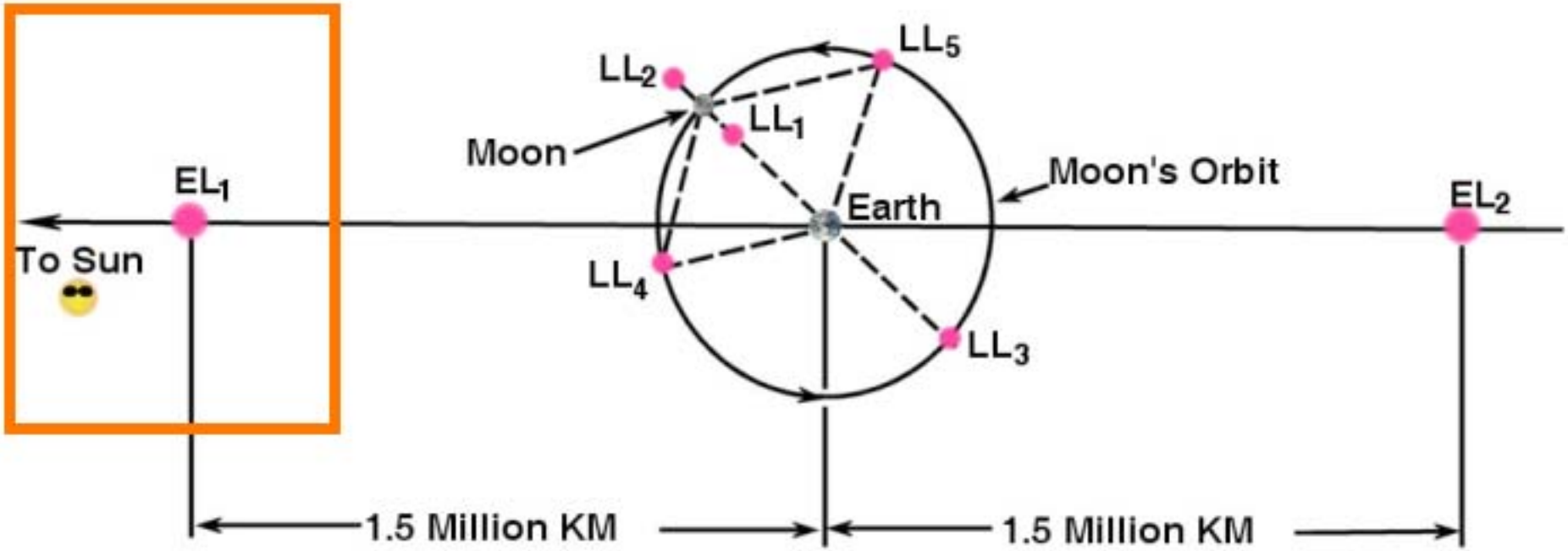

Comet Oterma (1910–1980) in Sun–Jupiter rotating frame


Earth's Neighborhood

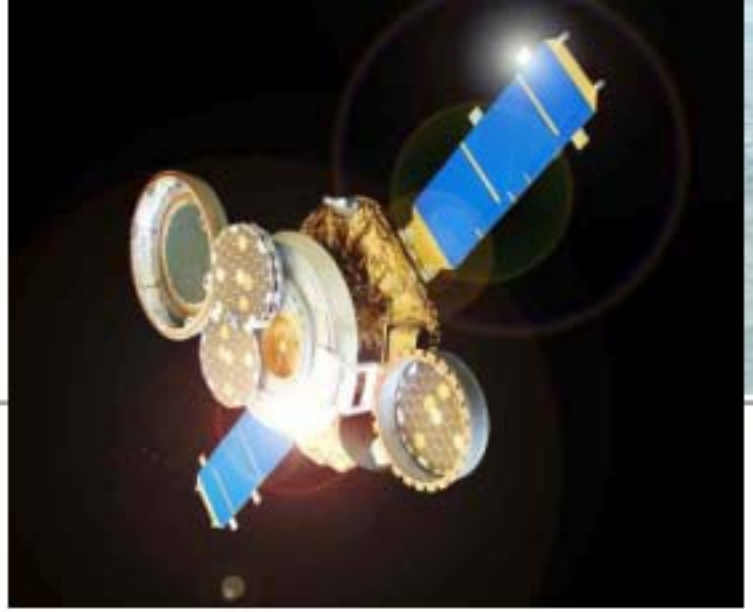
- Sun-Earth-Spacecraft: EL_1, EL_2, …
- Earth-Moon-Spacecraft: LL_1, LL_2, … LL_5

