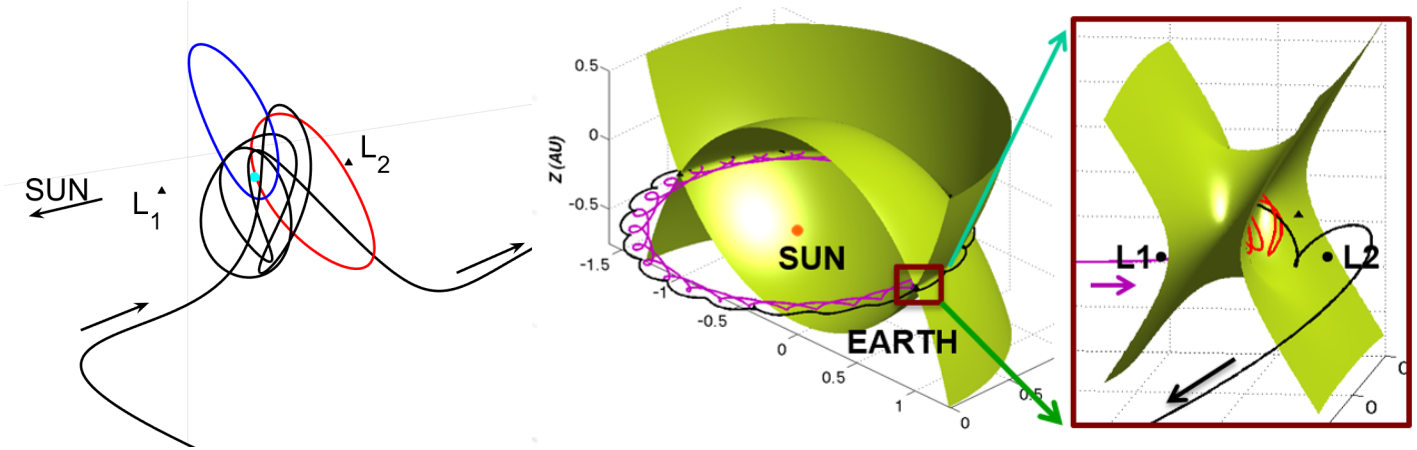

DYNAMICS OF ASTEROID 2006 RH120: PRE-CAPTURE &ESCAPE PHASES

26TH AAS/AIAA SPACE FLIGHT MECHANICS MEETING, NAPA, CA

BRIAN D. ANDERSON, UNIVERSITY OF SOUTHERN CALIFORNIA, LOS ANGELES, CA.

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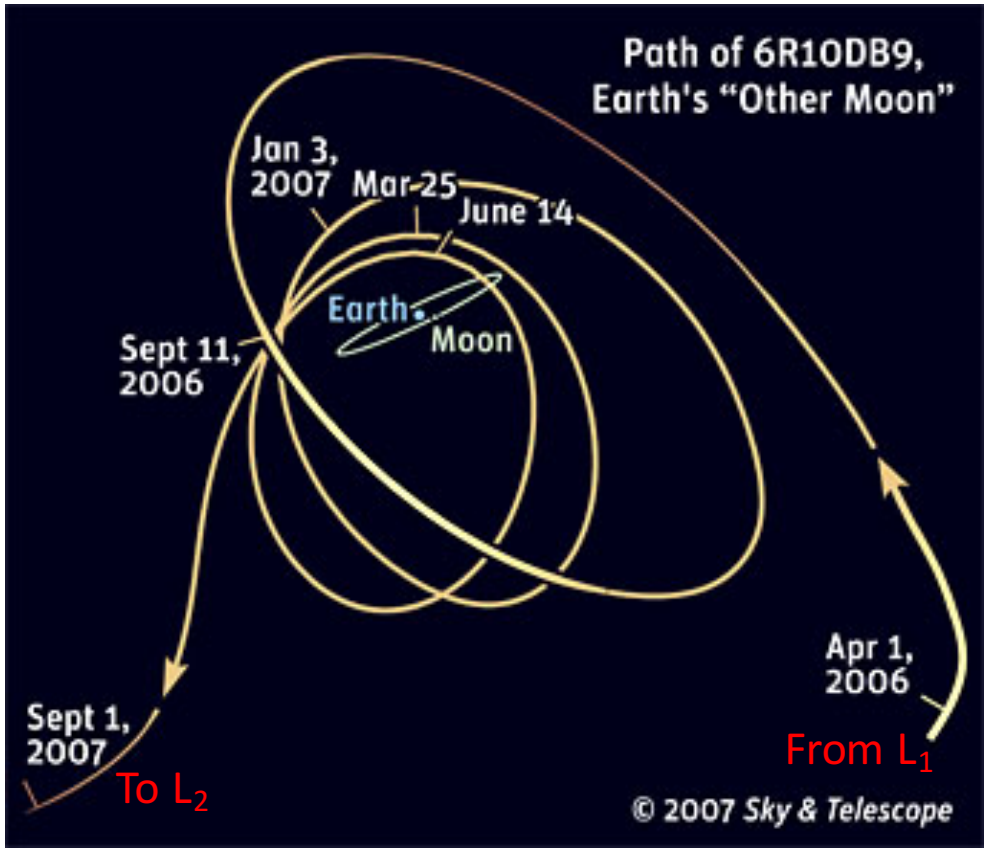
MONDAY, FEBRUARY 15, 2015

Asteroid 2006 RH120 Temporary Capture

- Discovered 14 September 2006
- ~5 m Diameter
- Orbited Earth 3 times
- Closest perigee ~0.7 Lunar Distances
- Perhaps an L_1 to L_2 heteroclinic connection that happens to have multiple Earth revolutions
- Analysis of this segment deferred to a future paper
- Minimoon: Granvik et al. 2012

Sky & Telescope



Data Source: *JPL Horizons*

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Minimoons: Prime Targets for Rendezvous & Retrieval

- Asteroid 2006 RH120 first observed temporary moon of Earth
- Numerical studies indicate that they may be abundant
  - Granvik et al. 2012: Minimoon
  - Astronomers working to verify this NEO population
- Prime targets for potential asteroid rendezvous or retrieval
  - Minimoons have low relative speed during Temporary Capture
  - Would require less ΔV, time, cost for rendezvous or capture into long-term orbit
- We do not fully understand the dynamics involved in Temporary Capture
  - How to identify & locate potential Minimoons inNEO population?
  - What controls capture & escape of Minimoons?

