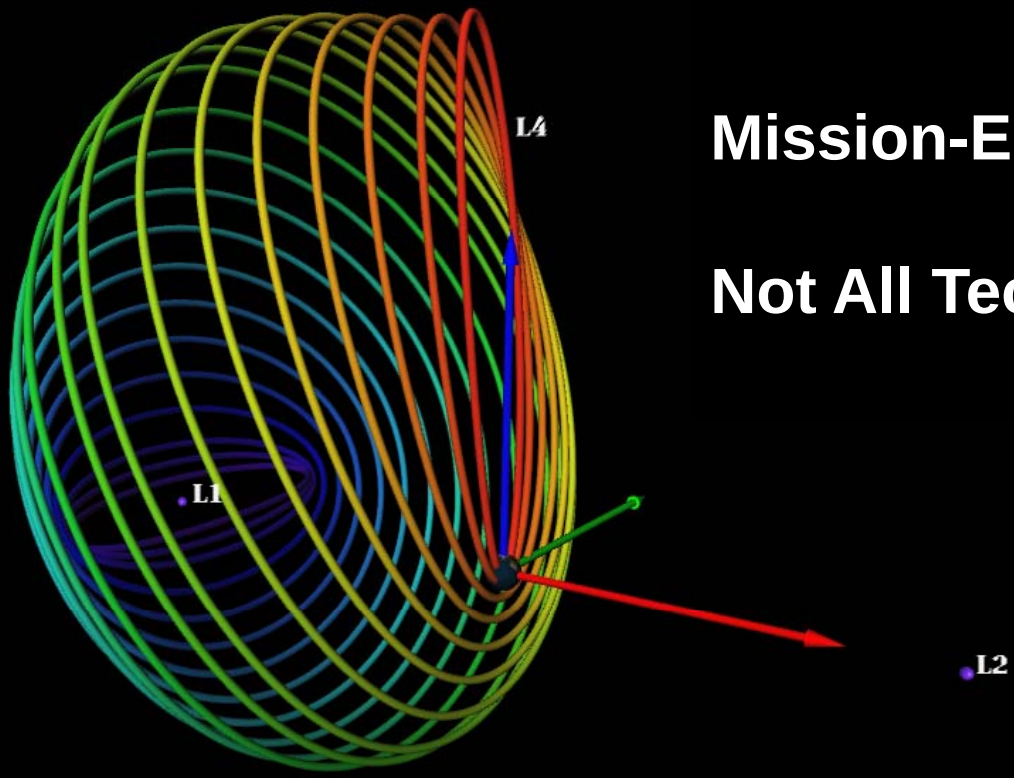
What is the InterPlanetary Superhighway?

Kathleen Howell
Purdue University

Trajectory → Key Space Technology



Mission-Enabling Technology

Not All Technology is hardware!

The InterPlanetary Superhighway (IPS)

- **Low Energy Orbits for Space Missions**
- **InterPlanetary Superhighway—"a vast network of winding tunnels in space" that connects the Sun, the planets, their moons, AND many other destinations**
- **Systematic mapping properly known as InterPlanetary Transport Network**

Simó, Gómez, Masdemont / Lo, Howell, Barden / Howell, Folta / Lo, Ross / Koon, Lo, Marsden, Ross / Marchand, Howell, Lo / Scheeres, Villac/ …….

Poincaré (1854-1912)

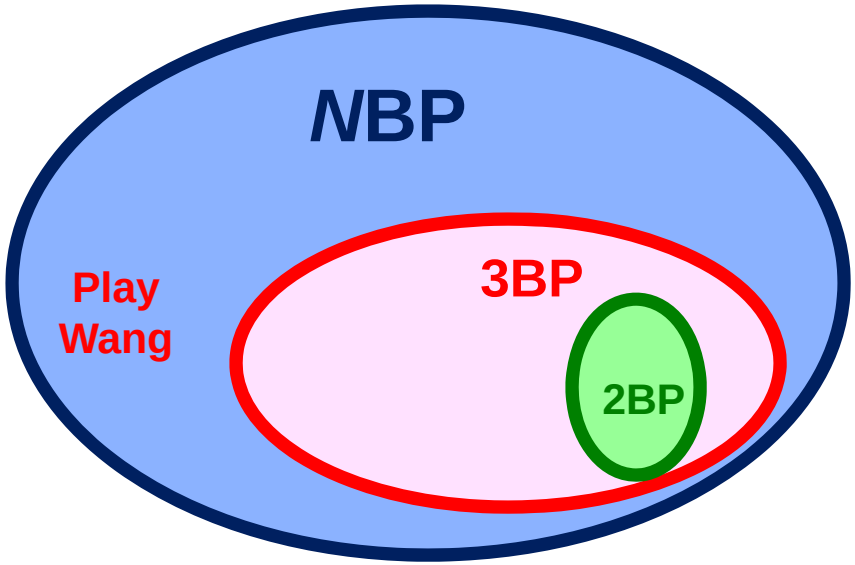
Originates with Poincaré (1892)

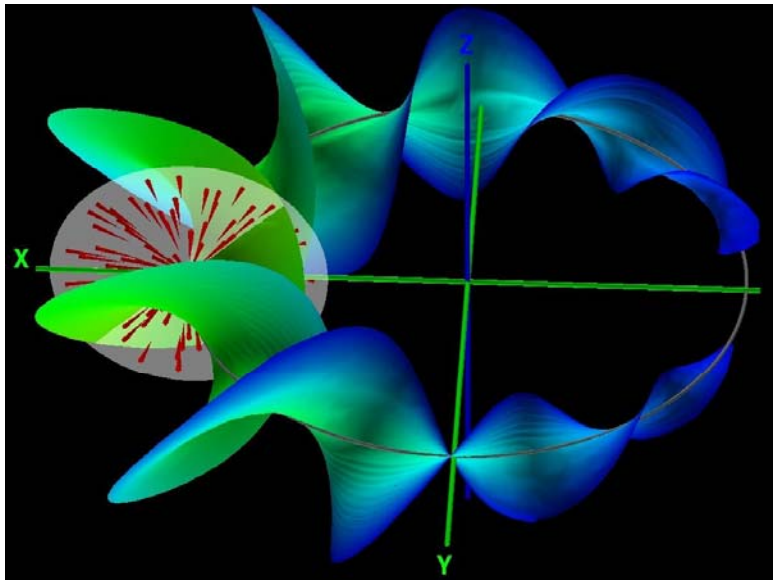
Applications to wide range of fields

Different View of Problems in *N*-Bodies

- **Much more than Kepler and Newton imagined**
- **Computationally challenging**

"Mathematics is the art of giving the same name to different things"
Jules Henri Poincaré

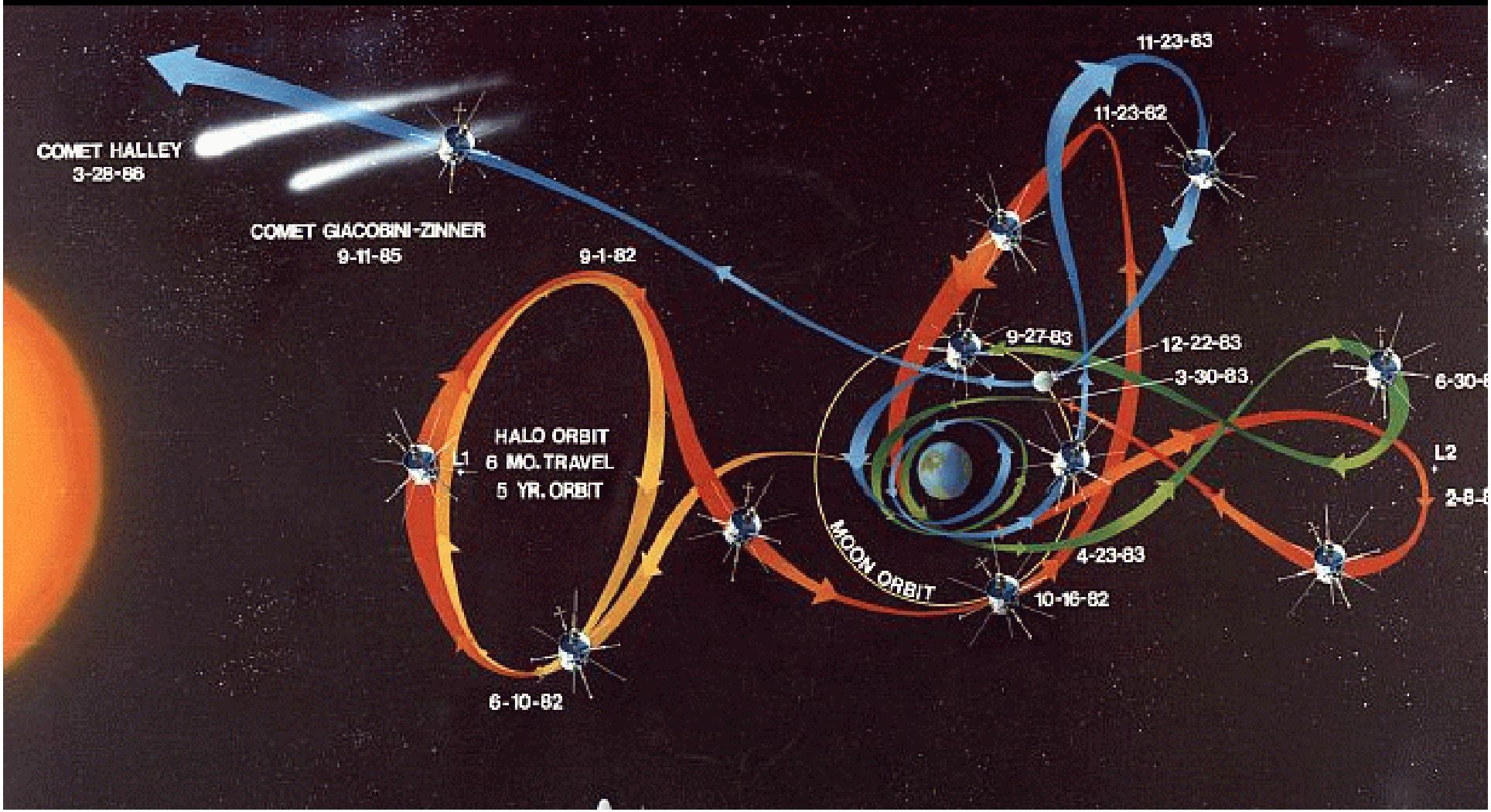




New Era in Celestial Mechanics

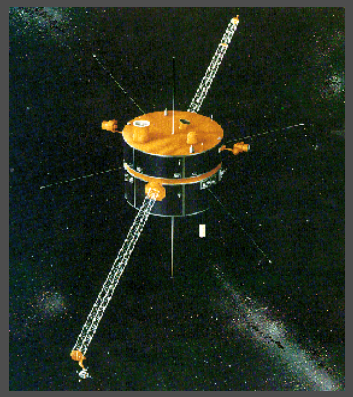
Pioneering Work: Numerical Exploration by Hand

(Breakwell, Farquhar and Dunham)



Current Libration Point Missions

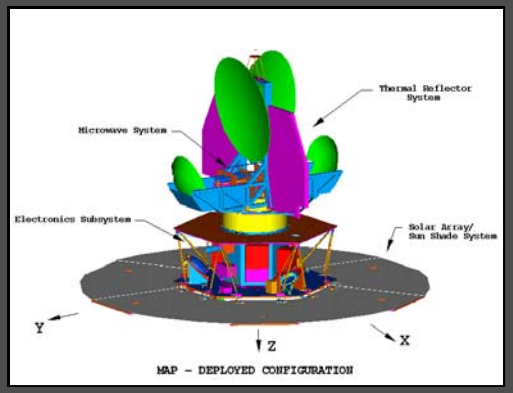
Goddard Space Flight Center



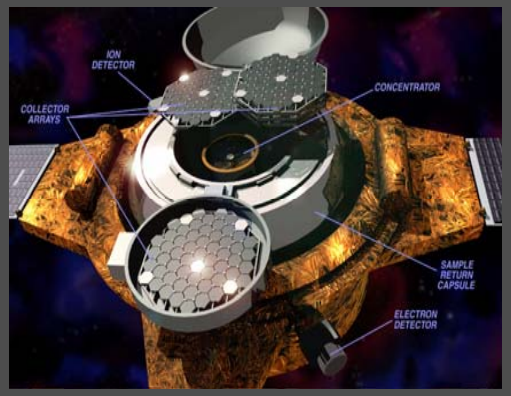
WIND

SOHO

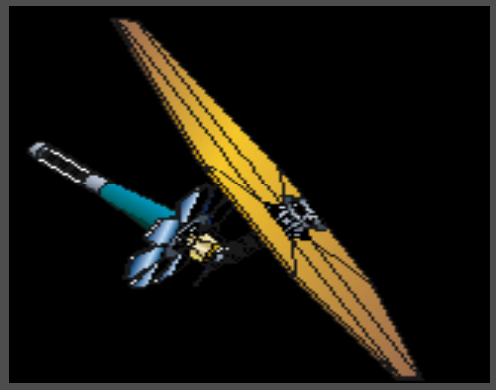
ACE



MAP



GENESIS

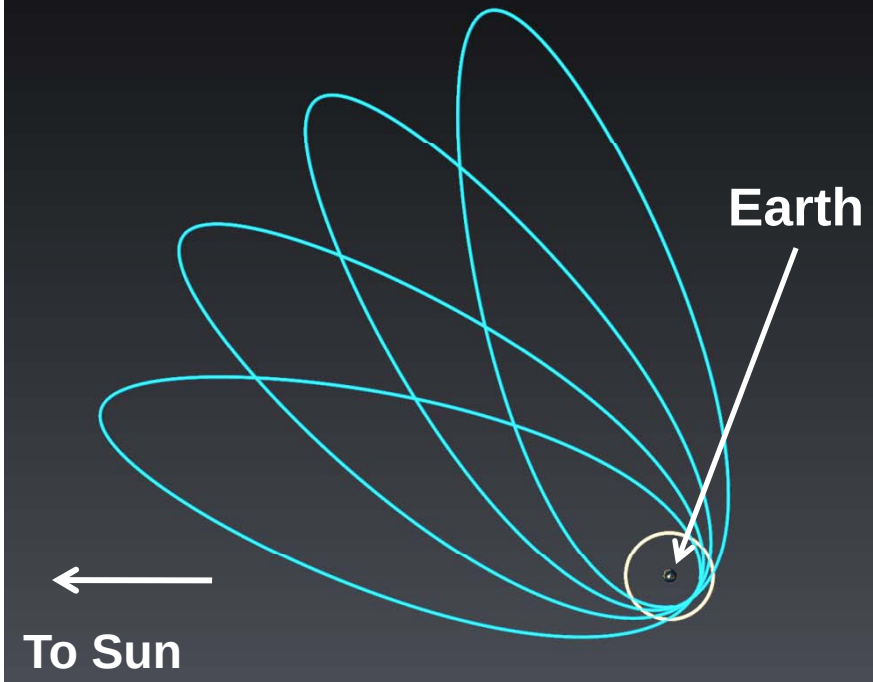


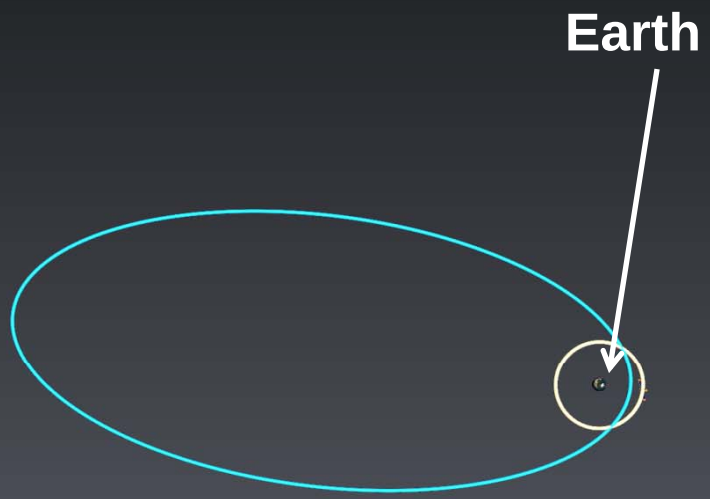
NGST

Courtesy of D. Folta, GSFC

Multi-Body Problem

- Change our perspective



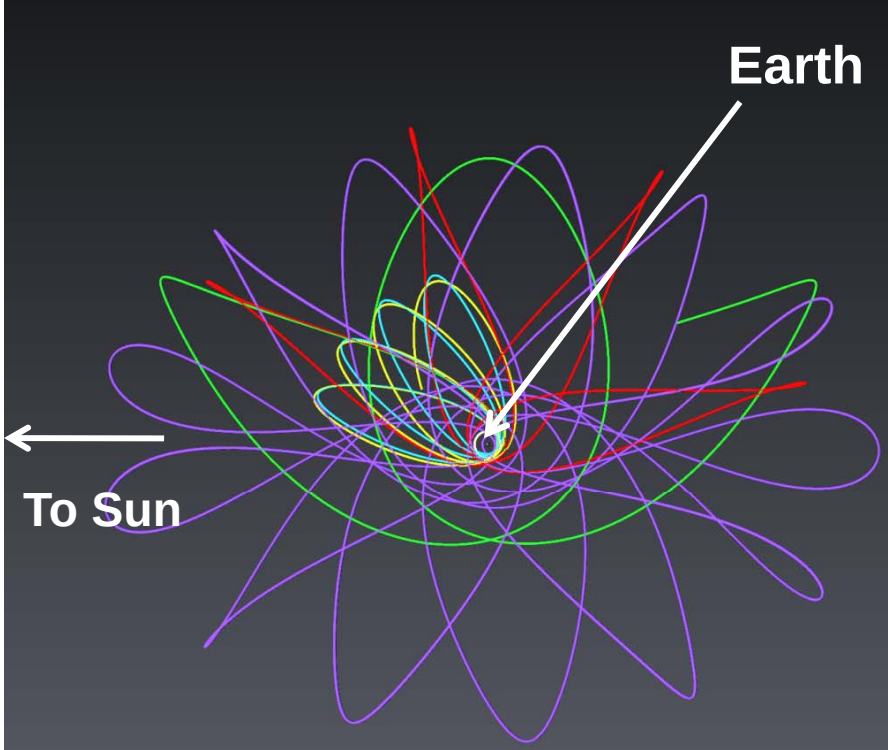


Rotating View
(Rotates with two bodies)

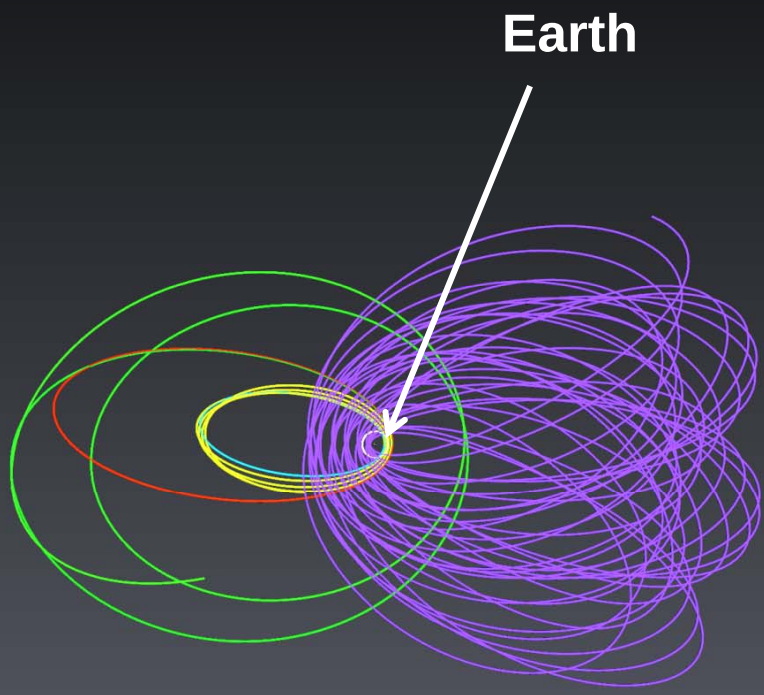
Inertial View

Multi-Body Problem

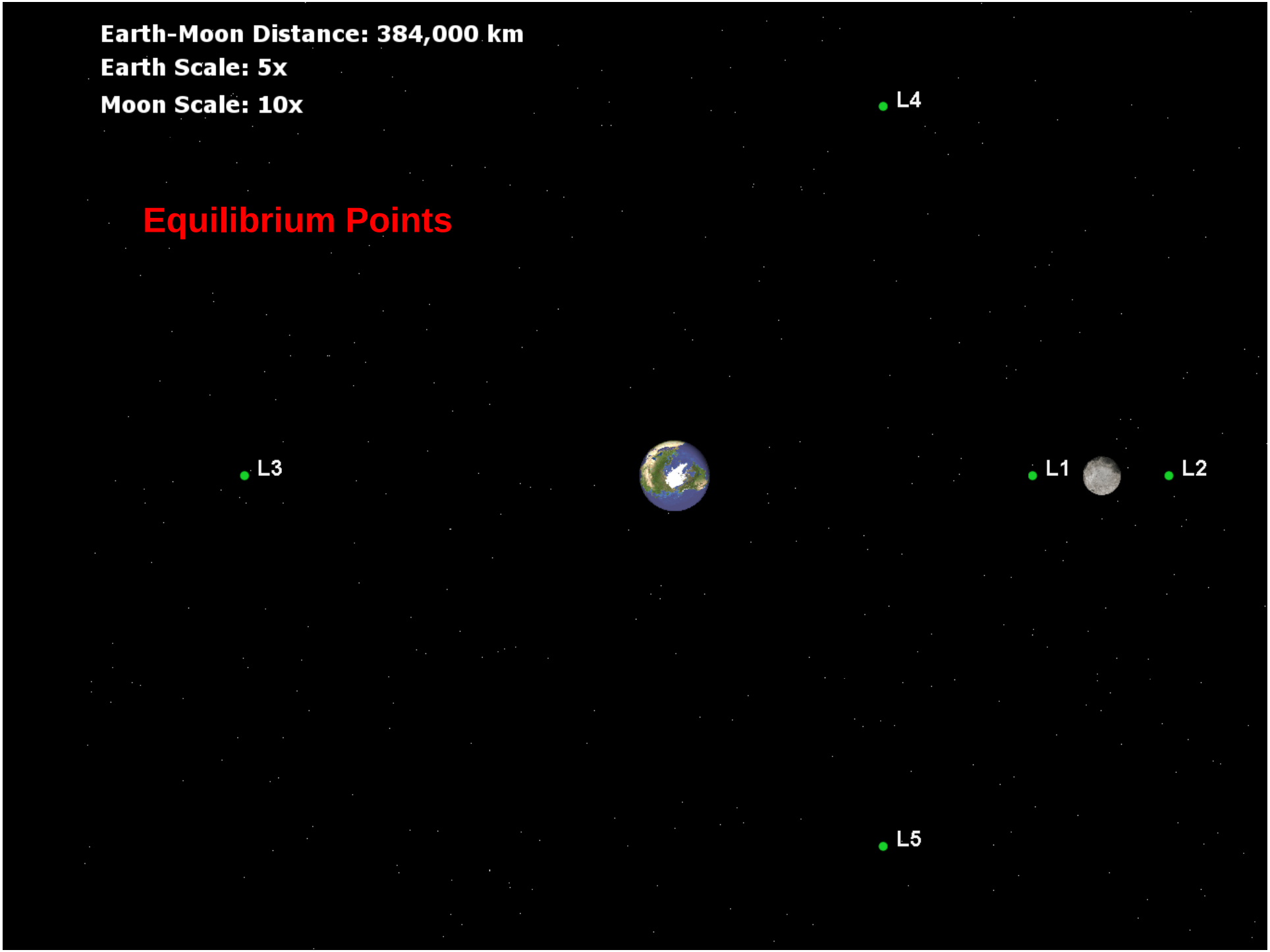
- Change our perspective
- Effects of added gravity fields