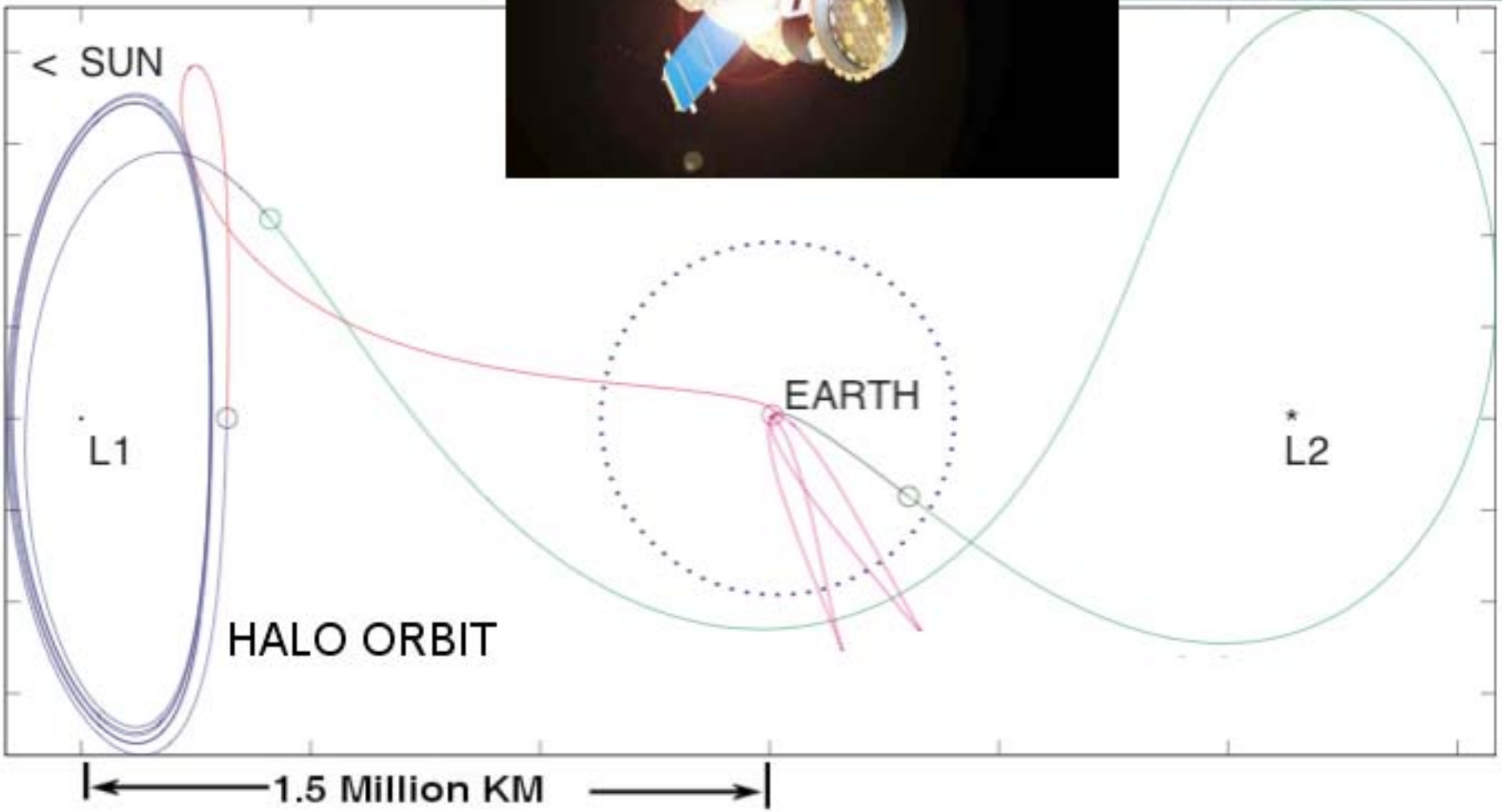


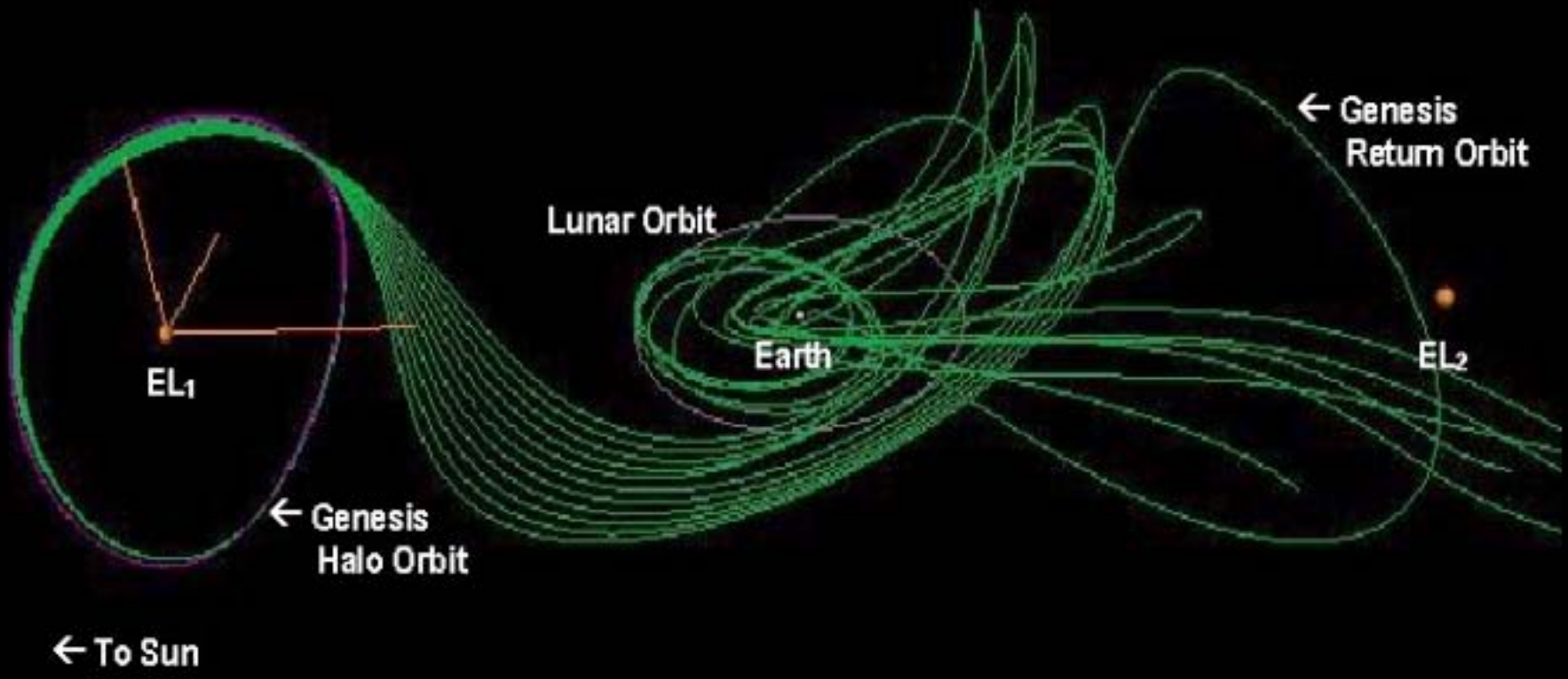
- Sun-Earth-Spacecraft: EL_1, EL_2, …
- Earth-Moon-Spacecraft: LL_1, LL_2, … LL_5