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Circular Restricted Three Body Problem (CRTBP)

Quasi-potential

$$\Omega = \frac{1-\mu}{r_1} + \frac{\mu}{r_2} + \frac{x^2+y^2}{2}$$

$$r_1 = (x+\mu)^2 + y^2 + z^2$$

$$r_2 = (x-1+\mu)^2 + y^2 + z^2$$

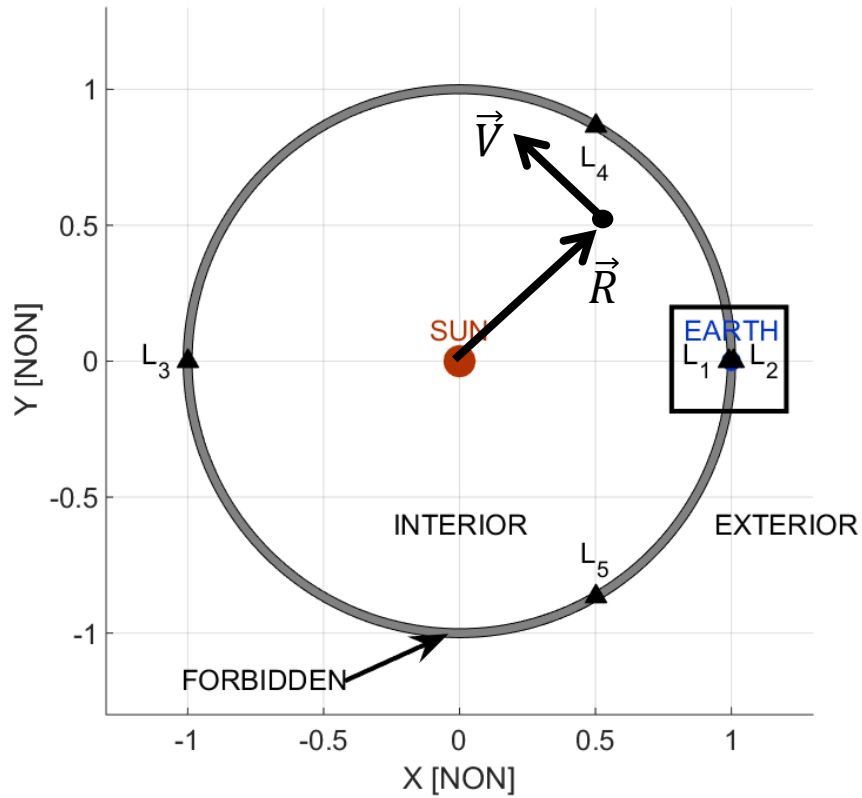
Integral of Motion (Jacobi constant)

$$C = 2\Omega - (\dot{x}^2 + \dot{y}^2 + \dot{z}^2)$$

Equations of Motion

$$\vec{R} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad \vec{V} = \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix}$$

$$\frac{d^2\vec{R}}{dt^2} = \nabla\Omega$$



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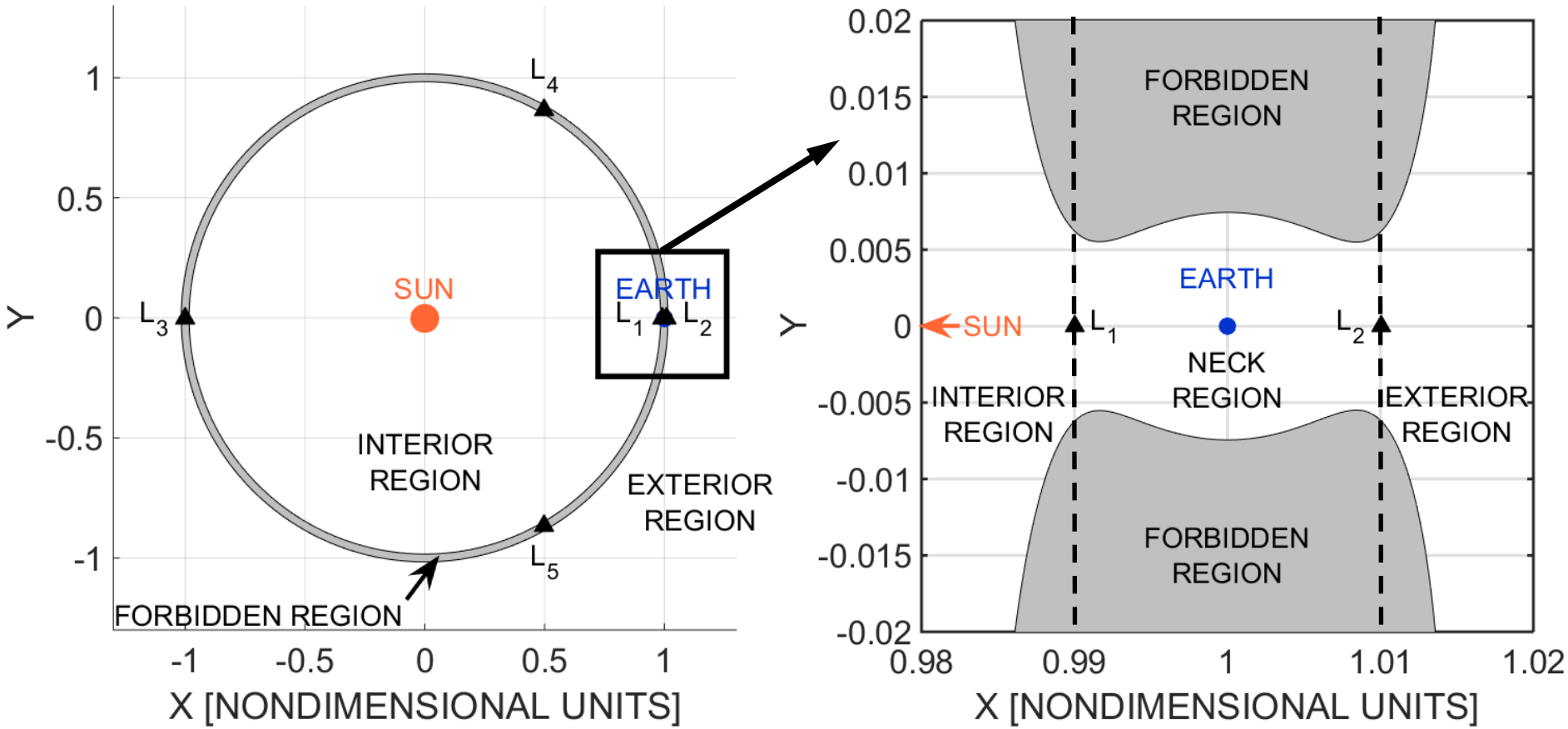
Circular Restricted Three Body Problem (CRTBP)



