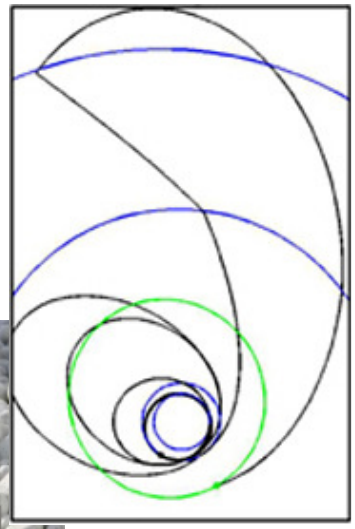
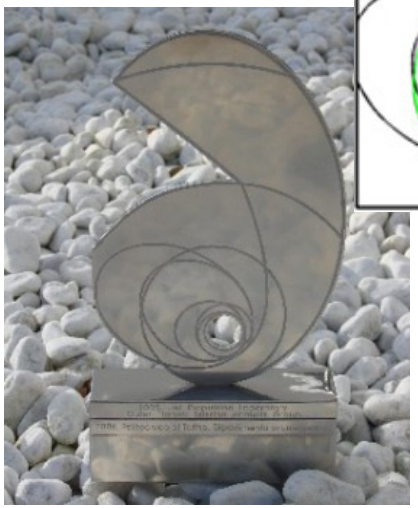
The Competition: GTOC

GTOC: Global Trajectory Optimisation Competition

- Like the "World Cup" in space orbit design
- A yearly / bi-yearly competition
- First organized by the Advanced Concepts Team of the European Space Agency (ESA) in 2005
- A common platform for researchers and engineers to test and improve their skills and tools
- HUMAN vs COMPUTER ?



GTOC1 Winning Trajectory



The GTOC Trophy

Contact

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More info:

http://sophia.estec.esa.int/gtoc_portal/

The Past GTOCs

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2012	GTOC6 – Global mapping of Galilean Moons	???	34

Winner organizes the next competition…

Challenge...and Response

Challenge

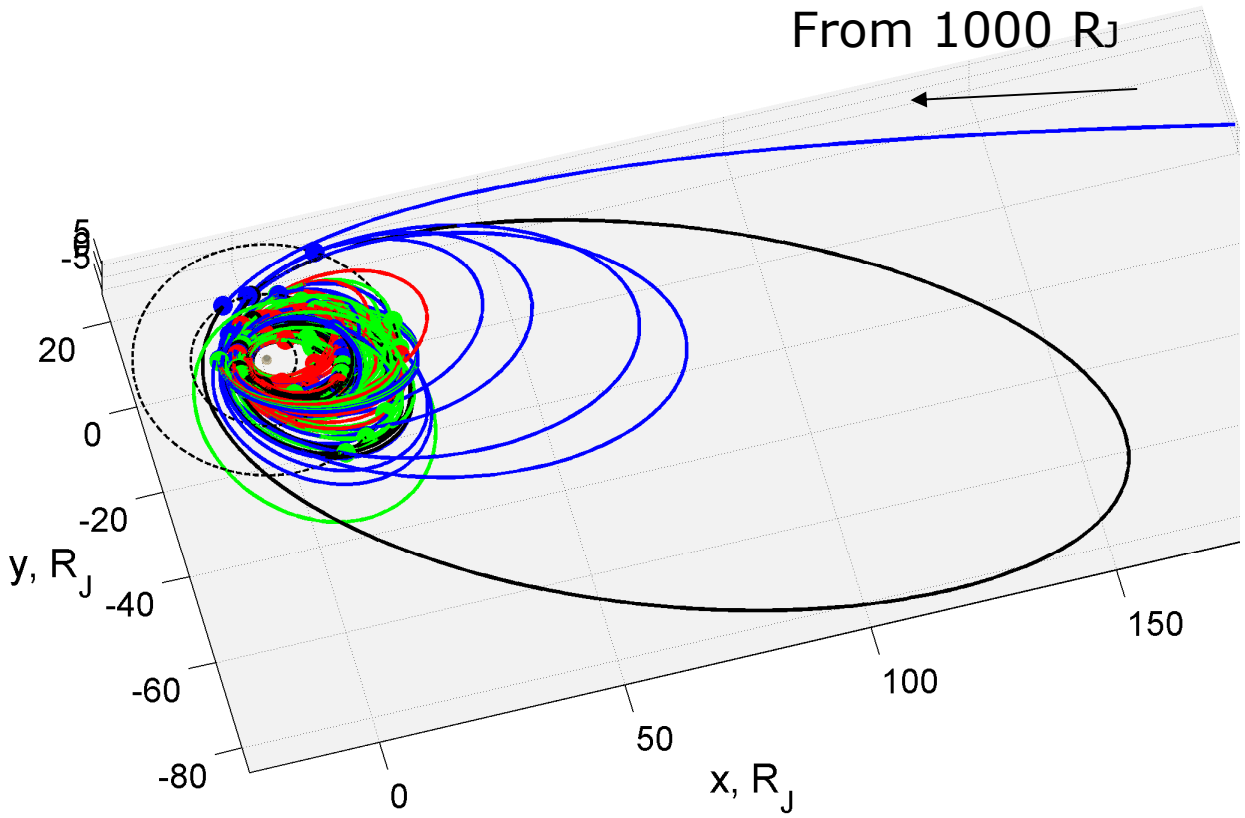
- Non-typical problem (no "can" solution / algorithm available)
- Very complex (many different possibilities)

