Jovian Tour Design for Orbiter and Lander missions to Europa

Stefano Campagnola (JAXA/ISAS),
Brent B. Buffington, Anastassios E. Petropoulos (NASA/JPL)

When in the late 1990s the Galileo spacecraft found compelling evidence of an ocean of liquid water beneath Europa's icy shell, the Galilean moon surged as one the most interesting bodies in the solar system, as it may possess all the ingredients for extraterrestrial life.

For this reason, over the last decade NASA and ESA have studied a variety of mission concepts dedicated to the exploration of Europa[1, 2, 3, 4, 5], often finding that the estimated costs or risks where too high for the current technological and budgetary constraints. Following the recommendation in the Planetary Decadal Survey[6] however, NASA commissioned a new study for three de-scoped missions: a flyby mission, an orbiter mission, and a lander mission[7]. This paper presents trajectory options for the lander and for the orbiter missions, while the trajectory design for the flyby option was presented in a previous work[8].

Using a new design approach for the last part of the moon tours, the final Δv cost and the radiation dose are efficiently minimized. The rest of the tour is then designed backward in time to patch the arrival conditions at the Jupiter system.

Low levels of radiation dose are achieved by minimizing the number of phasing loops in the transfer between Ganymede and Europa, while satisfying the mission requirements and constraints at Europa Orbit Insertion (EOI). This approach was further exploited in the development of the "Banzai-pipeline"[5].

Low Δv costs are achieved using low-energy transfers. In particular, multi-body dynamics are exploited to transfer the spacecraft from Callisto to Europa via high-altitude Ganymede flybys. In the orbiter mission design, Tisserand-leveraging maneuvers[9] and low-energy capture further reduce the Δv requirements.

Figure 1 shows the lander tour 12-L01, including the trajectory plot and the time history of the distance from Jupiter and of the accumulated dose. Table 1 shows details of the flybys and of the deep space maneuvers.

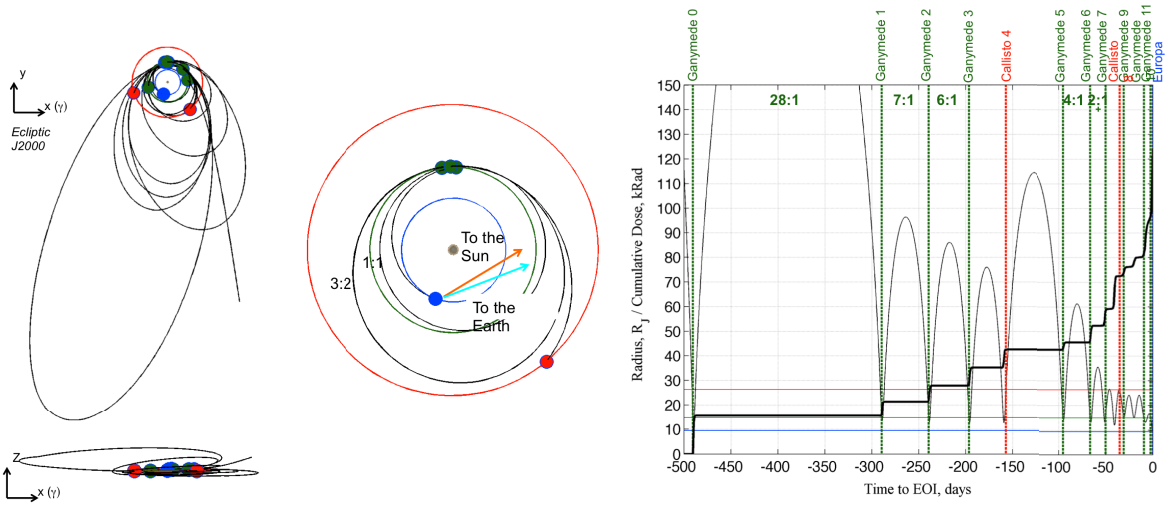

Figure 1: Europa lander trajectory

Figure 2 shows the final Europa approach of the orbiter tour 11-O02. In this particular example, the spacecraft is temporarily captured around Europa to add a redundant option for EOI. Table 2 compare the Δv and radiation dose of the last part of tour 11-O02 to other trajectory options in literature[10, 4].

Table 1: Lander 12-L01

EVENT	DATE (ET Calendar)	DSM Δv (km/s)	FLYBY v∞ (km/s)	Alt. (km)	In /Out
Ganymede 0	2028 APR 03 06:23:42		9.218	500	In
JOI	2028 APR 03 16:48:10	0.839			
PJR	2028 JUN 26 17:48:59	0.162			
Ganymede 1	2028 OCT 21 06:22:24		5.698	294	In
DSM	2028 NOV 15 07:26:46	0.007			
Ganymede 2	2028 DEC 10 08:31:35		5.629	185	In
DSM	2028 DEC 31 19:43:06	0.005			
Ganymede 3	2029 JAN 22 06:48:18		5.595	109	In
Callisto 4	2029 MAR 02 13:49:54		6.314	200	Out
DSM	2029 APR 02 14:12:58	0.005			
Ganymede 5	2029 MAY 03 11:41:02		3.806	205	In
Ganymede 6	2029 JUN 01 01:59:33		3.814	559	In
Ganymede 7	2029 JUN 17 10:33:28		3.715	2170	Out
Callisto 8	2029 JUL 02 15:23:51		1.816	2879	In
Ganymede 9	2029 JUL 06 20:19:05		1.489	15818	In
DSM	2029 JUL 12 00:14:13	0.017			
Ganymede 10	2029 JUL 28 10:32:00		1.347	581	In
Ganymede 11	2029 AUG 04 09:29:41		1.396	3970	In
EOI	2029 AUG 06 15:37:13	1.076		50	