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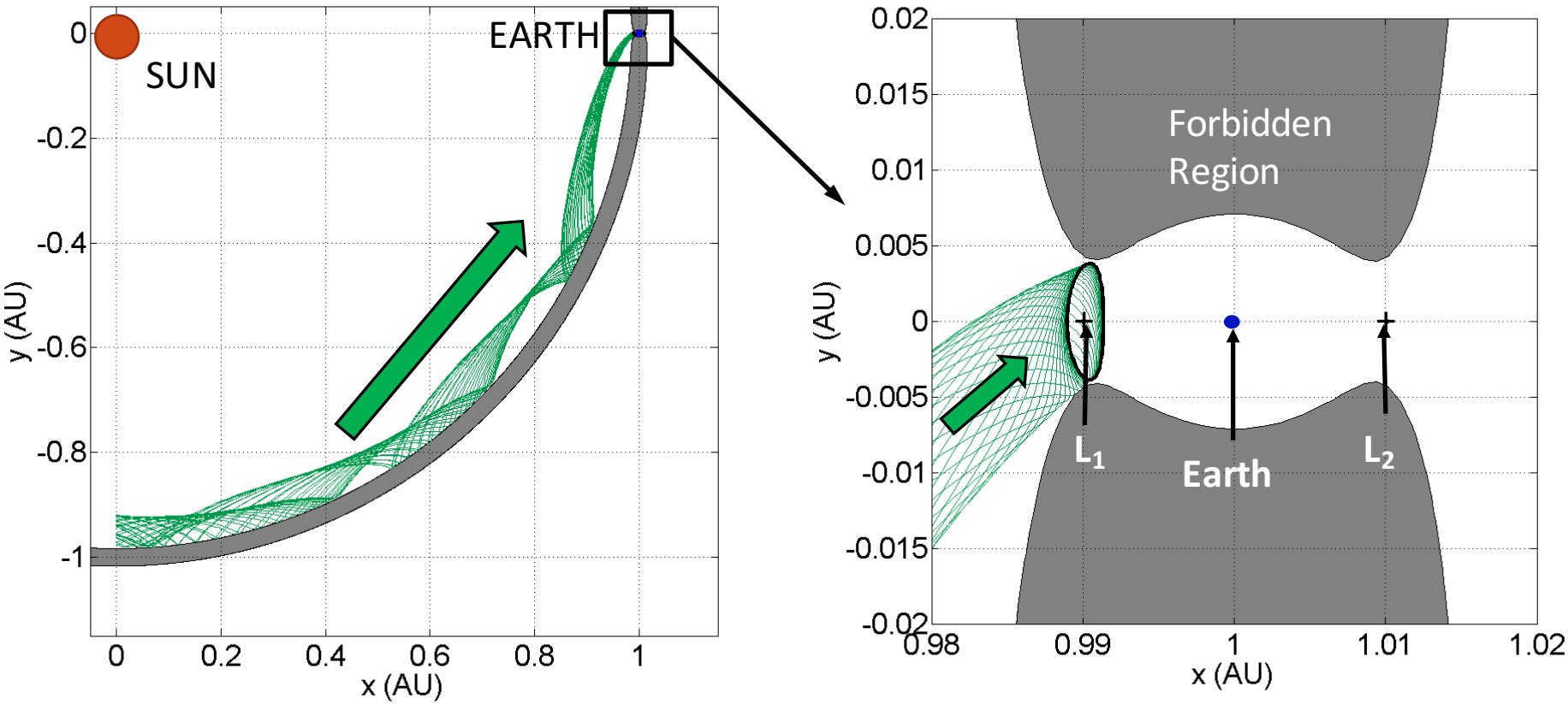
Invariant Manifolds Transit Dynamics



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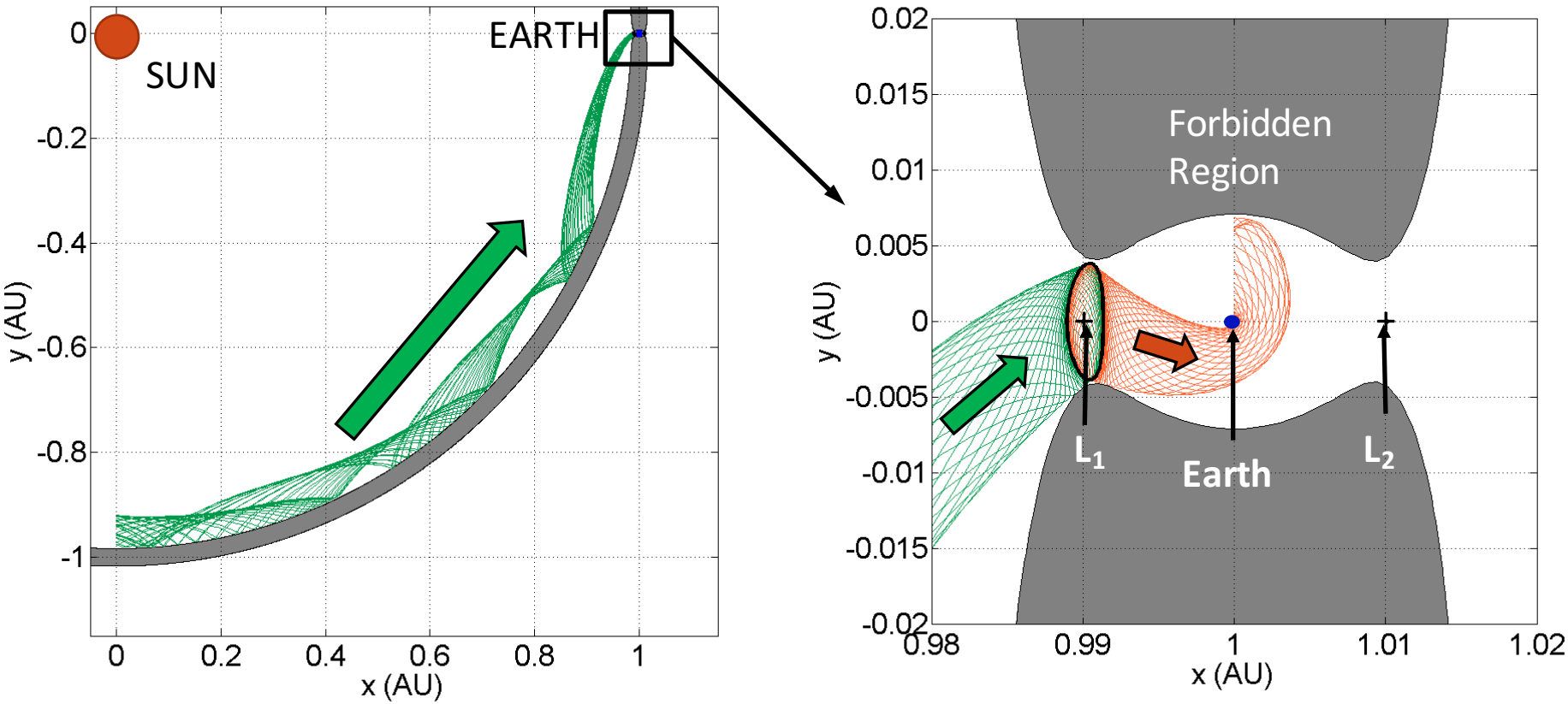
Invariant Manifolds Transit Dynamics