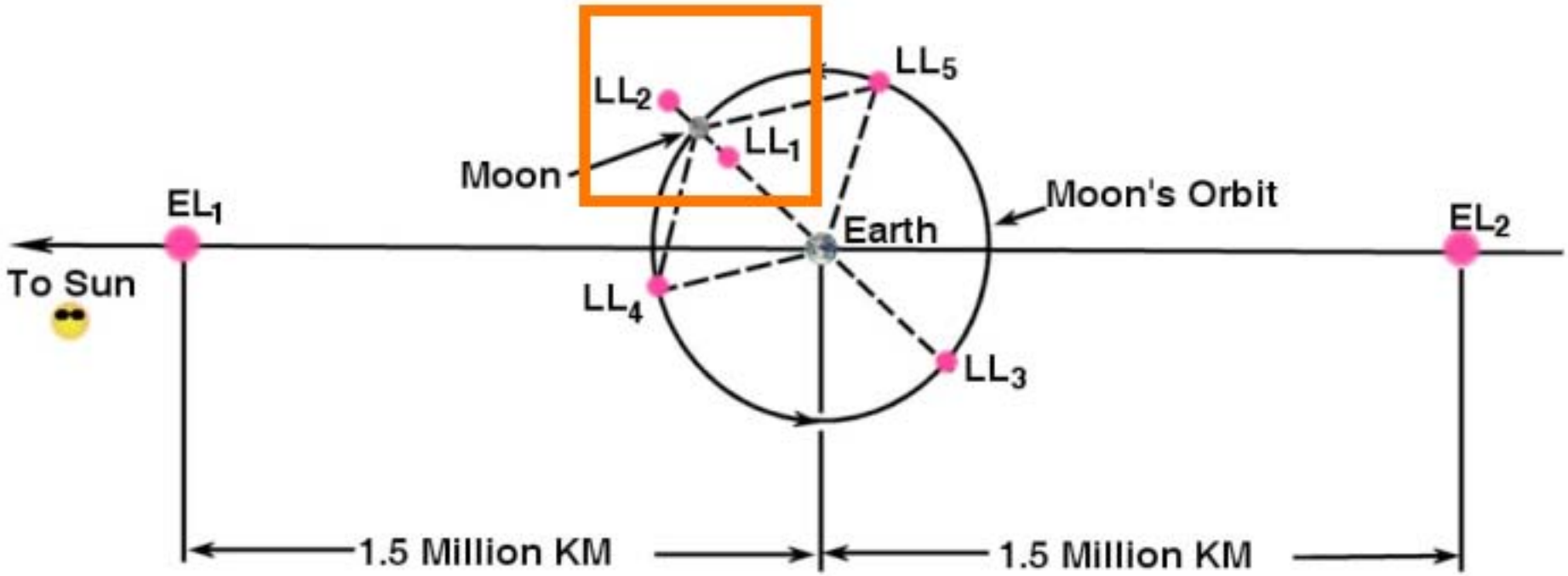


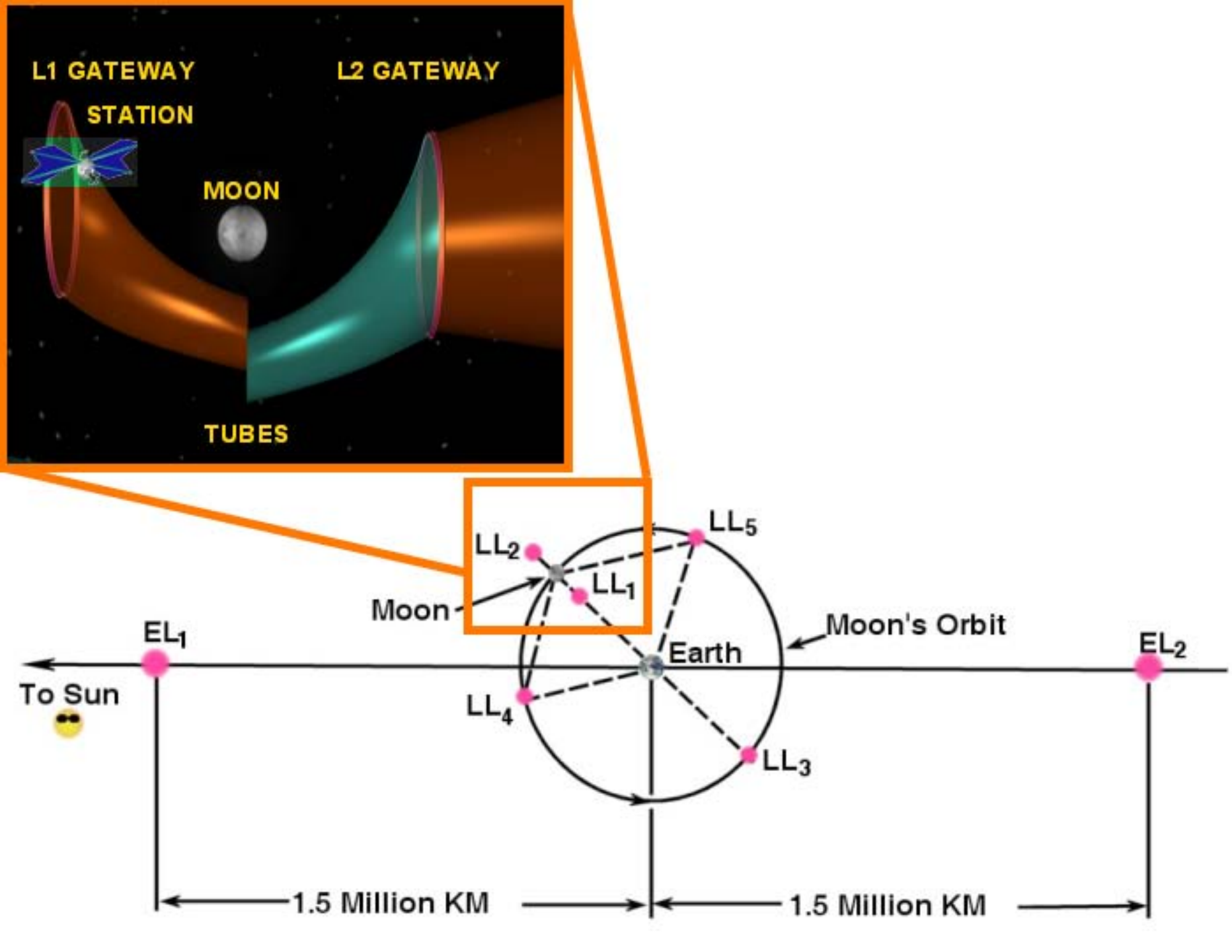
Genesis Sample Return Mission

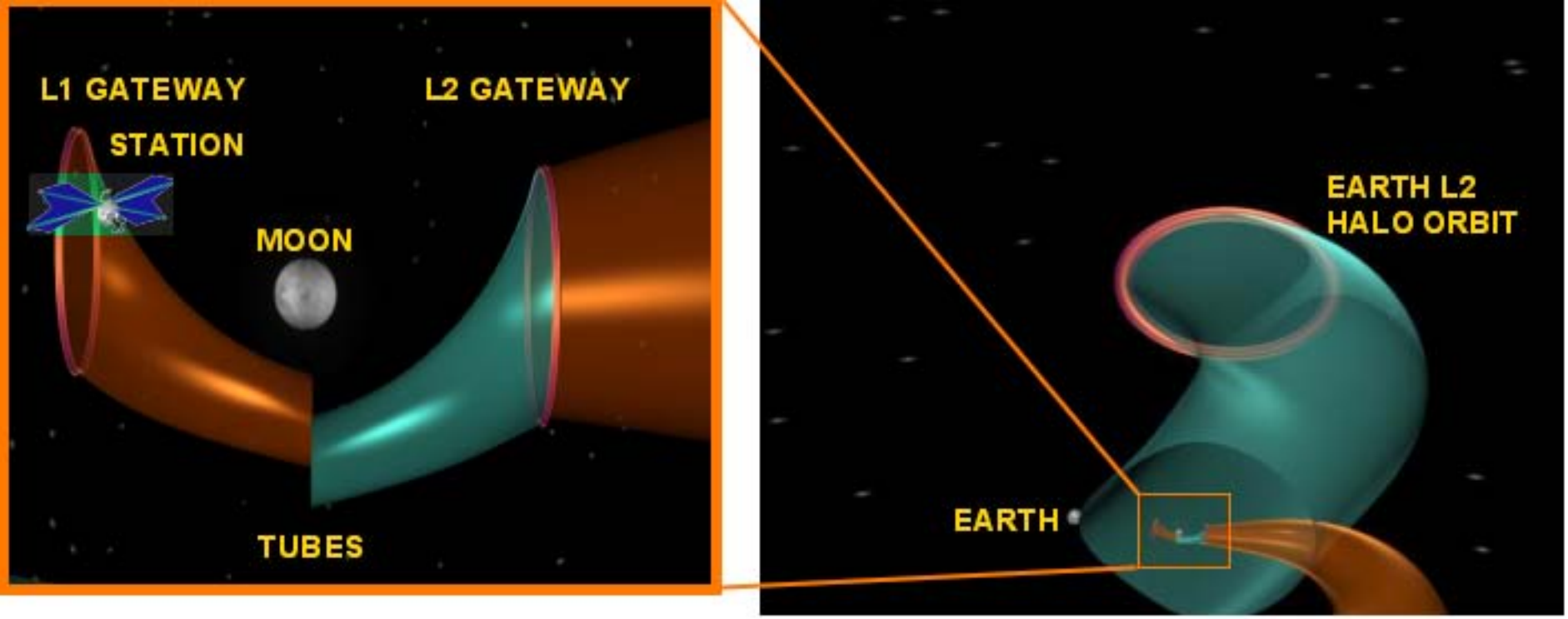





← Genesis
Return Orbit
Lunar Orbit
Earth
EL2
EL1
← Genesis
Halo Orbit
← To Sun

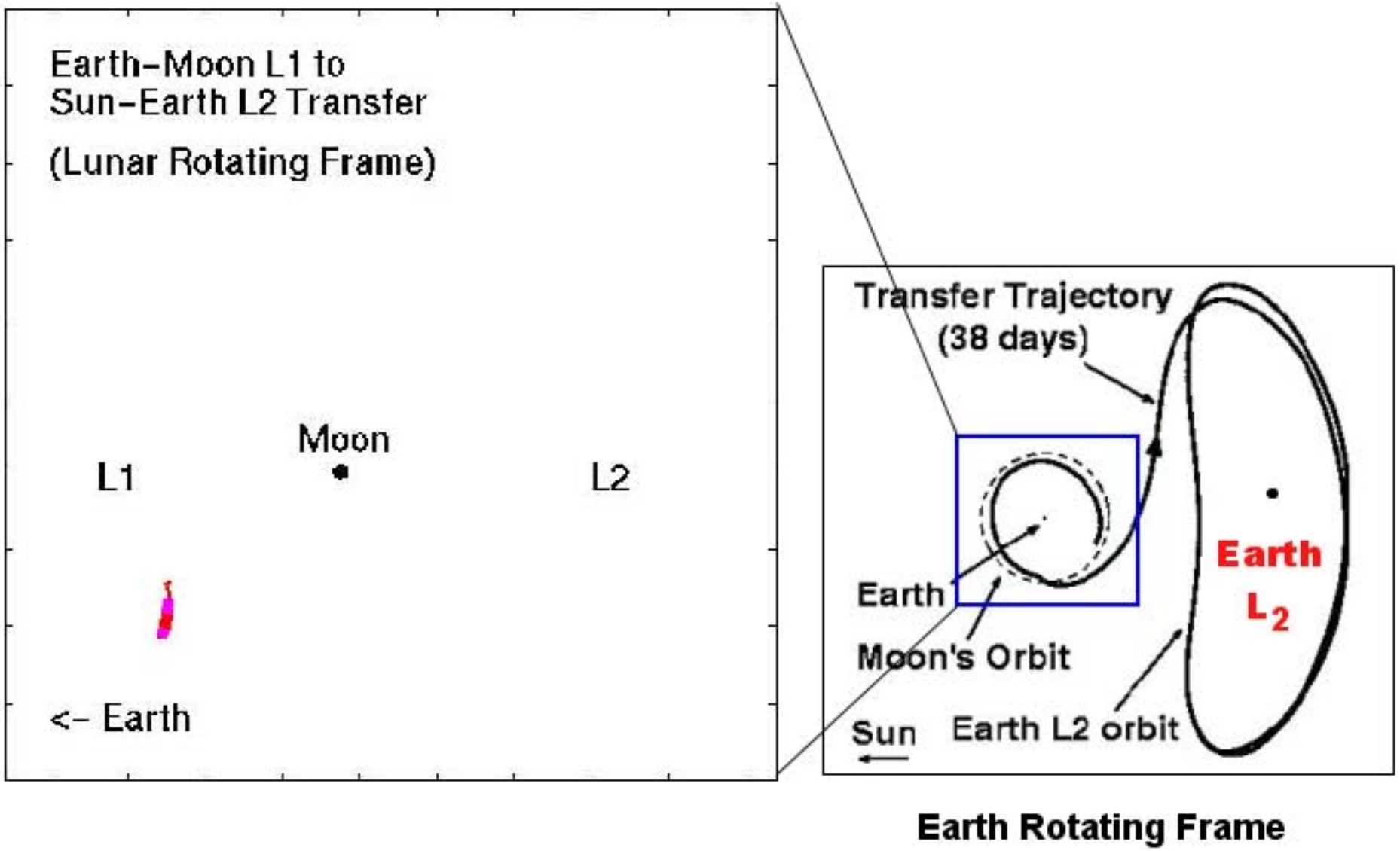

LL5
LL2
LL1
Moon
Moon's Orbit
EL1
Earth
EL2
To Sun
LL4
LL3
1.5 Million KM
1.5 Million KM


