



Seeds of disruptive innovation?

Dario Izzo



Bizzarrini: 1966



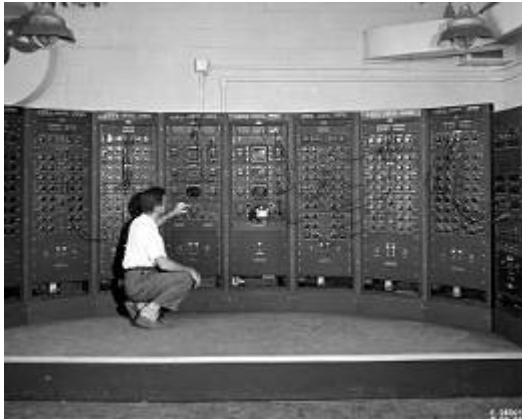
Ferrari: 2008



Boeing: 1970



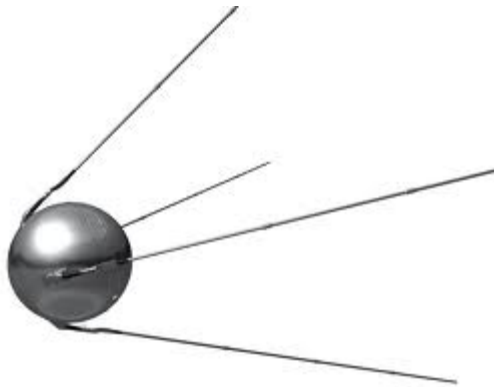
Airbus: 2010



60s



2010



60s



2010



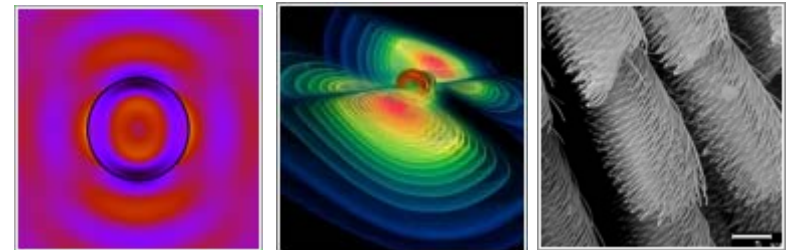
- The Advanced Concepts Team
- Consolidated results
 - a. Global optimization methods for trajectory design
 - b. Asteroid deflection
 - c. Swarm intelligence for distributed control of space systems (missing)
- Recent projects
 - d. Neural analysis of image saliency
 - e. Neuromorphic approach to planetary landing
 - f. PaGMO: A swarm of algorithms for massively parallel engineering optimization



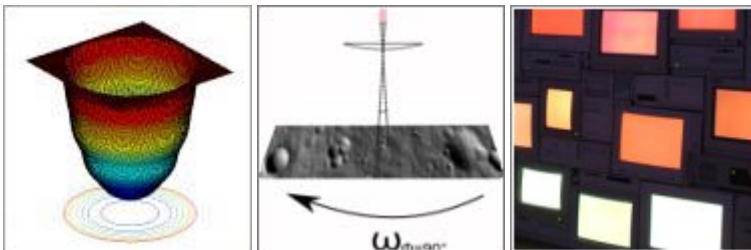
monitor, perform and **foster** research on advanced space systems,
innovative concepts and working methods



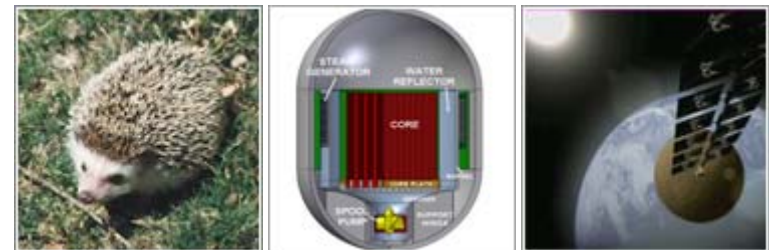
scientific domains with weak links to space



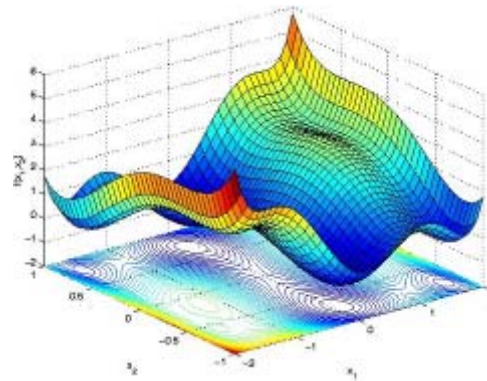
too immature for regular ESA programmes or projects



techniques developed in basic scientific research

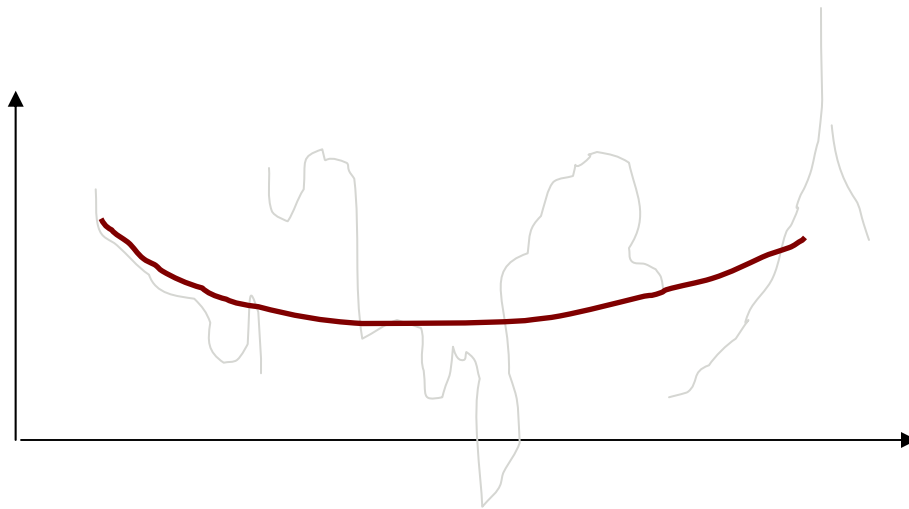


topics on which ESA is expected to have a position

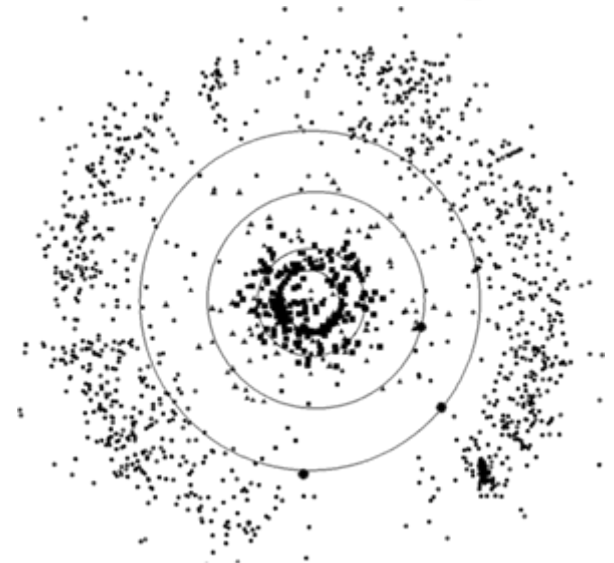
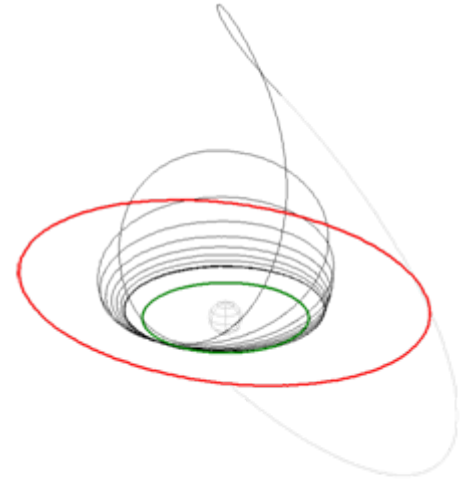