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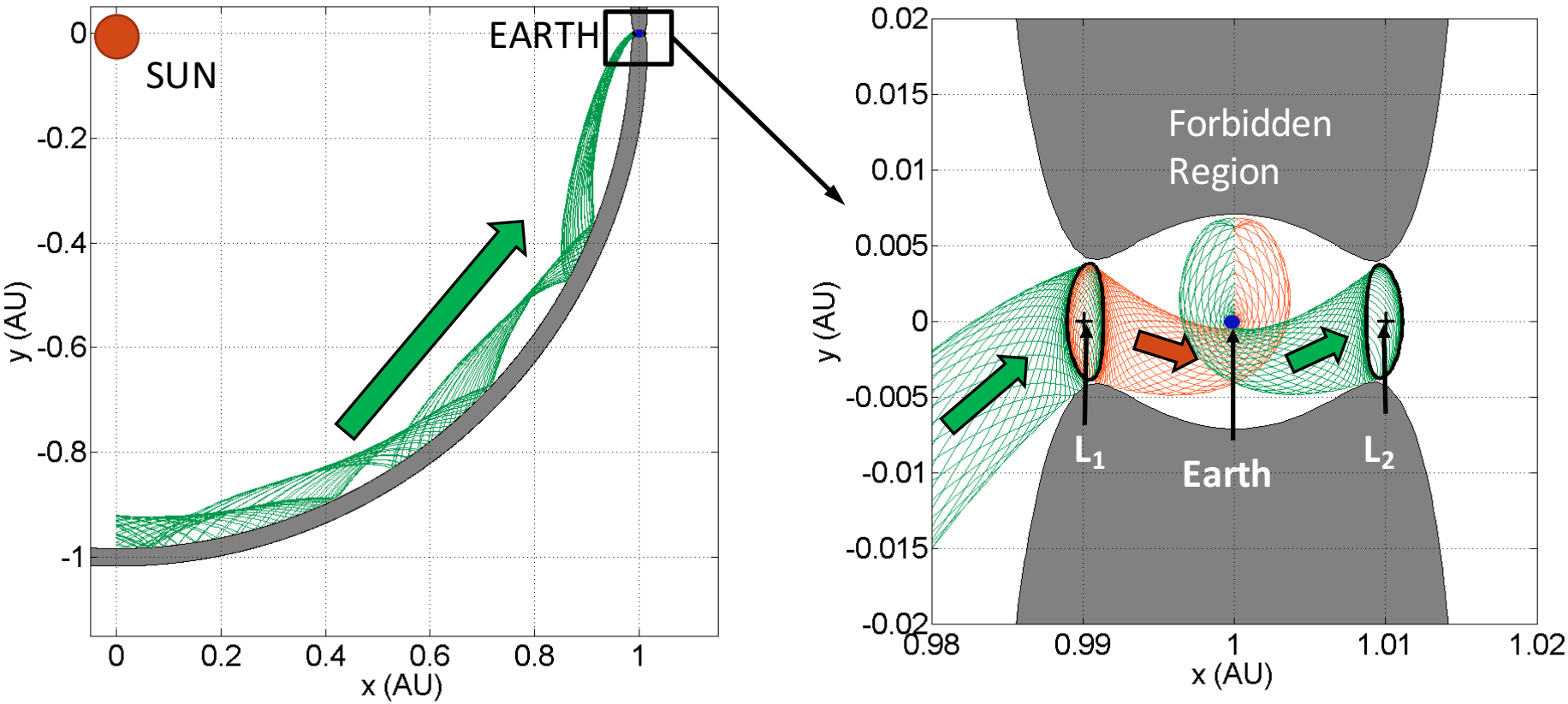
Invariant Manifolds Transit Dynamics



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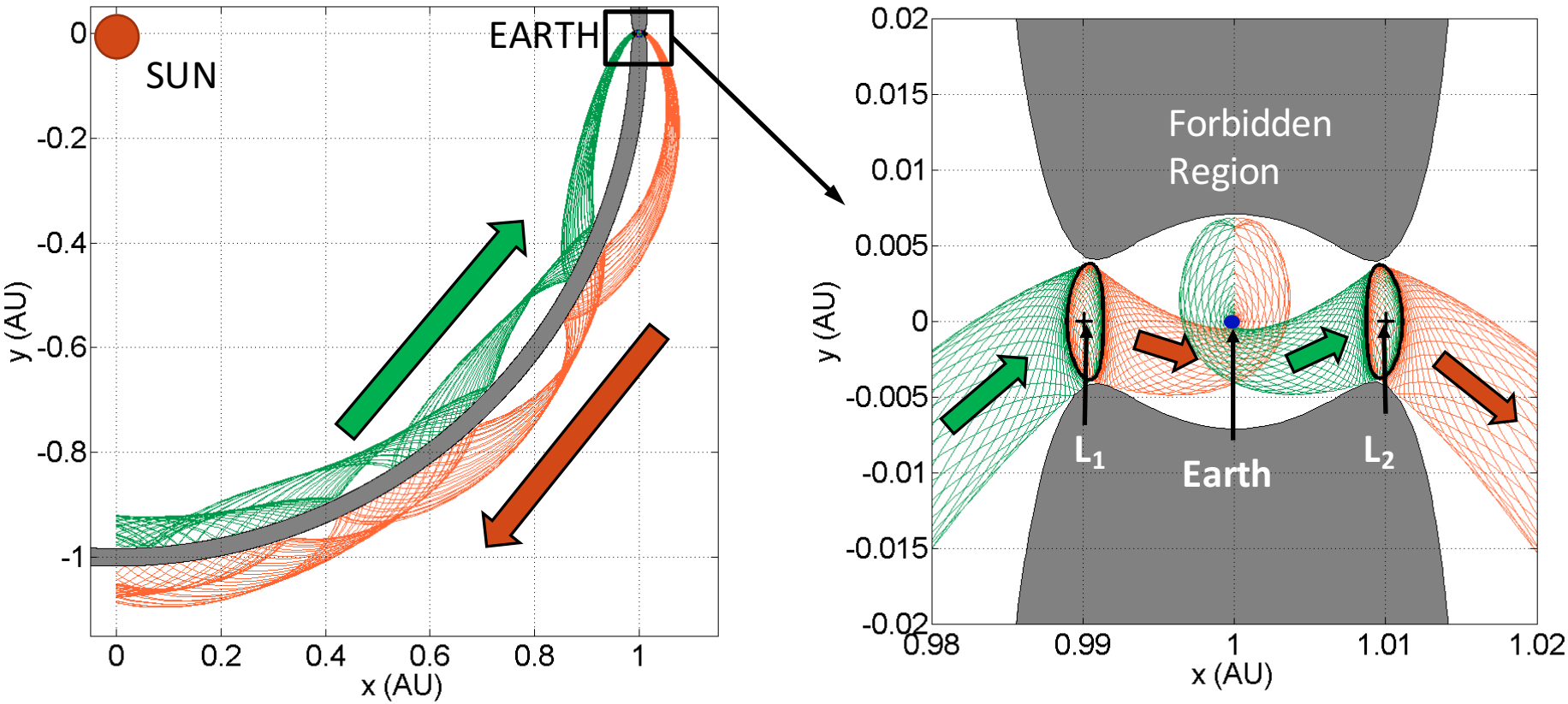
Invariant Manifolds Transit Dynamics