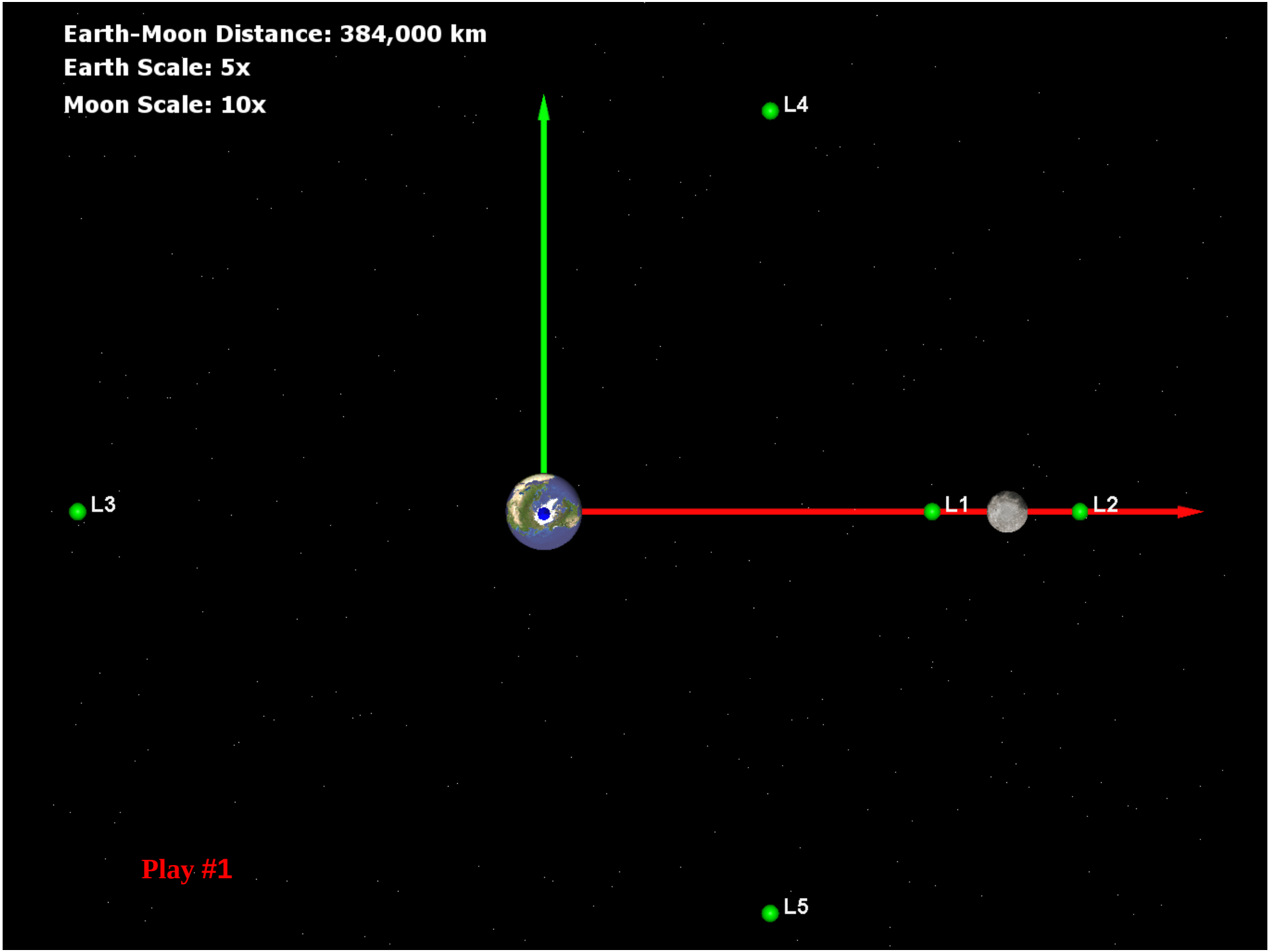


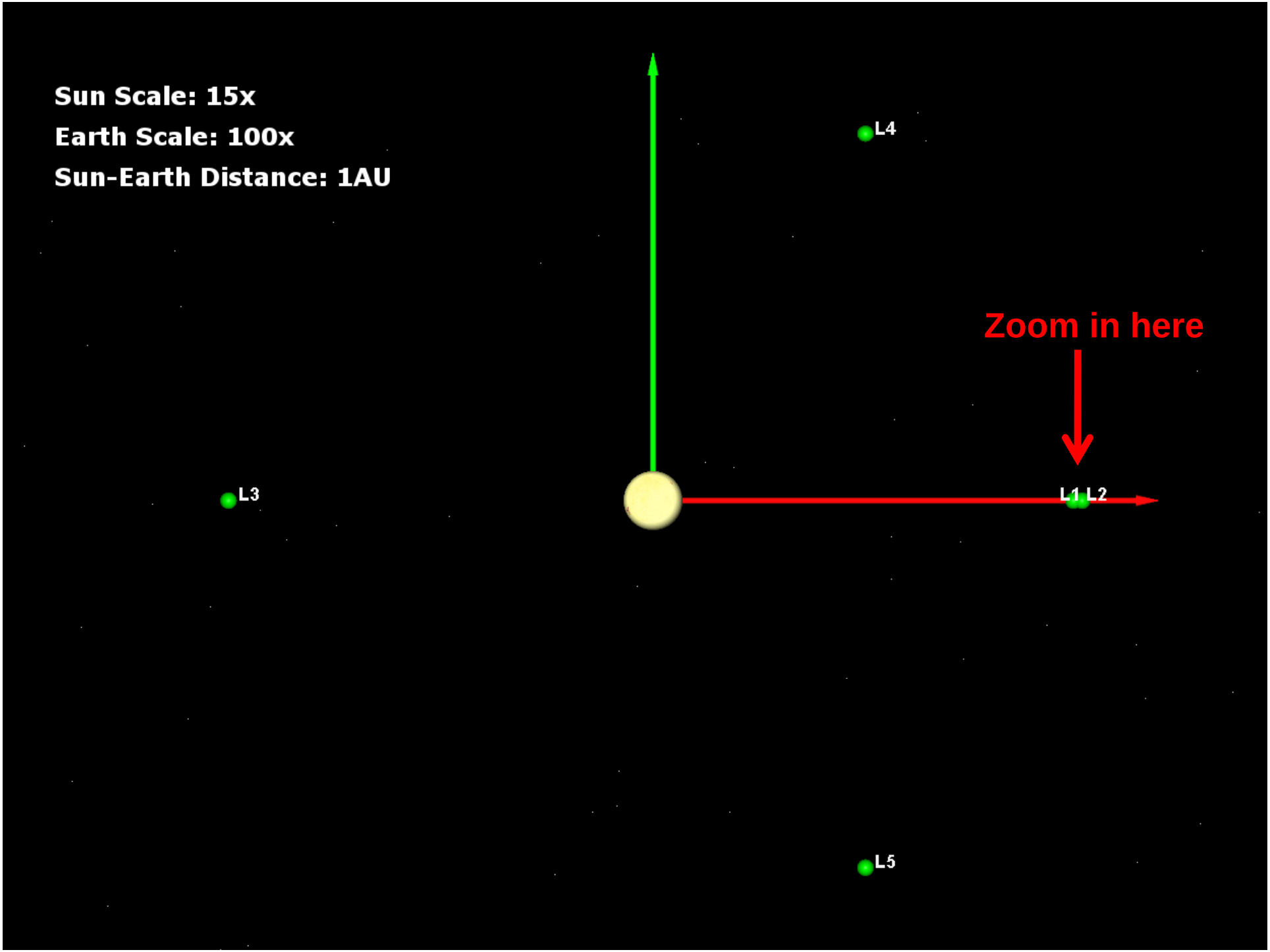
Rotating View

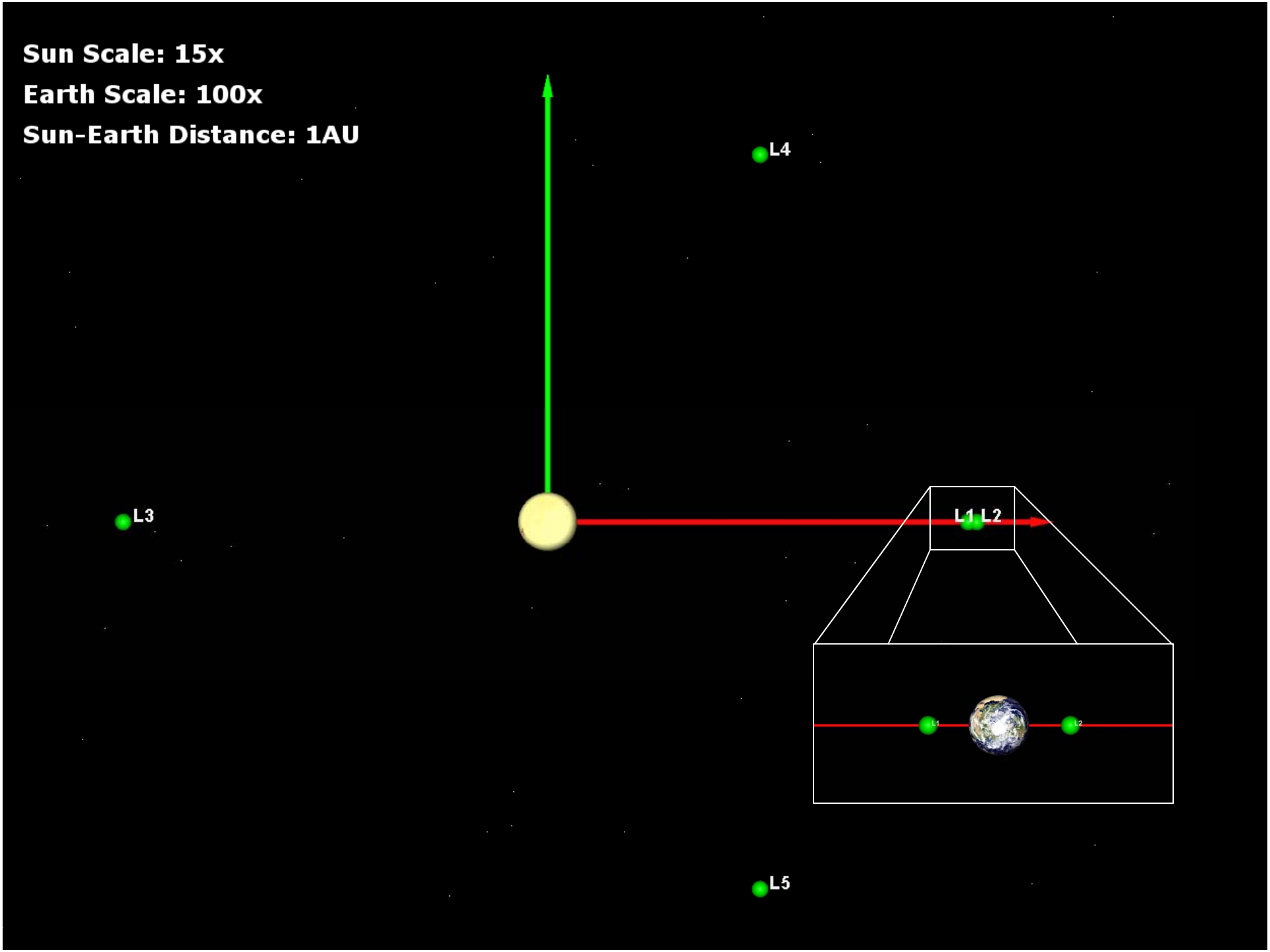


Inertial View

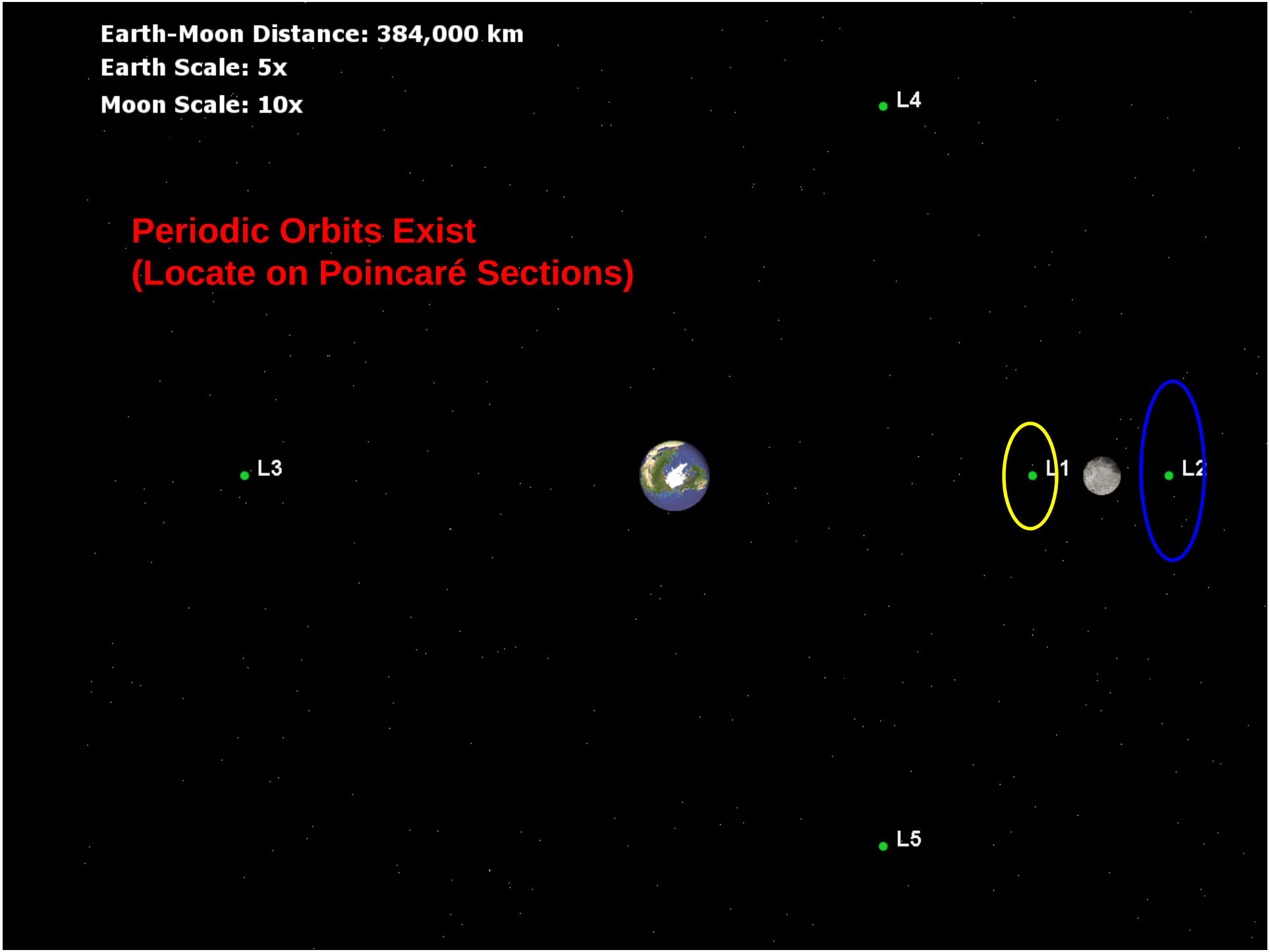

Earth-Moon Distance: 384,000 km
Earth Scale: 5x
Moon Scale: 10x
L4
Equilibrium Points
L3
L1
L2
L5

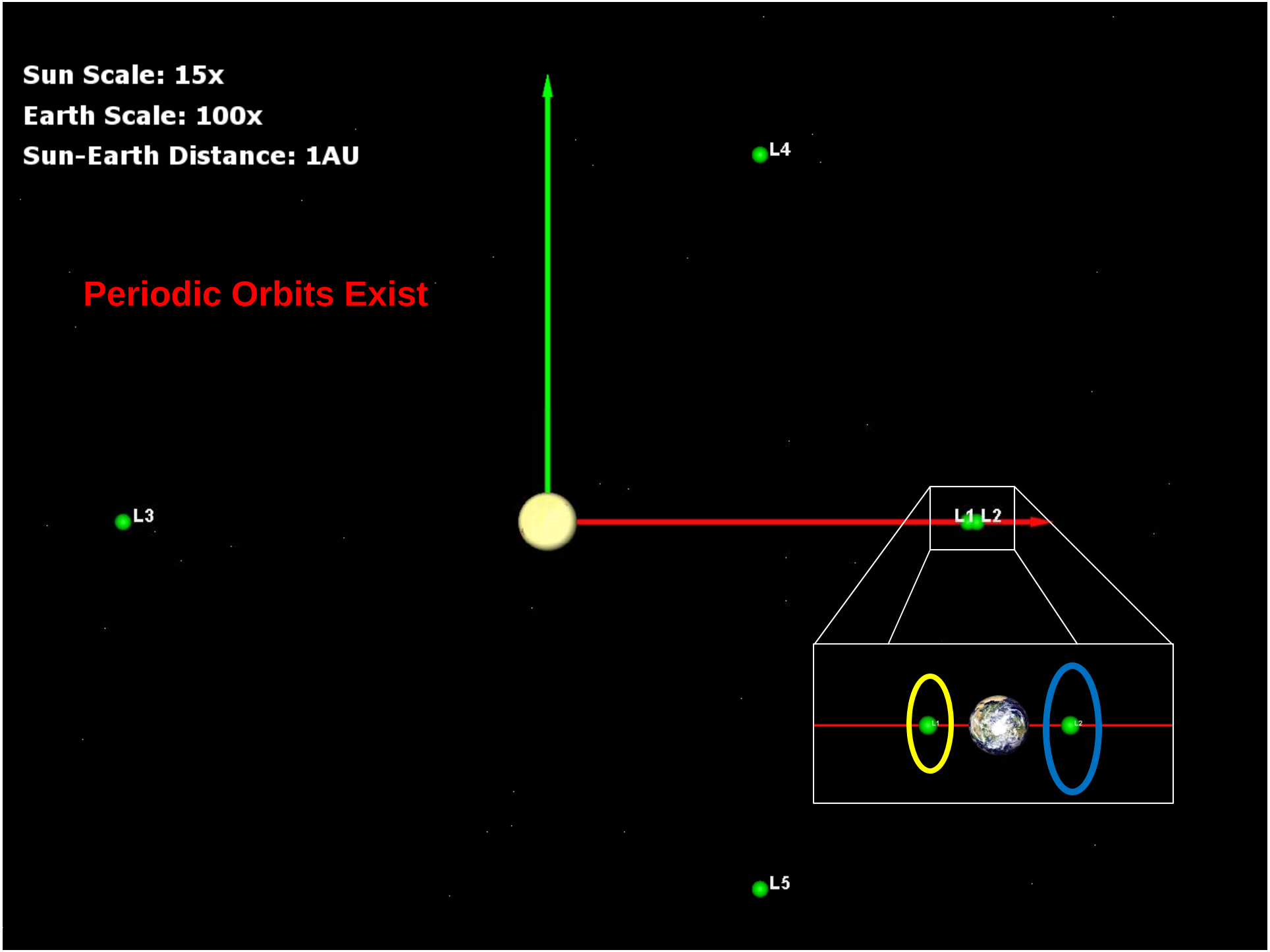

Earth-Moon Distance: 384,000 km
Earth Scale: 5x
Moon Scale: 10x
L4
L3
L1
L2
Play #1
L5

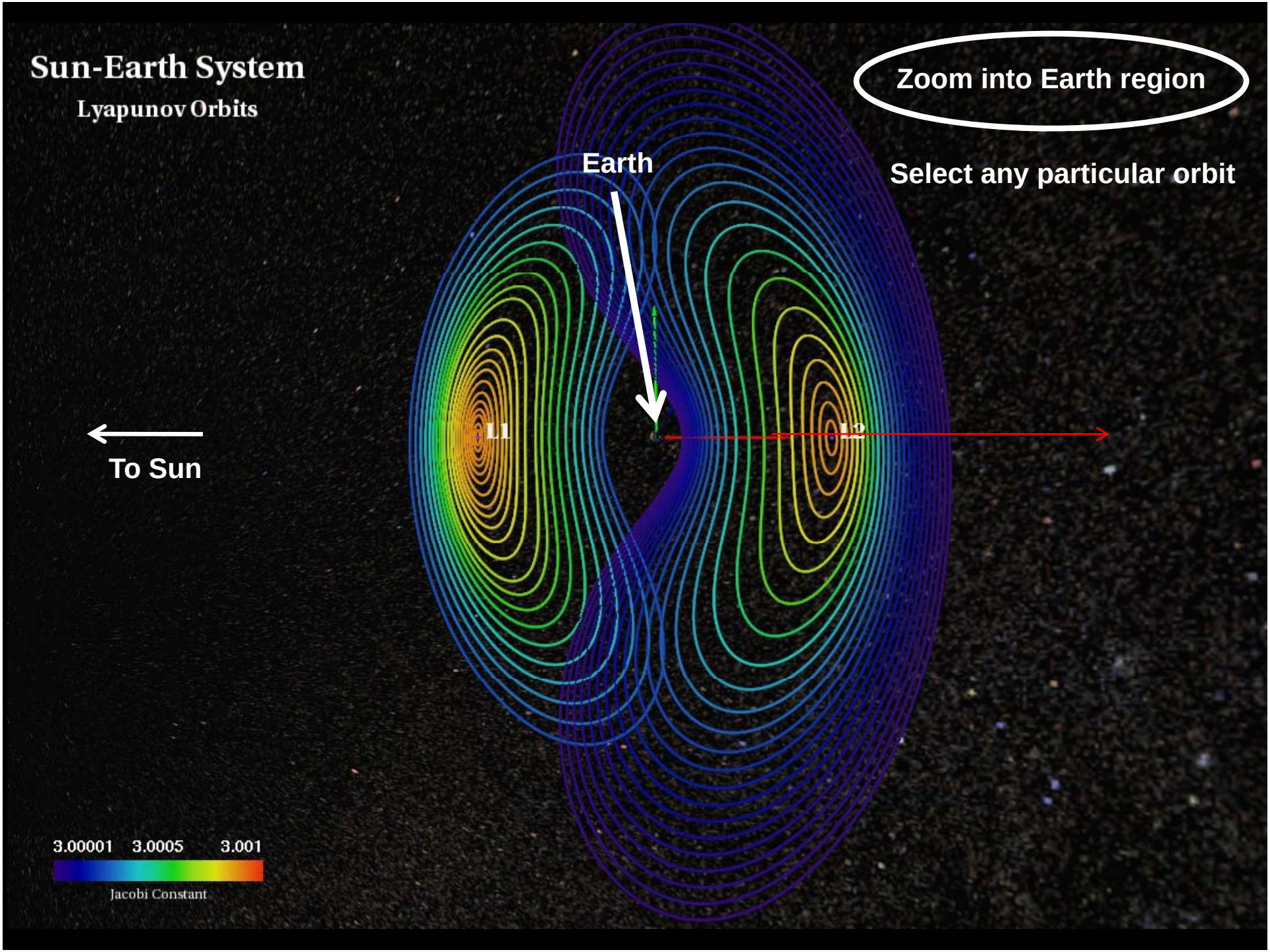

Sun Scale: 15x
Earth Scale: 100x
Sun-Earth Distance: 1AU
L4
Zoom in here
L3
L1 L2
L5


Sun Scale: 15x
Earth Scale: 100x
Sun-Earth Distance: 1AU
L4
L3
L1 L2
L5

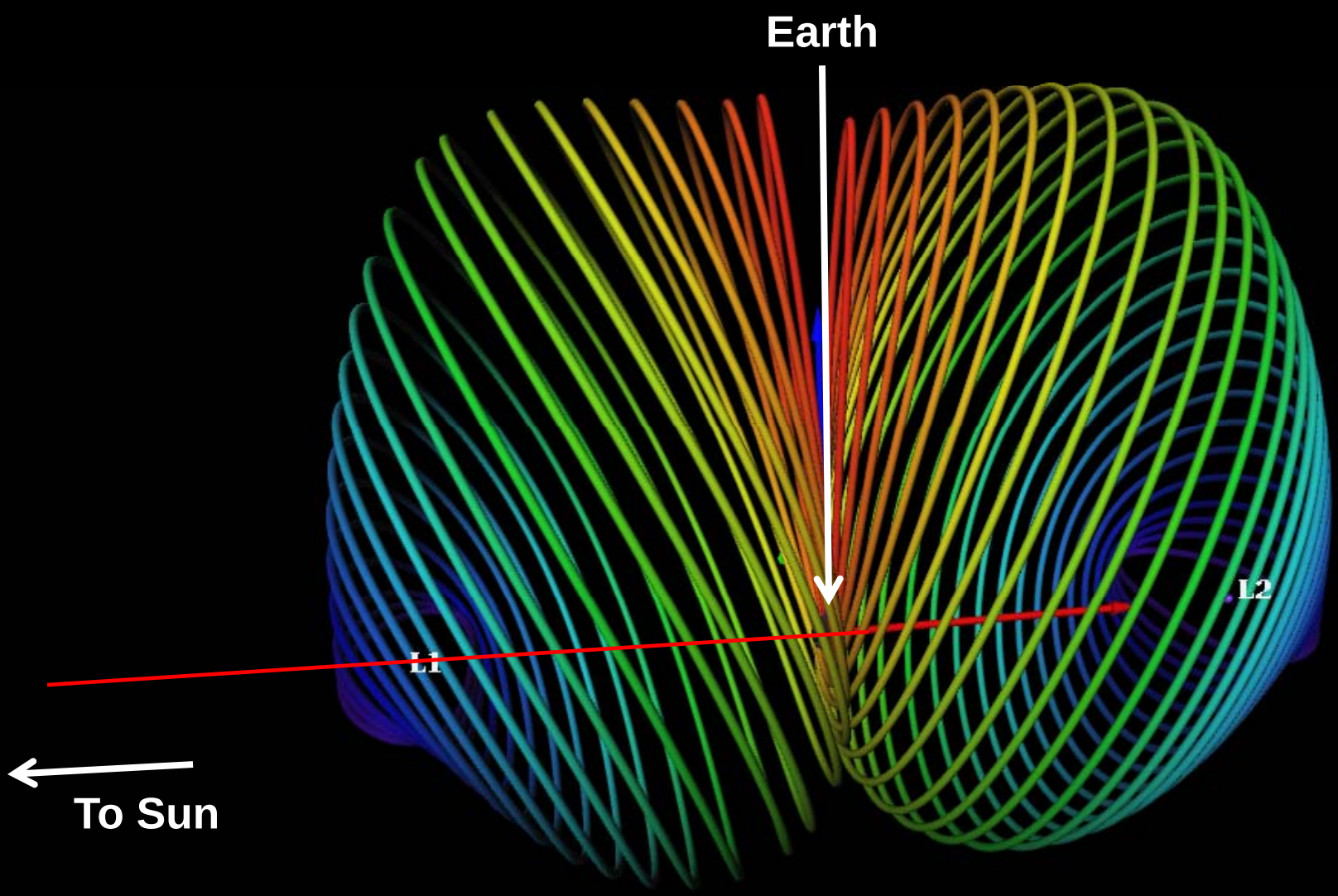
Sputnik Orbit


Earth-Moon Distance: 384,000 km
Earth Scale: 5x
Moon Scale: 10x
L4
Periodic Orbits Exist
(Locate on Poincaré Sections)
L3
L1
L2
L5


Sun Scale: 15x
Earth Scale: 100x
Sun-Earth Distance: 1AU
Periodic Orbits Exist
L4
L3
L1 L2
L5


Sun-Earth System
Lyapunov Orbits
Zoom into Earth region
Earth
Select any particular orbit
L1
L2
To Sun
3.00001
3.0005
3.001
Jacobi Constant