L1 GATEWAY
STATION
L2 GATEWAY
MOON
TUBES
LL2
LL5
LL1
Moon
Moon's Orbit
EL1
Earth
EL2
To Sun
LL4
LL3
1.5 Million KM
1.5 Million KM


L1 GATEWAY
L2 GATEWAY
STATION
MOON
TUBES
EARTH L2
HALO ORBIT
EARTH

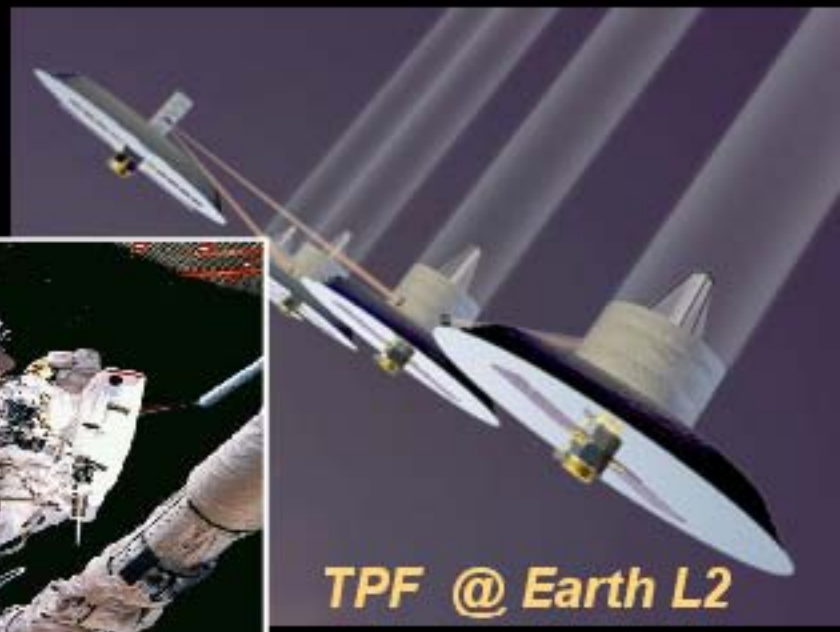
Tube Hopping

Deploying Deep Space Telescopes

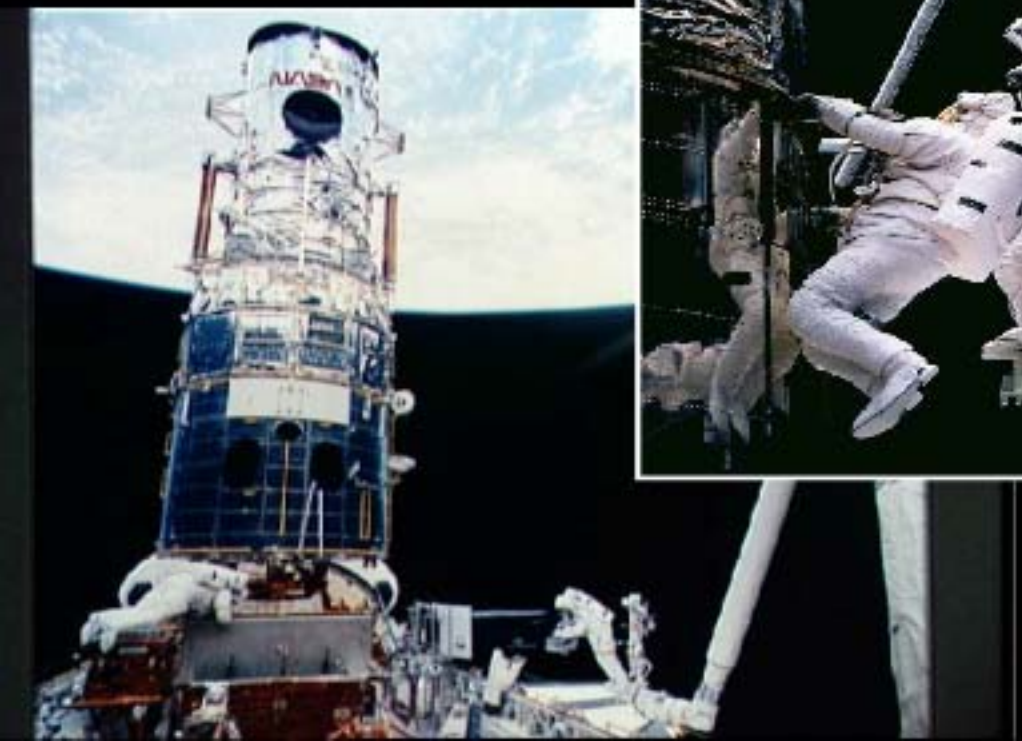