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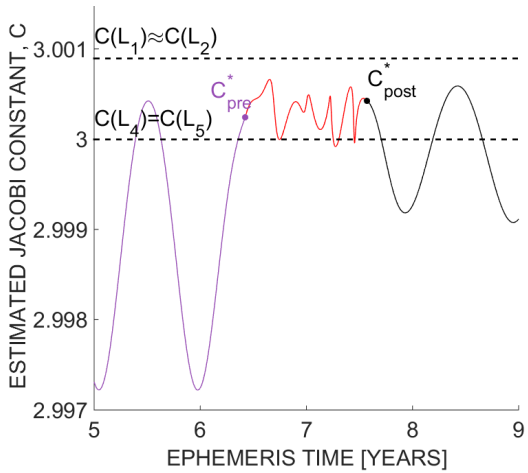
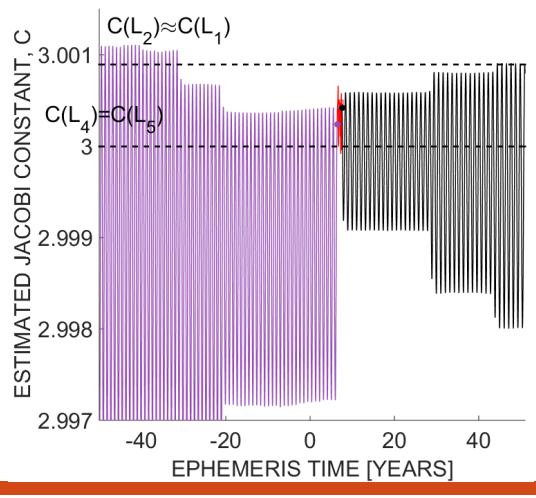
Analysis of Asteroid 2006 RH120





- Convert DE431 Ephemeris data to CRTBP
  - Variable Method
  - Fixed Method
- Estimate Jacobi constant for Pre- and Post-Capture Phases
- Estimate Pre- and Post-Capture Resonances by 2 methods
  - CRTBP method
  - 2 body method
- Match Asteroid trajectory to invariant manifolds of periodic CRTBP orbits

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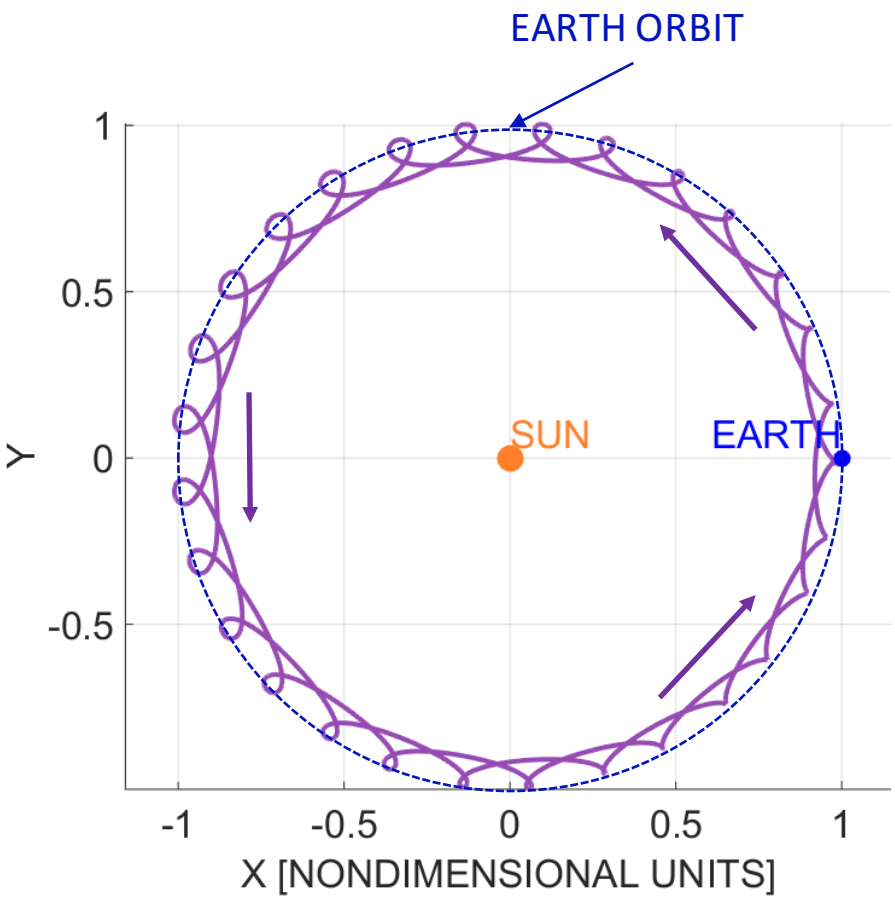
Pre-Capture Resonance



- July 1, 1979 – May 23, 2006
  - Asteroid captured 5/23/2006
  - Crossed L1 plane
- 29 heliocentric orbits
- 27 years
- **29:27 mean motion resonance**
- Previous encounter close enough to switch resonance
- 2-body period indicates 43:40 mean motion resonance
  - unlikely