a. Global optimization methods for trajectory design

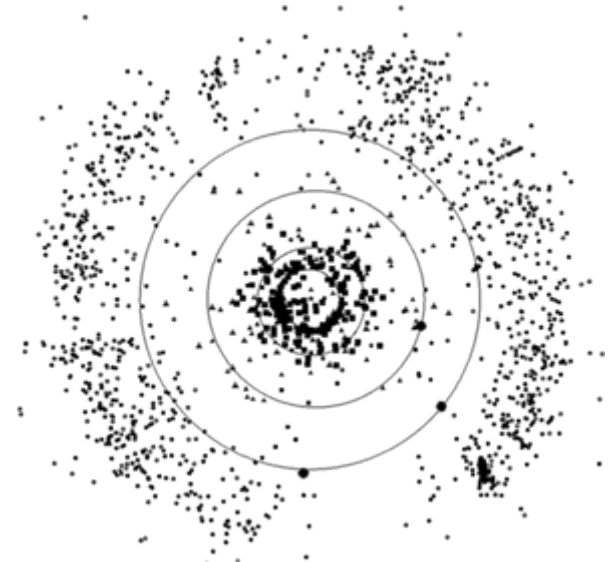
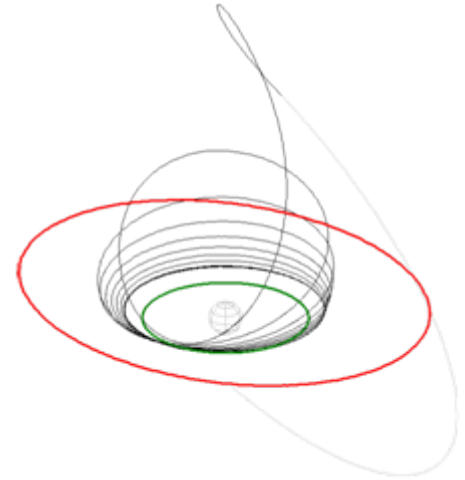
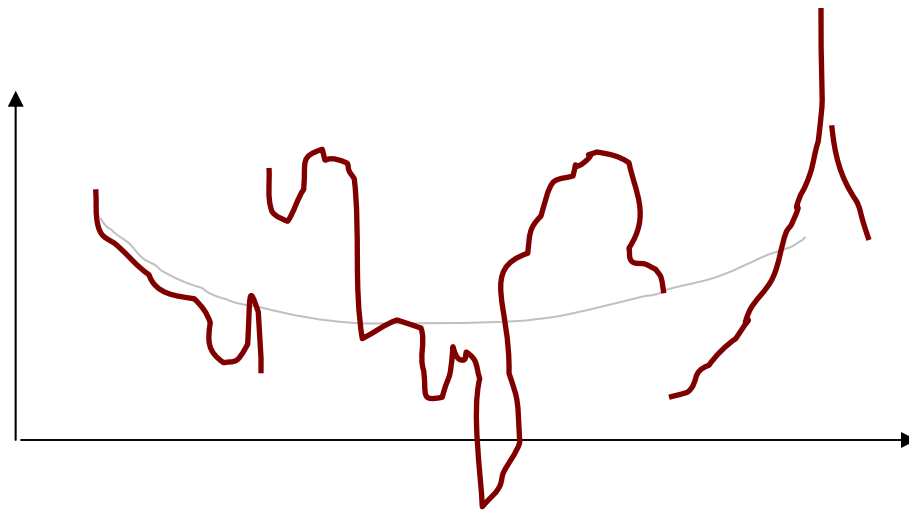
Minimise: $J(\mathbf{x})$
 Subject to: $\mathbf{f}(\mathbf{x}) \leq 0$



How difficult can it be?