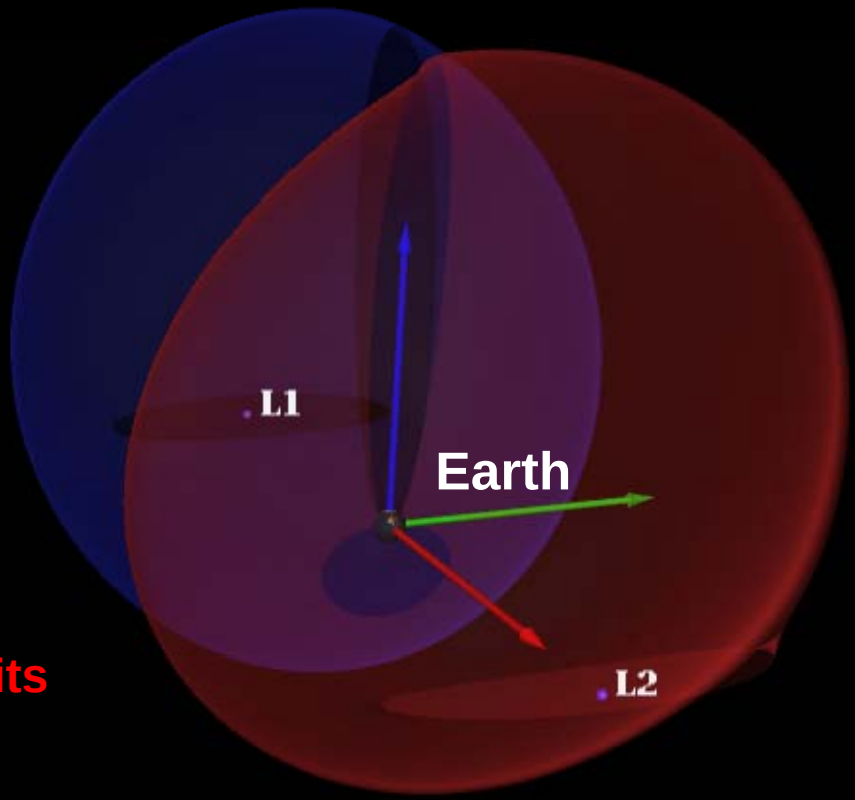
Sun-Earth Halo Orbits



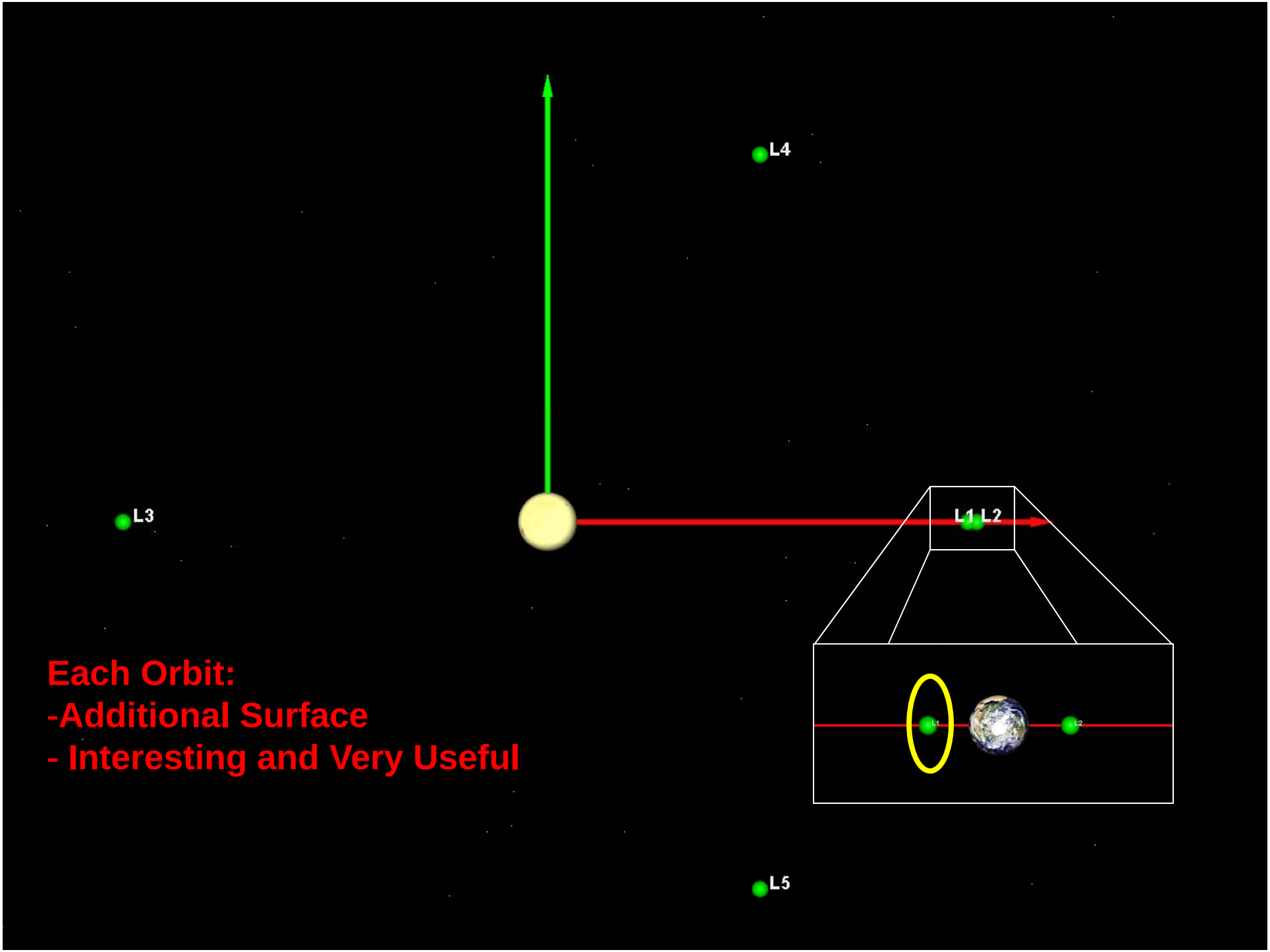
Play #2 → Any 3B System Play #3 → Surface Play #4