3. Only 1 month to solve and return a solution

Methodology

1. Make smart approximation and decision in the tree search
2. Develop models to check whether a point is inside a soccer grid or not
3. Accurate calculations on the final low-thrust trajectory

Our Solution



Red: high scores, Green: mid, Blue: low

Score 308
141 flybys at the moons

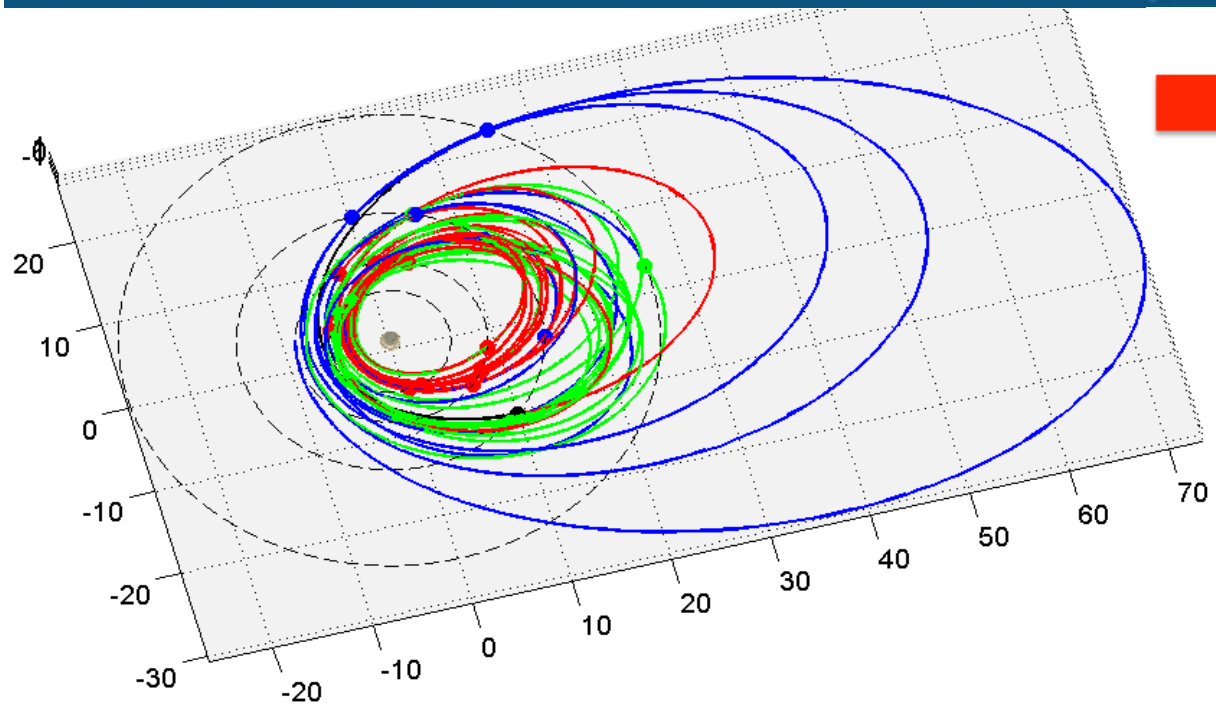
Io: 31/32 faces
Europa: 31/32 faces
Ganymede: 31/32 faces
Callisto: 23/32 faces