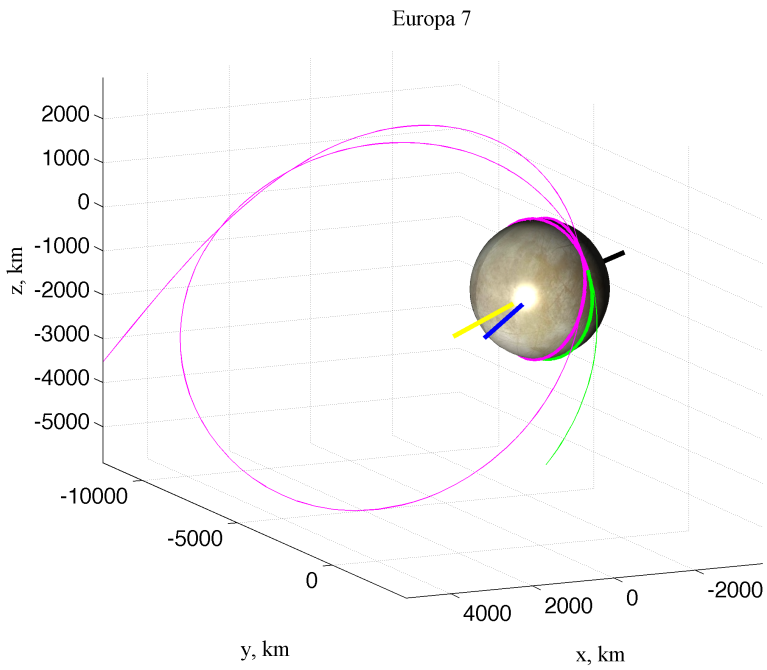

Figure 2: Europa orbiter - gravitational capture at Europa

Table 2: Comparison of the endgames of three orbiter options. 11-O02 is presented in this paper. *Numerically integrated. $^{+}$ Patched-conics.

	Δv	Radiation dose
99-35*	650 m/s	0.95 Mrad
08-008^{+}	846 m/s	0.85 Mrad
11-O02*	**635 m/s**	**0.75 (+0.07) Mrad**

References

[1] J. R. Johannesen and L. A. D'Amario, "Europa Orbiter Mission Trajectory Design," *Advances in the Astronautical Sciences*, Vol. 103, part, 1999, pp. 895–908.

[2] M. Khan, S. Campagnola, and M. Croon, "End-to-End Mission Analysis for a Low-Cost, Two-Spacecraft Mission to Europa," *Advances in the Astronautical Sciences*, Vol. 119, PartI, Univelt, San Diego, 2004, pp. 463–472.

[3] G. Whiffen and T. Lam, "The Jupiter Icy Moons Orbiter Reference Trajectory," 2006.

[4] K. W. Kloster, A. E. Petropoulos, and J. M. Longuski, "Europa Orbiter tour design with Io gravity assists," *Acta Astronautica*, Vol. 68, Sept. 2010, pp. 931–946, 10.1016/j.actaastro.2010.08.041.

[5] T. P. McElrath, S. Campagnola, and N. J. Strange, "Riding the Banzai Pipeline at Jupiter : Balancing Low ΔV and Low Radiation to Reach Europa," *AIAA/AAS Astrodynamics Specialist Conference 13 - 16 August 2012, Minneapolis, MinnesotaAIAA 2012-4809*, No. August, 2012, pp. 1–13, 10.2514/6.2012-4809.

[6] NRC, *Vision and Voyages for Planetary Science in the Decade 2013-2022.* 2012.

[7] Europa Study Team, "EUROPA STUDY 2012 REPORT," tech. rep., May 2012.

[8] B. B. Buffington, S. Campagnola, and A. E. Petropoulos, "Europa multiple-flyby trajectory design," *AIAA/AAS Astrodynamics Specialist Conference 13 - 16 August 2012, Minneapolis, Minnesota AIAA 2012-5069*, No. August, 2012, 10.2514/6.2012-5069.

[9] S. Campagnola, A. Boutonnet, J. Schoenmaekers, D. J. Grebow, A. E. Petropoulos, and R. P. Russell, "Tisserand-leveraging transfers," *AAS 12-185 AAS/AIAA Space Flight Mechanics Meeting, Charleston, SC*, 2012.

[10] A. F. Heaton, N. J. Strange, J. M. Longuski, and E. P. Bonfiglio, "Automated design of the Europa Orbiter tour," *Journal of Spacecraft and Rockets*, Vol. 39, No. 1, 2002, pp. 17–22.