Sun-Earth Halo Orbits

Sun



Infinite Number Of Orbits
- Create Surface

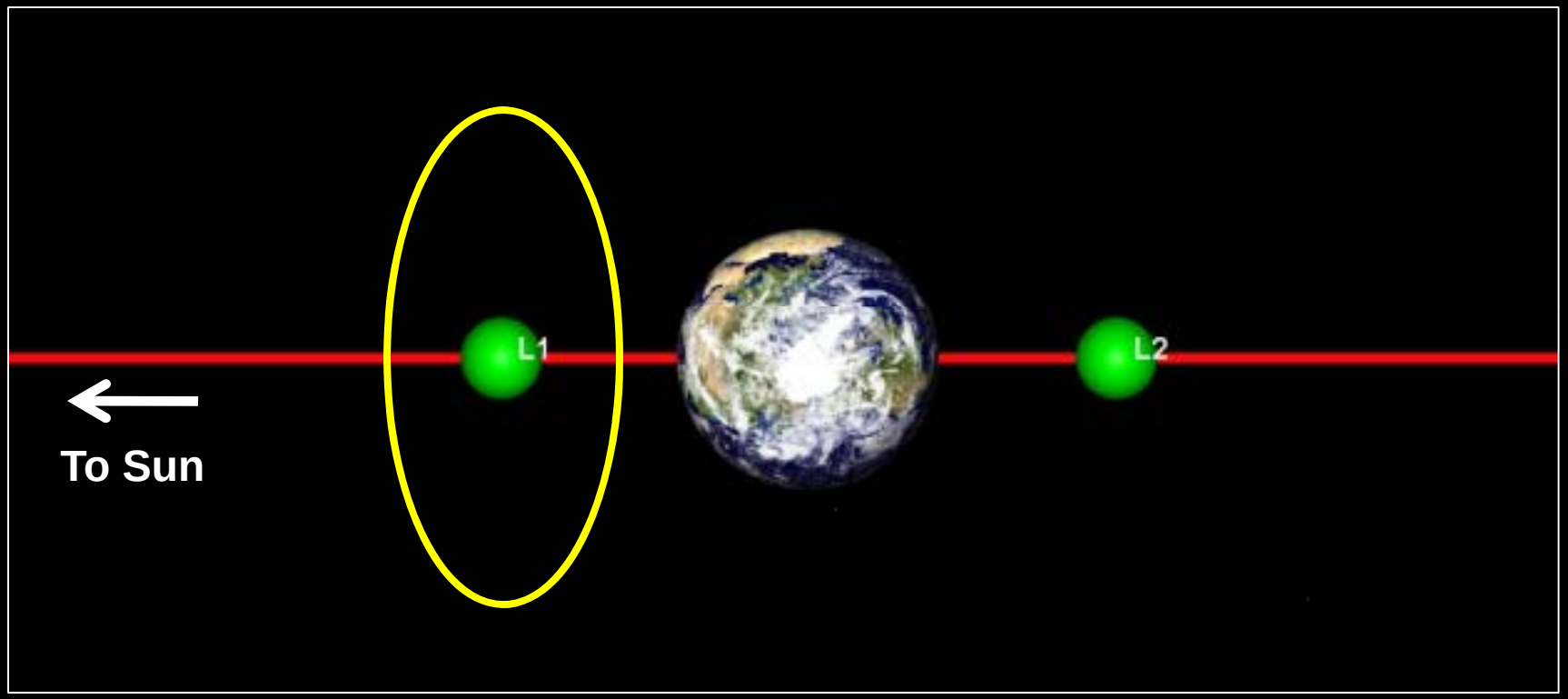


Each Orbit:
-Additional Surface
- Interesting and Very Useful

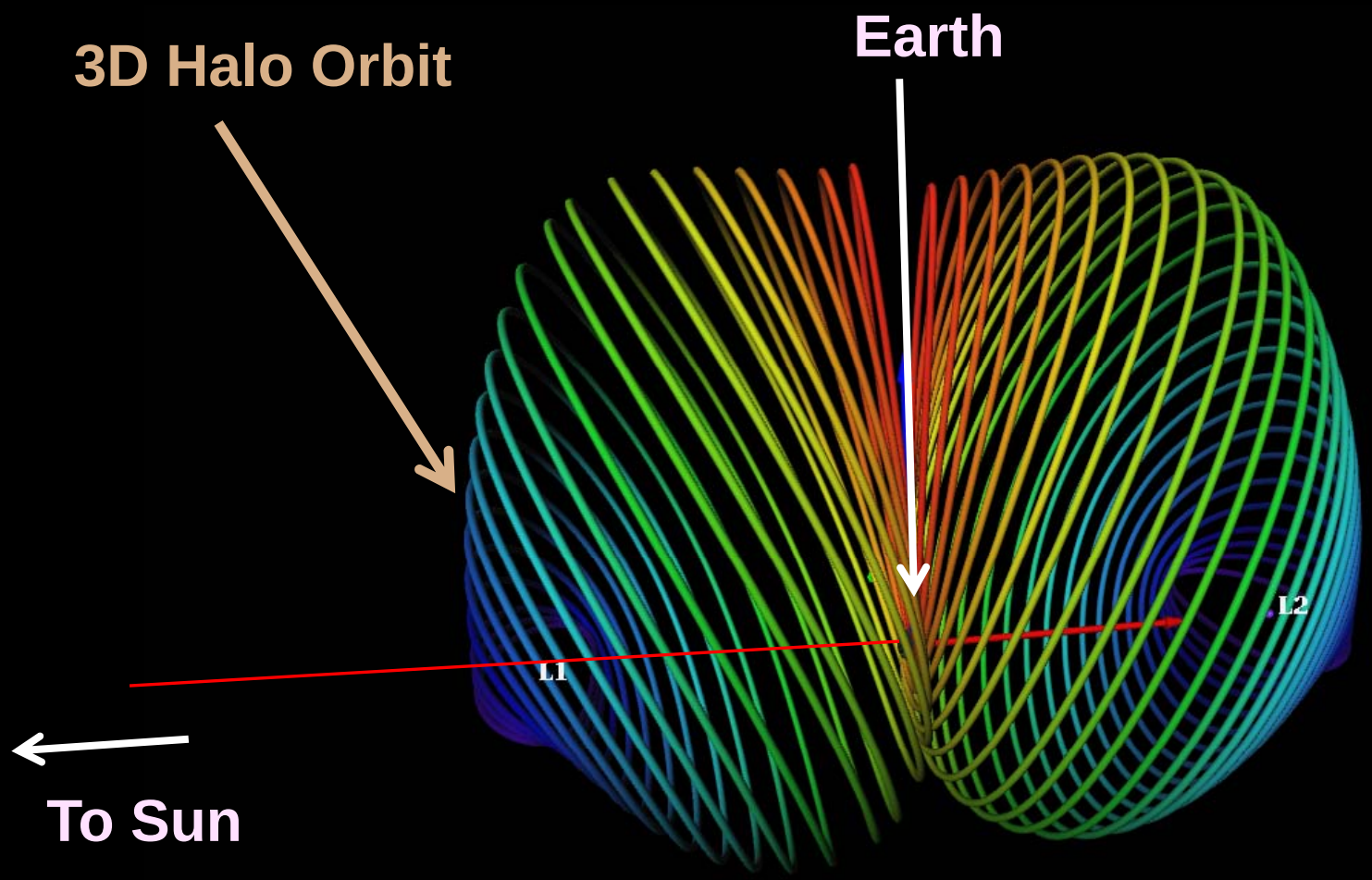
Sun Scale: 15x

Earth Scale: 100x

Sun-Earth Distance: 1AU



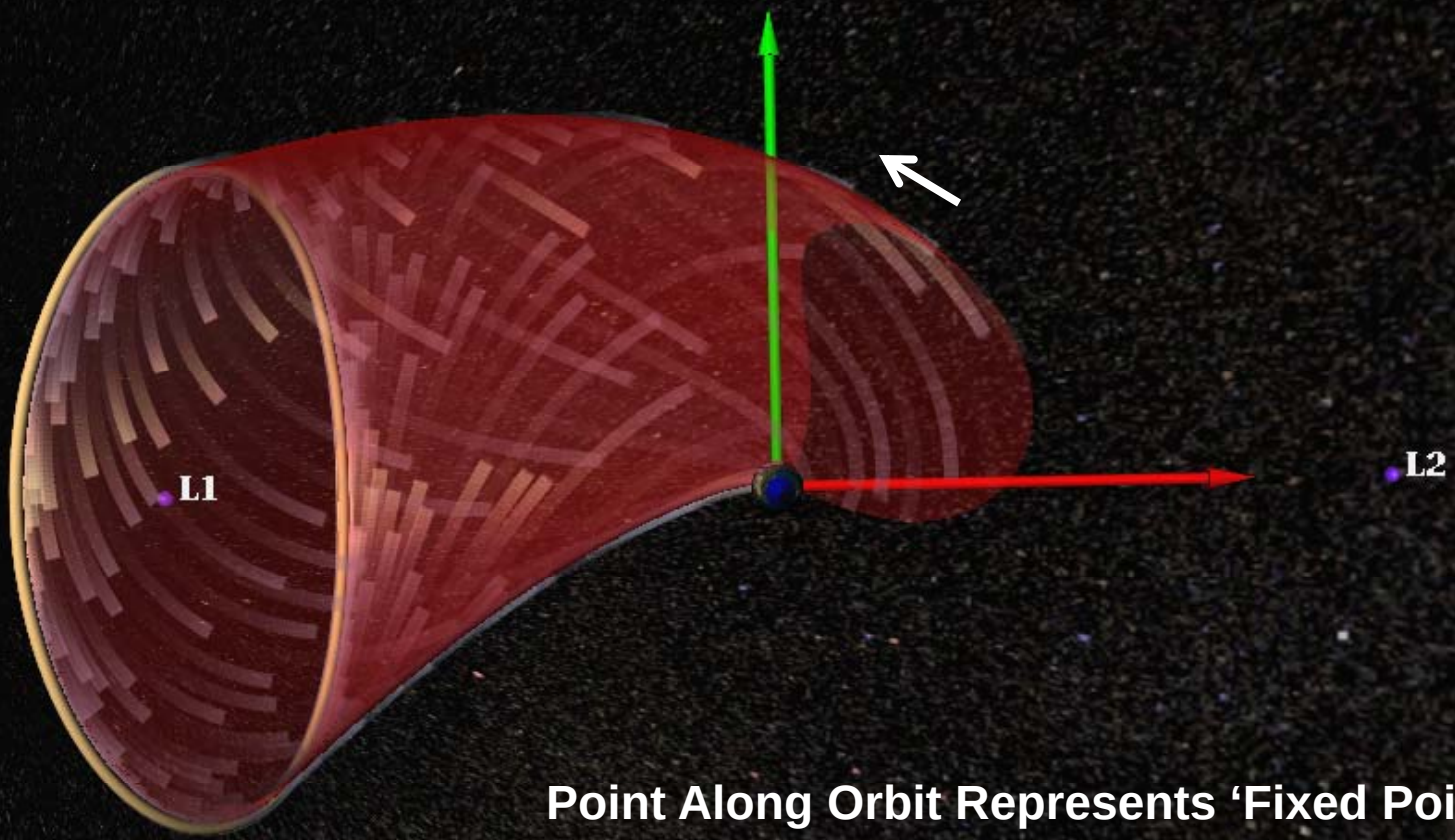
Select one Periodic Orbit



Key is Unstable Nature

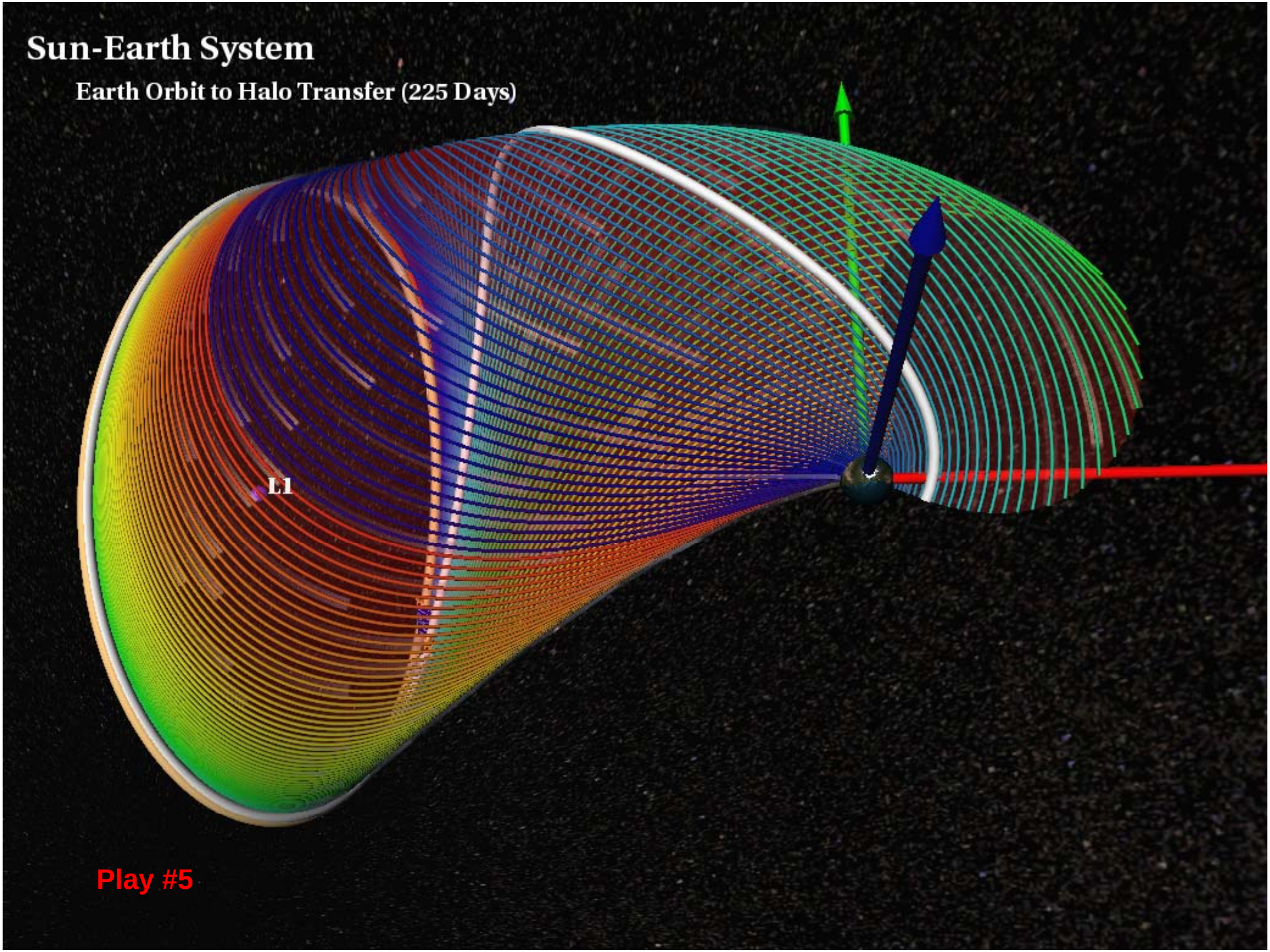
Sun-Earth System

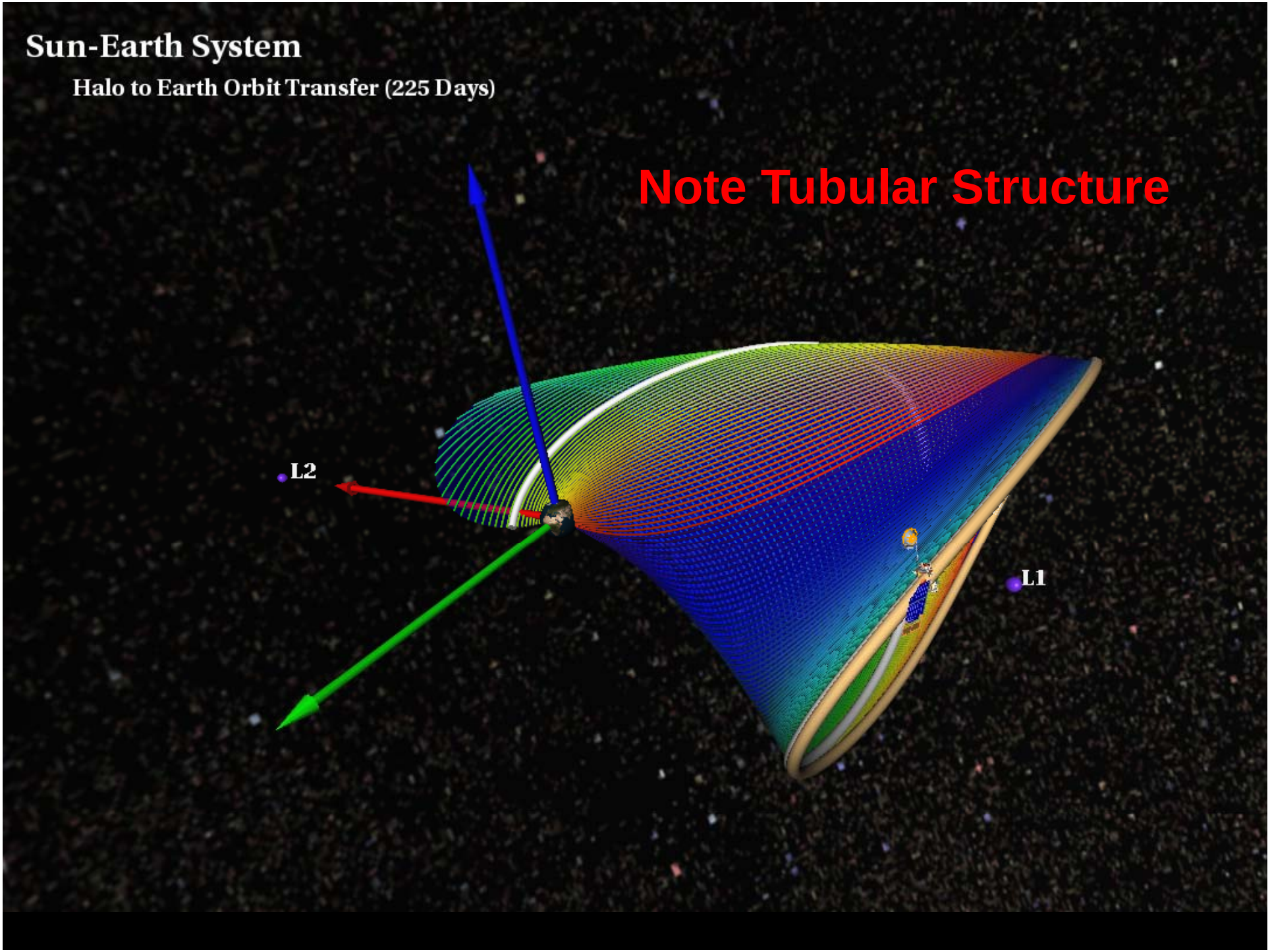
L1 Stable Manifold

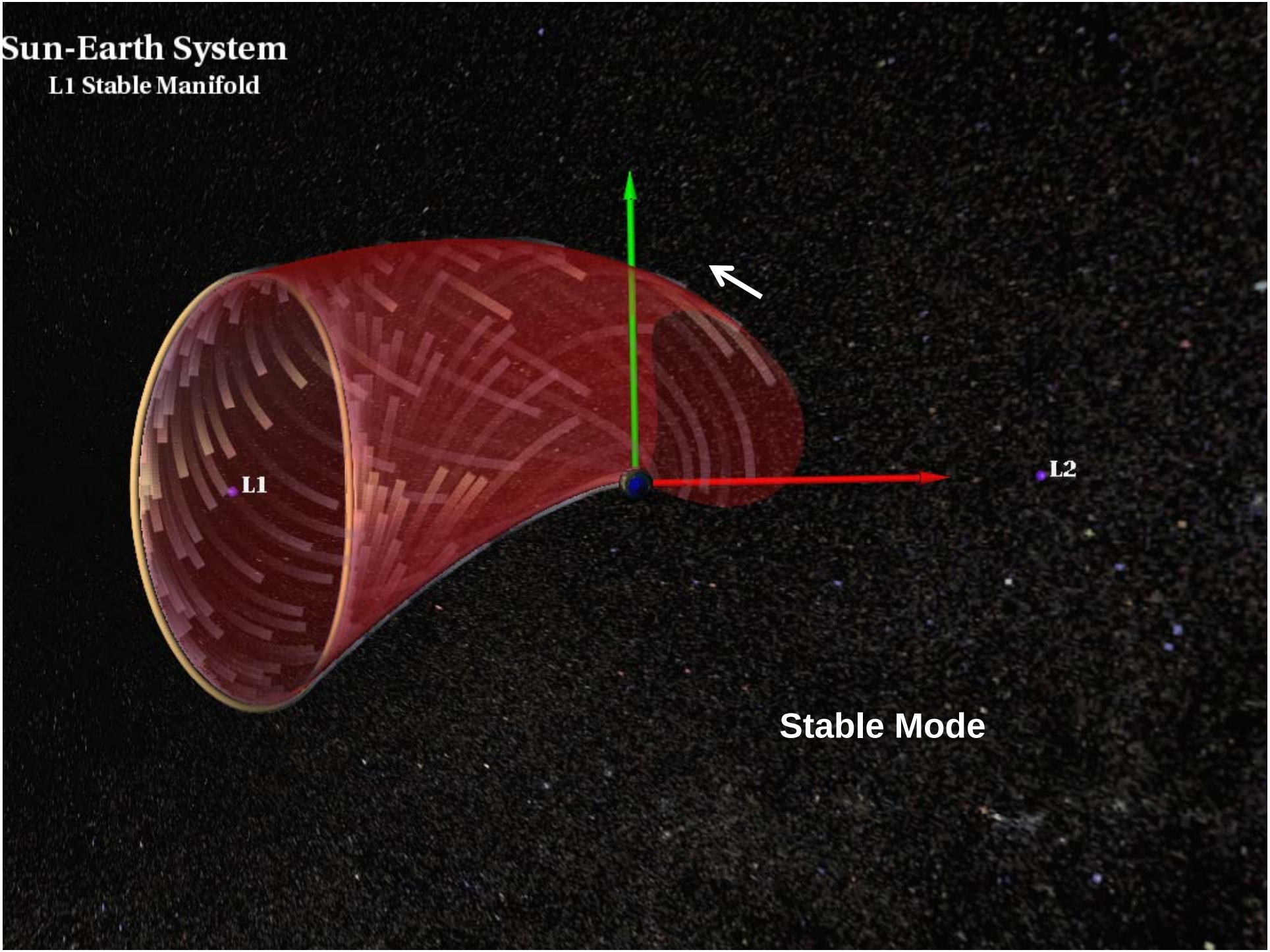


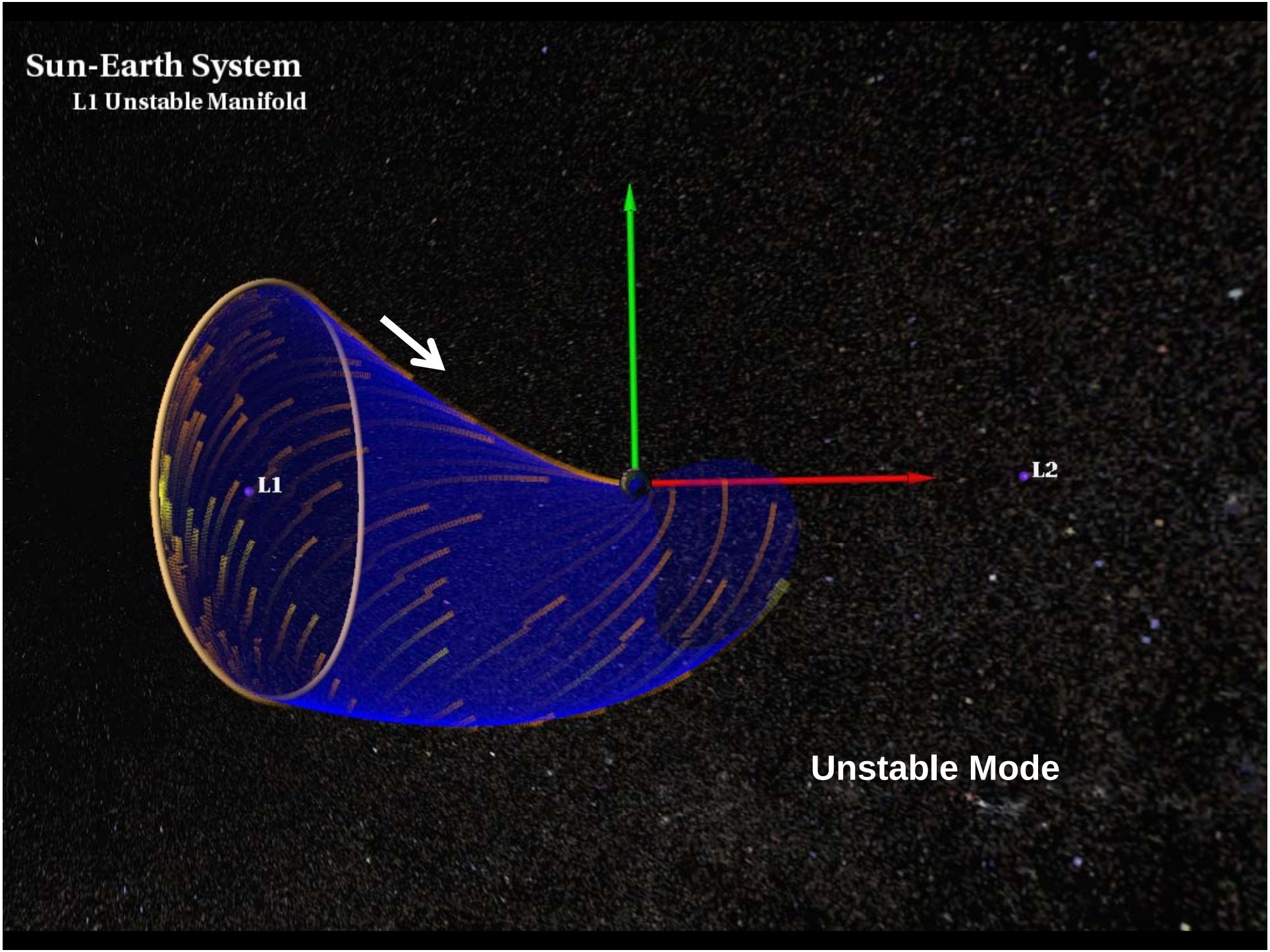
Point Along Orbit Represents 'Fixed Point'

- One Stable Mode
- Compute Trajectory in Negative Time
- Compute for All Points
- Creates Another Surface → Transfer Trajectories
- Asymptotic Arrival

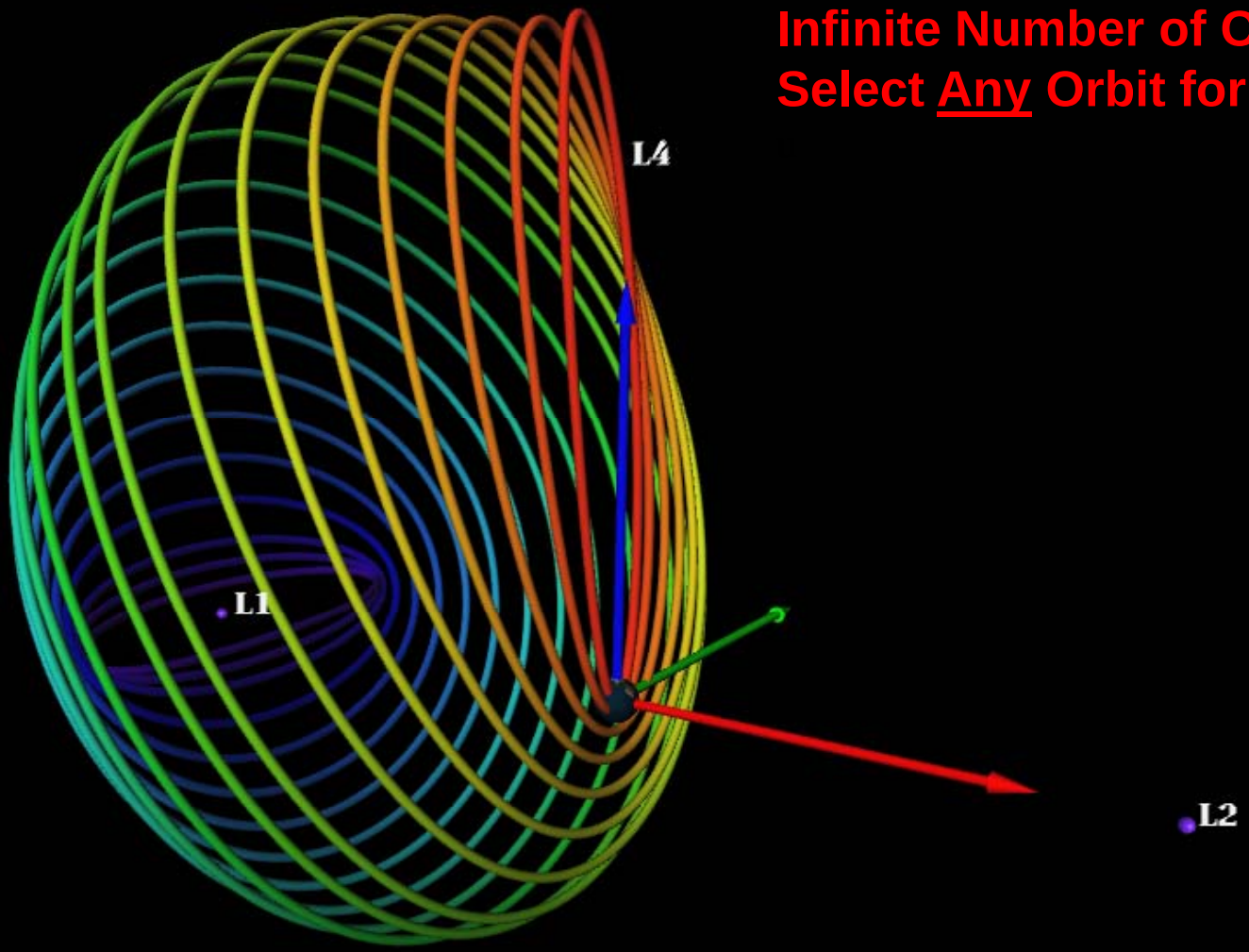

Sun-Earth System
Earth Orbit to Halo Transfer (225 Days)
L1
Play #5


Sun-Earth System
Halo to Earth Orbit Transfer (225 Days)
Note Tubular Structure
L2
L1


Sun-Earth System
L1 Stable Manifold
L1
L2
Stable Mode

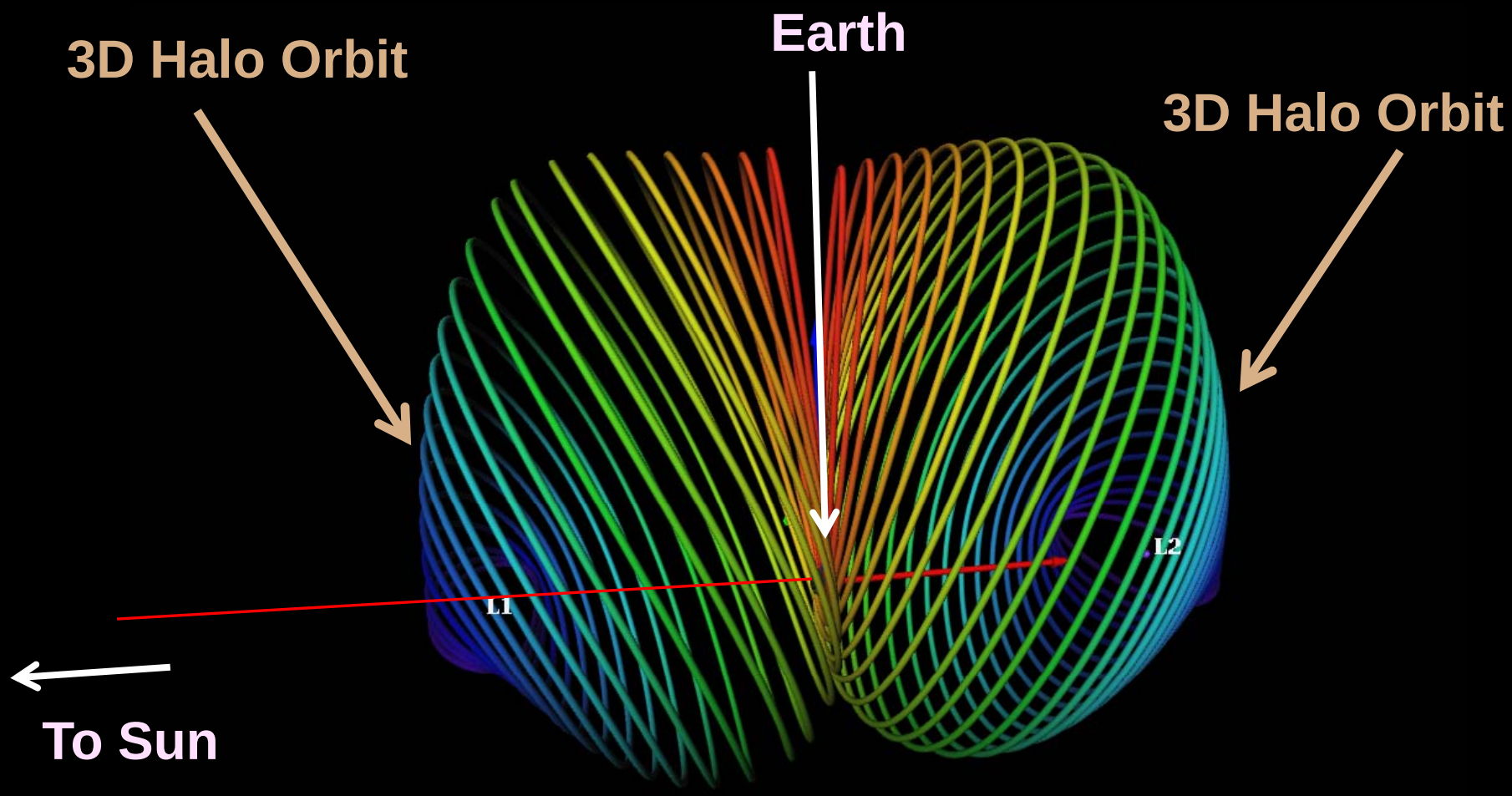

Sun-Earth System
L1 Unstable Manifold
L1
L2
Unstable Mode

Sun-Earth System
L1 Halo orbit Family

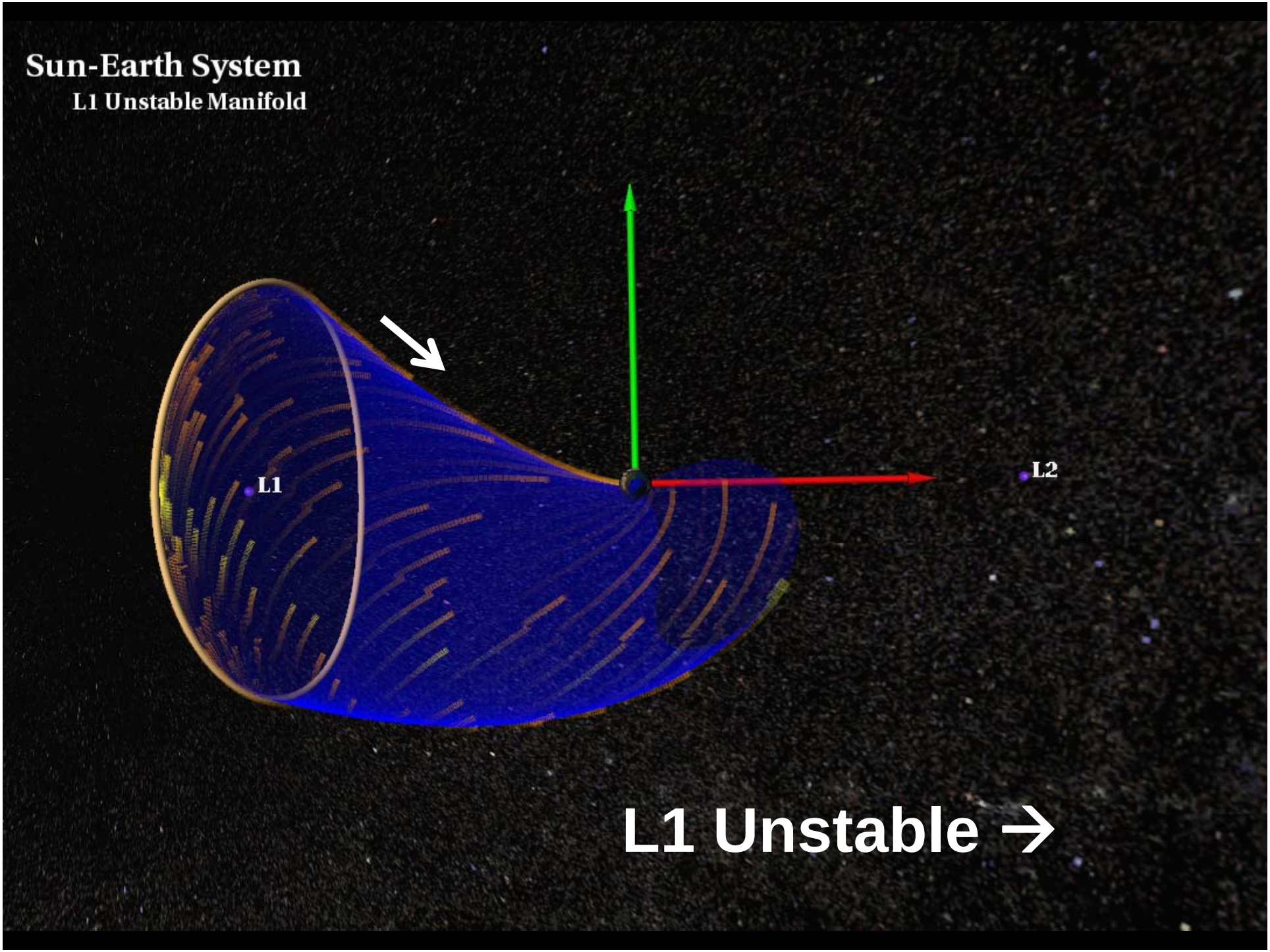


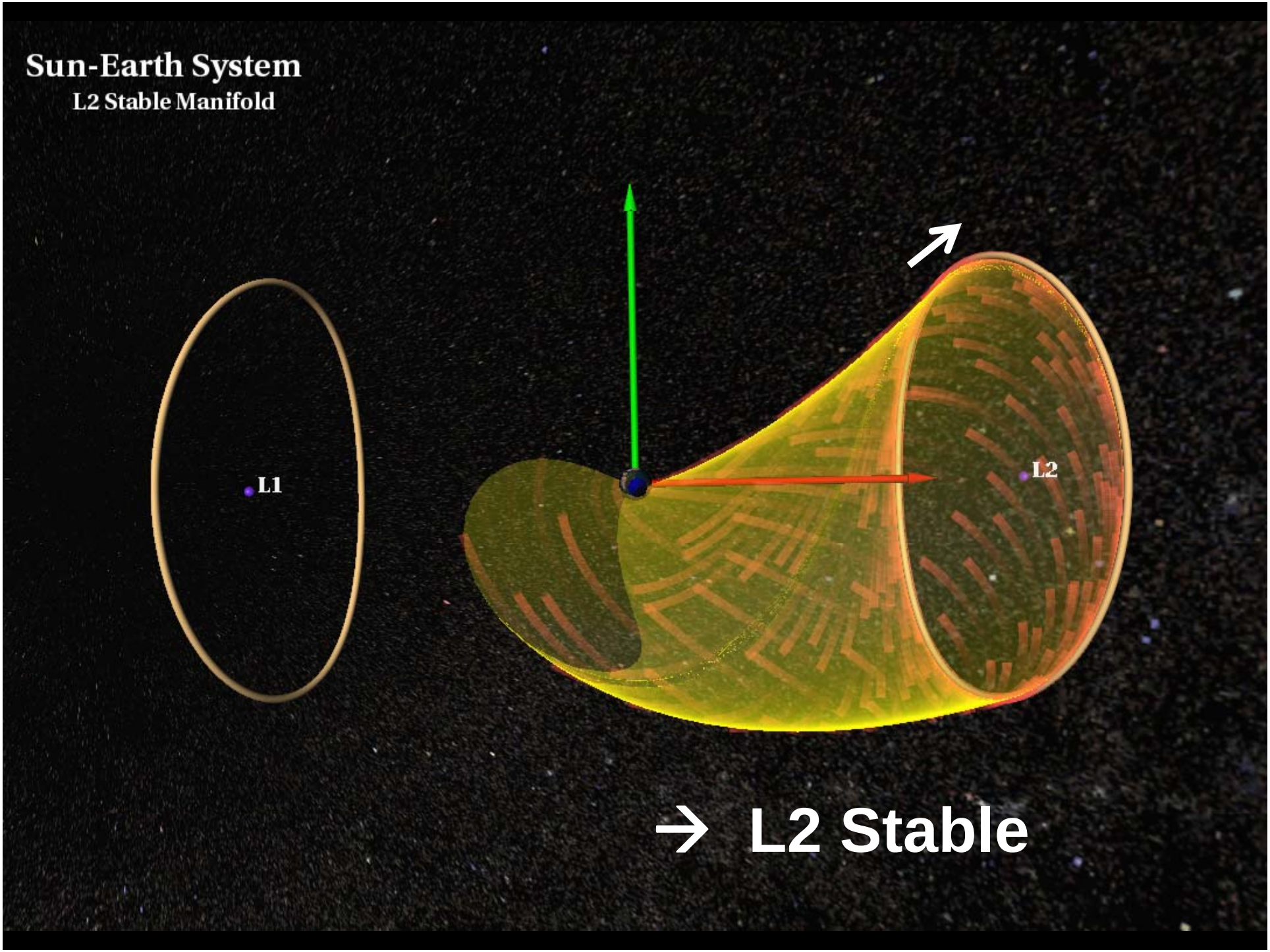
Infinite Number of Orbits
Select Any Orbit for Use!

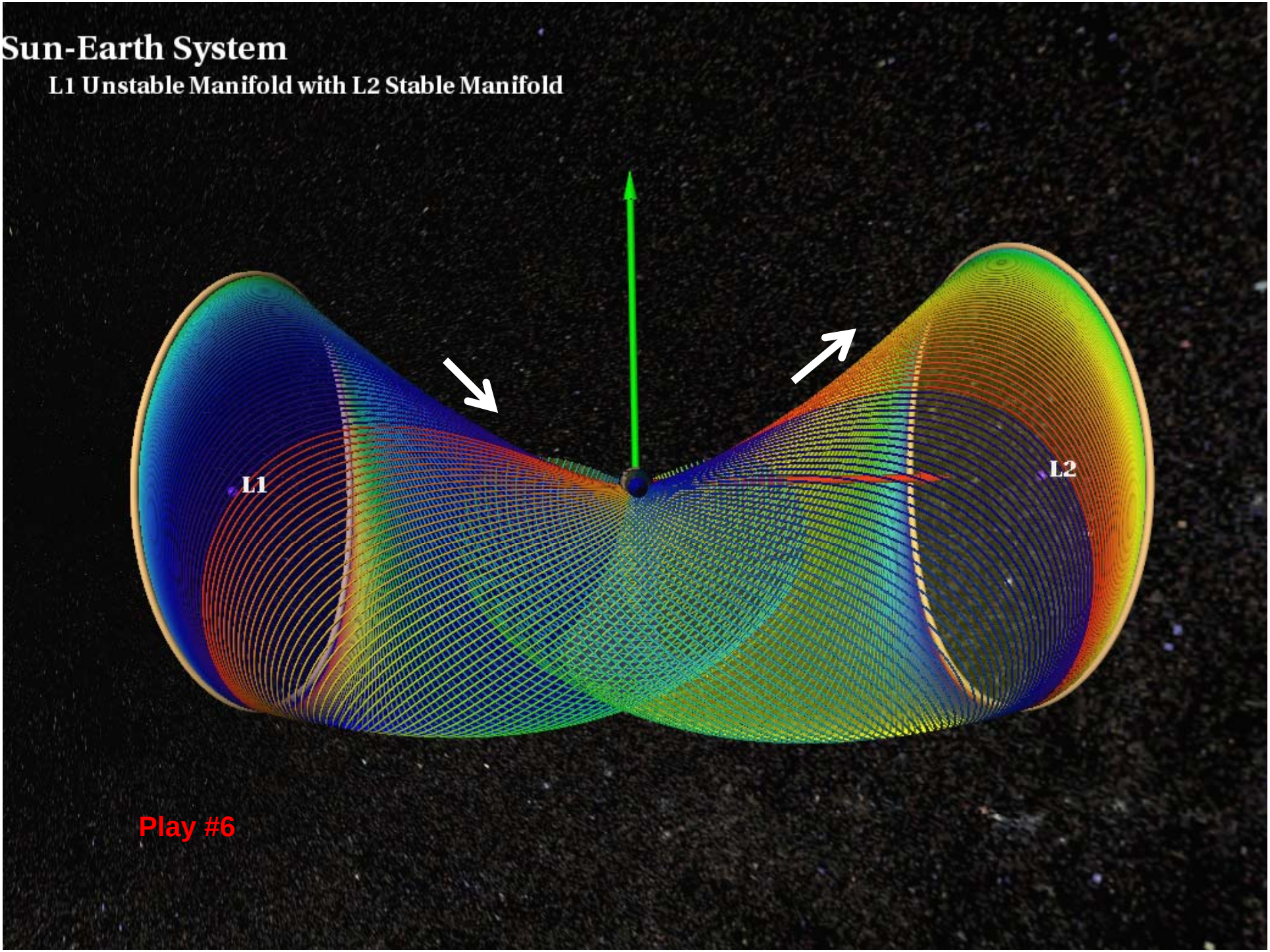
Trajectory Design:
Select one Periodic Orbit from each L1 and L2 Families