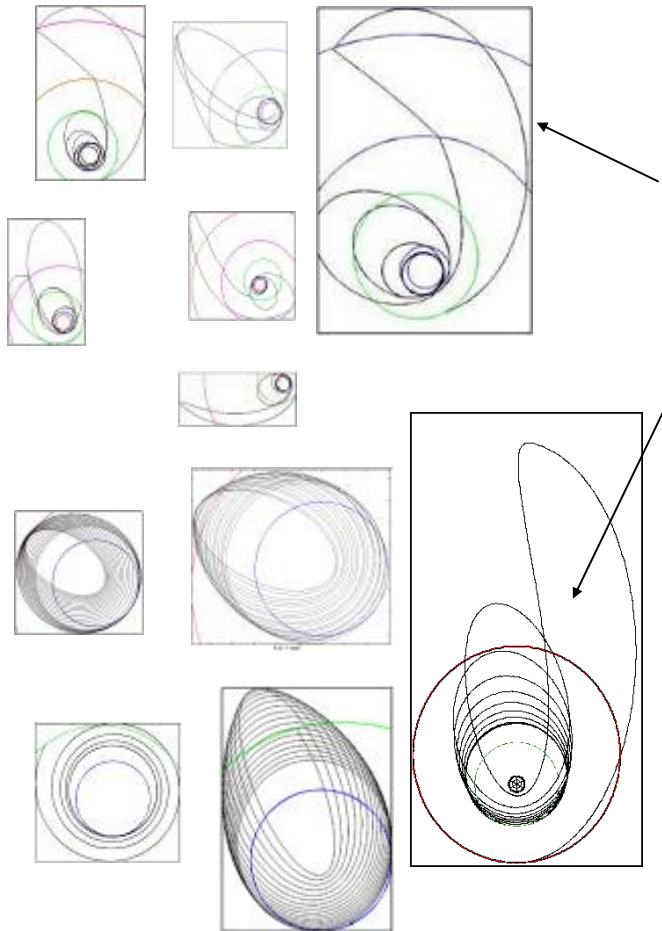


Minimise: $J(\mathbf{x})$
 Subject to: $\mathbf{f}(\mathbf{x}) \leq 0$

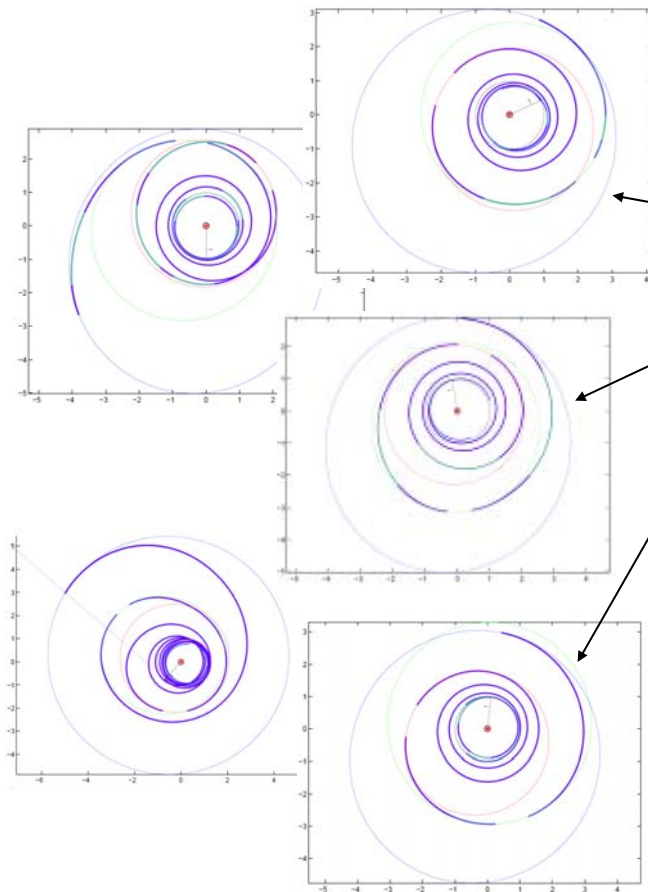




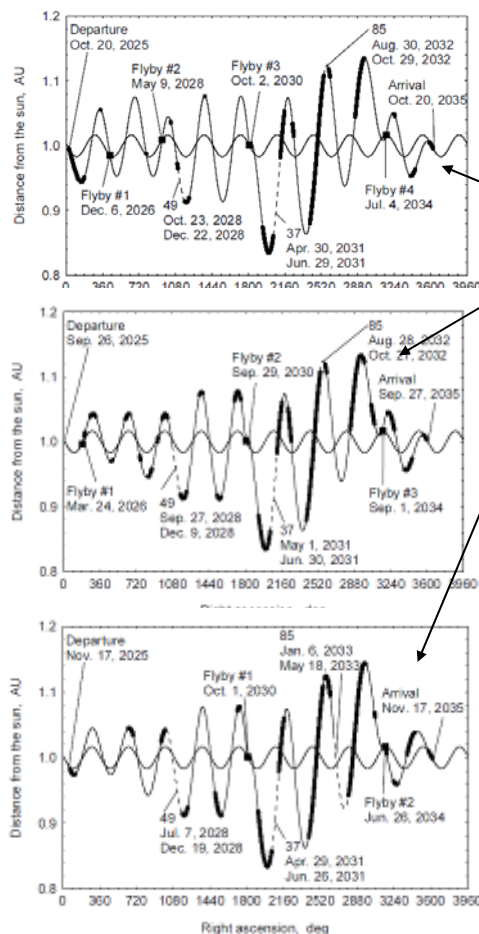
The winner sets the rules for the next edition



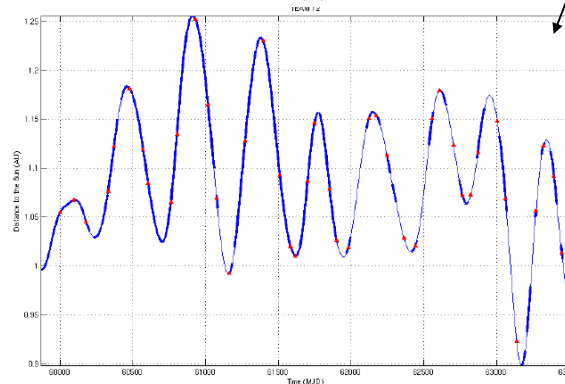
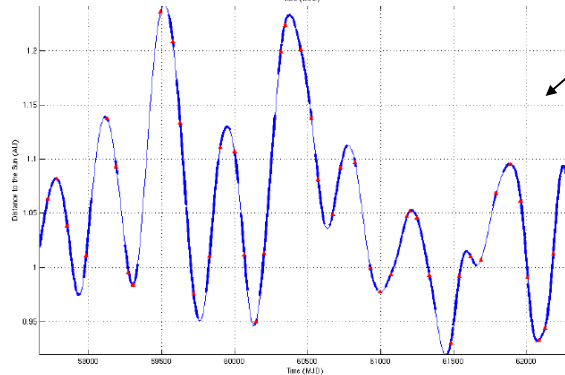
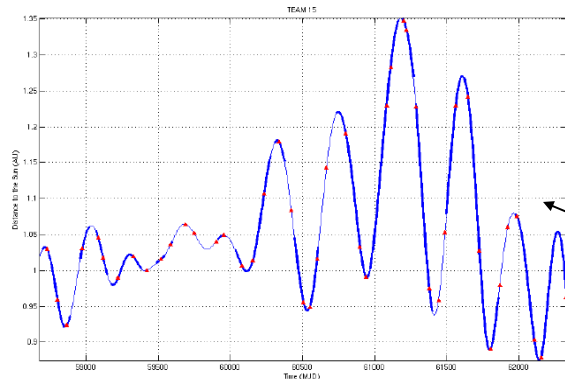
	Team name	Value
1.	Jet Propulsion Laboratory	1,850,000
2.	Deimos Space	1,820,000
3.	GMV Aerospace and Defence	1,455,000
	Moscow Aviation Institute and Khrunichev State Research	1,364,000
	Politecnico di Torino	1,290,000
	CNES/CS	1,194,000
	Glasgow University	385,000
	Moscow University	351,152
	Alcatel	330,385
	DLR	330,000
	Tsinghua University	89,000



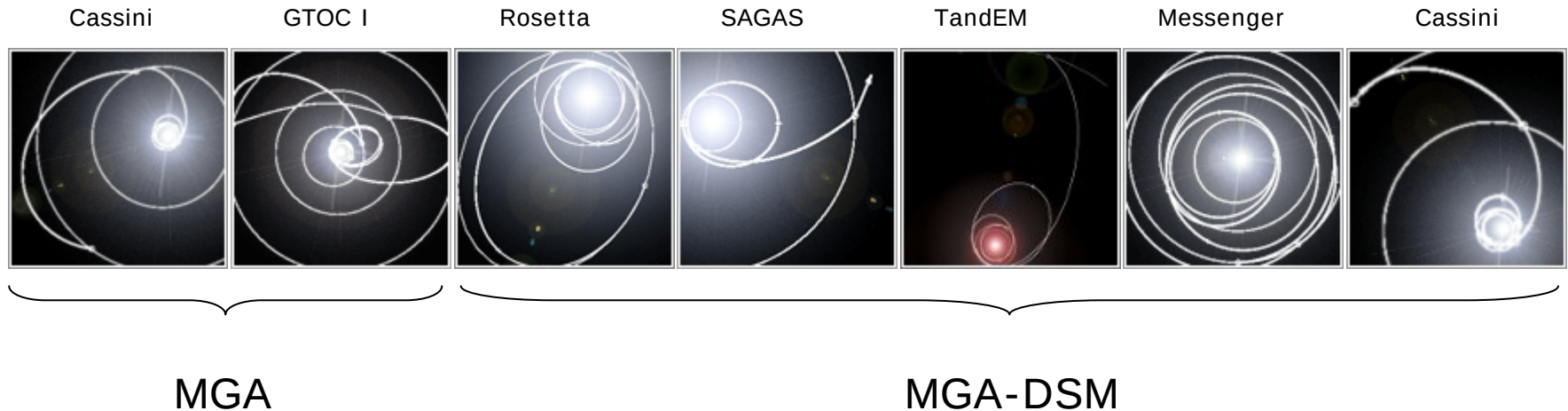
	Team name	Value
1.	Politecnico di Torino	98.64
2.	Moscow Aviation Institute and Khrunichev State Research	87.93
3.	<i>Advanced Concepts Team</i>	<i>87.05</i>
	Centre National d'Etudes Spatiales	85.43
	GMV Aerospace and Defence	85.28
	German Aerospace Center (DLR)	84.48
	Politecnico di Milano	82.48
	Alcatel Alenia Space	76.37
	Moscow State University	75.08
	Tsinghua University	56.87
	Carnegie Mellon University	27.94



	Team name	Value
1.	Centre National d'Etudes Spatiales	1733
2.	Jet Propulsion Laboratory	1730
3.	Georgia Tech	1721
	Deimos Space	1717
	The Aerospace Corporation	1647
	Thales Alenia Space	1647
	Moscow Aviation Institute and Khrunichev State Research	1658
	GMV Aerospace and Defence	1649
	Moscow State University	1633
	Glasgow University et al.	1606
	Tsinghua University	1565



	Team name	Value
1.	Moscow State University	44, 553.46
2.	The Aerospace Corporation	44, 516.83
3.	<i>Advanced Concepts Team</i>	42
	Deimos Space	39, 605.44
	GMV Aerospace and Defence	39, 516.30
	Jet Propulsion Laboratory	38
	University of Texas at Austin	36
	University of Glasgow & University of Strathclyde	32
	Thales Alenia Space	29
	University of Trento	27
	University of Bremen, Politecnico Milano	26



