The Genesis Trajectory and Heteroclinic Cycles

Martin W. Lo, Wang Sang Koon, Shane Ross, Jerrold Marsden
Jet Propulsion Laboratory
California Institute of Technology

The **Genesis Mission** [Lo et al 8/1998] will be NASA's first robotic sample return mission. The purpose of this mission is to collect solar wind samples for two years in an **L_1 halo orbit** and return it to the Utah Test and Training Range (UTTR) for mid-air retrieval by helicopters. This requires the entry at UTTR to occur during daylight hours. However, the natural dynamics of the return to Earth from L_1 halo orbits is for a night side return. In order to achieve a day-side return, it is necessary for the Genesis spacecraft to make an excursion into the region around L_2. This transfer between L_1 and L_2 requires no deterministic maneuvers and is provided by the existence of **heteroclinic cycles**. The Genesis trajectory was designed with the knowledge of the conjectured existence of these heteroclinic cycles. Koon et al has now provided the first semi-analytic construction of such cycles.

A heteroclinic cycle is an **asymptotic orbit** which connects two **periodic orbits**. In the case where the two periodic orbits are identical, the cycle is called homoclinic. Poincare was the first to discover heteroclinic and homoclinic behavior in the three body problem in his celebrated memoir [Barrow-Green]. [McGehee] provided the first existence proof for heteroclinic orbits in the three body problem. [Llbre et al] next computed the first homoclinic orbits about L_1. Recently, [Koon et al] provided the first semianalytic construction of heteroclinic cycles between two periodic orbits around L_1 and L_2. The existence of heteroclinic cycles is extremely interesting because from dynamical systems theory, as first observed by Poincare, these cycles bring about the so-called heteroclinic tangle which causes chaotic motions within the system. Hence the discovery of heteroclinic cycles is equivalent to the demonstration of the existence of chaotic motions.

The complete dynamical picture provides a homoclinic orbit for the L_1 periodic orbit, a heteroclinic orbit connecting two periodic orbits about L_1 and L_2, and finally, a homoclinic orbit around the L_2 periodic orbit. The homoclinic orbits are huge heliocentric orbits. These orbits form the dynamical backbone for the torus of zodiacal dust around the orbit of Earth [Lo and Ross, 1997] which have been observed by IRAS and COBE. This is somewhat ironic as at the turn of the century, it was conjectured that L_1 and L_2 may be responsible for the zodiacal light. However, modern observations indicate that there is no material gathered near these unstable points and it is thought that L_1 and L_2 have nothing to do with zodiacal dust. Now at the end of this millenia, it seems we have come full circle: L_1 and L_2 do exert control over the zodiacal dust cloud, not in the immediate vicinity of the libration points, but in a huge torus around the planet's orbit.

The fact that the Genesis trajectory falls within a chaotic regime of phase space is by no means a surprise. It is because of this dynamics that the Genesis trajectory requires only a single deterministic delta-V of 6 m/s from launch to Earth return. However, this dynamics also explains the sensitive nature of the Genesis trajectory where a slight change to the nominal trajectory can cause the delta-V budget to soar unexpectedly. A deeper understanding of this dynamics is crucial for the success of the Genesis mission and for future applications of this dynamics. This requires a thorough understanding of the heteroclinic and homoclinic orbit structures around L_1 and L_2.

The heteroclinic cycle provides several interesting potential applications for future missions [Lo and Ross, 1998]. First of all, this cycle provides a rapid low-energy dynamical channel between L_1 and L_2 such as used by the Genesis mission. Second, the heteroclinic cycle provides a dynamical mechanism for the temporary capture of objects around the planet without propulsion. This is most clearly demonstrated by the family of Jupiter comets like Oterma or Geherals3. For example, Near Earth Comets or Asteroids might be captured for mining using this low-energy mechanism. Conversely, this same low-energy dynamics may be used to deflect Earth-crossing objects to avoid catastrophic collisions with the Earth. Third, a thorough understanding of this dynamics is essential for an optimal design of any constellations to study the magenetosphere region. The chaotic dynamics may be used to deploy and control the constellation using minimal propulsion. Lastly, an understanding of the resonance structure of this dynamical regime may provide new strategies for low energy planetary captures at Mars or Europa.

References:

Barrow-Green, J., [1997] Poincare and the Three Body Problem, American Mathematical Society

McGehee, R. [1969] Some Homoclinic Orbits for the Restricted Three Body Problem, Ph.D. Thesis, University of Wisconsin

Llbre, J., R. Martinez, C. Simo [1985] Transversality of the Invariant Manifolds Associated to the Lyapunov Family of Periodic Orbits Near L2 in the Restricted Three-Body Problem, Journal of Differential Equations 58, 1985, 104-156.

Koon, W.S., Lo, M., Ross, S., Marsden, J., [1999], Heteroclinic Connections between Liapunov Orbits and Resonance Transitions in Celestial Mechanics, draft

Lo, M., et al, [1998] Genesis Mission Design, AAS/AIAA Astrodynamics Conference, Boston, MA, August 1998, Paper AIAA 98-4468

Lo, M., and Ross, S., [1997], SURFing the Solar System: Invariant Manifolds and the Dynamics of the Solar System, JPL IOM 312/97.

Lo, M., and Ross, S., [1998], Low Energy Interplanetary Transfers Using Invariant Mnaifolds of L_1 and L_2 and Halo Orbits, AAS/AIAA Space Flight Mechanics Meeting, Monterey, CA, Feb 9-11, 1998.