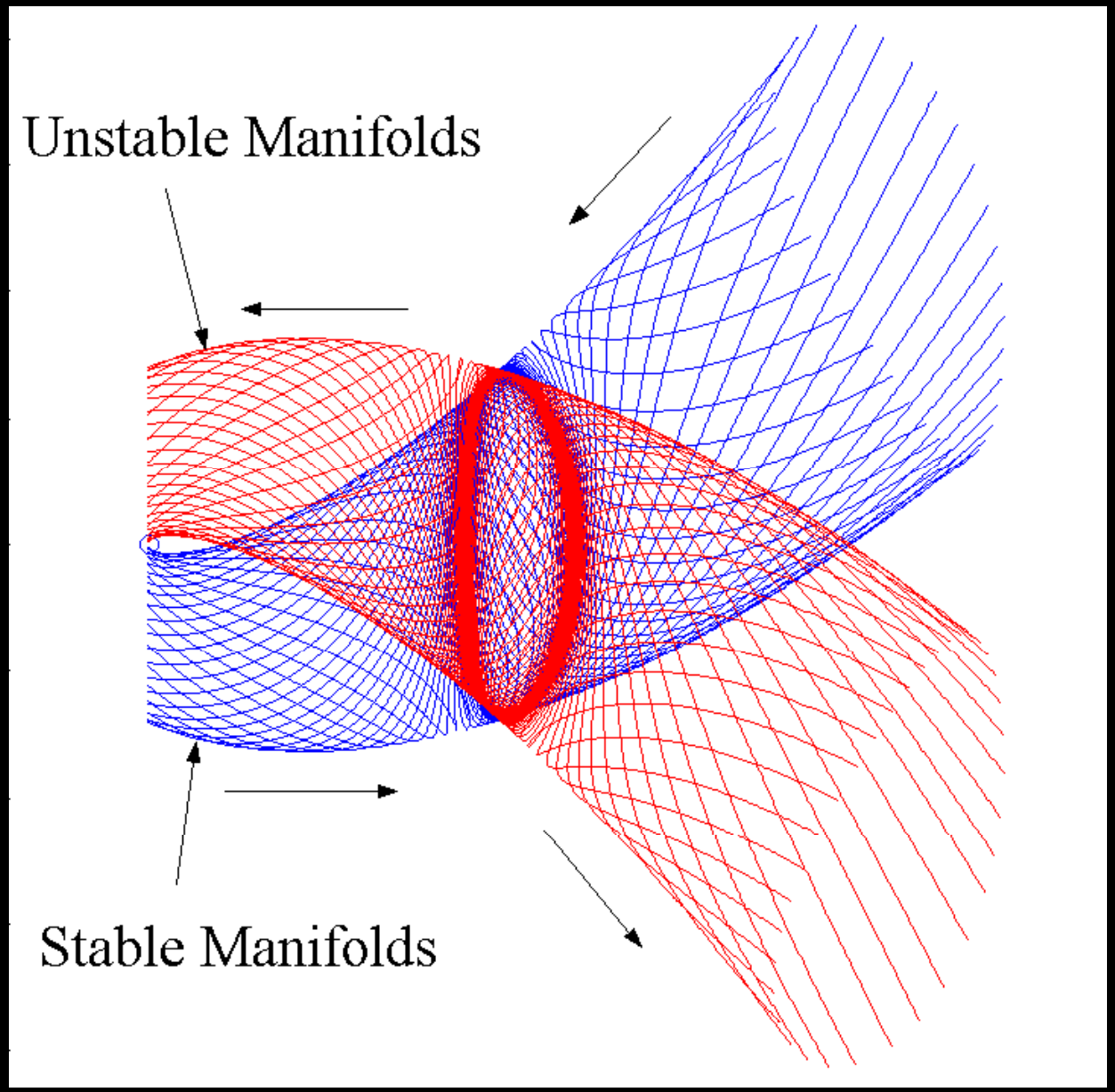


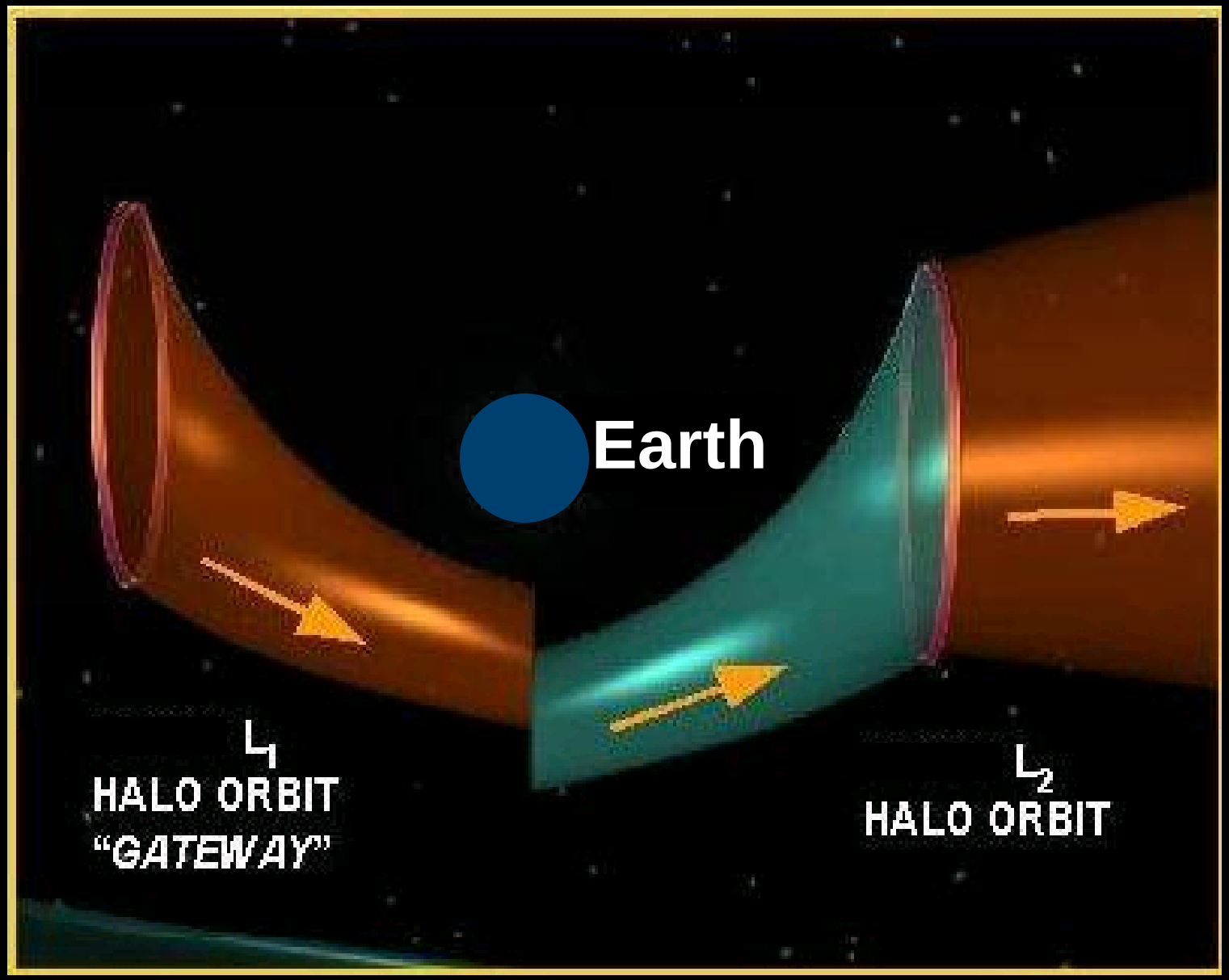
Key is Unstable Nature


Sun-Earth System
L1 Unstable Manifold
L1
L2
L1 Unstable →


Sun-Earth System
L2 Stable Manifold
L1
L2
→ L2 Stable


Sun-Earth System
L1 Unstable Manifold with L2 Stable Manifold
L1
L2
Play #6


Unstable Manifolds
Stable Manifolds

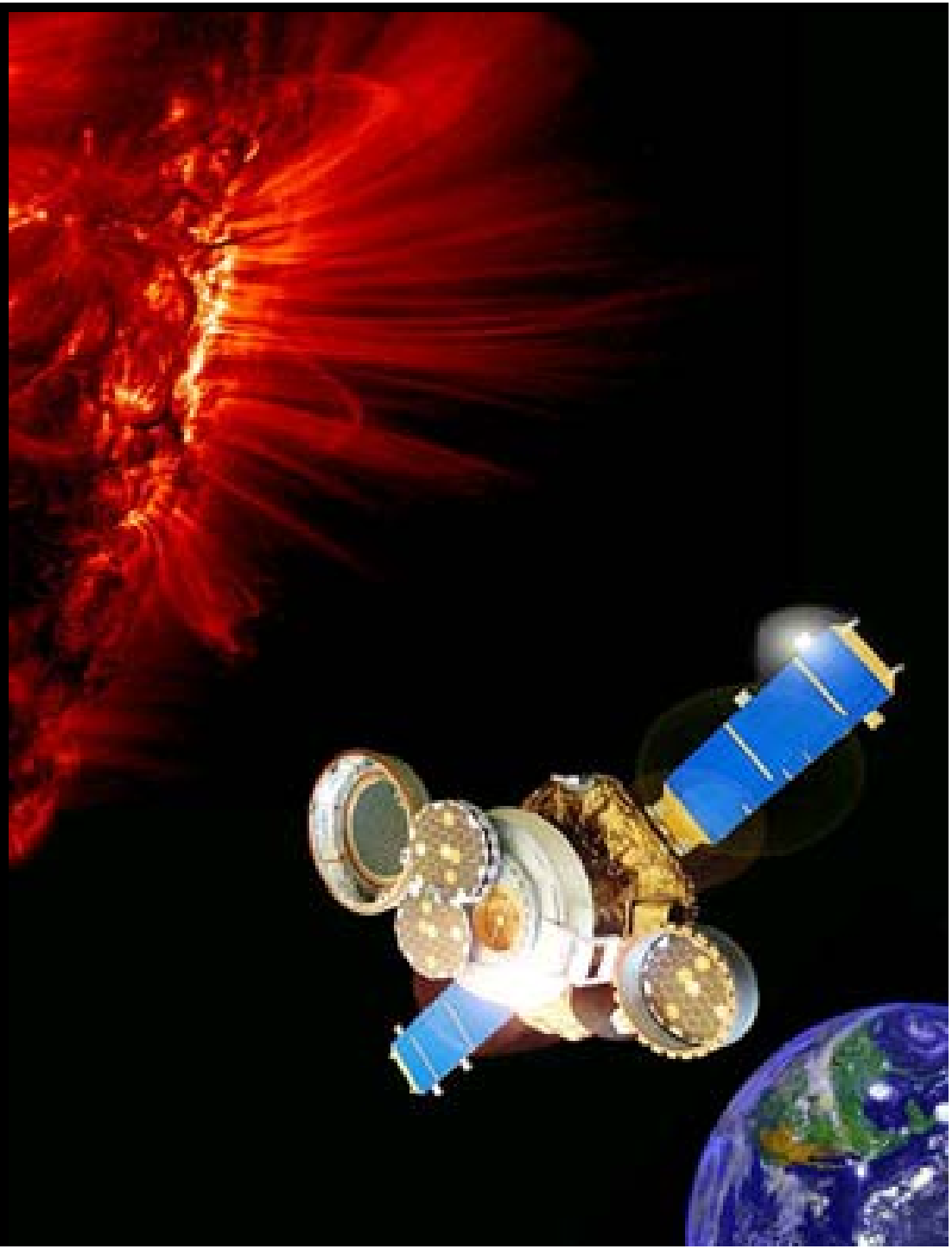


Lo and Ross

Genesis

Launch: Aug 8, 2001

Landing: Sept 8, 2004

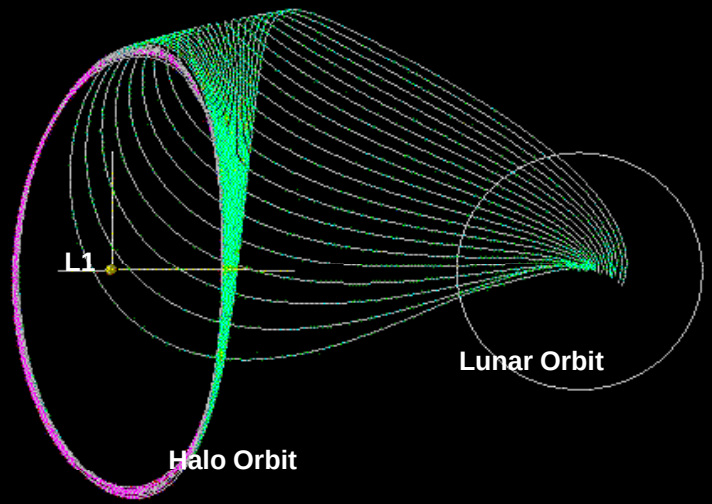


Purdue University

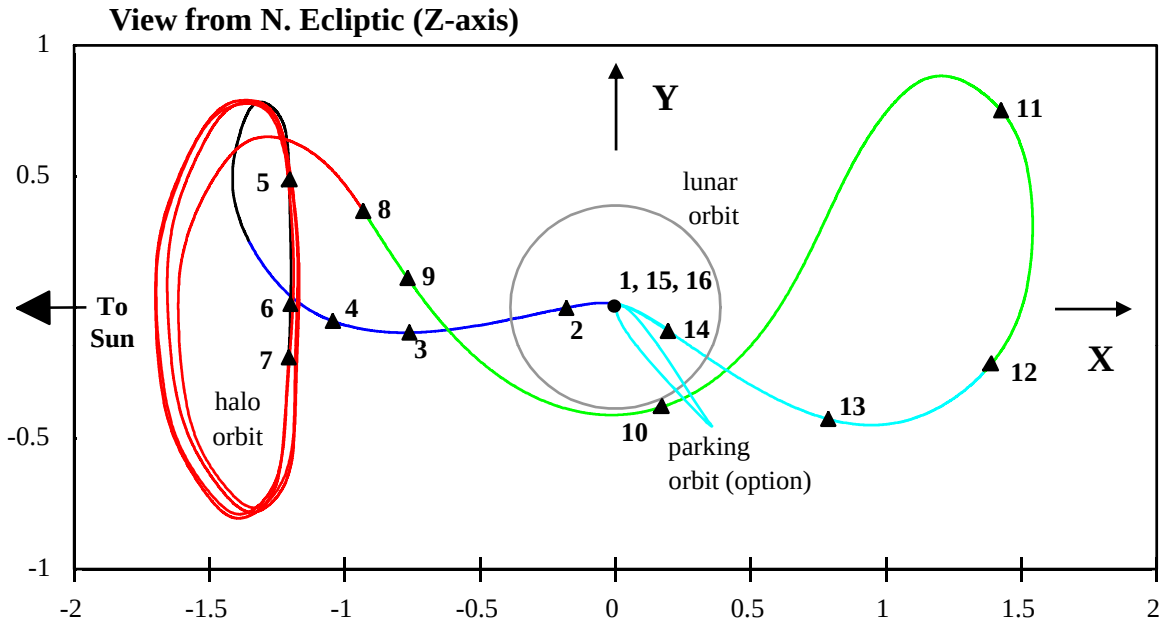
Genesis Design

JPL

Earth to L1 Halo

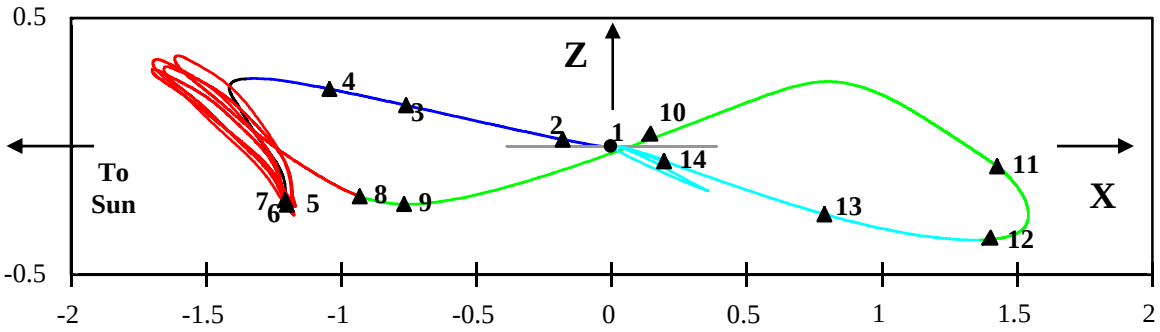


GENESIS Nominal Mission Trajectory

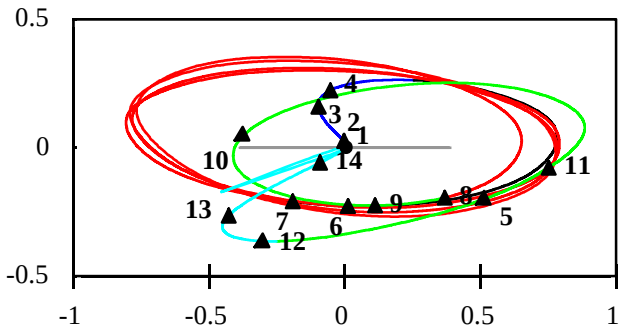


1	Launch	01/07/01
2	TCM-1	01/07/01
3	TCM-2	01/14/01
4	TCM-3	01/21/01
5	TCM-4	04/13/01
6	Halo Orbit Insertion (TCM-5)	04/23/01
7	Begin Science Phase	04/30/01
8	End Science Phase	03/22/03
9	Halo Orbit Departure (TCM-6)	04/01/03
10	TCM-7	04/15/03
11	TCM-8	06/10/03
12	TCM-9	07/20/03
13	TCM-10	08/09/03
14	TCM-11	08/18/03
15	Entry	08/19/03
16	Backup Entry	09/07/03

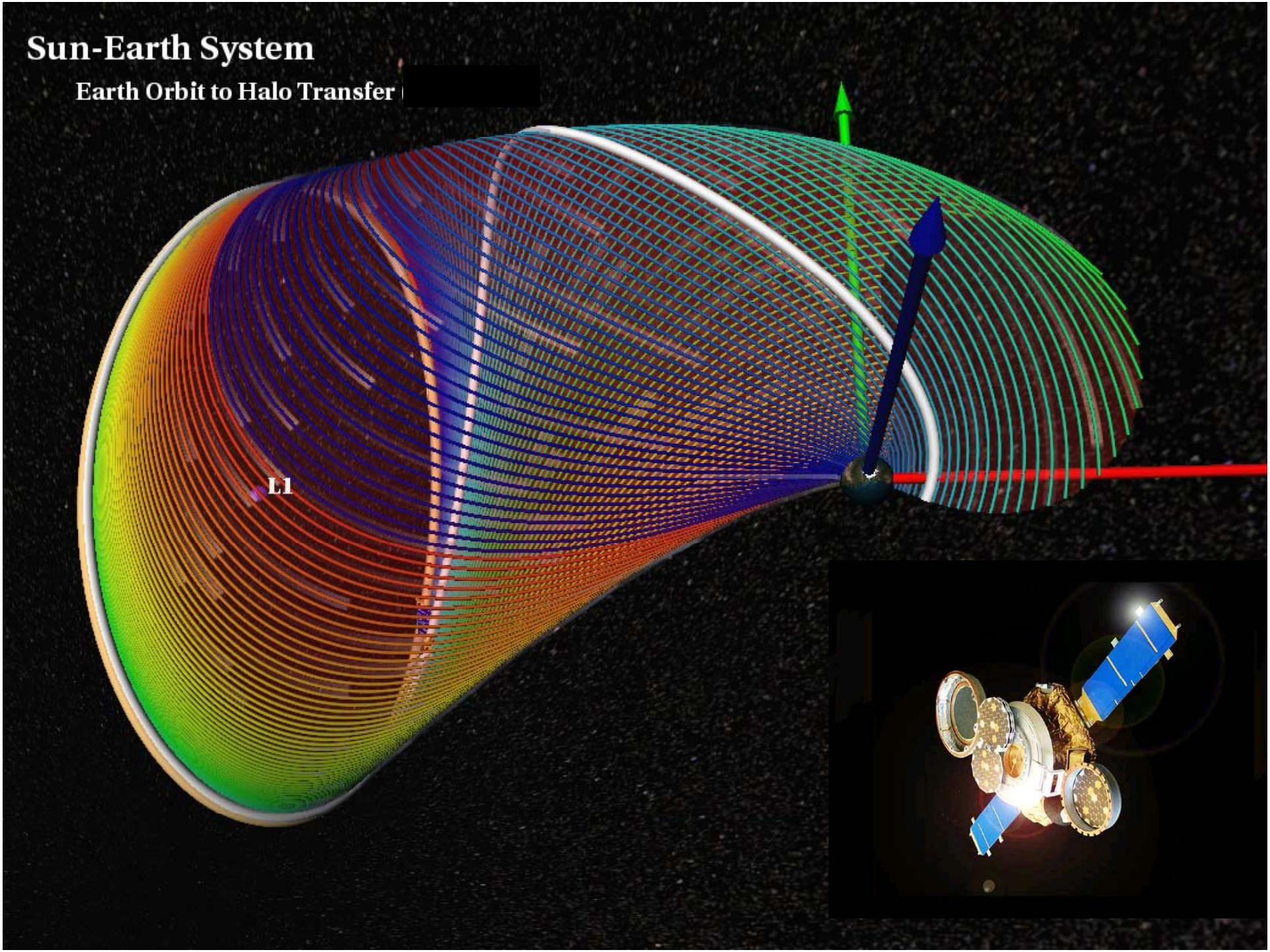
L+30d Transfer Science
Return Recovery



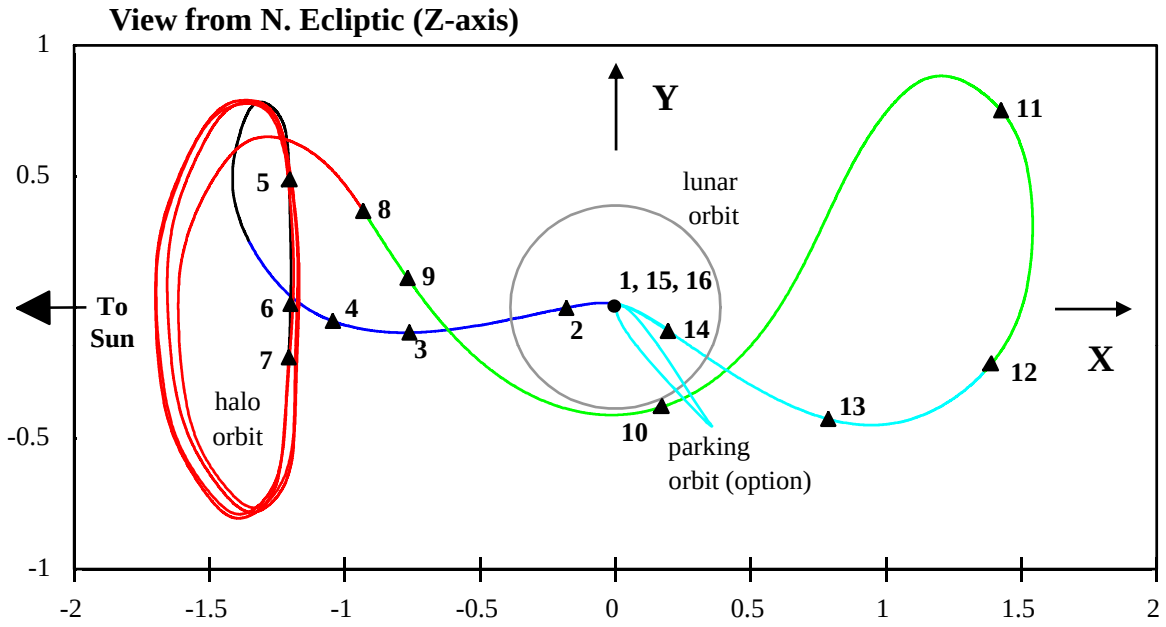
View from Anti-Earth Velocity (-Y-axis)



View from Anti-Sun (X-axis)

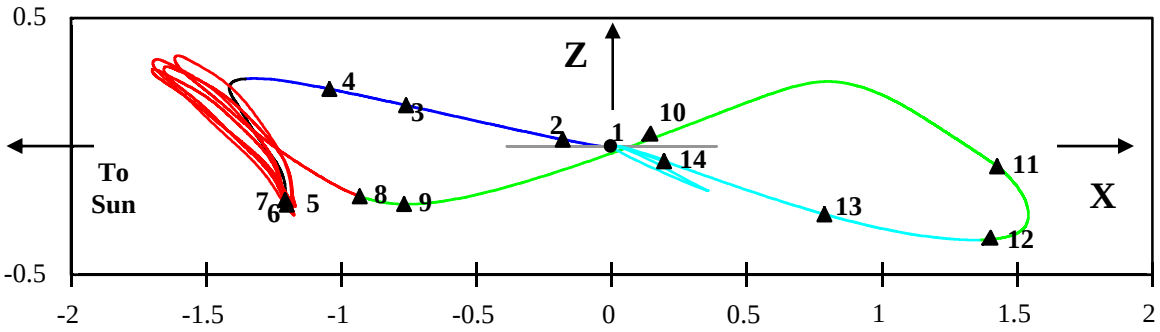

Sun-Earth System
Earth Orbit to Halo Transfer
L1

GENESIS Nominal Mission Trajectory

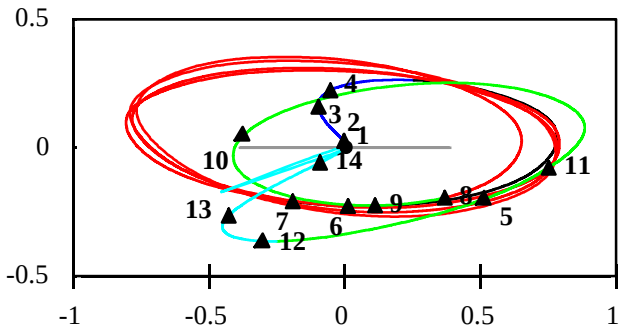


1	Launch	01/07/01
2	TCM-1	01/07/01
3	TCM-2	01/14/01
4	TCM-3	01/21/01
5	TCM-4	04/13/01
6	Halo Orbit Insertion (TCM-5)	04/23/01
7	Begin Science Phase	04/30/01
8	End Science Phase	03/22/03
9	Halo Orbit Departure (TCM-6)	04/01/03
10	TCM-7	04/15/03
11	TCM-8	06/10/03
12	TCM-9	07/20/03
13	TCM-10	08/09/03
14	TCM-11	08/18/03
15	Entry	08/19/03
16	Backup Entry	09/07/03

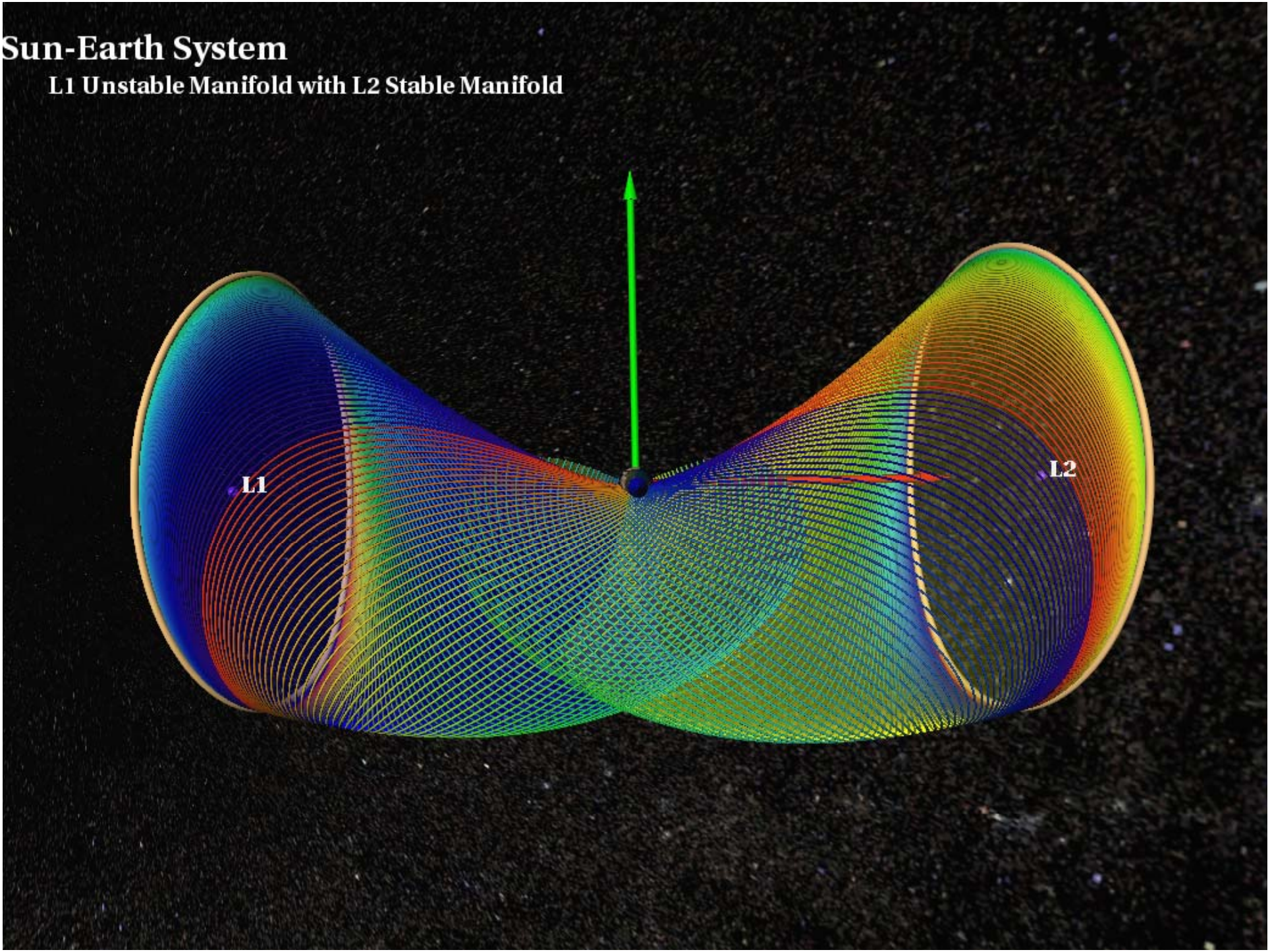
L+30d Transfer Science
Return Recovery



View from Anti-Earth Velocity (-Y-axis)