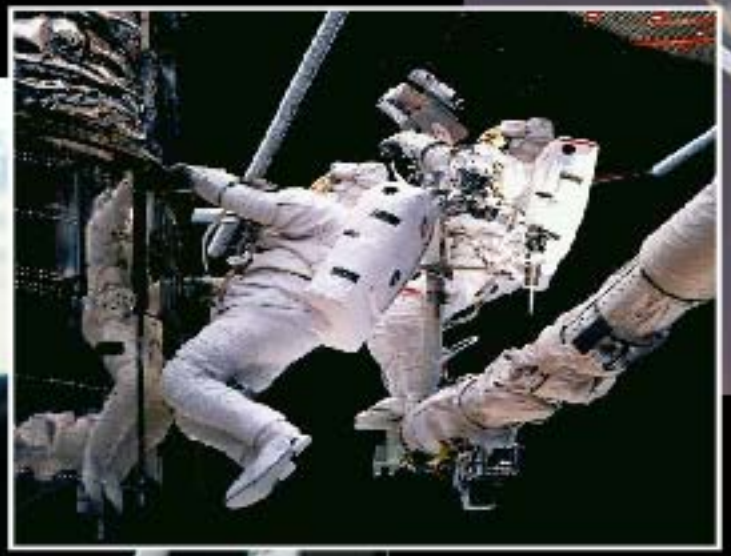
Lunar L1 Gateway Station

Telescope Servicing



TPF @ Earth L2





STA-103 astronauts repairing the Hubble Space Telescope

Servicing Halo Missions at the Lunar L1 Gateway

Animation Source: Martin Lo, JPL

Transportation Hub

Deep Space Telescopes

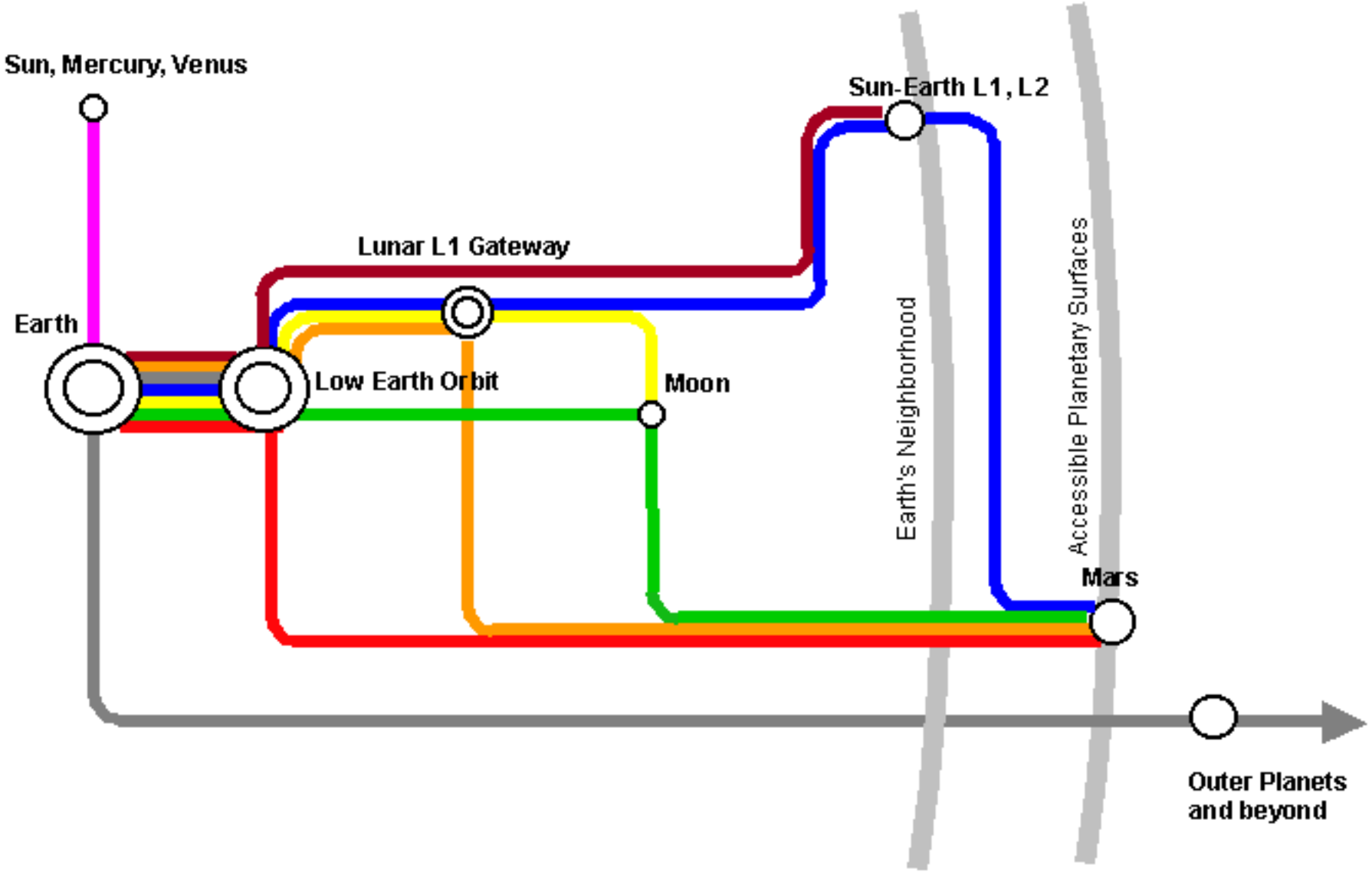
Lunar L1
Gateway Station