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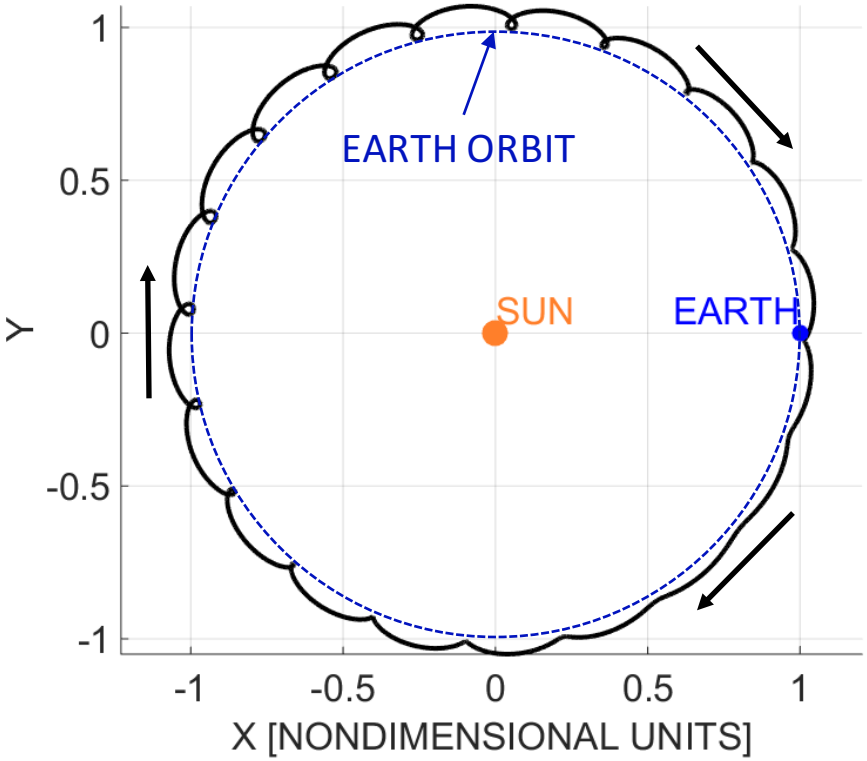
Post-Capture Resonance



- July 28, 2007 – November 1, 2028
  - Asteroid escaped 7/28/2007
  - Crossed L2 plane
- 20 heliocentric orbits
- 21 years
- **20:21 mean motion resonance**
- Future encounter close enough to switch resonance
- 2-body period also indicates 20:21 mean motion resonance

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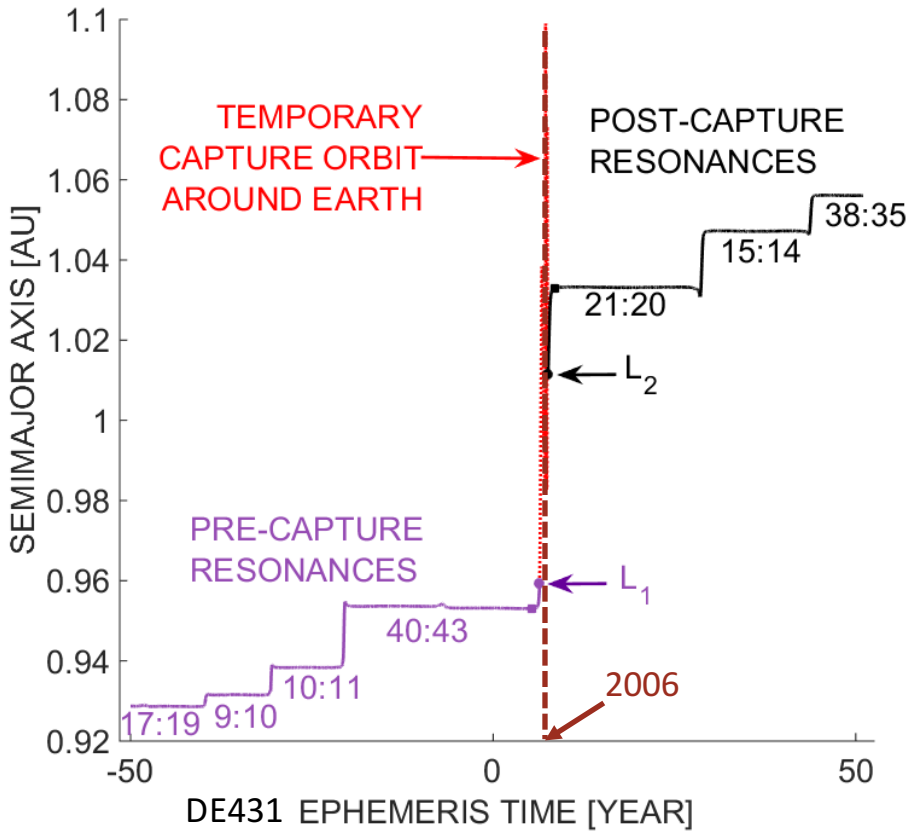
Resonance Hopping



- Resonances approximated 1950-2050
- Keplerian analysis shows several resonance cycles both Pre- and Post-Capture
- Indicates several repeated near-Earth encounters
- Increasing semimajor axis

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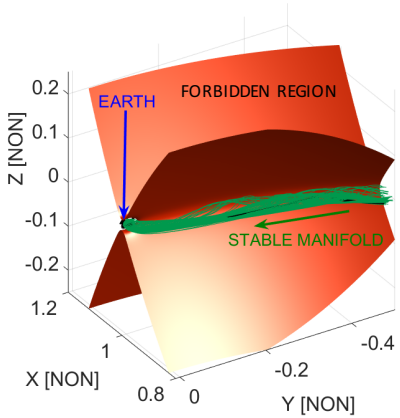
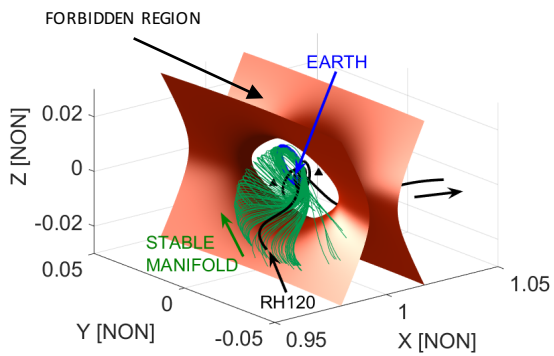
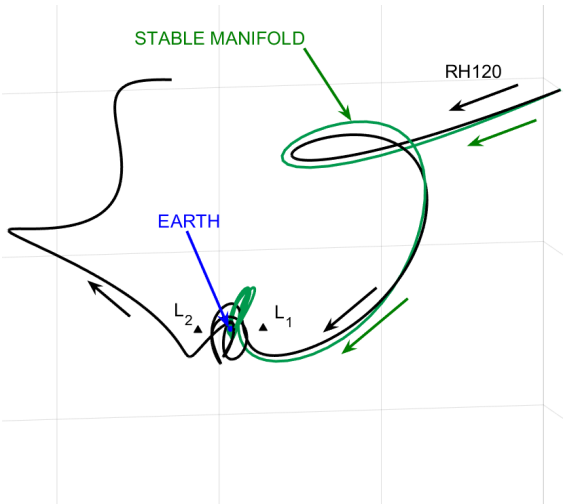
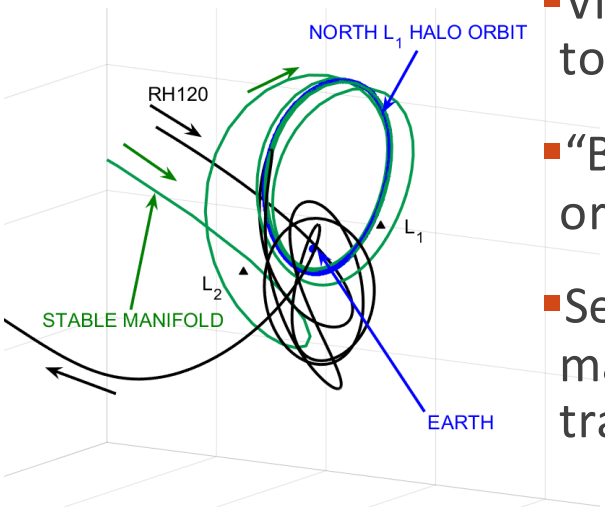
Earth Approach L_1 North Halo Orbit