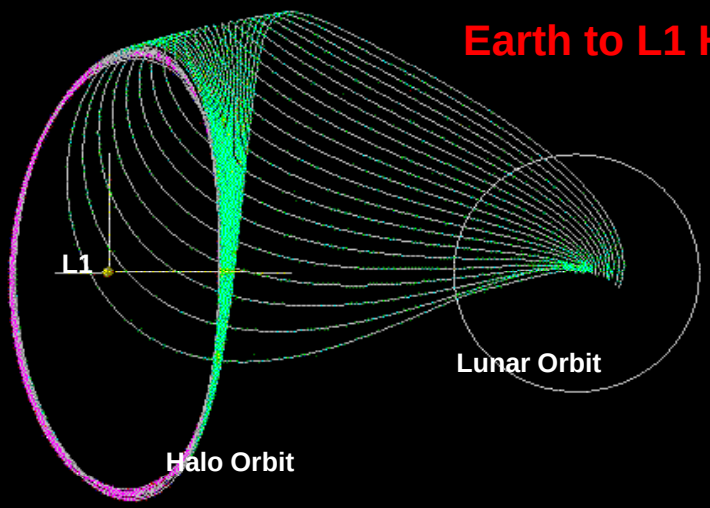
View from Anti-Sun (X-axis)

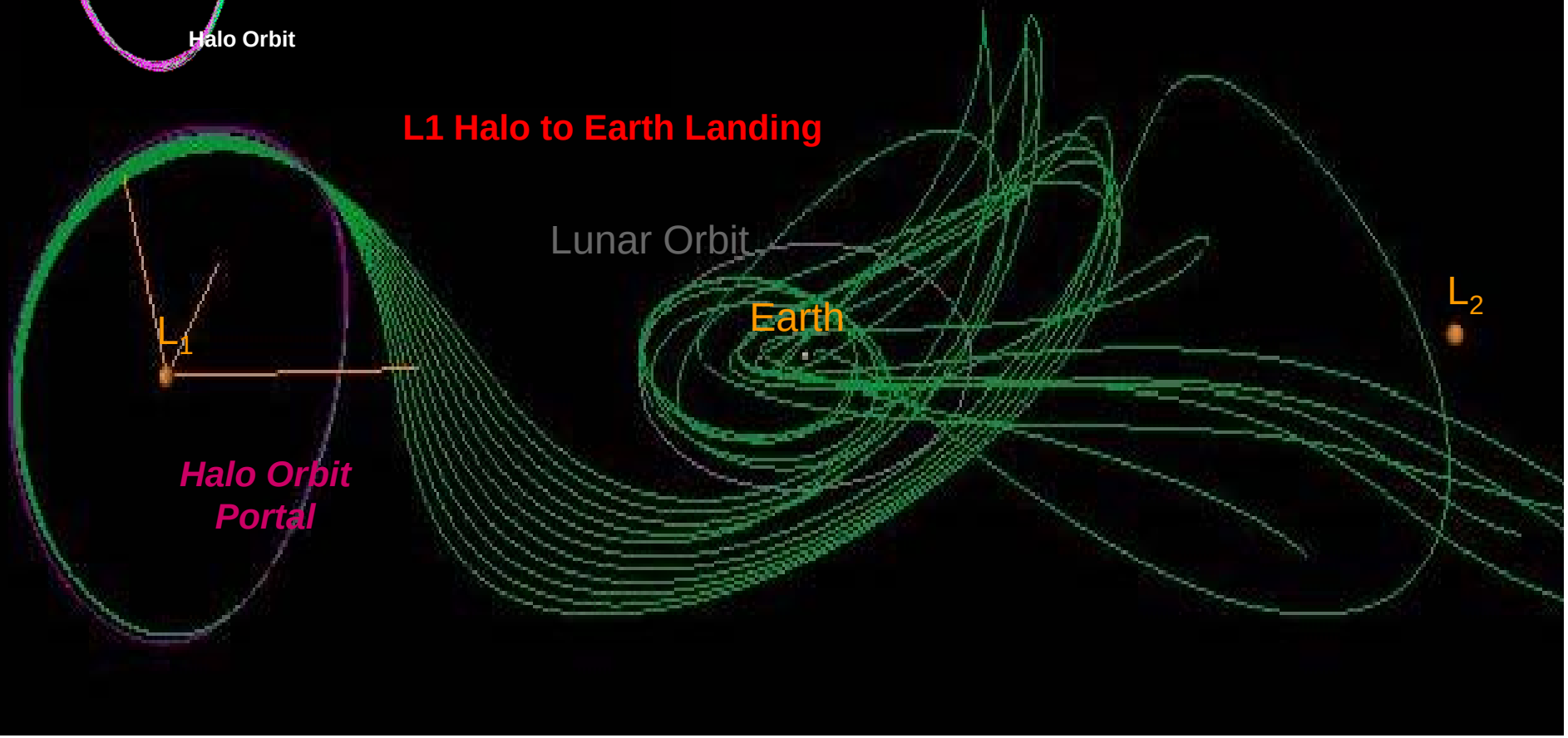

Sun-Earth System
L1 Unstable Manifold with L2 Stable Manifold
L1
L2

Purdue University

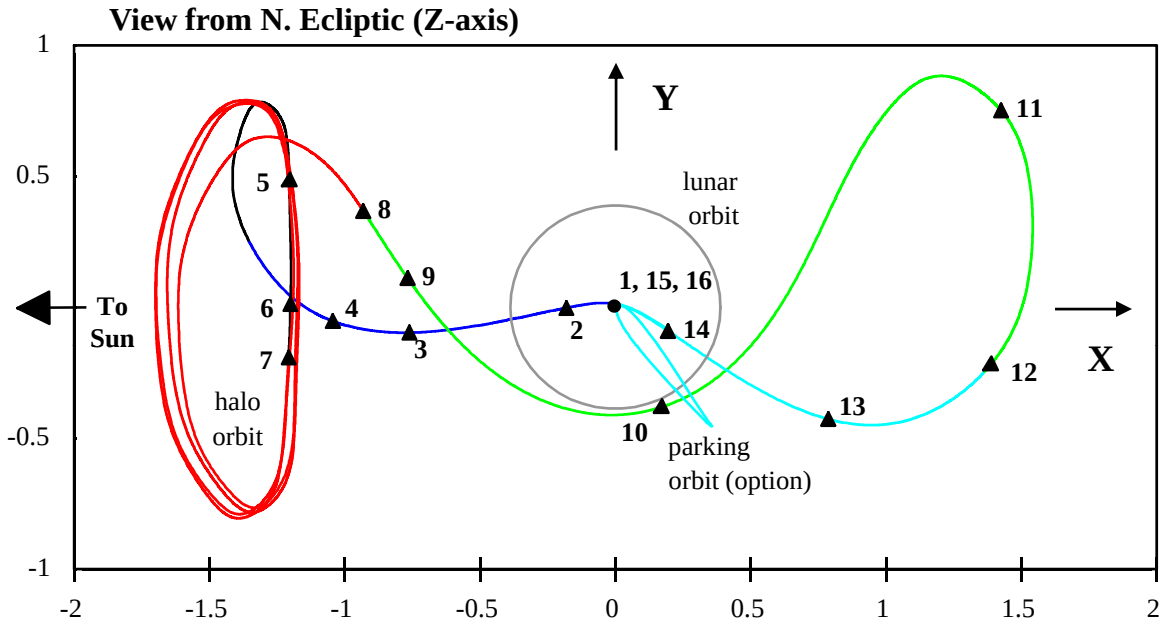
Genesis Design

JPL



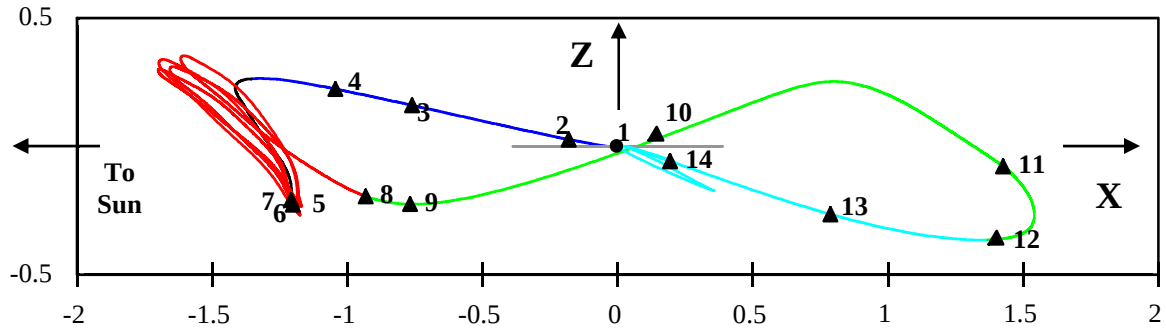


GENESIS Nominal Mission Trajectory

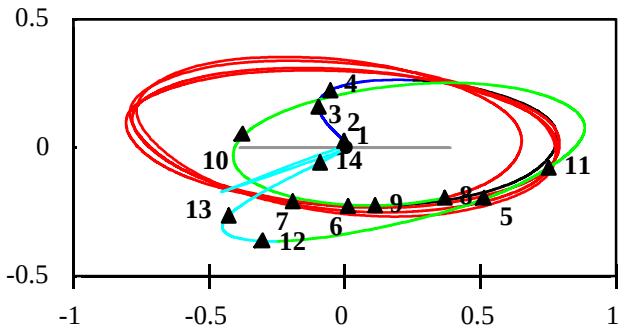


1	Launch	01/07/01
2	TCM-1	01/07/01
3	TCM-2	01/14/01
4	TCM-3	01/21/01
5	TCM-4	04/13/01
6	Halo Orbit Insertion (TCM-5)	04/23/01
7	Begin Science Phase	04/30/01
8	End Science Phase	03/22/03
9	Halo Orbit Departure (TCM-6)	04/01/03
10	TCM-7	04/15/03
11	TCM-8	06/10/03
12	TCM-9	07/20/03
13	TCM-10	08/09/03
14	TCM-11	08/18/03
15	Entry	08/19/03
16	Backup Entry	09/07/03

L+30d Transfer Science
Return Recovery



View from Anti-Earth Velocity (-Y-axis)

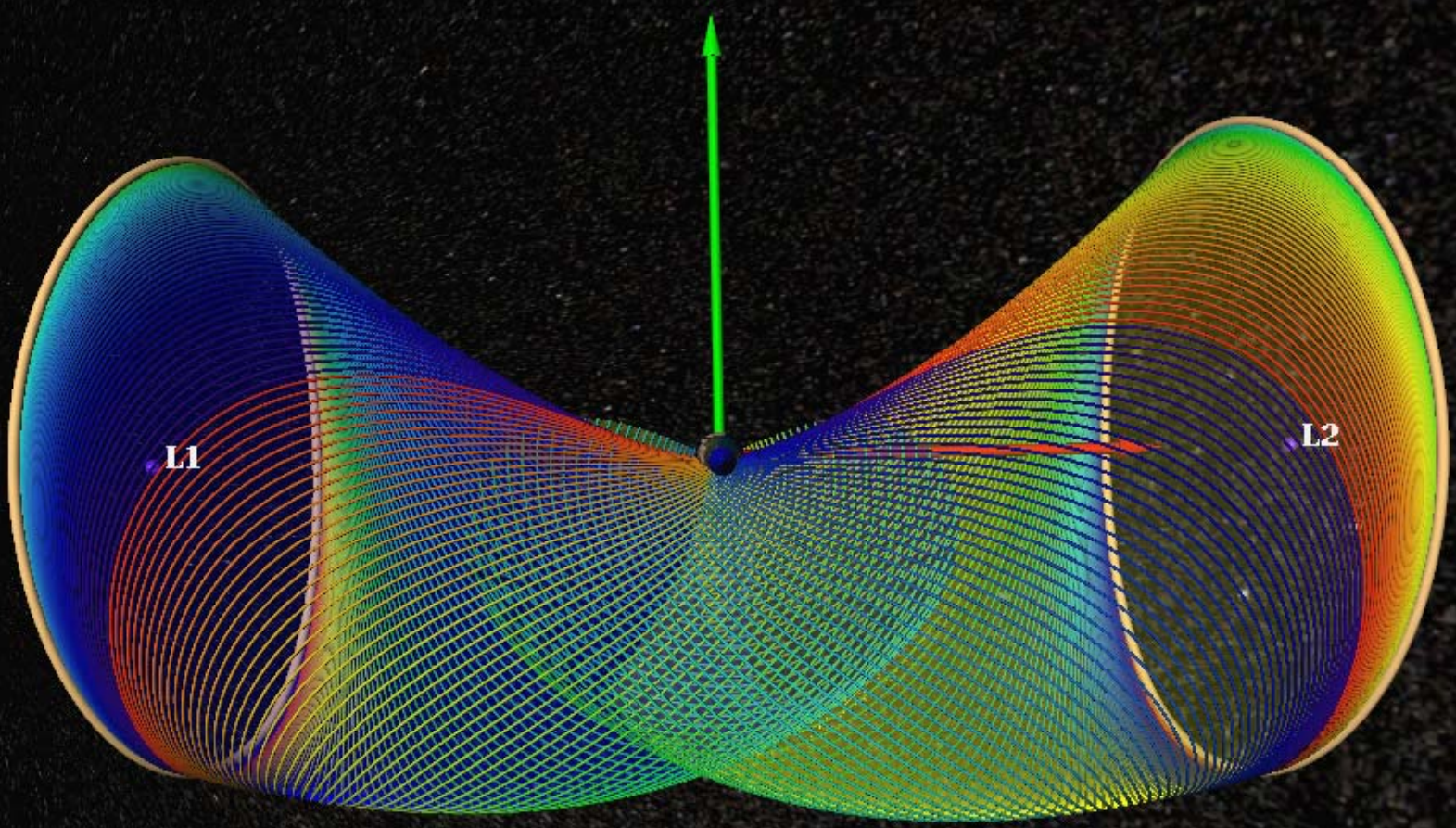


View from Anti-Sun (X-axis)

L1 Unstable → L2 Stable Then L2 Unstable for Return

Sun-Earth System

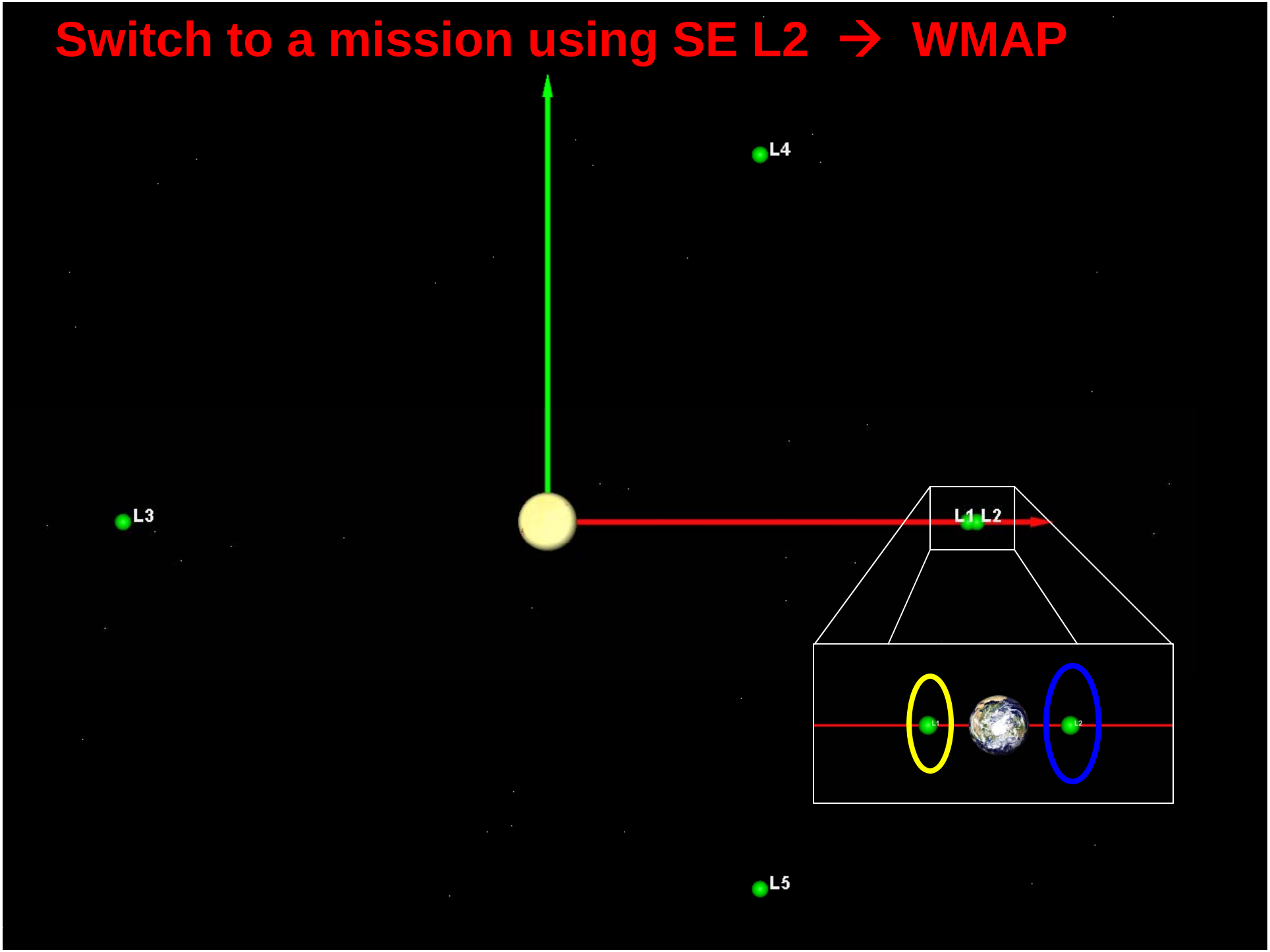
L1 Unstable Manifold with L2 Stable Manifold

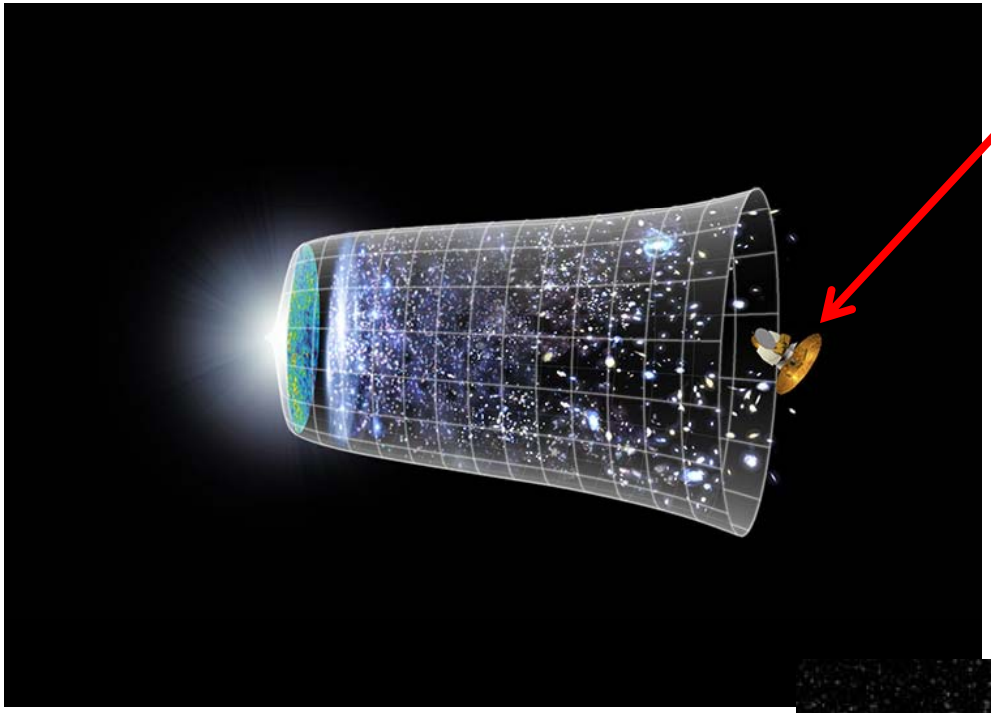


Also Natural Objects:
Sun-Jupiter System → some comets follow manifold tube structure

Lo – Talk Thurs

Switch to a mission using SE L2 → WMAP



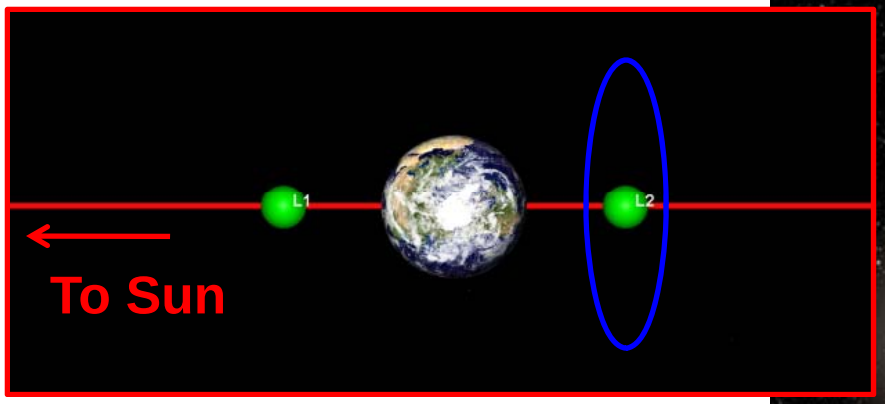


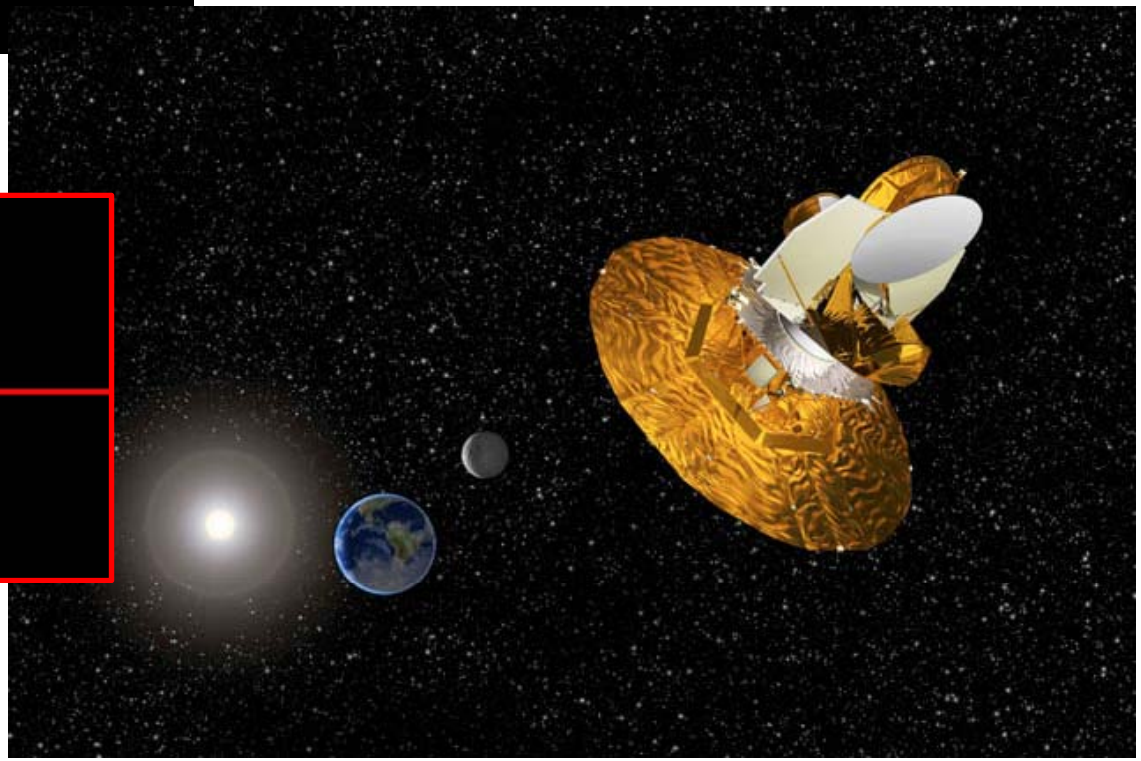
WMAP

Nominal mission: 27 months + several years extension

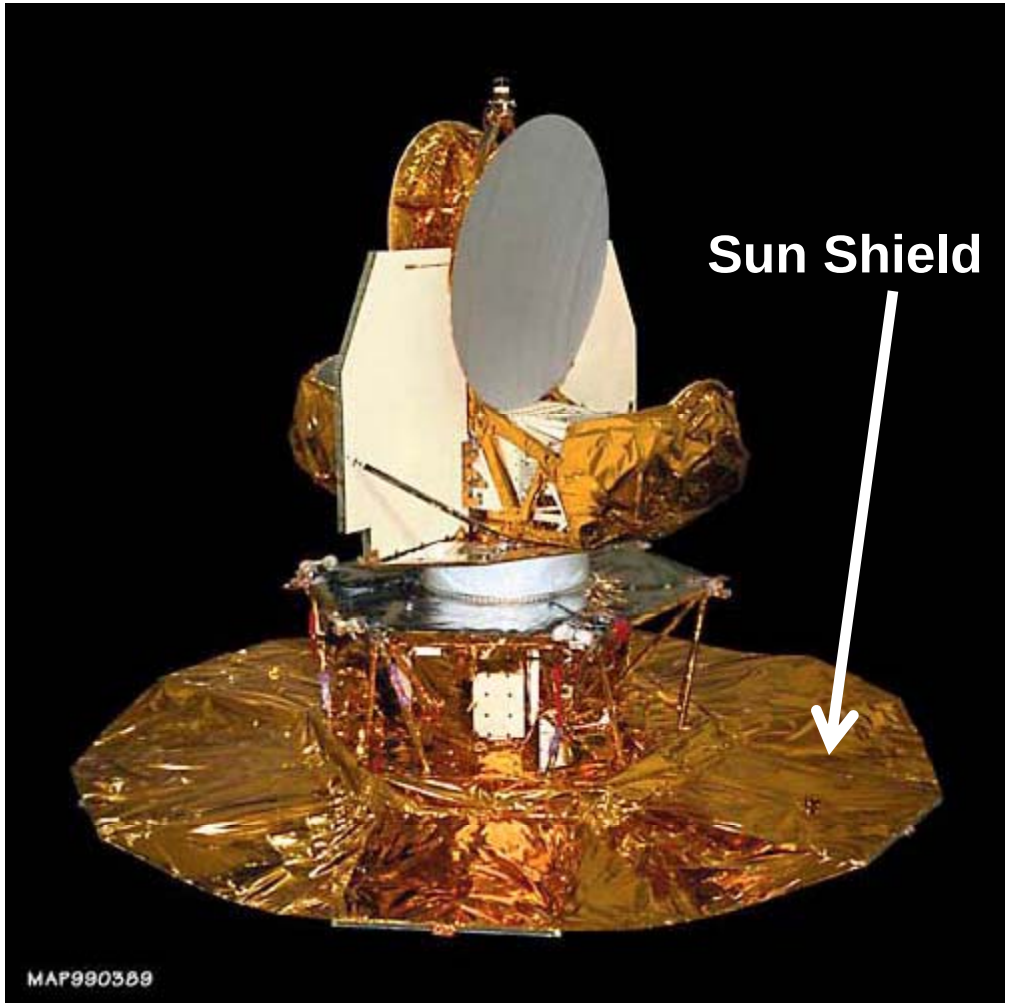
Total Payload ~ 830 kg

WMAP instruments continuously shaded from the Sun, Earth, and Moon to lower thermal disturbances