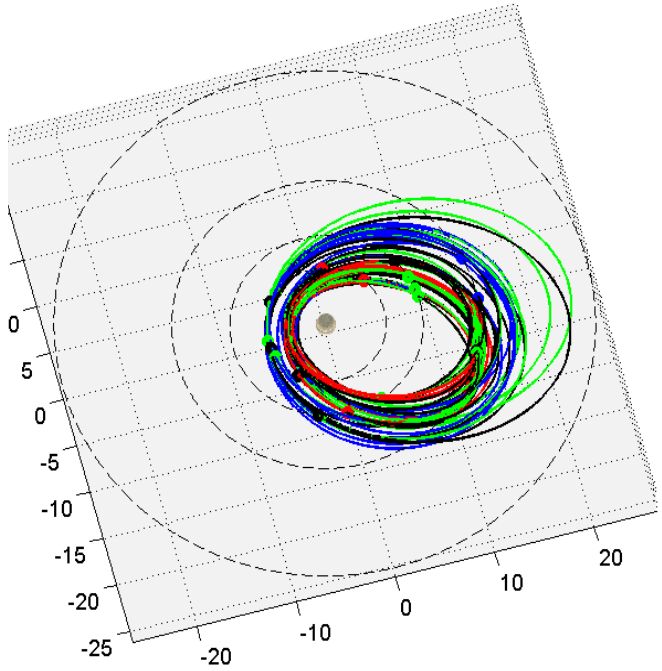
Departure: December 2020

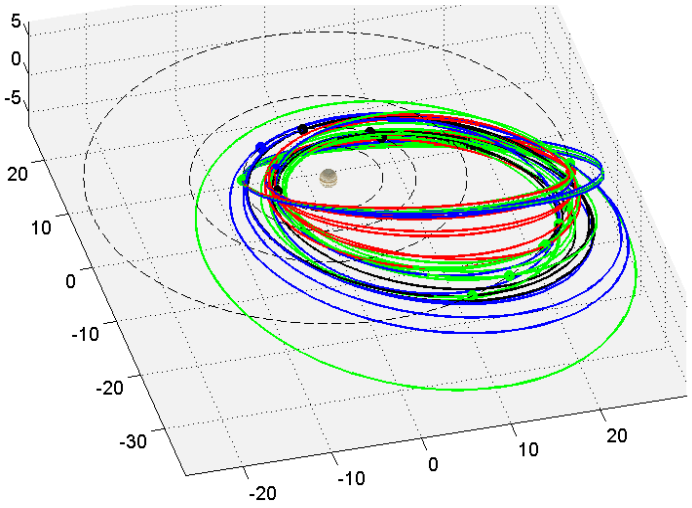
Total flight time: 4 years

Mass expenditure: 999.6 kg

Tour de Jupiter's Moons







Score 308
141 flybys at the moons
Total time: 4 years

GTOC6 Ranking

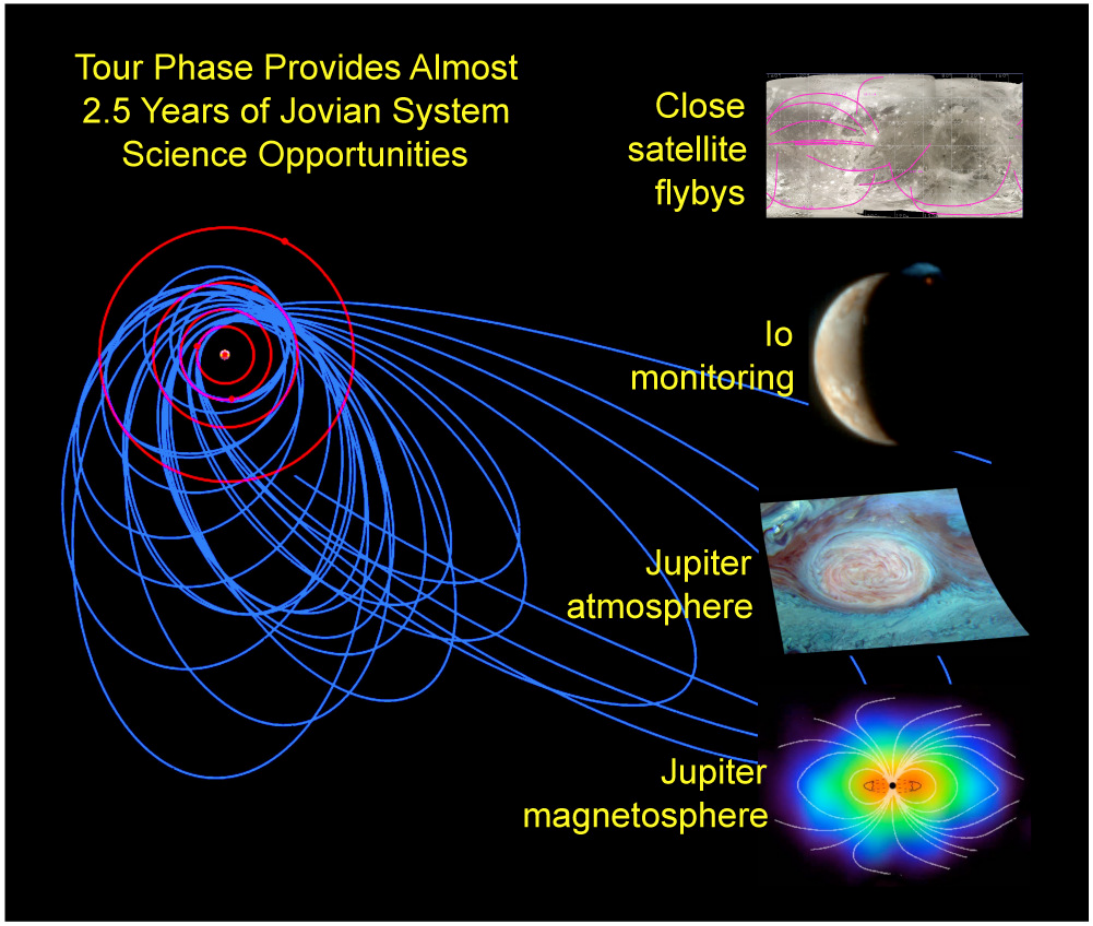
Score

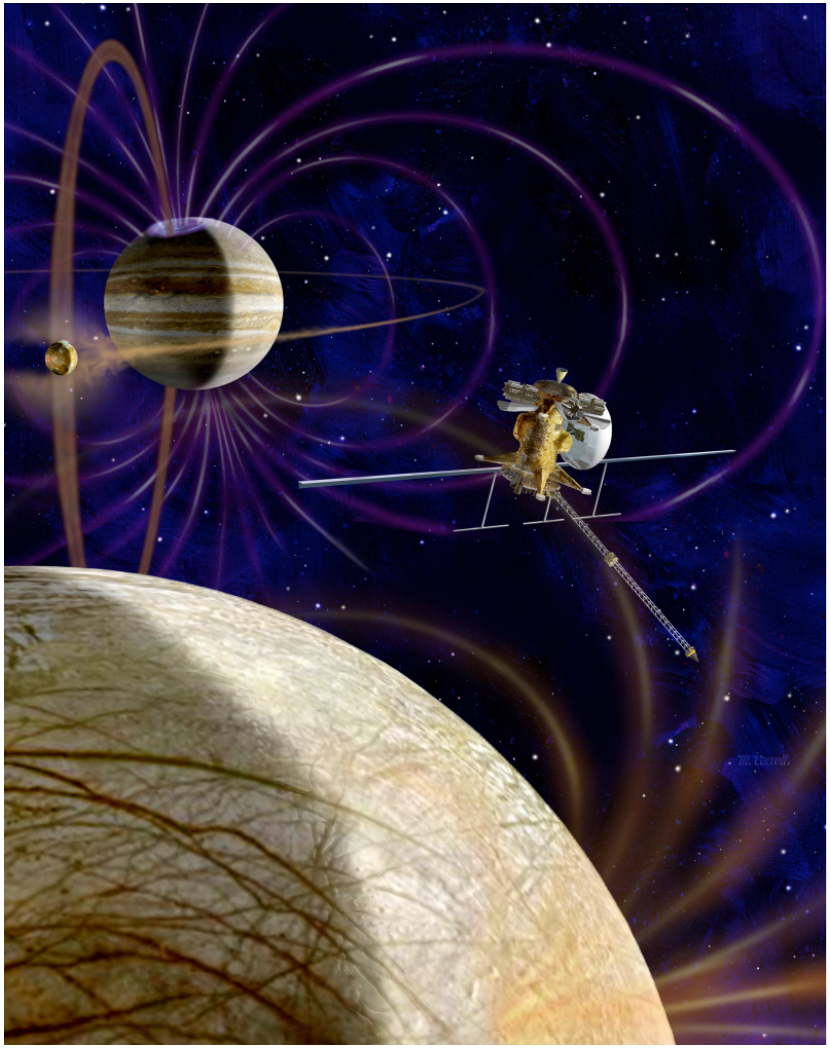
Rank	J	#Fby	Team	
1	311	123	Team 5	Politecnico di Torino & U. di Roma "Sapienza" Italy
2	308	141	Team 6	ESA-ACT & Hong Kong Univ. of Science and Technology
3	267	98	Team 2	University of Texas at Austin, USA
4	246	126	Team 4	DLR, Germany
5	240	103	Team 8	State Key Laboratory & Chinese Academy of Sciences
6	178	92	Team 28	Analytical Mechanics Associates, Inc., USA
7	176	84	Team 14/9	Tsinghua University, China
8	163	137	Team 10	The Aerospace Corp., USA