Derivative free optimization of interplanetary trajectories

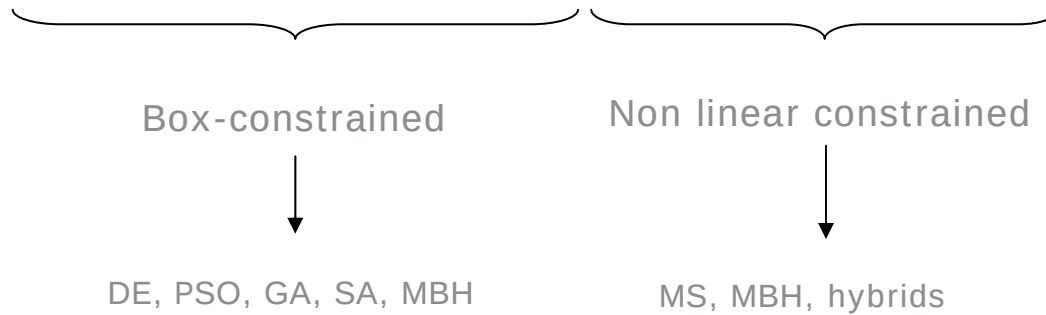
More than 50 blackbox problems provided

Code provided in: C++ , MATLAB

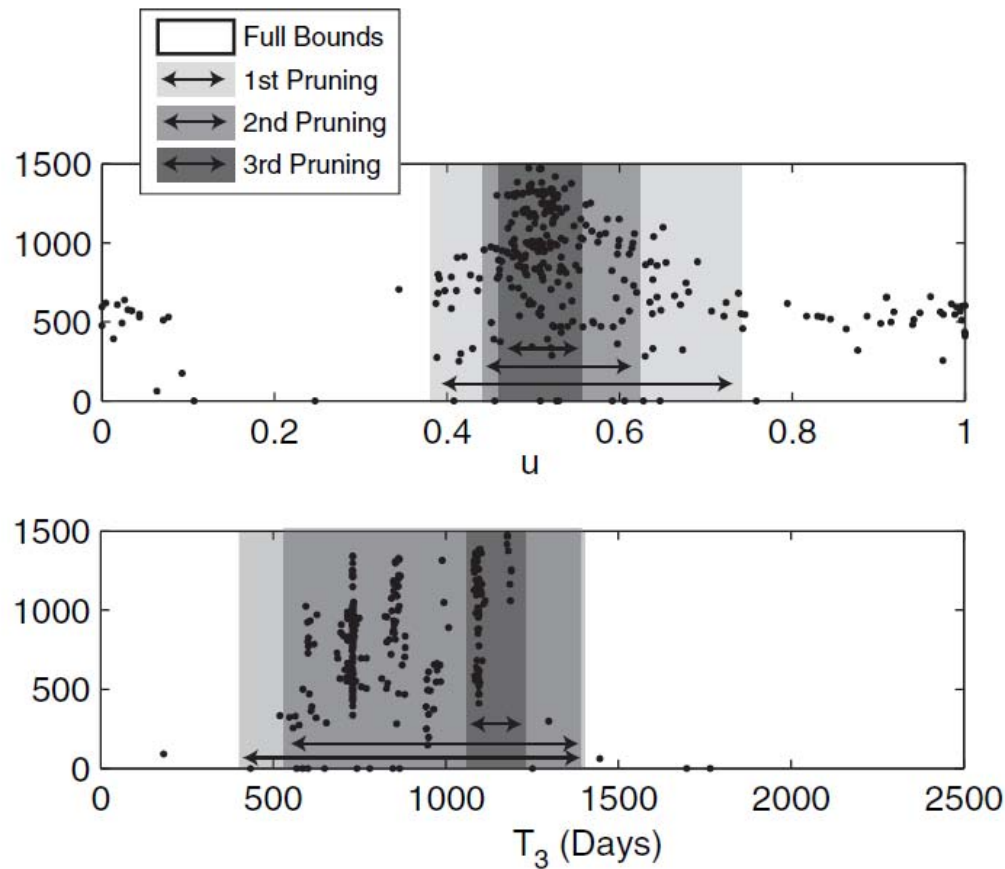
Records from: University of Florence, Max-Planck-Institut fuer
Astronomie, University of Birmingham, Advanced Concepts Team,
University of Catania, University of Glasgow

A common framework: the impulsive transcription

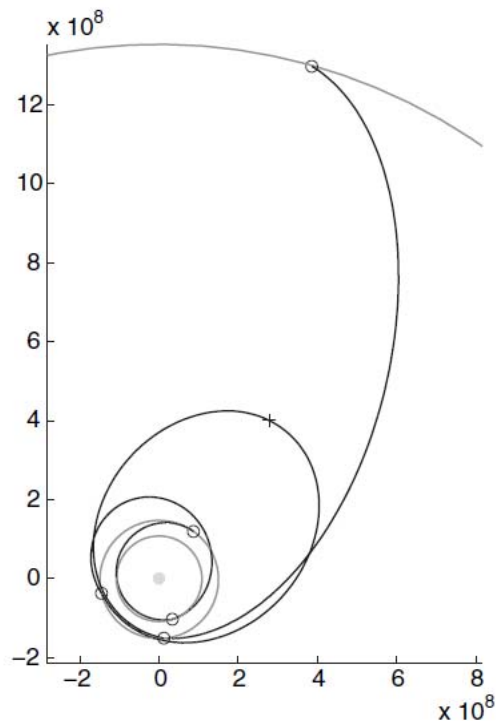
Taxonomy: MGA, MGA-DSM, MR-DSM, MGA-LT, MR-LT, TBP



Pruning is necessary in difficult problems: GASP for MGA, cluster pruning for MGA-DSM

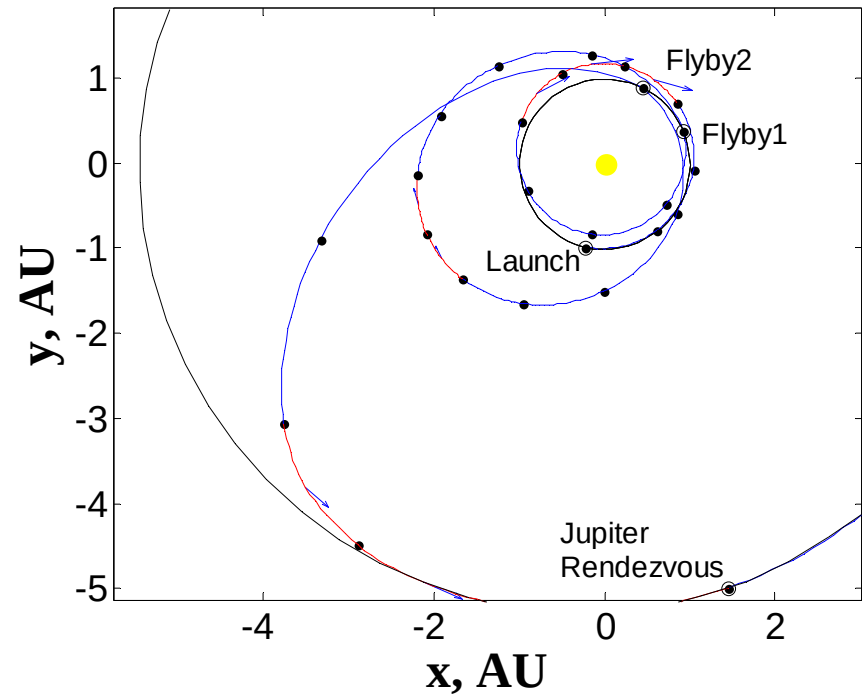
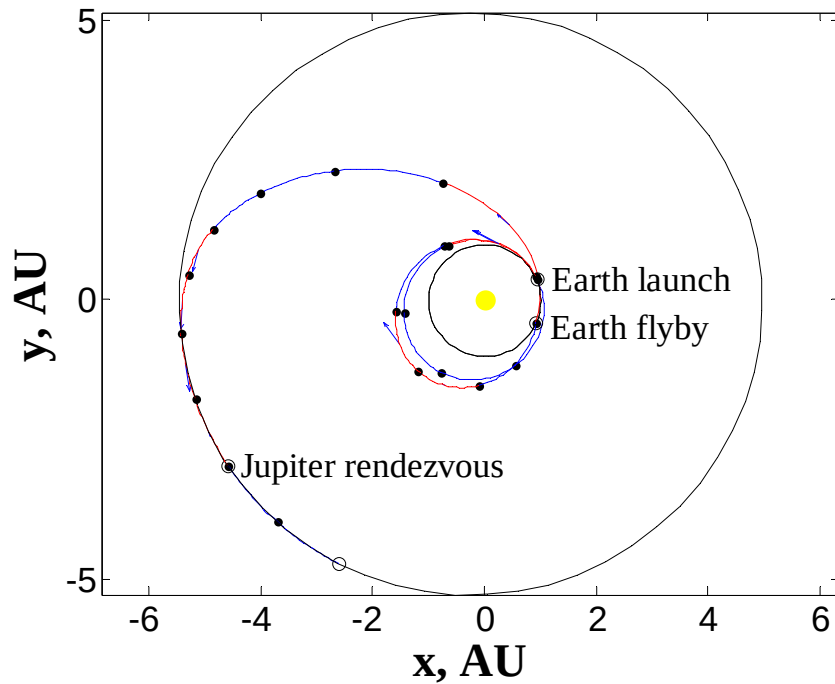