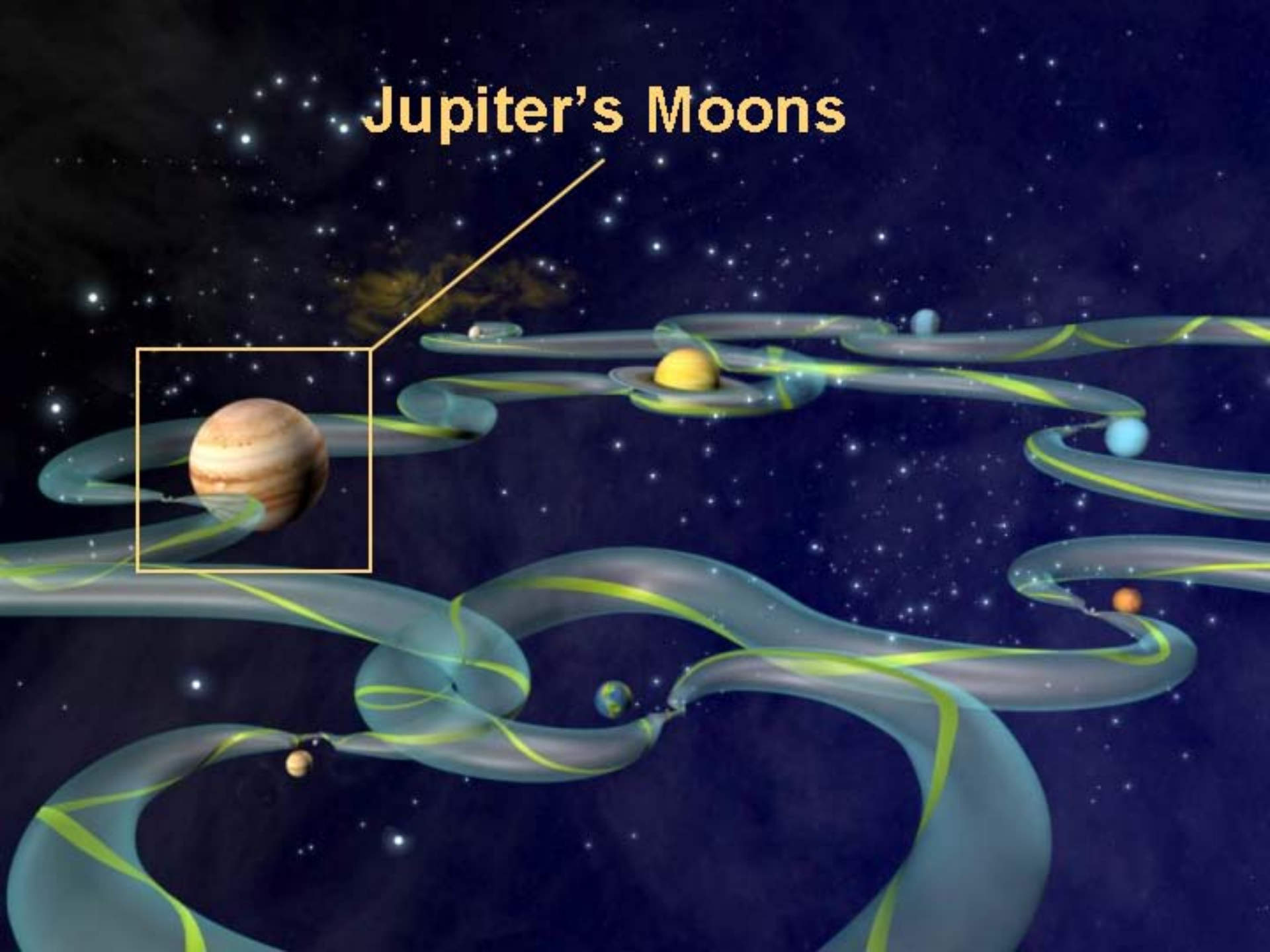
Moon

Asteroids

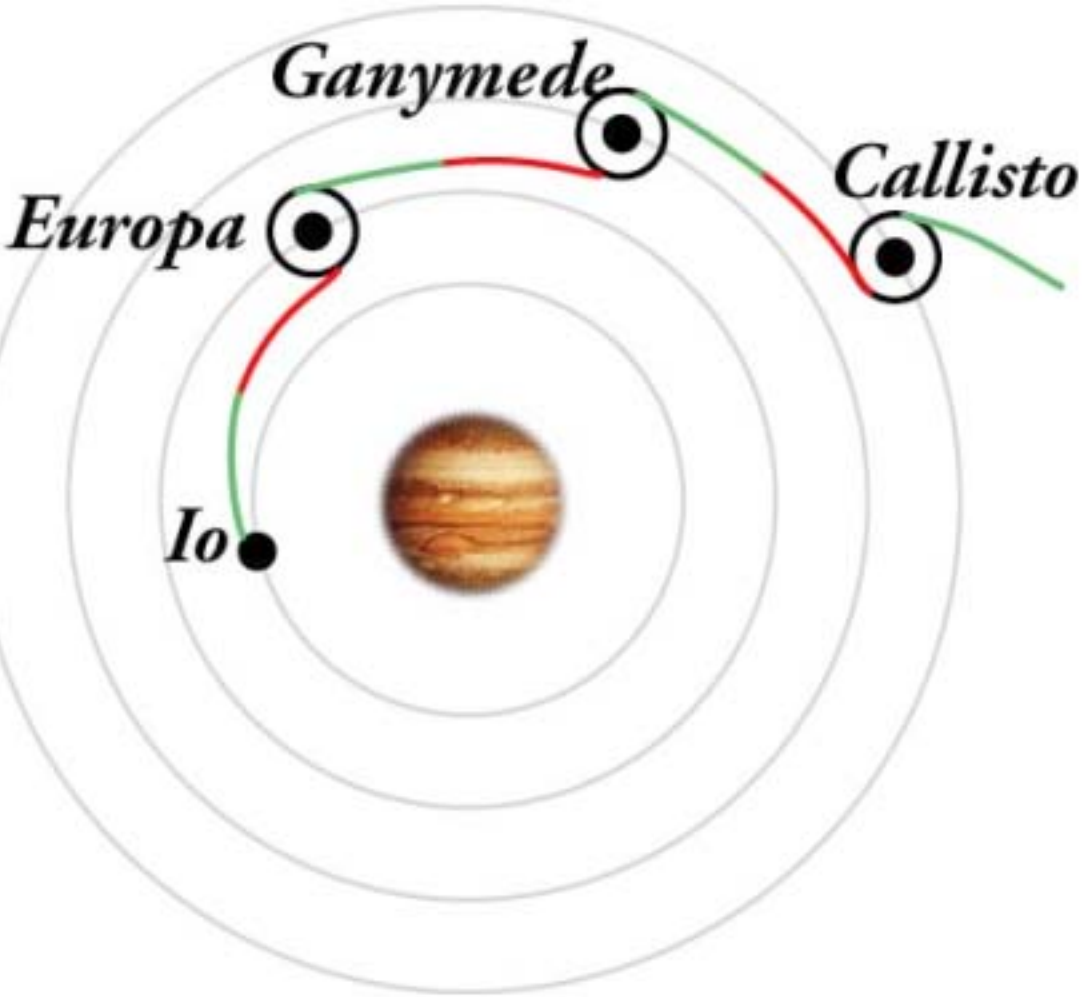
Mars

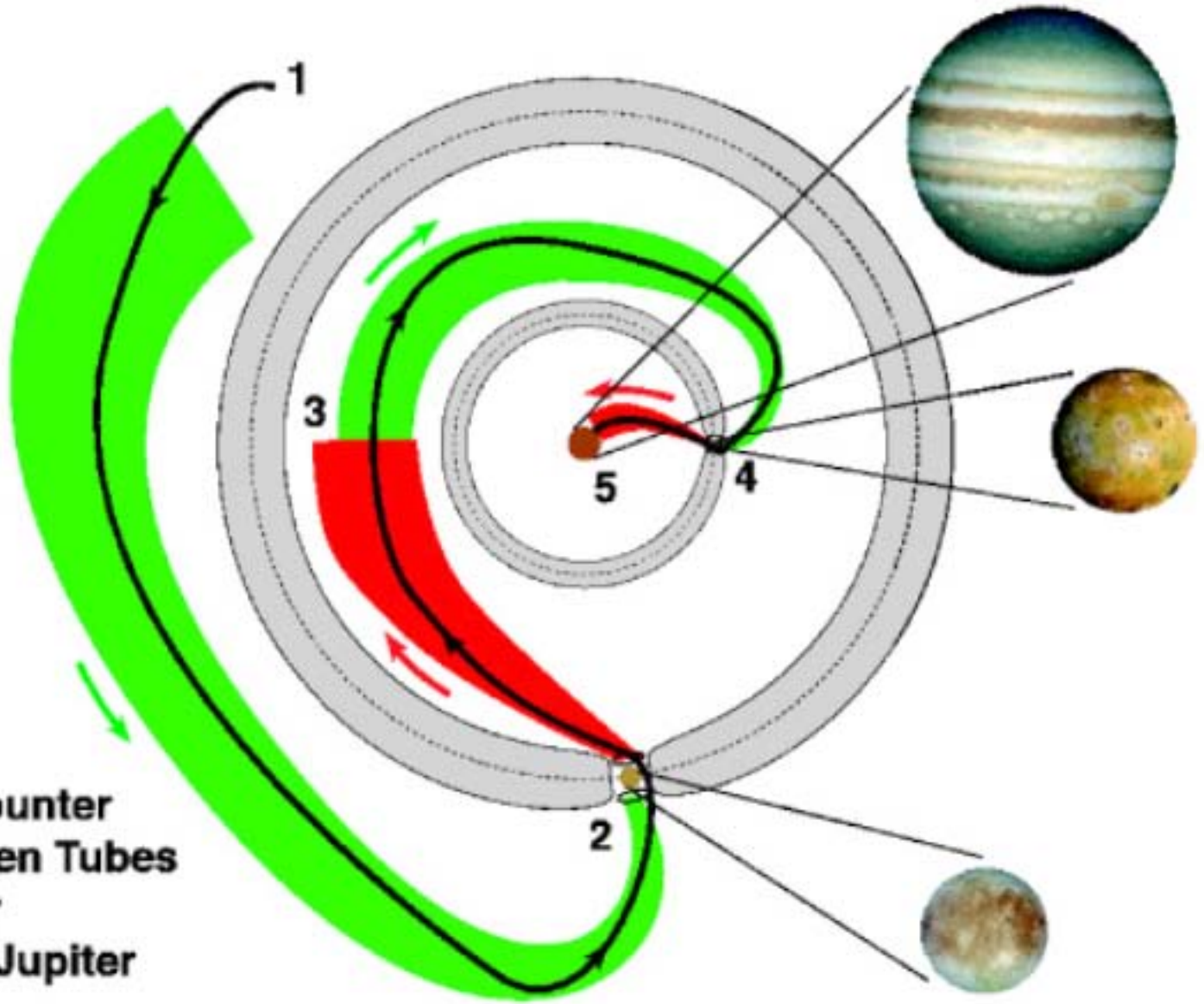
Solar System Metro Map



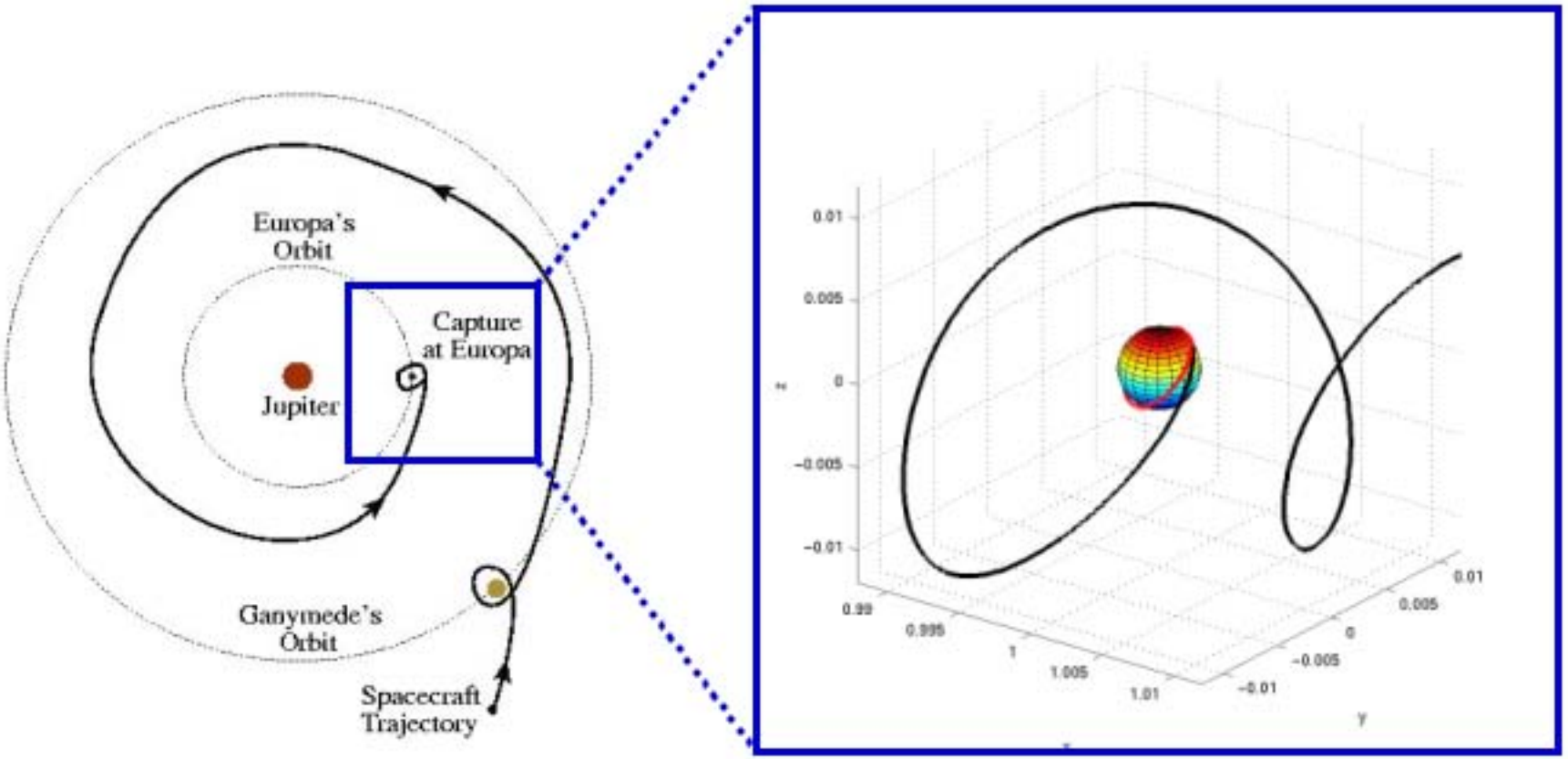

Jupiter's Moons

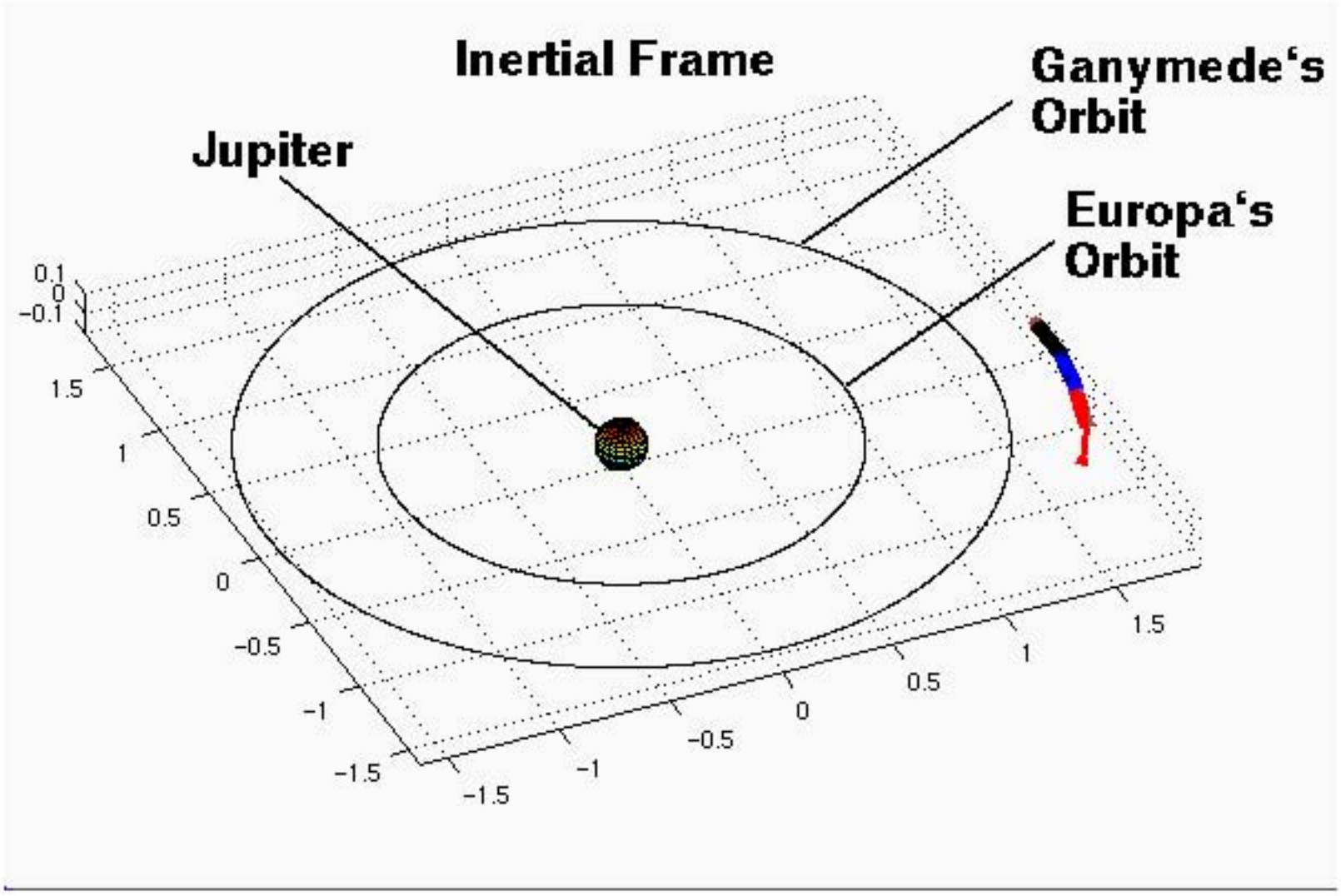
Multi-Moon Orbiter

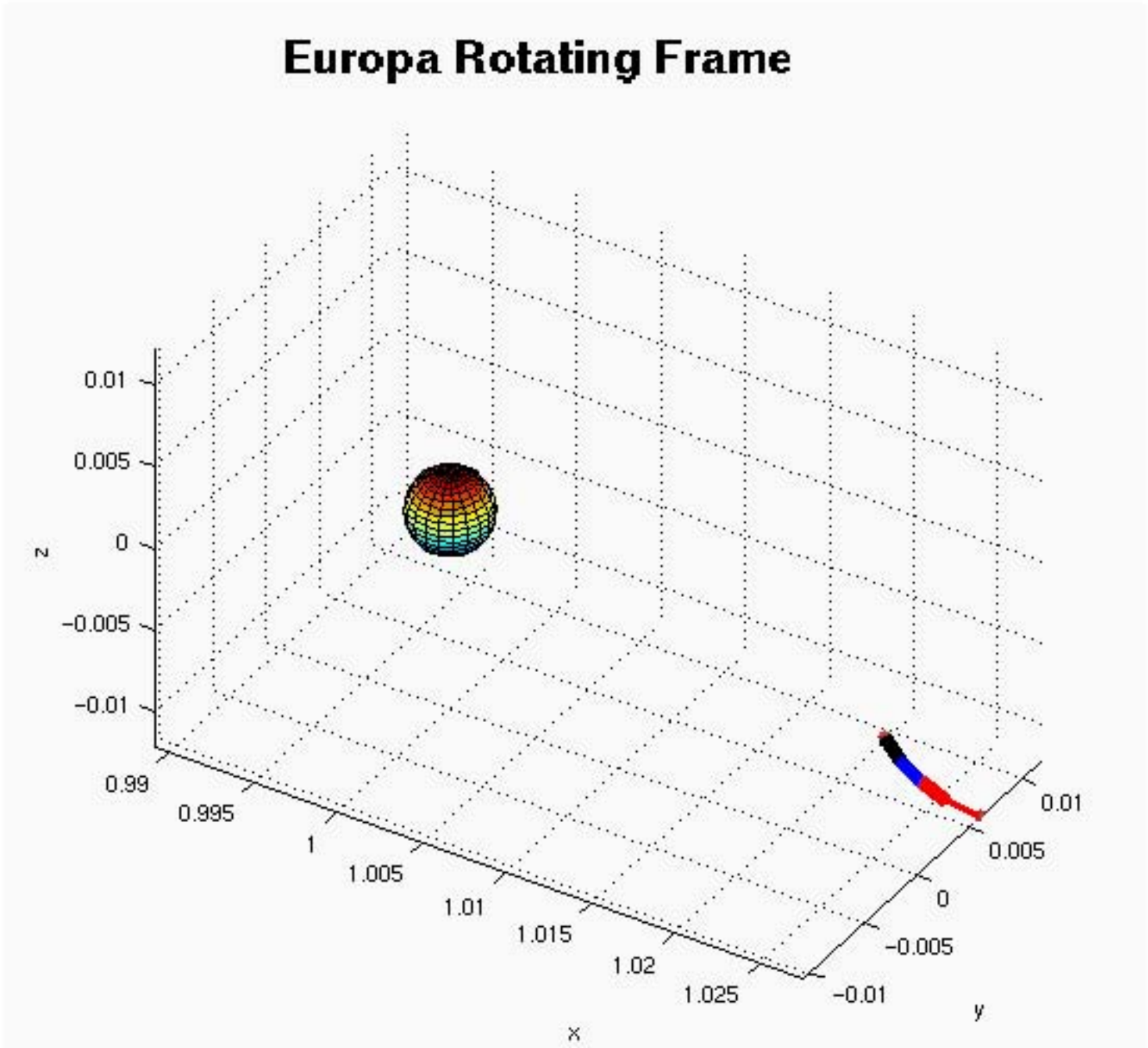