9	154	83	Team 18	University of Colorado, Boulder, USA
10	87	53	Team 3	U. of Jena, Germany & TU Delft, The Netherlands
11	83	23	Team 21	Beihang University, Beijing, China
12	73	17	Team 15	University of Hawaii at Manoa, USA
13	15	3	Team 1	Michigan Technological University, USA
consequential violations in altitudes and dynamics				
	18	10	Team 26	Peking University, Beijing, China
incomplete or discontinuous trajectories or other severe violations				
	xx	~3	Team 13	University of Trento, Italy
	xx	2	Team 24	Francesco Santilli, Turin, Italy

Possible Applications…

NASA's Jupiter Europa Orbiter (JEO) Mission Concept

Proposed launch in 2020



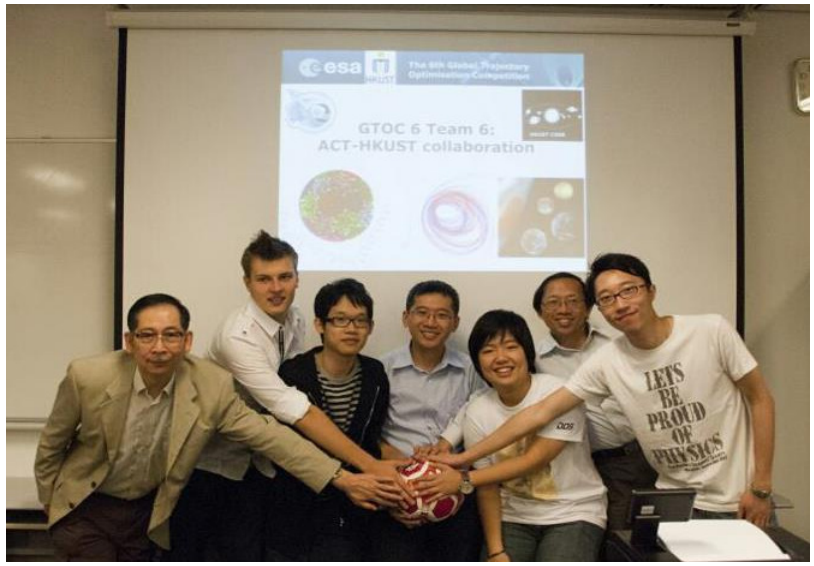


Credit: NASA JEO mission concept:
http://opfm.jpl.nasa.gov/europajupitersystemmissionejsm/jupitereuropaorbiterconcept/