Developed as part of the work for the joint JPL/ESA Outer Planets Mission Analysis Working Group (2007-2008)

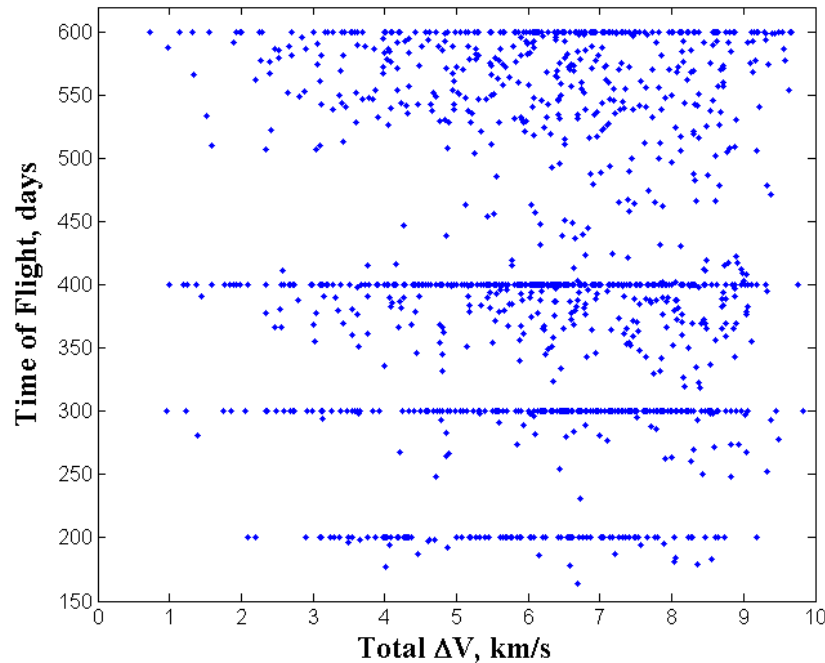


Spacecraft	
Departure mass	2085.44 kg
Arrival mass	1476.03 kg
I_{sp}	312 s
Departure	
Epoch	15/11/2021
V_{∞}	3.34 km/s
Declination	3.1 deg
Cruise	
Venus fly-by	30/04/2022
Earth fly-by	04/04/2023
DSM Epoch	13/01/2025
DSM ΔV	167 m/s
Earth fly-by	25/06/2026
Arrival	
Epoch	03/07/2031
V_{∞}	0.676 km/s
Total flight time	9.63 years

- Full automated design, no initial guess needed
- Record holder in GTOP database
- Also found independently by Stephen Kemble of the outer planet mission analysis working group
- Same algorithm found the best Messenger (full) record



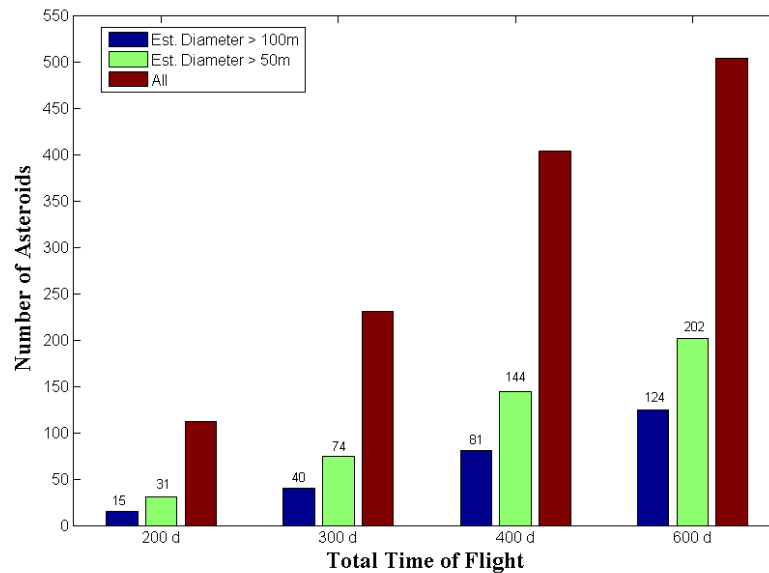
- It is possible to perform global optimization directly on low-thrust models!!!



- Asteroid selection from the MPCORB database
- ~50.000 GO problems solved in 3 hours!!
- MGA-DSM model



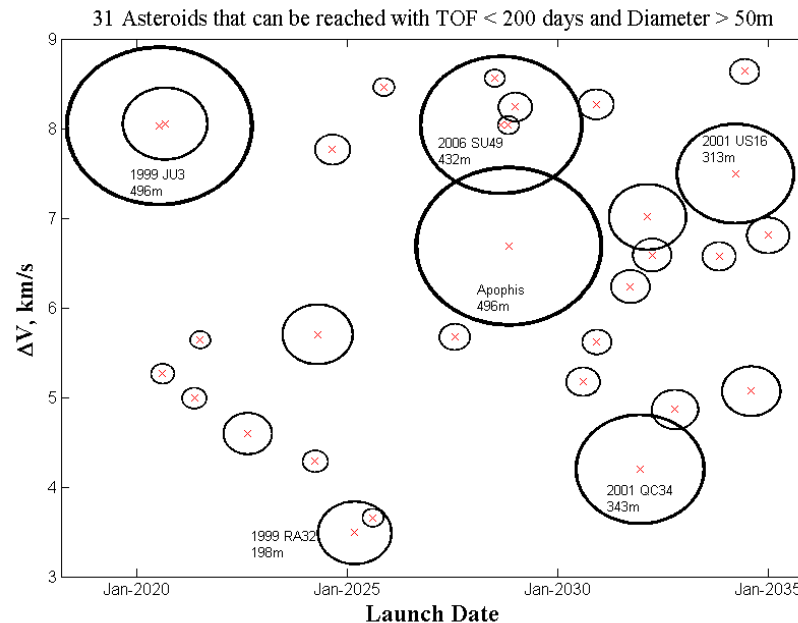
Obama's vision



- Asteroid selection from the MPCORB database
- ~50.000 GO problems solved in 3 hours!!
- MGA-DSM model



Obama's vision



- Asteroid selection from the MPCORB database
- ~50.000 GO problems solved in 3 hours!!
- MGA-DSM model