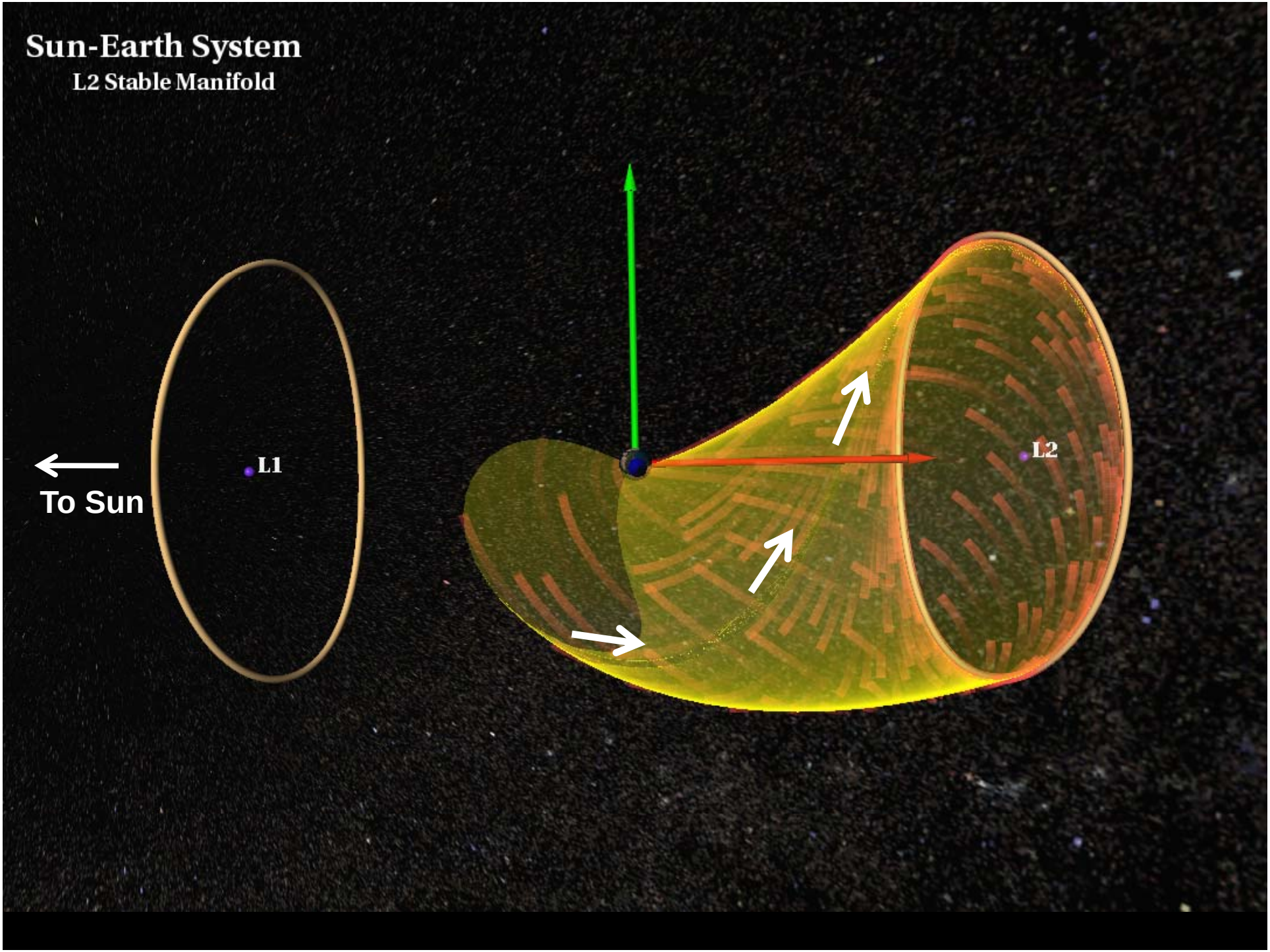




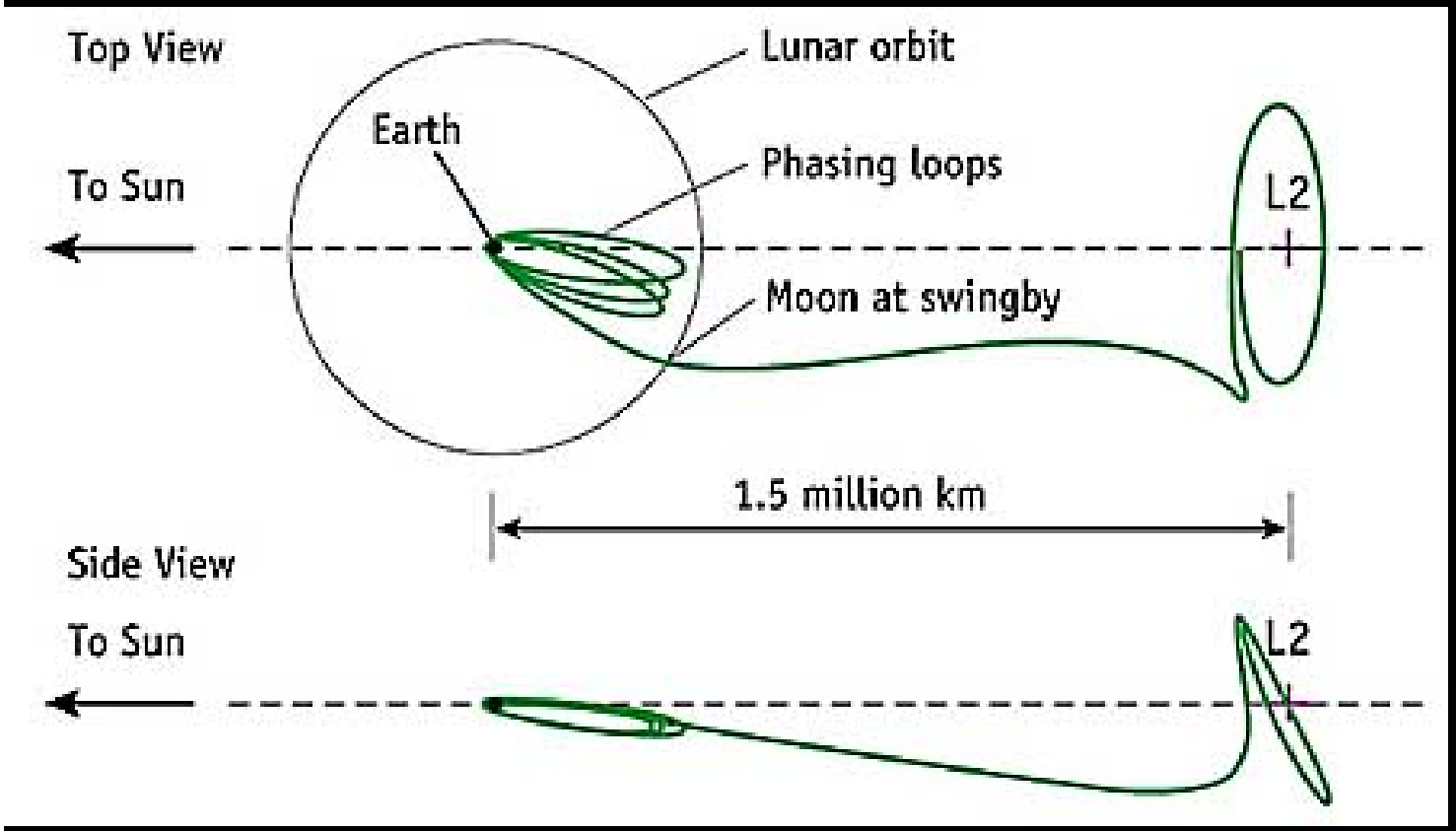
WMAP

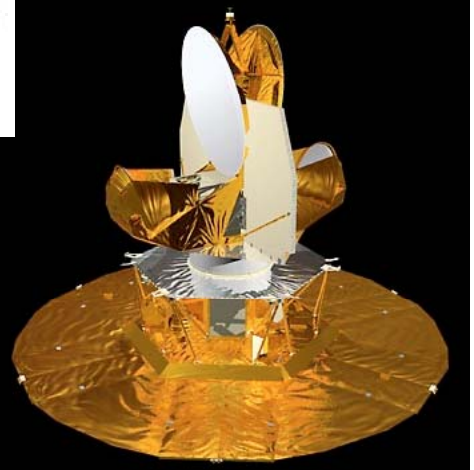


- Proposed 1995
- WMAP Delta II Rocket Launch
- Launched June 30, 2001
- Kennedy Spaceflight Center Launch, Pad 17B
- Almost perfect launch -- on time to the sec

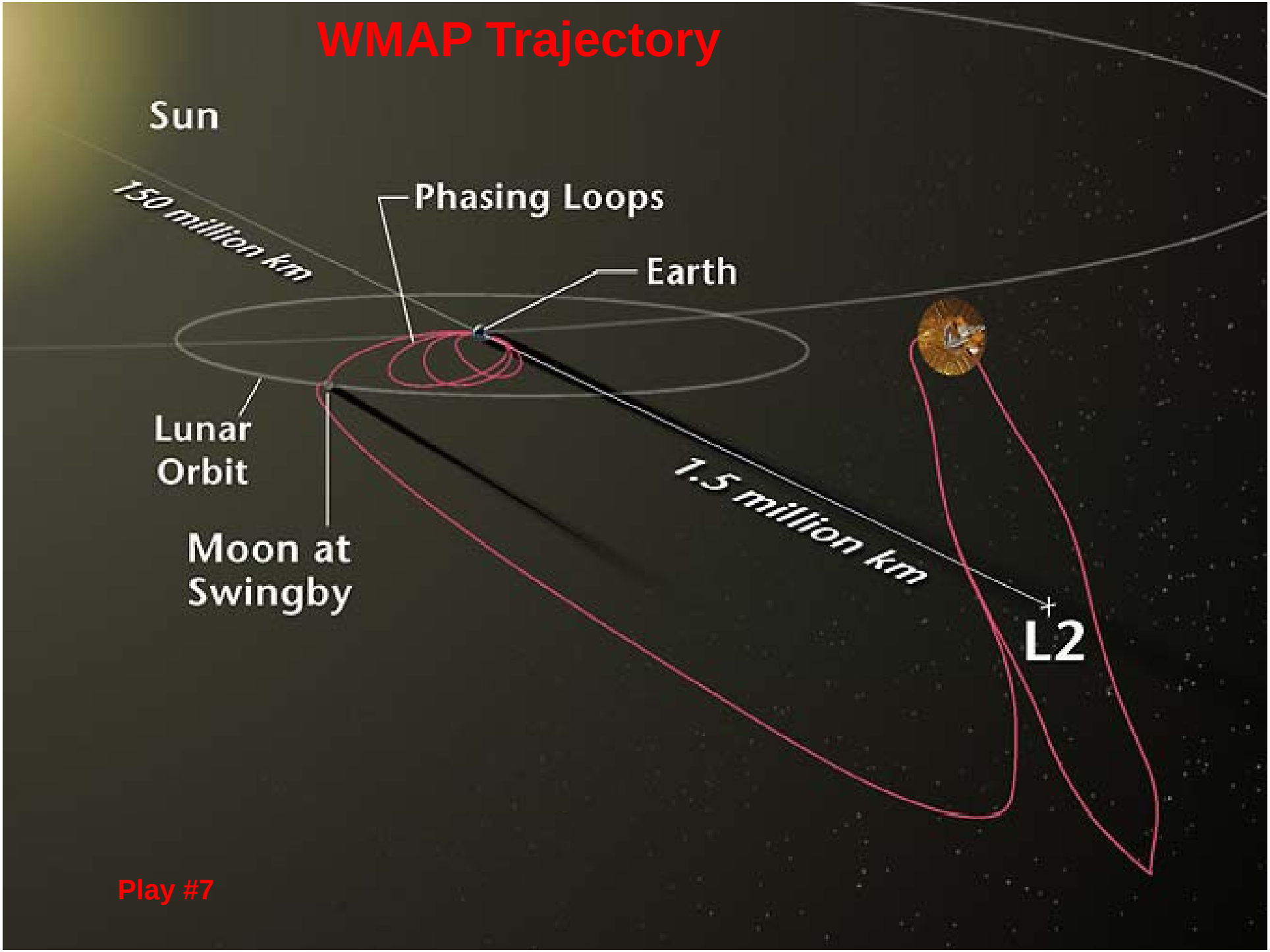

Sun-Earth System
L2 Stable Manifold
To Sun
L1
L2

WMAP Spacecraft Trajectory



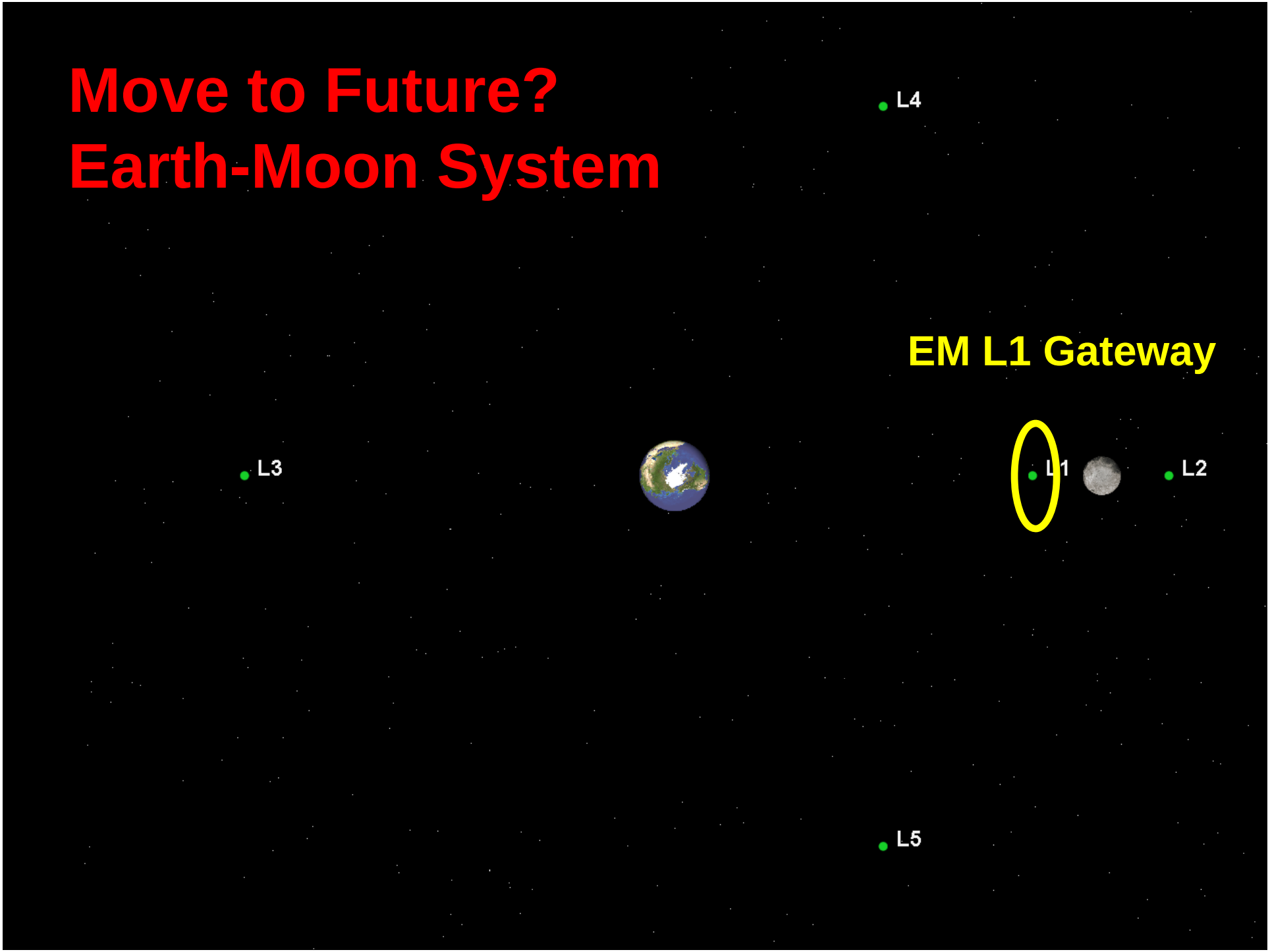


WMAP Trajectory



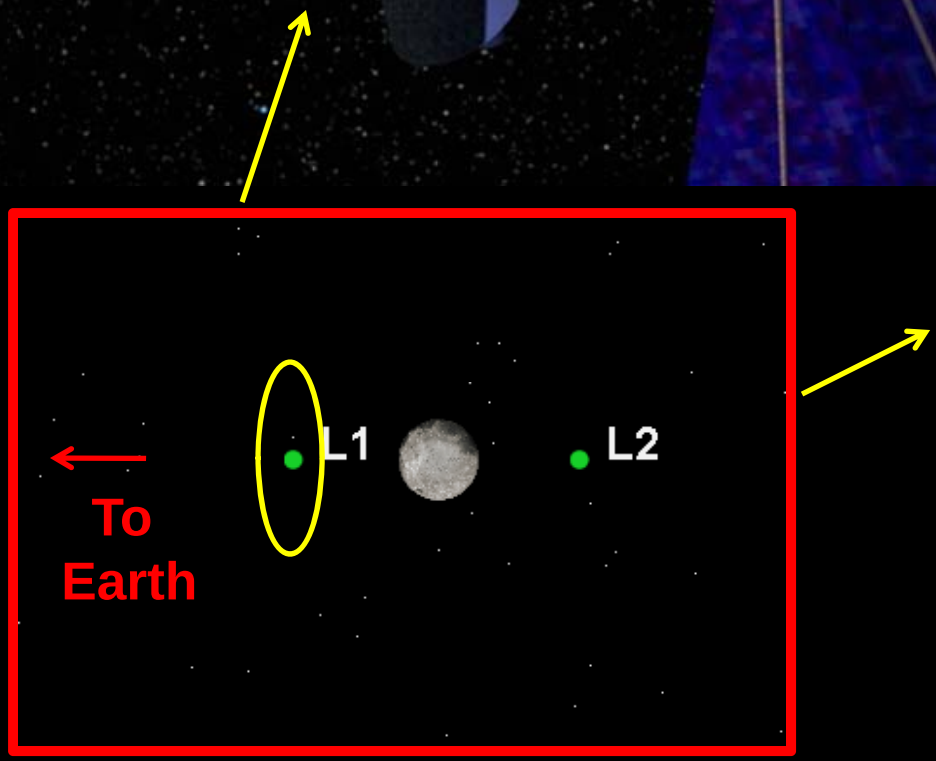
Play #7

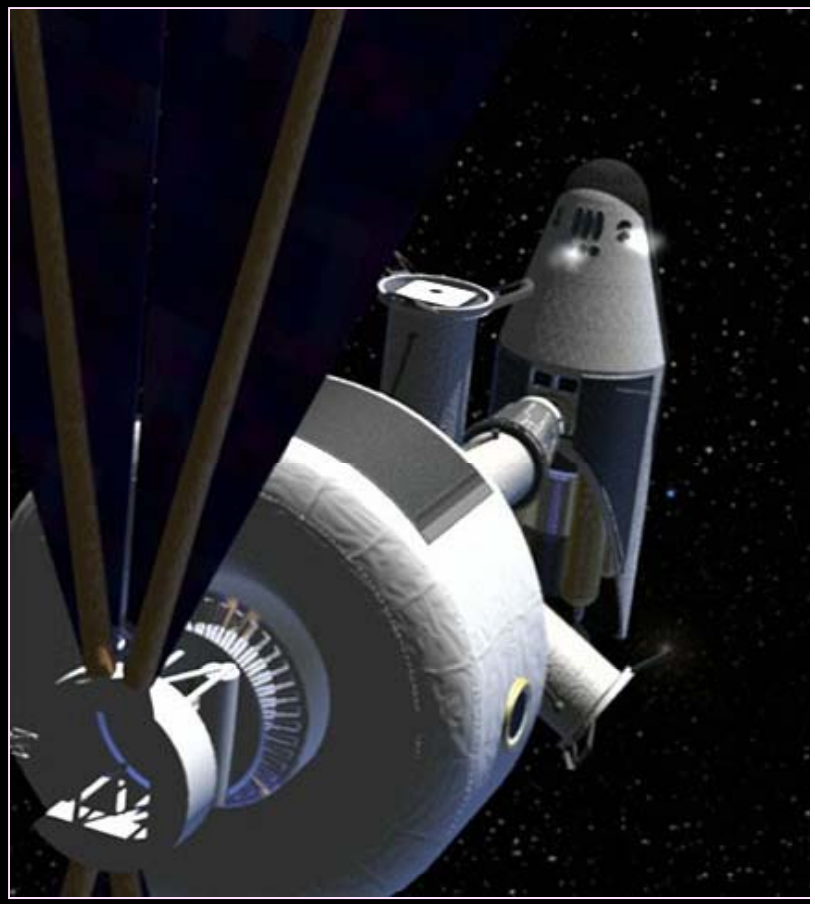
Move to Future?
Earth-Moon System



Space Station at EM L1 Gateway

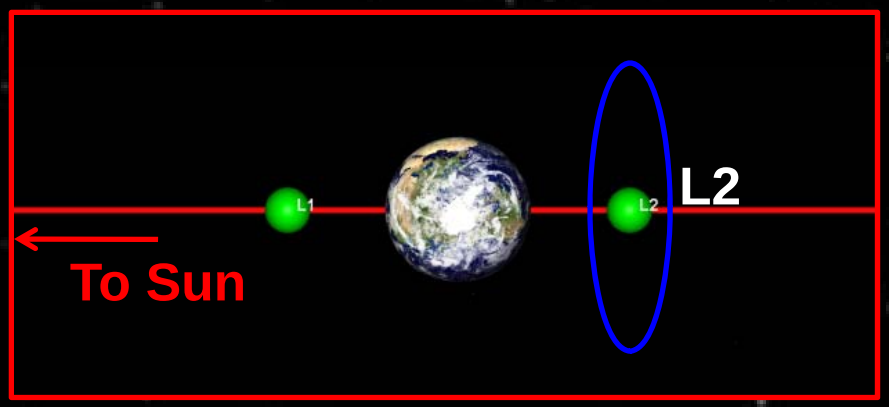
Approach



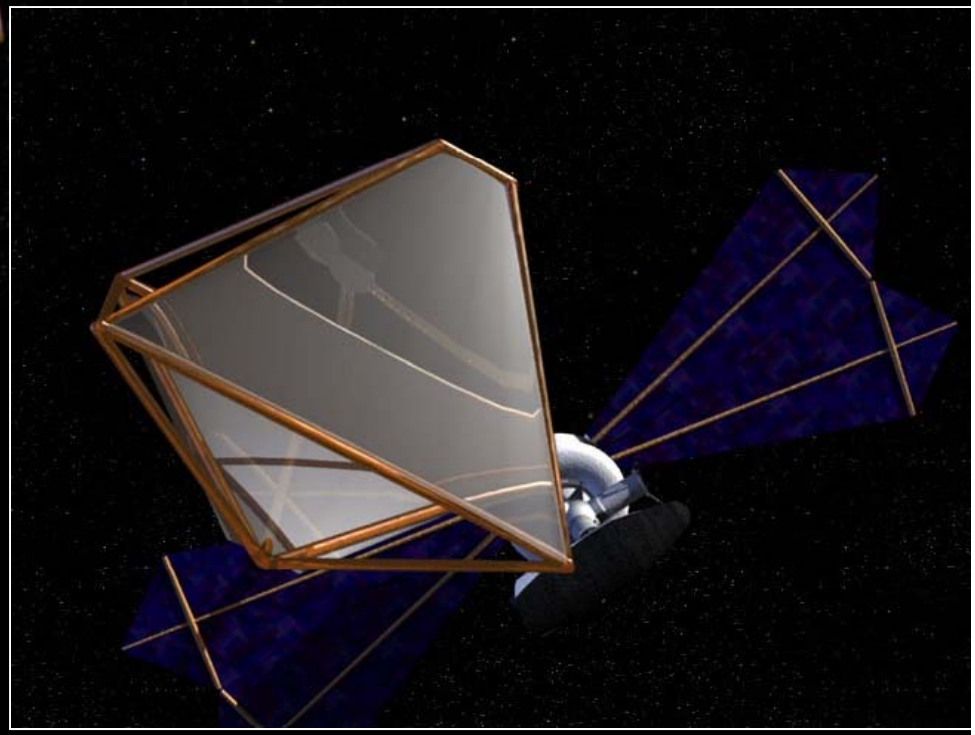


Docked at EM L1 Gateway

Telescope Ops at Libration Points
Advanced Telescope Array at SE L2



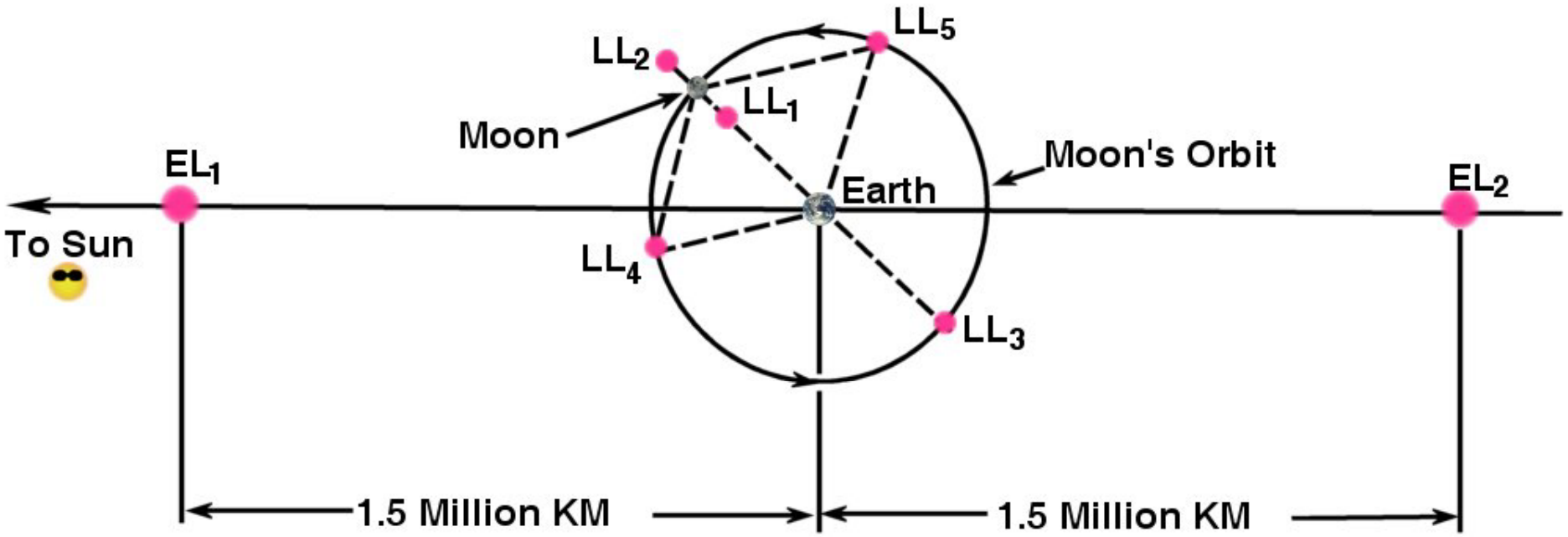
Advanced Telescope Stationed at SE L2
Serviced at EM L1 Gateway