The ESA-HKUST Joint Team

Advanced Concepts Team

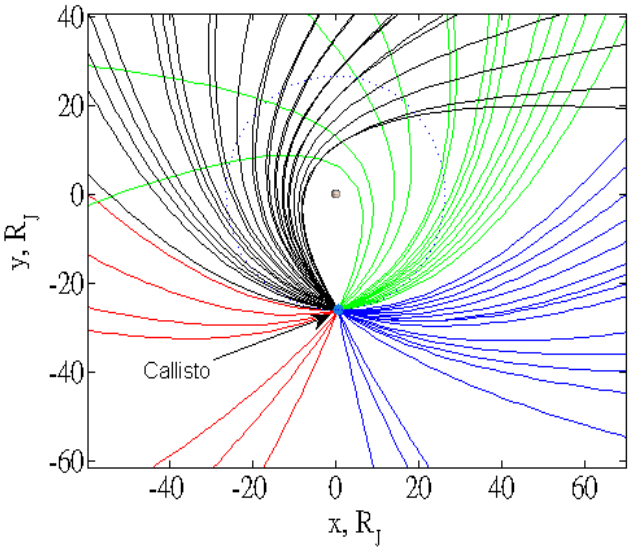
Center for Space Science Research

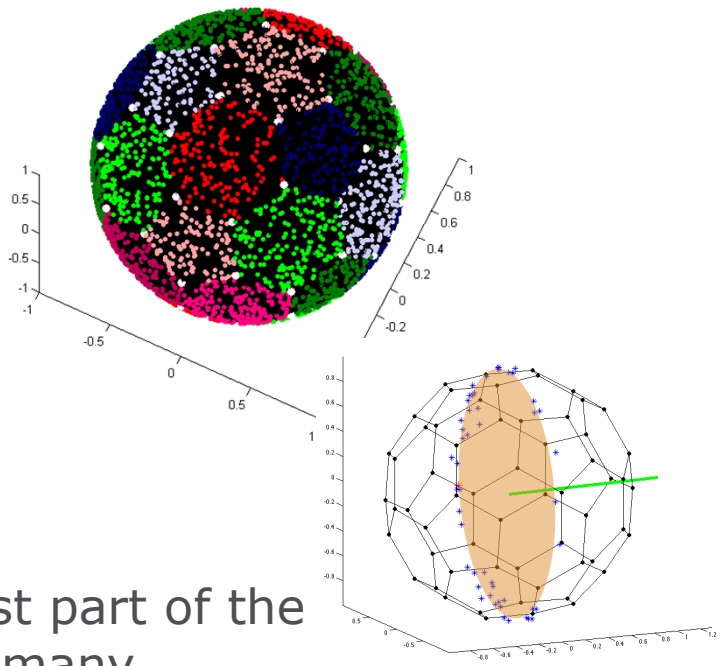


Advanced Concepts Team European Space Agency:
Dario Izzo, Luis Felismino Simoes, Marcus Marteens, Guido de Croon, Aurelie Heritier

Center for Space Science Research
Hong Kong University of Science and Technology:
Chit Hong Yam, Tsz Yan So, Kin Chiu Chu, Kai Yin Leung, Hermanni Heimonen, Kwing Lam Chan, Kwok Yee Michael Wong

Some Key Contributions





Herman: worked on first part of the trajectory, searched for many possibilities at the 4 moons

Cathie: develop a "re-targeting" algorithm to accurately flyby at the desired grid

Alan: programming, debugging, and mass calculations

Prof. Chan and Prof. Wong: develop algorithms based on linear algebra to check which face the spacecraft fly on during close encounter at the moons

Lawrence: convert the guess solutions from ESA to an accurate low-thrust model

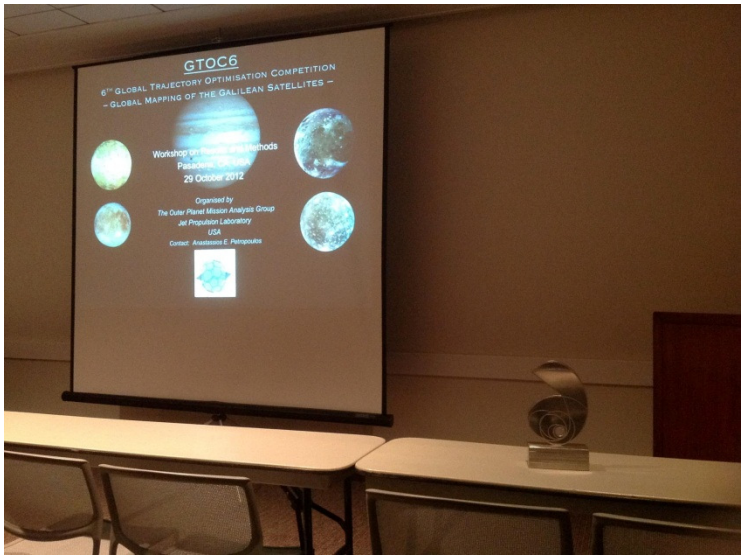
Hippo: coordinate and try to manage…and submit the final trajectory

One Small Step for HKUST and Hong Kong

1. First time participation in the GTOC: an international competition in the astrodynamics field

2. Undergraduate students with no prior background to compete against professional teams in the world

3. Excellent results given the difficulty of the problem



The GTOC6 Workshop in USA

Future Plans

1. Organize workshops and seminars to share our experience and knowledge
2. Organize mini-competitions in HK
3. Continue the research in astronautics and space science