Obama's vision



b. Asteroid deflection

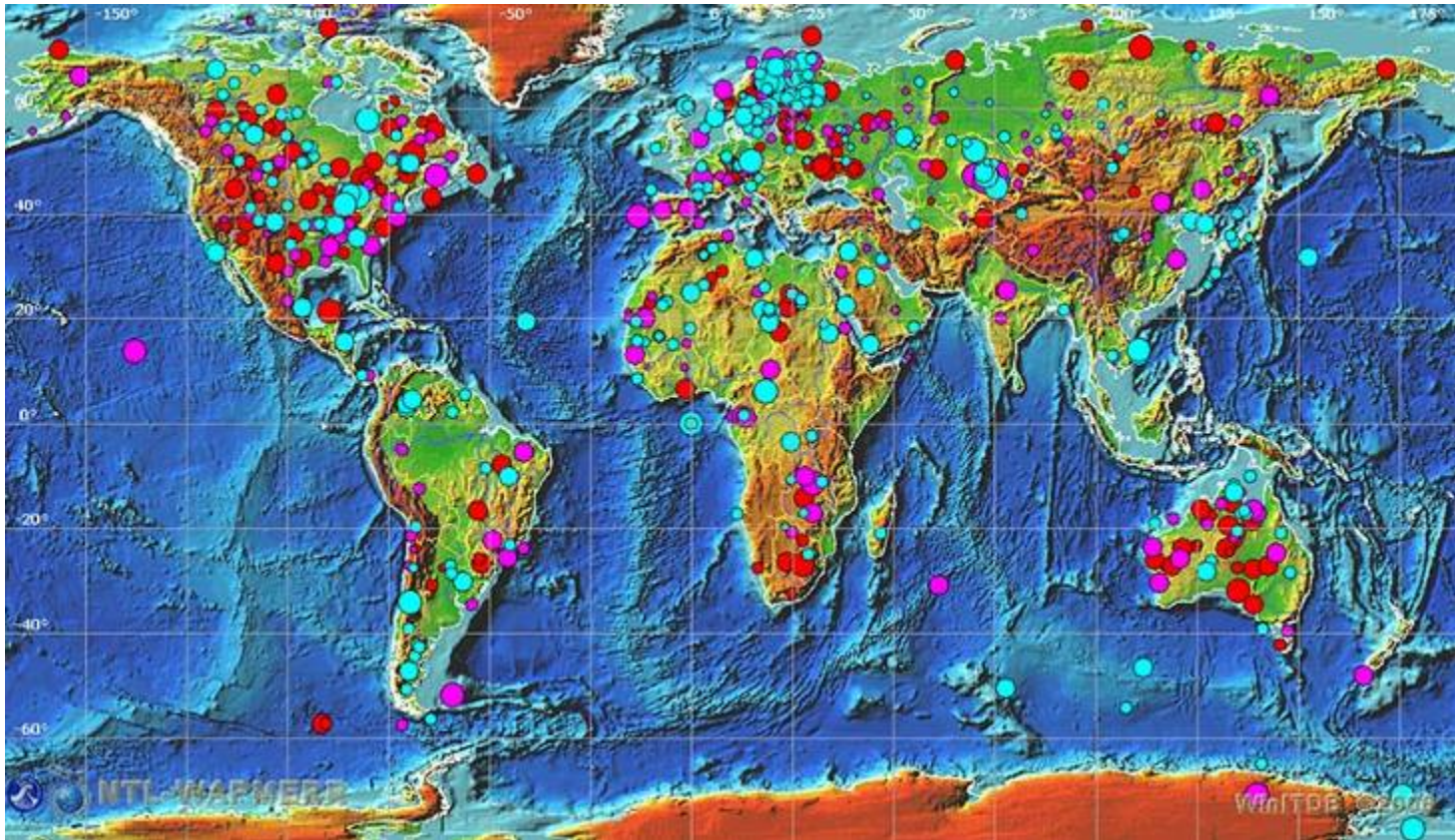
- Impacts happen!!!
- From mass extinctions to regional to local damage
- We know of ~500,000 asteroids in the solar system
- ~800 are potentially hazardous



Tunguska 1908 (icy comet? Small asteroid?)



Winslow, Arizona (~49.000 years ago)



Map of confirmed (red), perspective for verification (magenta) and proposed for further study (blue) impact structures on the Earth. Size of circles is proportional to the crater diameter.

Source: Institute of Computational Mathematics and Mathematical Geophysics. Novosibirsk, RUSSIA

- 2003: 6 industrial studies on the topic of NEOs characterization and hazard mitigation
- 2004: DQ is recommended as highest priority for near-term implementation of NEO missions (NEOMAP): “Don Quijote has the potential to teach us a great deal, not only about the internal structure of a NEO, but also about how to mechanically interact with it”
- First time that the deflection of a celestial body may be proved and studied

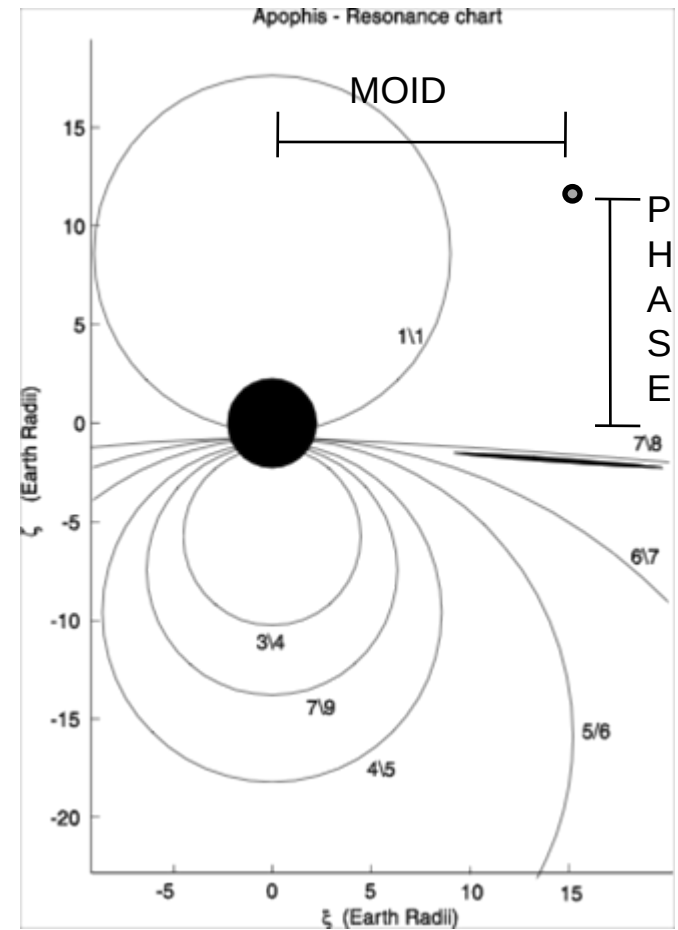
The orbital mechanics of moving asteroids needed to be studied in more details