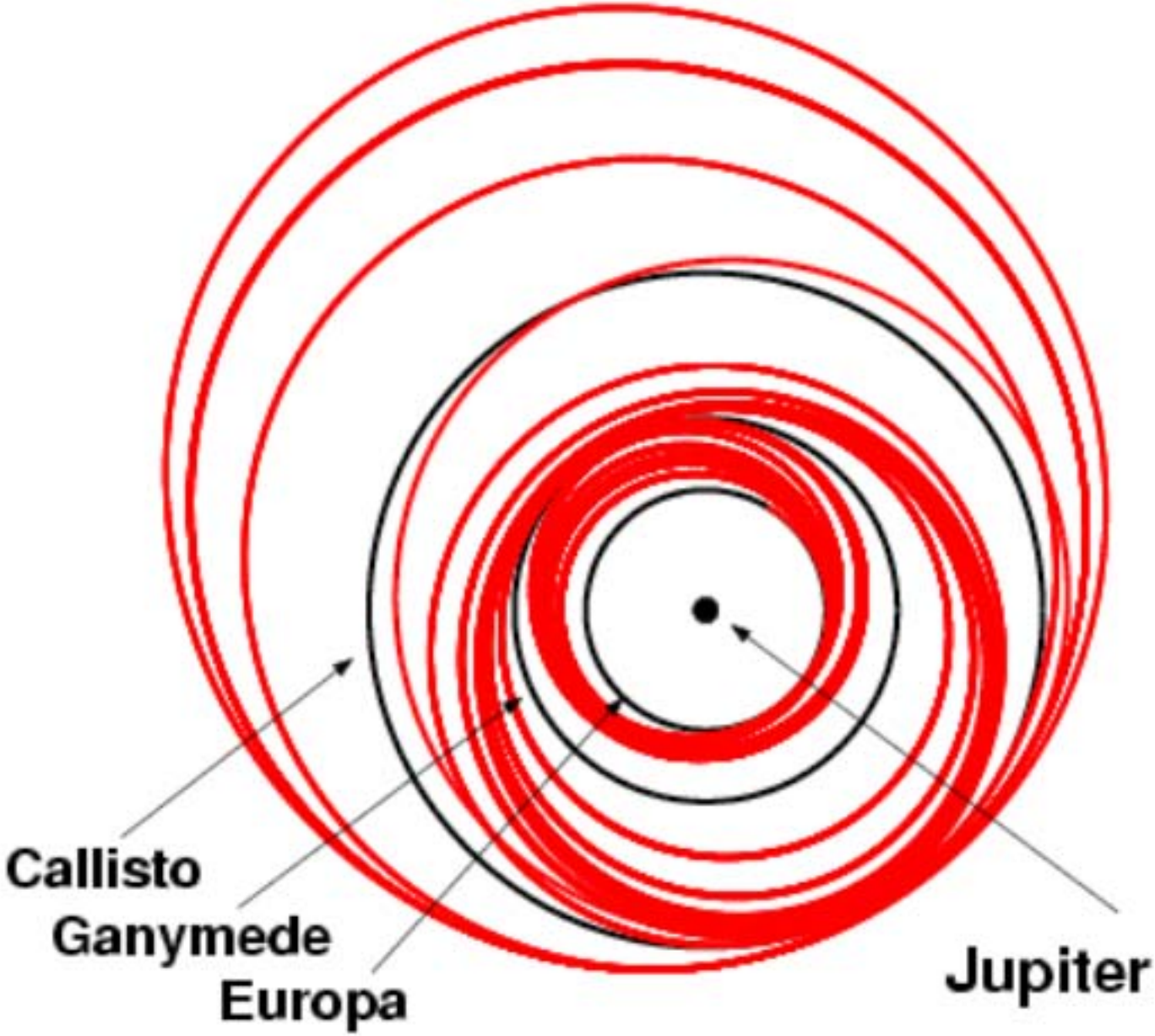


1: Begin Tour
2: Europa Encounter
3: Jump Between Tubes
4: Io Encounter
5: Collide with Jupiter

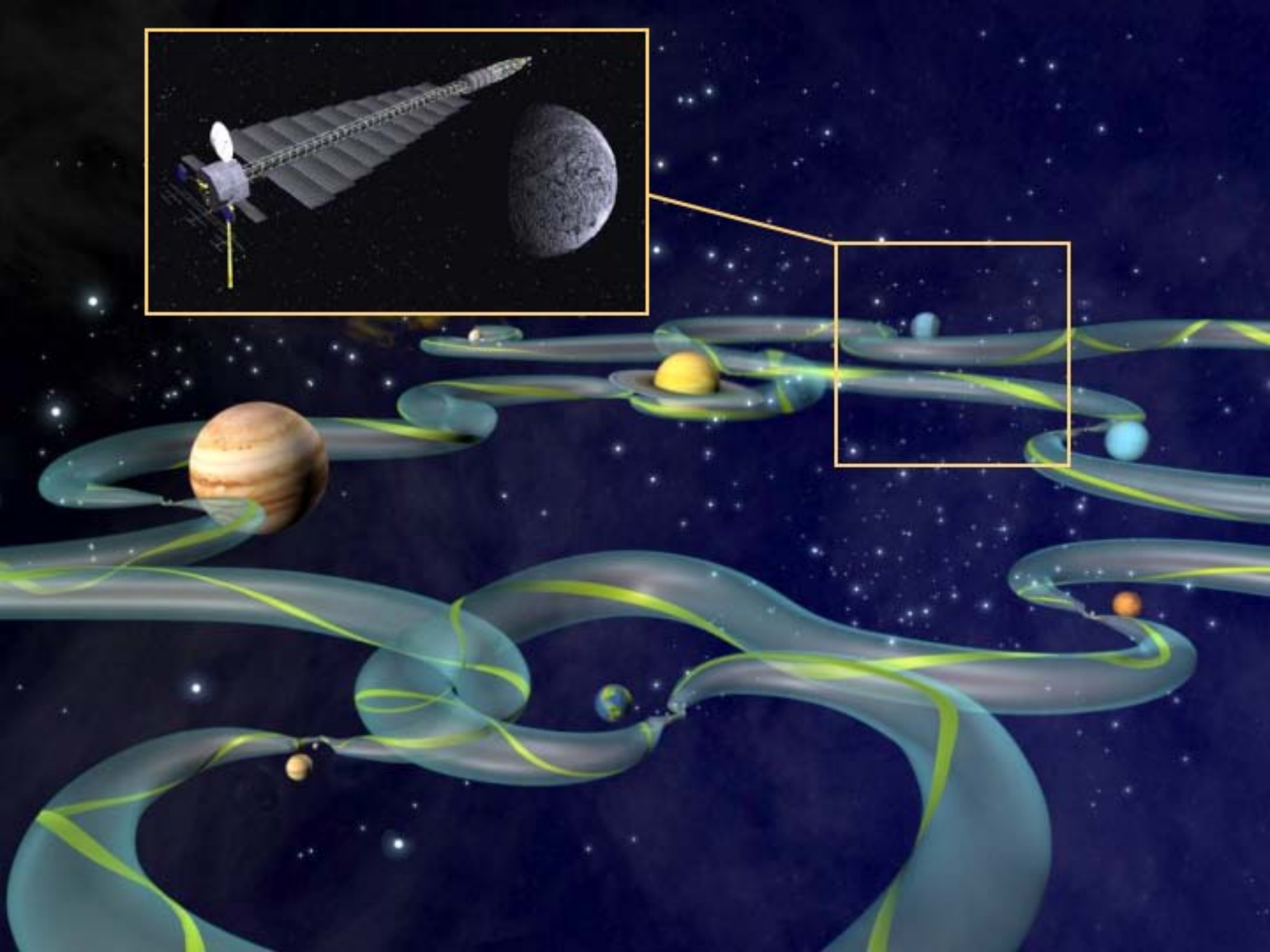

Europa's
Orbit
Capture
at Europa
Jupiter
Ganymede's
Orbit
Spacecraft
Trajectory
0.01
0.005
0
−0.005
−0.01
z
0.99
0.995
1
1.005
1.01
x
0.01
0.005
0
−0.005
−0.01
y


Inertial Frame
Ganymede's Orbit
Jupiter
Europa's Orbit
0.1
0
−0.1
1.5
1
0.5
0
−0.5
−1
−1.5
−1.5
−1
−0.5
0
0.5
1
1.5


Europa Rotating Frame
0.01
0.005
0
−0.005
−0.01
z
0.99
0.995
1
1.005
1.01
1.015
1.02
1.025
x
0.01
0.005
0
−0.005
−0.01
y


Callisto
Ganymede
Europa
Jupiter

Jupiter Icy Moons Orbiter (JIMO)



Much more mapping to be done!

The End