Tour at the Jet Propulsion Lab

Suggested Chinese Terms

Center for Space Science Research 太空科學研究中心
Galilean moons 伽利略衛星
Europa 歐羅巴（木衛二）
Close flyby 近距離飛越
European Space Agency (ESA) 歐洲太空總署
Jet Propulsion Laboratory (JPL) 噴射推進實驗室
Global Trajectory Optimisation Competition (GTOC)
國際太空軌道設計比賽

Team Members from HKUST

數學系陳炯林教授，物理學系王國彝教授，任哲航博士，數學系的蘇芷茵、
物理學系的梁啟彥、朱建釗及 Heimonen, Hermanni Juuso Elias (Herman)

Prof Kwing-lam Chan, Prof Kwok-yee Wong, Dr Chit-hong Yam, Tsz-yan So,
Kai-yin Leung, Kin-chiu Chu and Heimonen, Hermanni Juuso Elias

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Backup Slides

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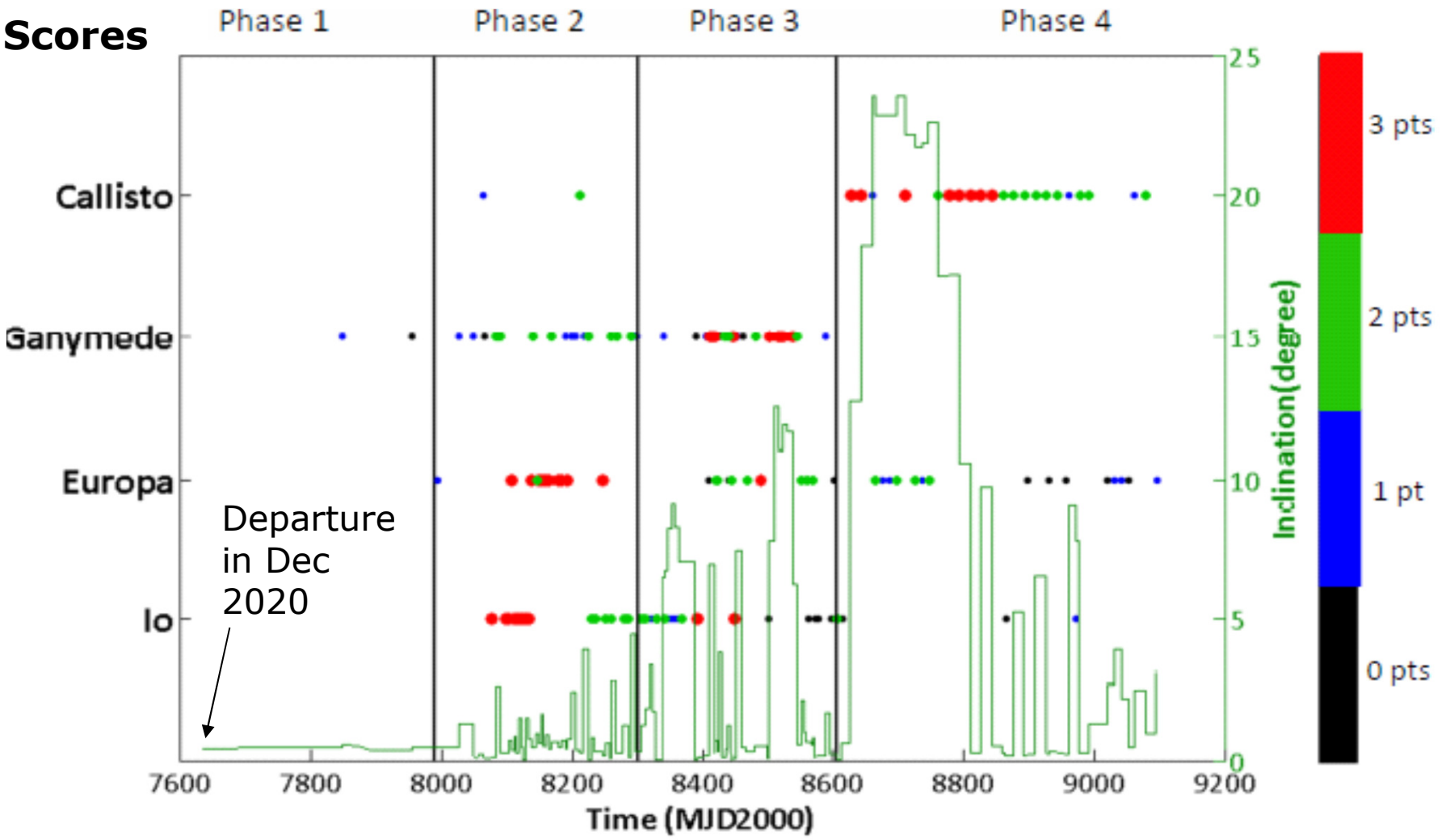
The 4 Phases of the Trajectory