Sancho Observing the impact

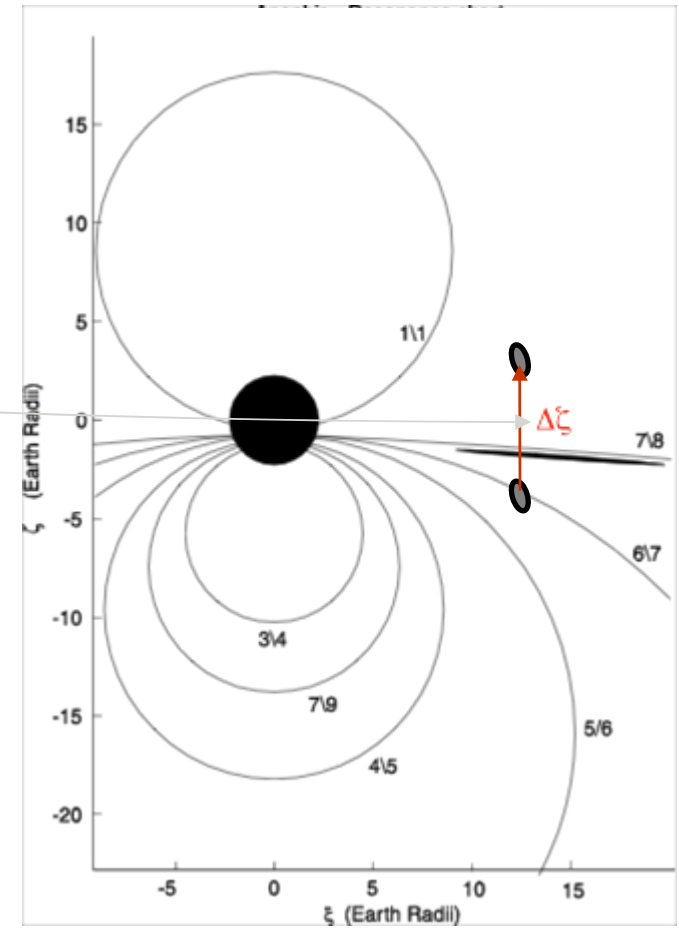


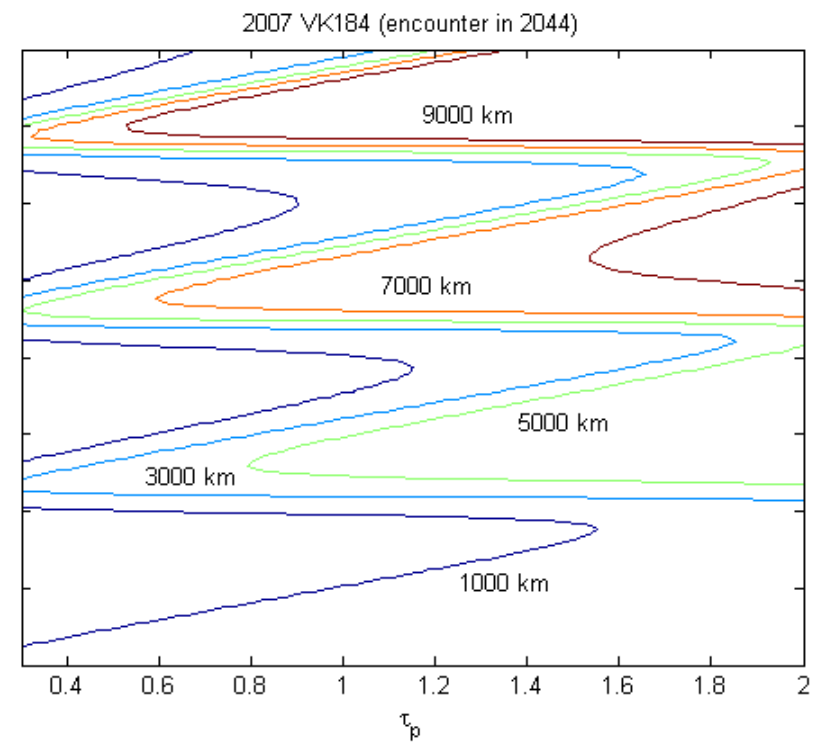
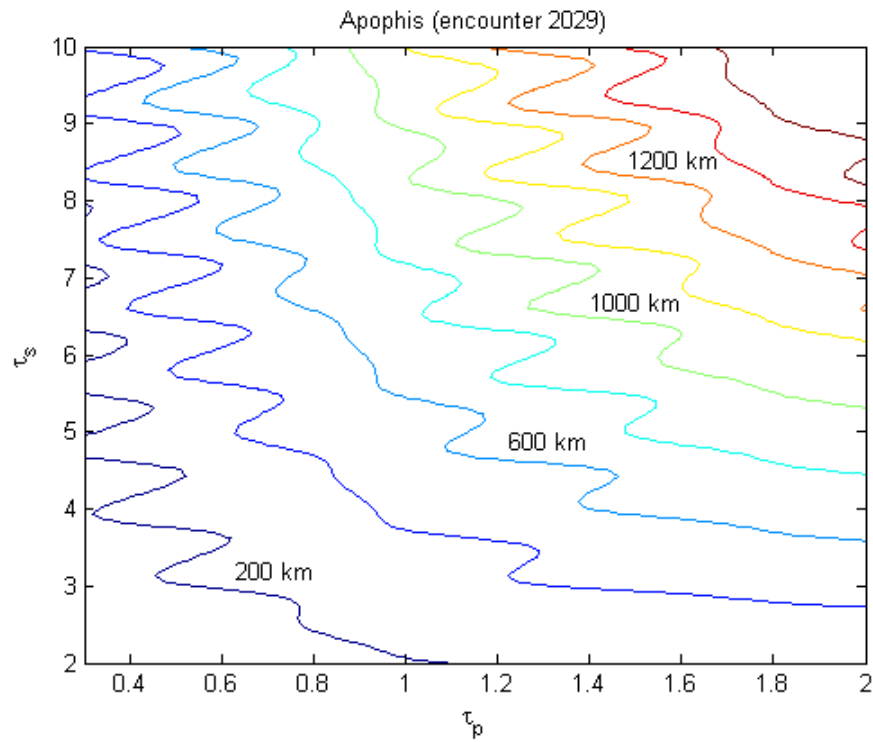
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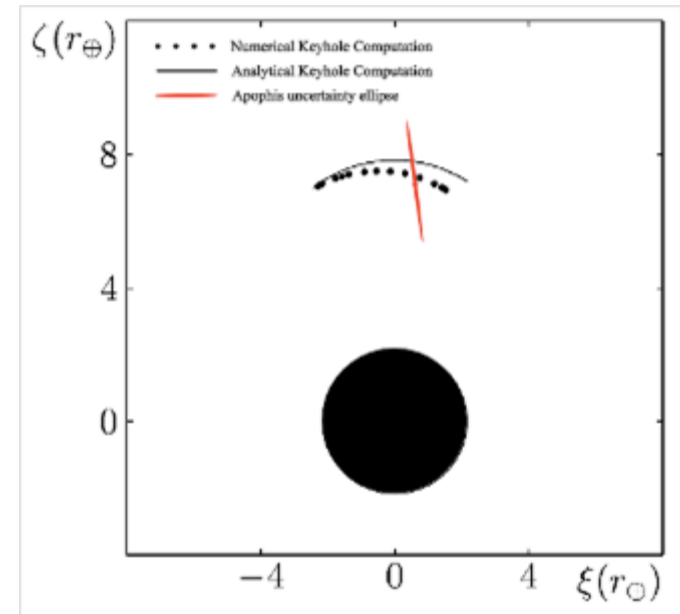
$$\Delta\zeta = \frac{3a}{\mu} V_E \sin \vartheta \int_0^{t_p} (t_s - \tau) \mathbf{v} \cdot \mathbf{A} d\tau$$

Valid for all non destructive deflection strategies!!

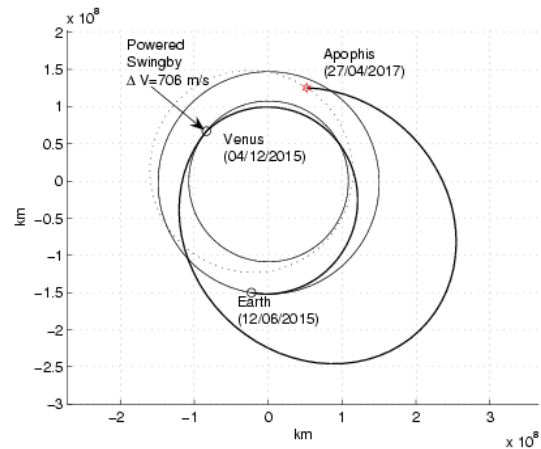
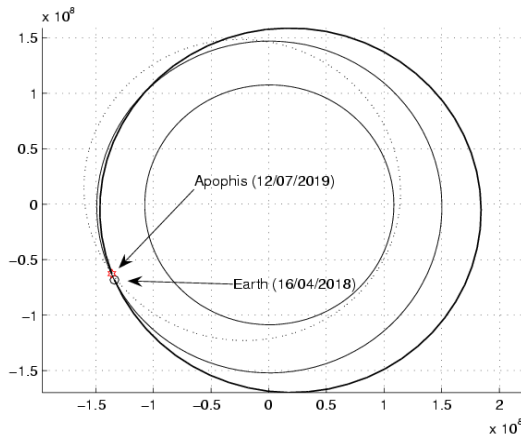




1. In late December 2004 impact monitoring robots found that NEA 2004 MN4 would have an extremely close approach with the Earth on the 13th of April 2029, with a probability of hitting our planet that rose up to 2.6% on the 27th of December.
2. In that date some previous observation data were mined from the Spacewatch archives and resulted in dropping significantly the impact risk.
3. Further observation from Arecibo, the 27th, 29th and 30th of January 2005 served to exclude the impact risk.