- Estimated C≈3.000228226120707
- Examined everal L_1 periodic orbits
  - Planar Lyapunov
  - Vertical Lyapunov
  - North/South Halo
- Visually compared stable manifolds to Asteroid trajectory
- "Best" match to Northern Halo orbit
- Selected single trajectory on manifold to match Asteroid trajectory

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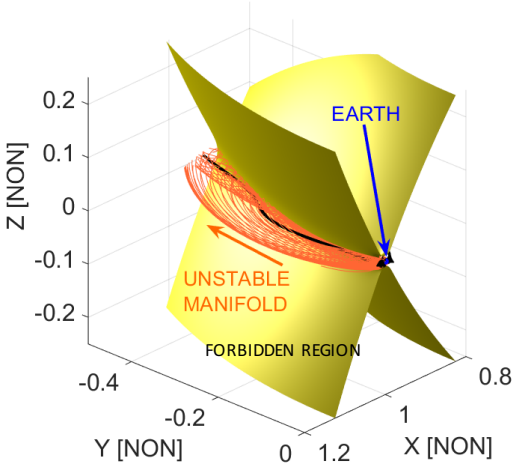
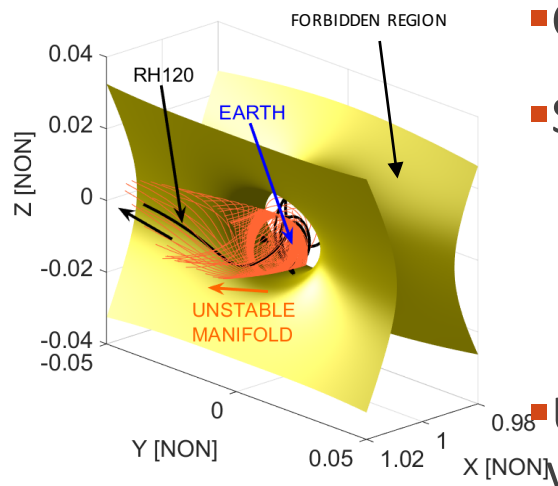
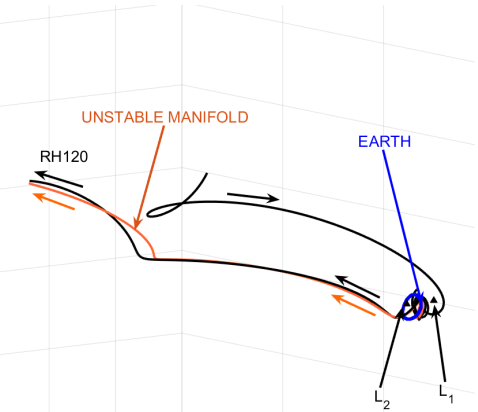
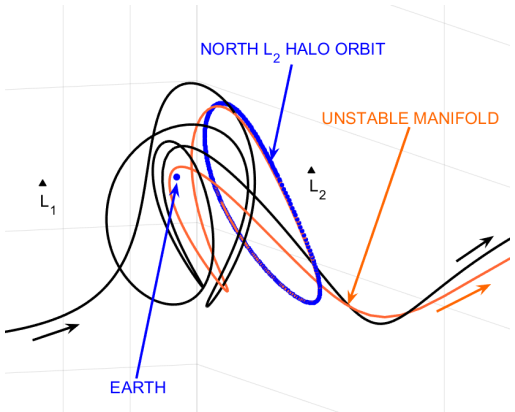
Earth Escape L_2 South Halo Orbit









- C≈3.000425683288712
- Several L_2 periodic orbits found
  - Planar Lyapunov
  - Vertical Lyapunov
  - North/South Halo
- Unstable manifolds compared visually to Asteroid trajectory
- Chosen match to Southern Halo orbit
- Single trajectory on manifold selected

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Conclusions

- Temporary Capture of Asteroid 2006 RH120 seems to be controlled by the invariant manifolds of periodic orbits in the CRTBP
  - Approach through stable manifold of L_1 North Halo Orbit
  - Escape through unstable manifold of L_2 South Halo Orbit
- Resonance cycles between repeated Earth encounters are long with mean motion resonances near 1:1
- Repeated mean motion resonance transitions near 1:1 resonance
  - This allows fortrajectories with low energy levels near libration orbits
  - This enables temporary captures by Earth
- Asteroid had several near encounters in the past and is predicted to have more in the future.
  - Each encounter raises the heliocentric semimajor axis
  - Largest change occurred during Temporary Capture
- We need to develop theories for transit and capture trajectories in the CRTBP at these energy levels.

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Future Work

- Temporary Capture Phase needs further study
- Determine lunar interaction in more detail
  - Earth-Moon CRTBP
  - Sun-Earth-Moon 4 Body Problem
- CRTBP Transit Dynamics need further study