Scores



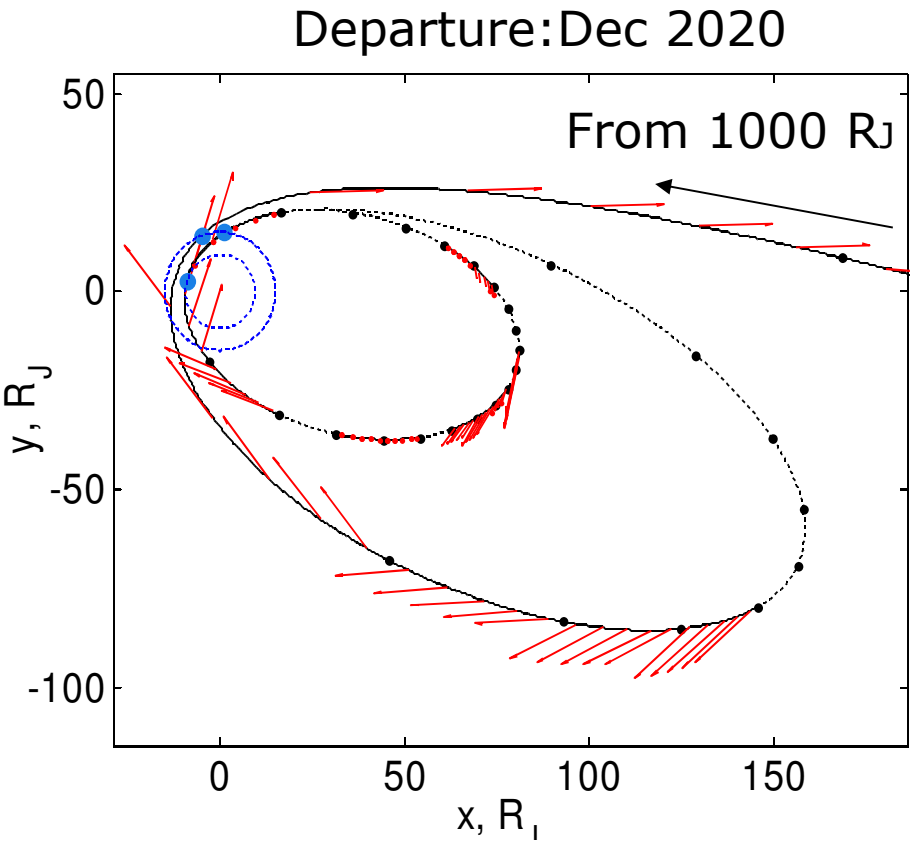
Capture into the Jovian System

Phase 1: Ganymede-Ganymede-Europa

TOF: 198 → 107 → 39 days

ΔV on chemical solution = ~300 m/s; required thrust level =0.035N

Low-thrust optimization based on Sims-Flanagan model (MALTO/GALLOP): Trajectory is divided into segments of constant thrust, numerically integrated.