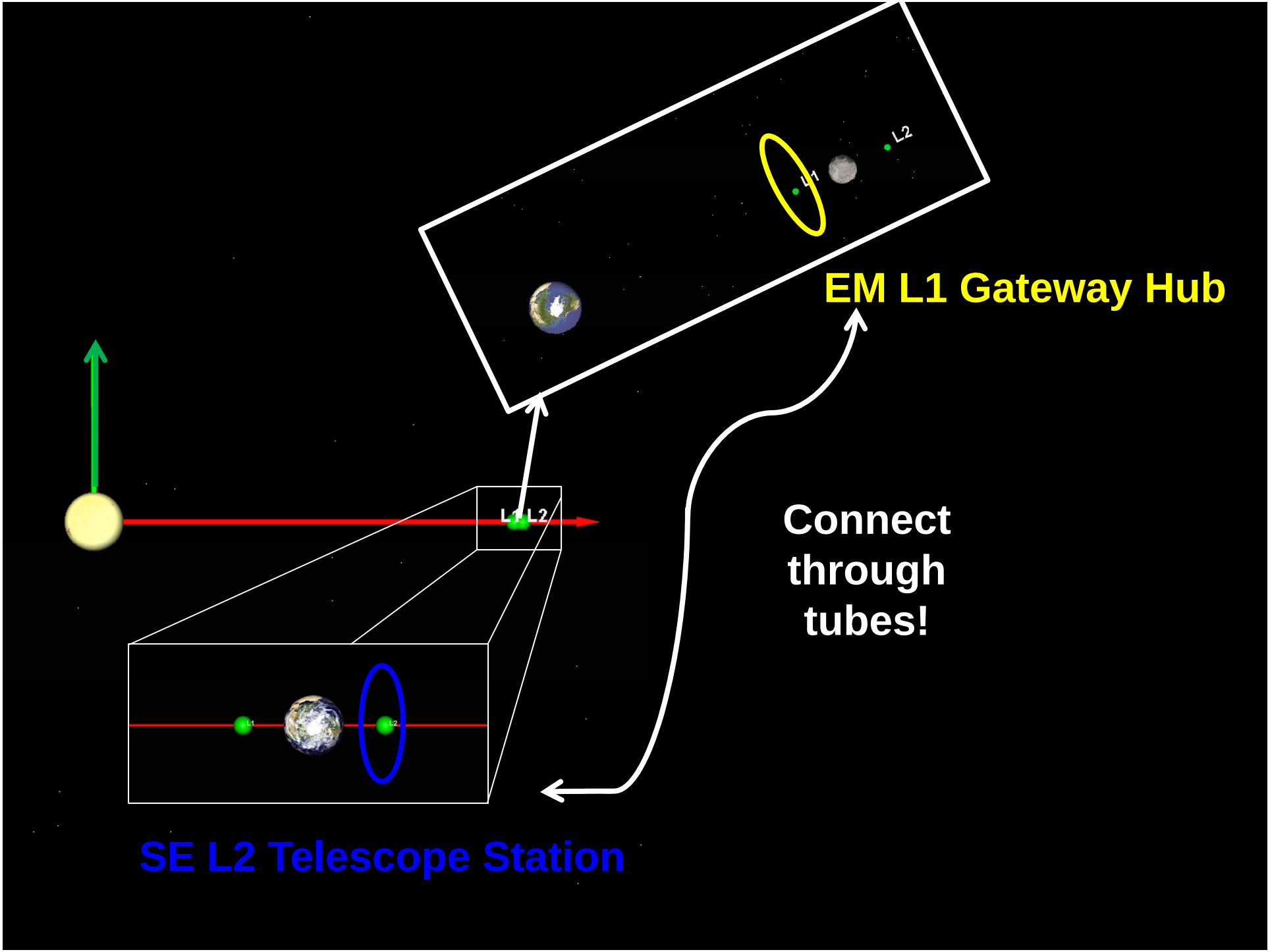
Libration Points in Earth's Neighborhood

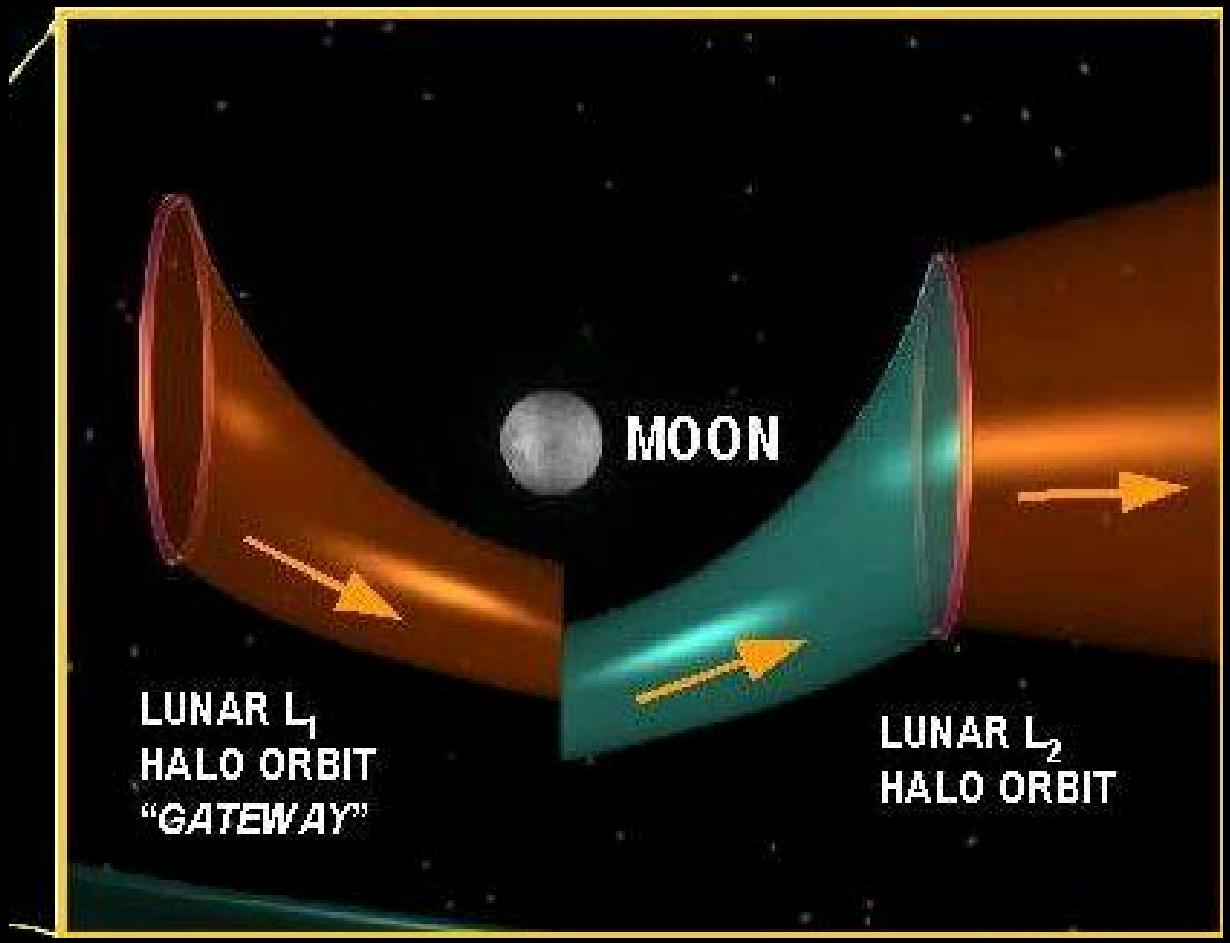
Every 3-Body System: 5 Fixed Libration Points

→ Generate the InterPlanetary Superhighway



M. Lo


L1
L2
EM L1 Gateway Hub
L1 L2
Connect
through
tubes!
L1
L2
SE L2 Telescope Station

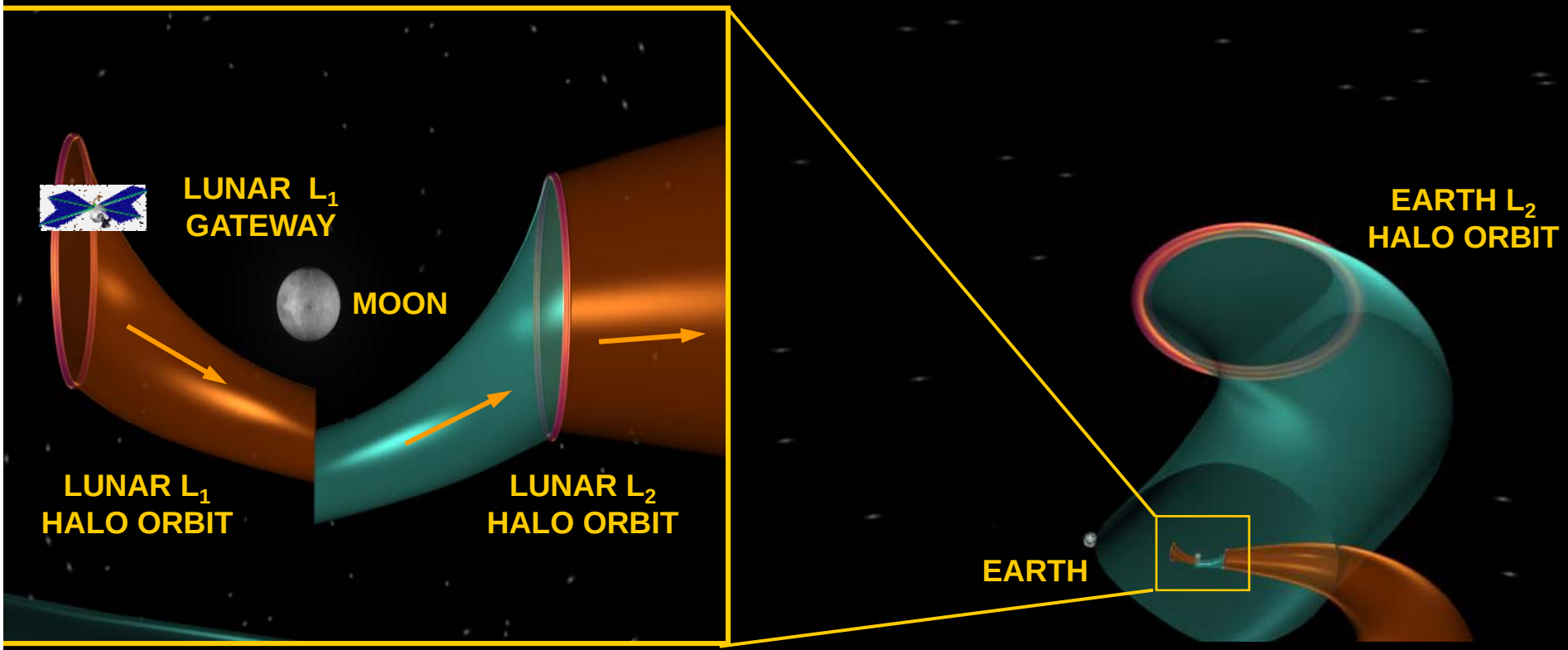


Play #8

Lo and Ross

Human Servicing at Lunar L_1 Gateway

- Build Instruments & S/C Lunar L_1 Gateway for EL_2
- Service S/C at Earth L_2 from Lunar L_1 Gateway Module

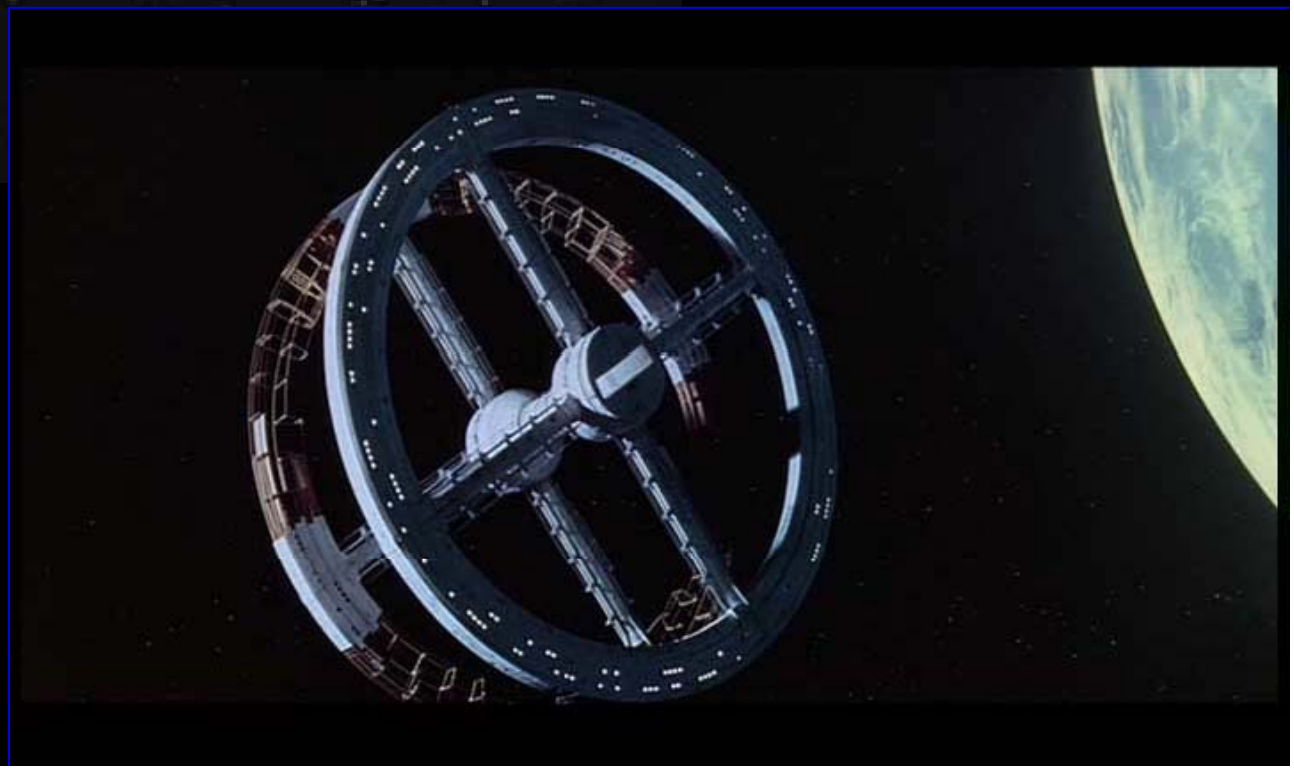


Lo and Ross

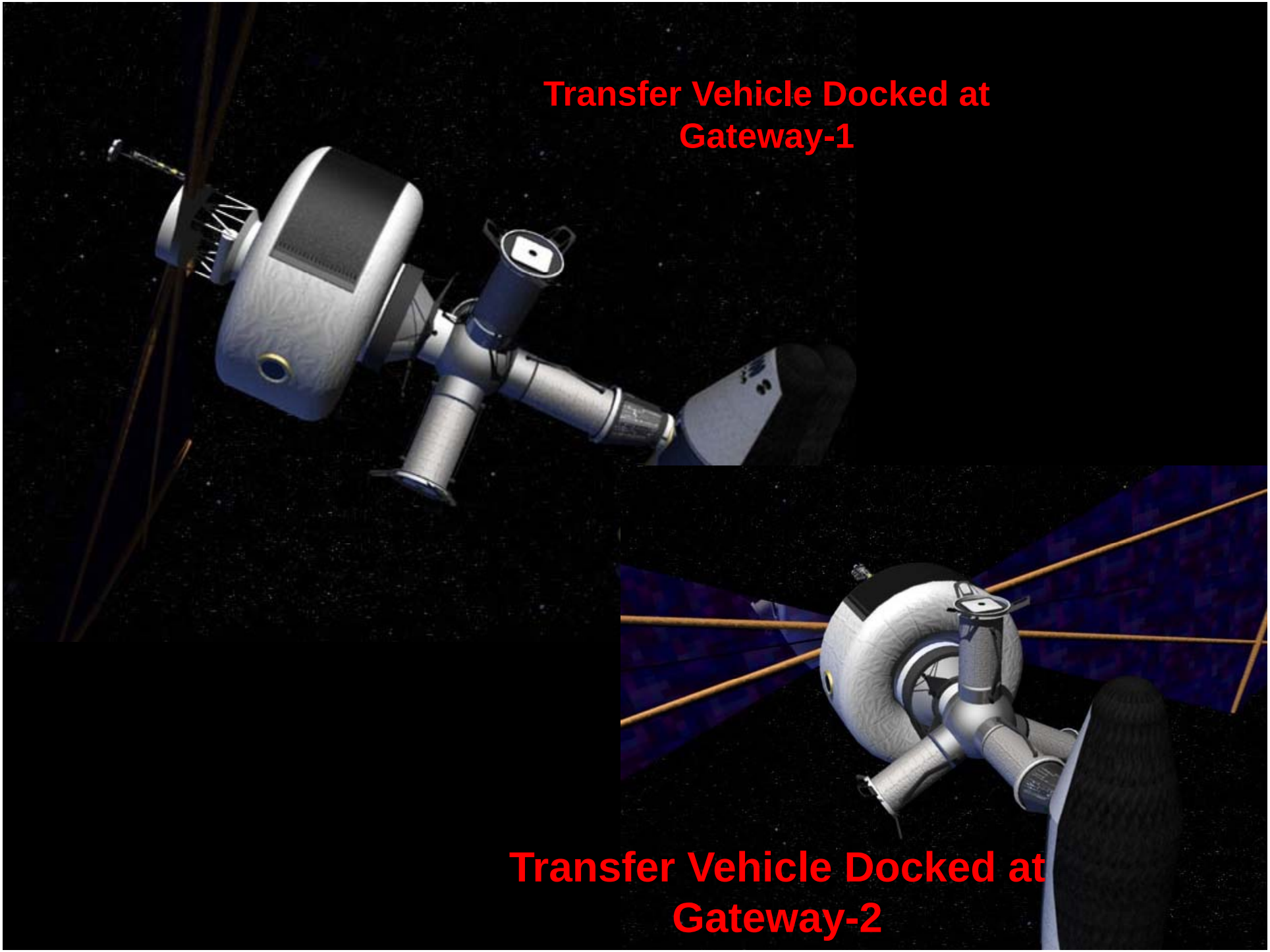
Following Tubes

Lo and Ross

Earth-Moon L1 Gateway Hub



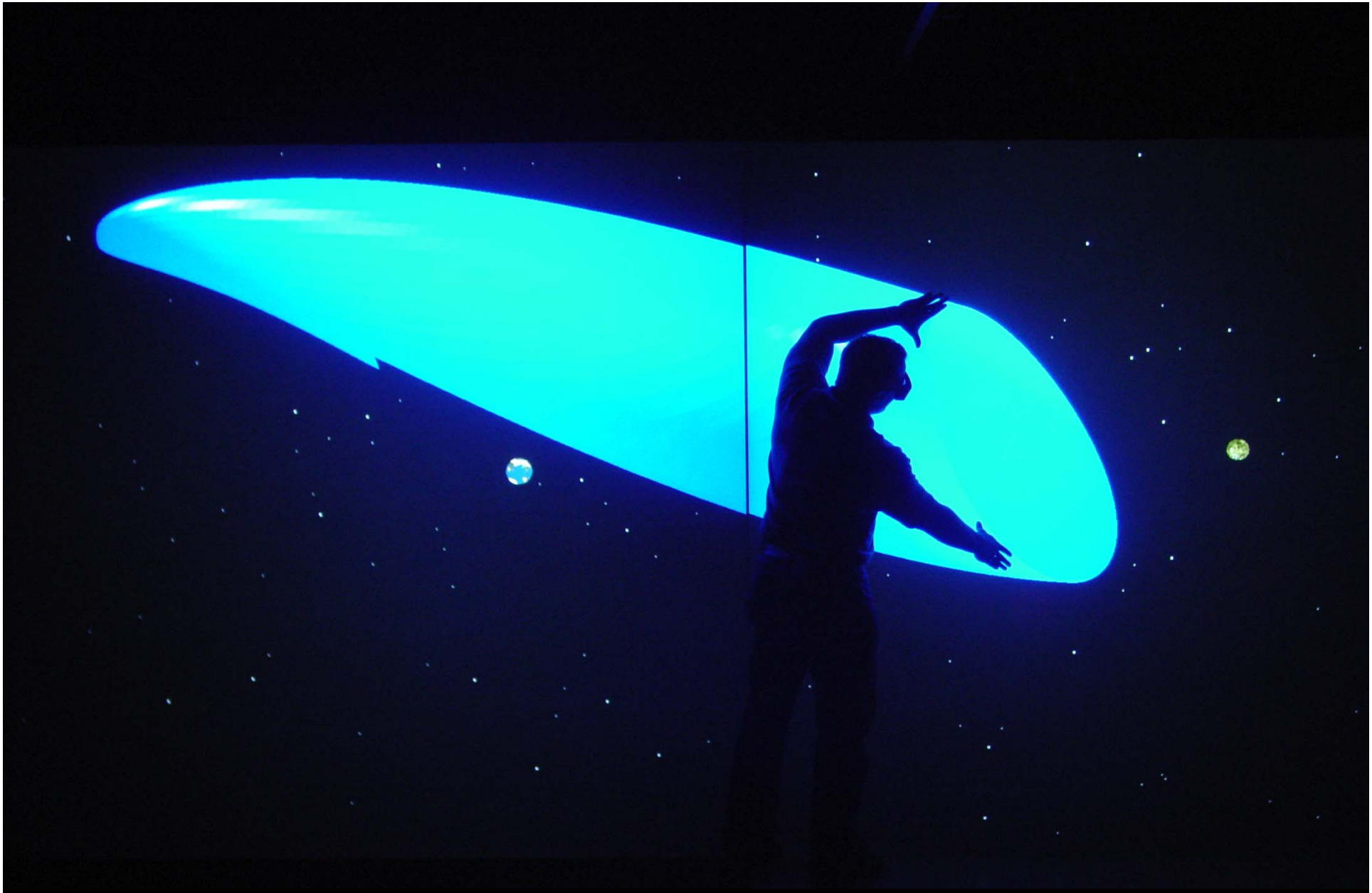
Lander at
Earth-Moon L1
Gateway Station


Transfer Vehicle Docked at Gateway-1
Transfer Vehicle Docked at Gateway-2

InterPlanetary Superhighway (IPS)
Planets; Moons within Planetary Systems

Lo and Ross

Spacecraft Between Earth and Moon Ride on Surfaces in Space
(Ozimek and Howell, Purdue University)



Manifold Surfaces in Earth-Moon System

(Ozimek and Howell, Purdue University)

L1 Gateway Station

We Want You !!!

JOHN SPENCER WITH KAREN L. RUGG

FOREWORD BY SPACE SHUTTLE COMMANDER RICK SEARFOSS