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IMAGE CREDITS

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Backup Slides

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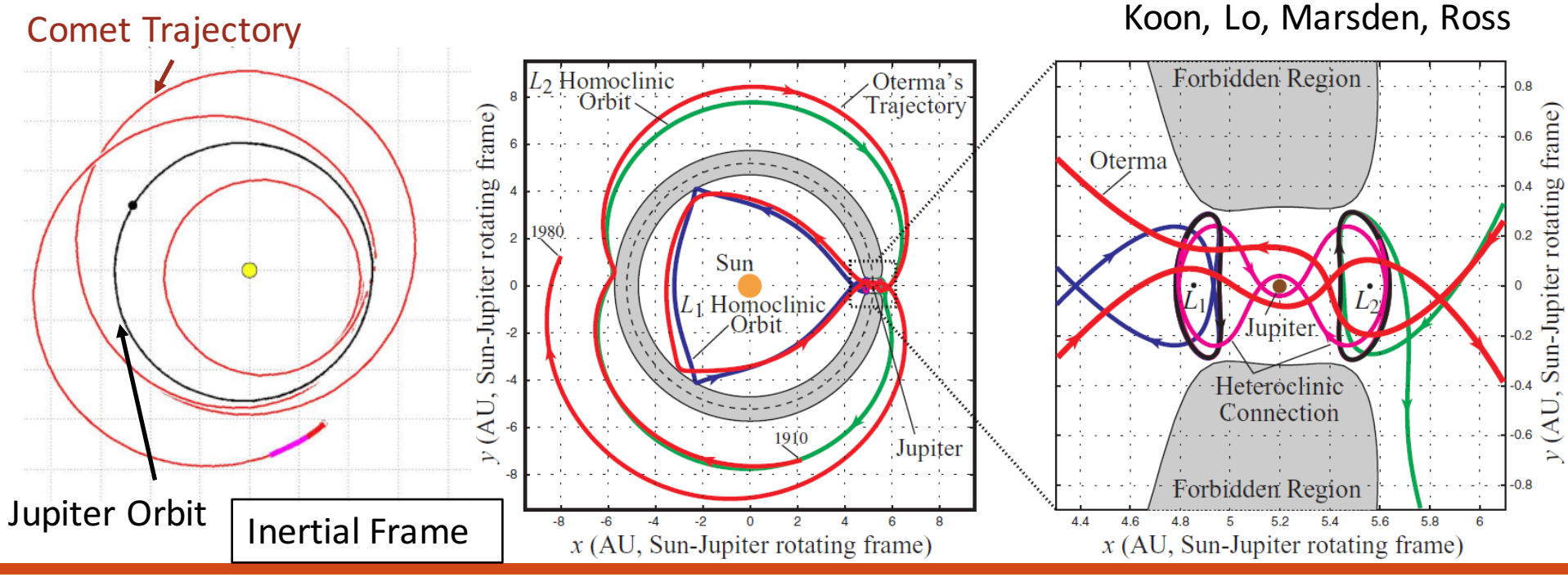
Example of Rapid Orbital Change

- Comet 39P/Oterma
- Repeated "hopping" between resonant orbits
- Heteroclinic connections between resonant orbits make this possible

Koon, Lo, Marsden, Ross



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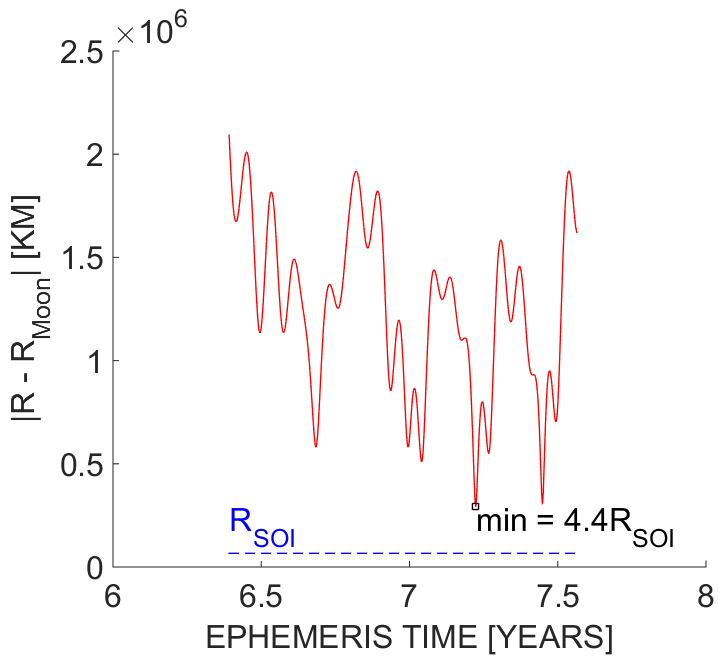
Lunar Interactions



- Lunar interactions during Temporary Capture considered
- Effects causing rapid changes not likely
- Small perturbations allowed to accumulate

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Conversion Method 1

For each t

1) R,V from ephemeris for Earth relative to Sun
2) Set length unit
3) Compute angular velocity
4) Set time and velocity units
5) Select rotating frame axes
6) Assemble Rotation matrix
7) Rotate position and velocity
8) Convert units
9) Adjust origin

1. DE431, $\vec{R}(t), \vec{V}(t)$
2. $LU = |\vec{R}|$
3. $\vec{\omega} = \frac{\vec{R}\times\vec{V}}{LU^2}$
4. $TU = |\vec{\omega}|^{-1}, VU = \frac{LU}{TU}$
5. $\hat{e}_1 = \frac{\vec{R}}{|\vec{R}|}, \hat{e}_3 = \frac{\vec{\omega}}{|\vec{\omega}|}, \hat{e}_2 = \hat{e}_3 \times \hat{e}_1$
6. $Q = \begin{bmatrix} \hat{e}_1 \\ \hat{e}_2 \\ \hat{e}_3 \end{bmatrix}$
7. $\vec{r}_D = Q\vec{r}_D^I, \vec{v}_D = Q\vec{v}_D^I - \vec{\omega} \times \vec{r}_D^I$
8. $\vec{r} = \frac{\vec{r}_D}{LU}, \vec{v} = \frac{\vec{v}_D}{VU}, t = \frac{t_D - t_{D,0}}{TU}$
9. $\vec{r} = \vec{r} + \begin{bmatrix} \mu \\ 0 \\ 0 \end{bmatrix}$

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Conversion Method 2

Once

Reference R,V from ephemeris for Earth relative to Sun for unit conversion

$$\vec{R}^* = \vec{R}(t^*), \vec{V}^* = \vec{V}(t^*), LU = |\vec{R}^*|, \vec{\omega}^* = \frac{\vec{R}^* \times \vec{V}^*}{LU^2}, \; TU = |\vec{\omega}^*|^{-1}, VU = \frac{LU}{TU}$$

For each t

1) R,V from ephemeris for Earth relative to Sun
2) Select rotating frame axes
3) Assemble Rotation matrix
4) Rotate position and velocity
5) Convert units
6) Adjust origin

1. DE431 $\vec{R}(t), \vec{V}(t)$
2. $\hat{e}_1 = \frac{\vec{R}}{|\vec{R}|}, \hat{e}_3 = \frac{\vec{\omega}}{|\vec{\omega}|}, \hat{e}_2 = \hat{e}_3 \times \hat{e}_1$
3. $Q = \begin{bmatrix} \hat{e}_1 \\ \hat{e}_2 \\ \hat{e}_3 \end{bmatrix}$
4. $\vec{r}_D = Q\vec{r}_D^I, \vec{v}_D = Q\vec{v}_D^I - \vec{\omega} \times \vec{r}_D^I$
5. $\vec{r} = \frac{\vec{r}_D}{LU}, \vec{v} = \frac{\vec{v}_D}{VU}, t = \frac{t_D - t_{D,0}}{TU}$
6. $\vec{r} = \vec{r} + \begin{bmatrix} \mu \\ 0 \\ 0 \end{bmatrix}$

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