Score: 3

Final mass: 1895 kg

Phase 2: Inner Moons Tour

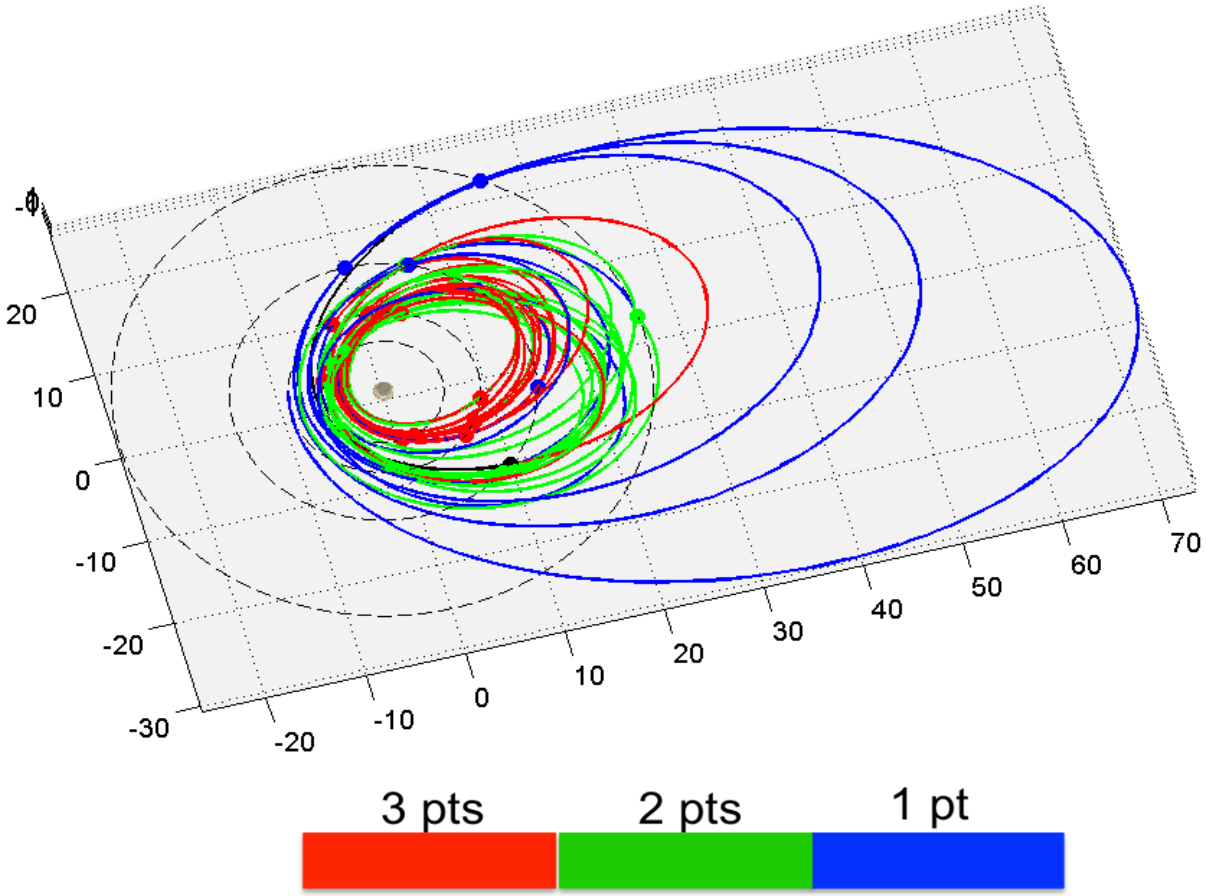
46 Flybys:
16I, 12E, 16G, 2C

Score: 138

Io and Europa are visited by resonance transfers. Mostly 2:1 (Io) and (1:1) resonances

Time of flight: 303 days

Final mass: 1653 kg



Phase 3: Ganymede and Inner Moons

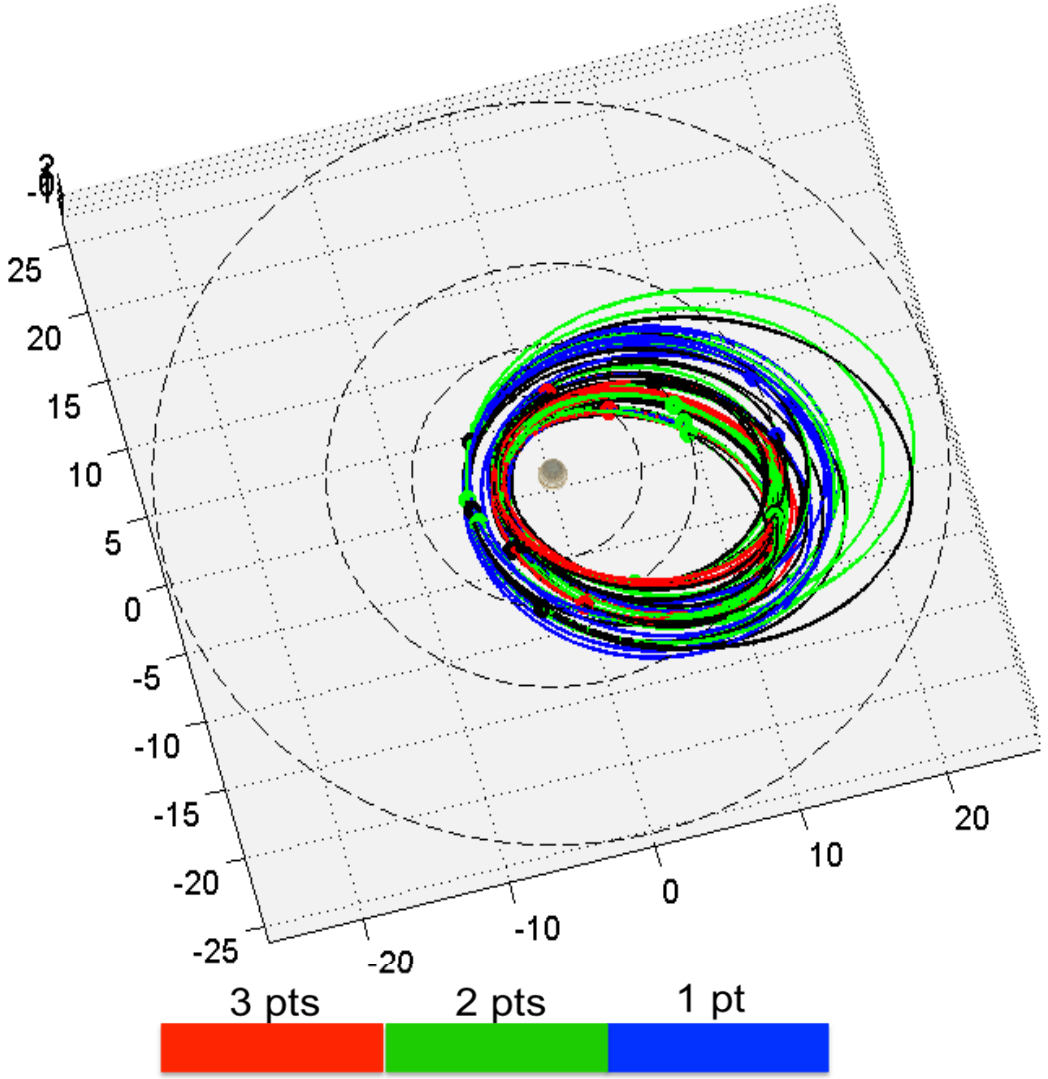
Visiting high scoring faces on Ganymede (1:1 res.) and low scoring faces on Io (3:1 res.) and Europa.

Time of flight: 317 days

Final mass: 1252 kg

54 flybys: 20I, 14E, 20G

Score: 91



Phase 4: Callisto Flybys

High-score faces of Callisto are mapped. Inclination is increased to map low-score faces of Europa (3:1 res.)

Time of flight: 418 days

54 flybys: 2I, 15E, 21C

Score: 76

Final mass: 1000.4 kg