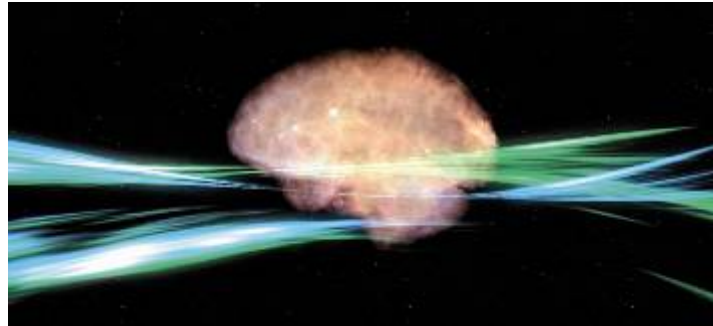
Apophis may teach us a lot on how to plan a real deflection mission



Departure	Impact	$ U $ km/sec	Deflection $\Delta\zeta$, km
16/4/2011	12/6/2012	7.93	87.8
25/4/2012	4/5/2013	8.14	63
25/9/2013	27/3/2014	8.29	43.5
3/6/2014	26/2/2015	10.9	18
16/4/2018	12/7/2019	7.32	57.58
17/4/2019	31/5/2020	8.02	43.37
29/12/2020	9/3/2021	7.15	47.4
8/9/2021	25/3/2022	9.01	17.23
2/3/2026	2/3/2027	7.09	10.05
1/4/2027	2/12/2027	7	3.96
5/2/2028	18/11/2028	5	0.45

Don Quijote spacecraft as designed by the Concurrent Design Facility at ESA (2004)

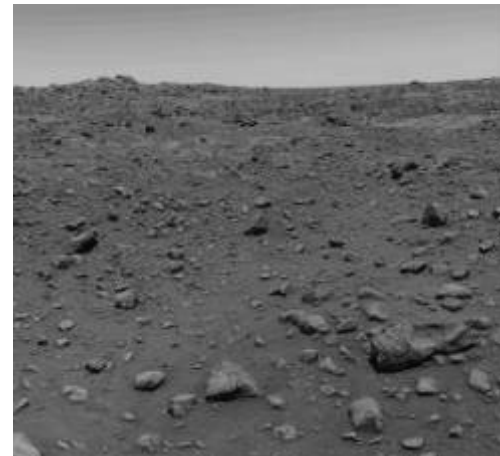
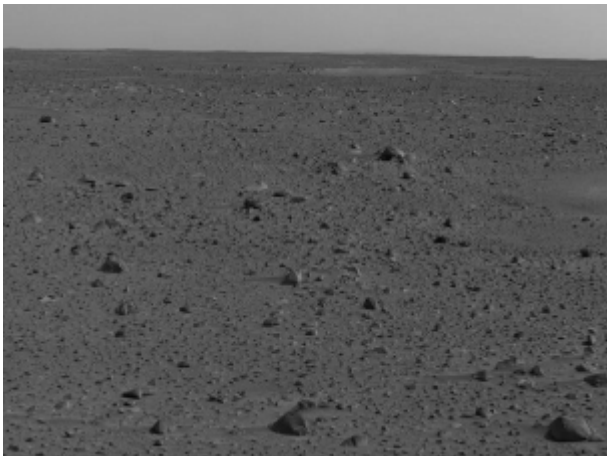
2006: Pre-keyhole deflection of Apophis is possible with DQ!!



d. Neural analysis of image saliency



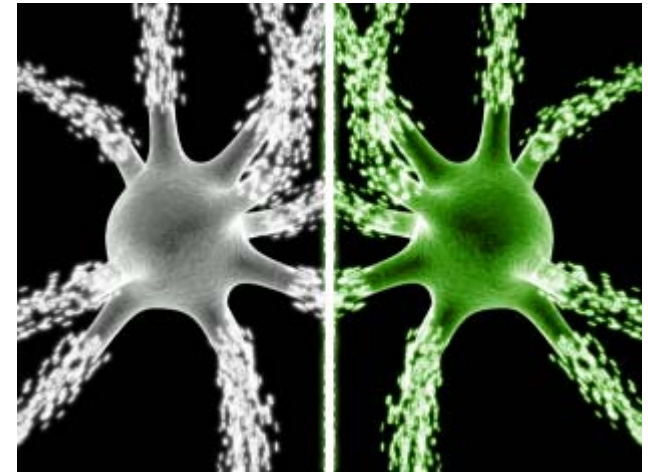
To capture movements or patterns



To capture the footprint of scientific interest

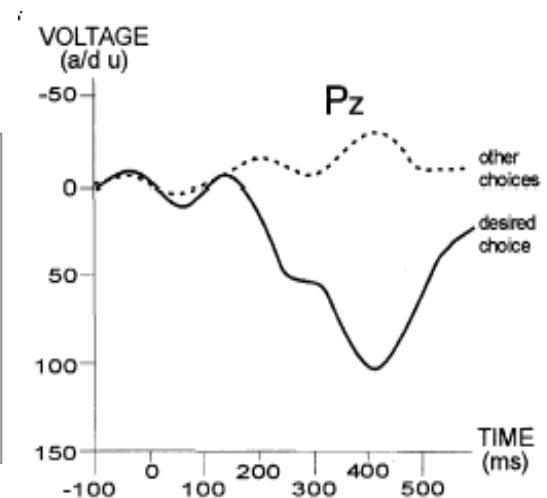


- Can we substitute the “interrogation” or the “push a button” techniques by accessing directly the same information from a biometric footprint?
- Candidates are event related potentials (ERP) and in particular P300 brain wave
- Possible advantages: speed, escape conscious filtering



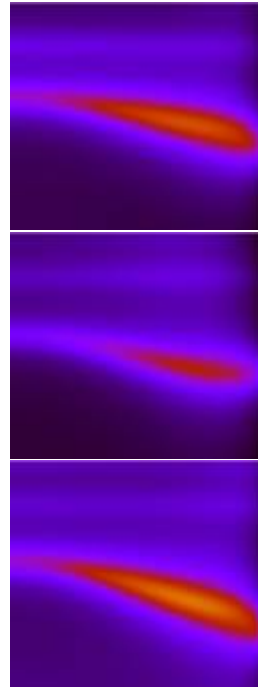
ERP = Electrical Potentials associated with specific sensory, perceptual, cognitive, or motor events

P300 = a positive voltage reading that occurs about 300 ms after the onset of the target/rare (oddball) stimulus

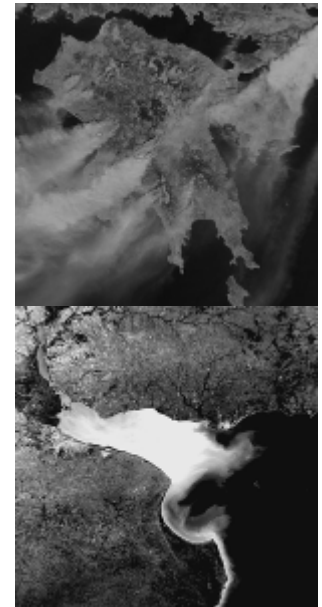




ESTEC rocks



Radiators



ENVISAT - Meris

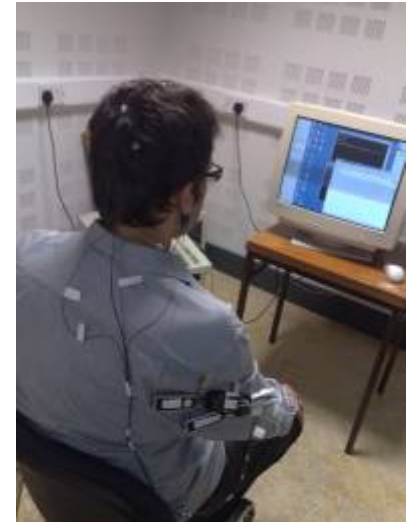
1 – Reliability vs speed

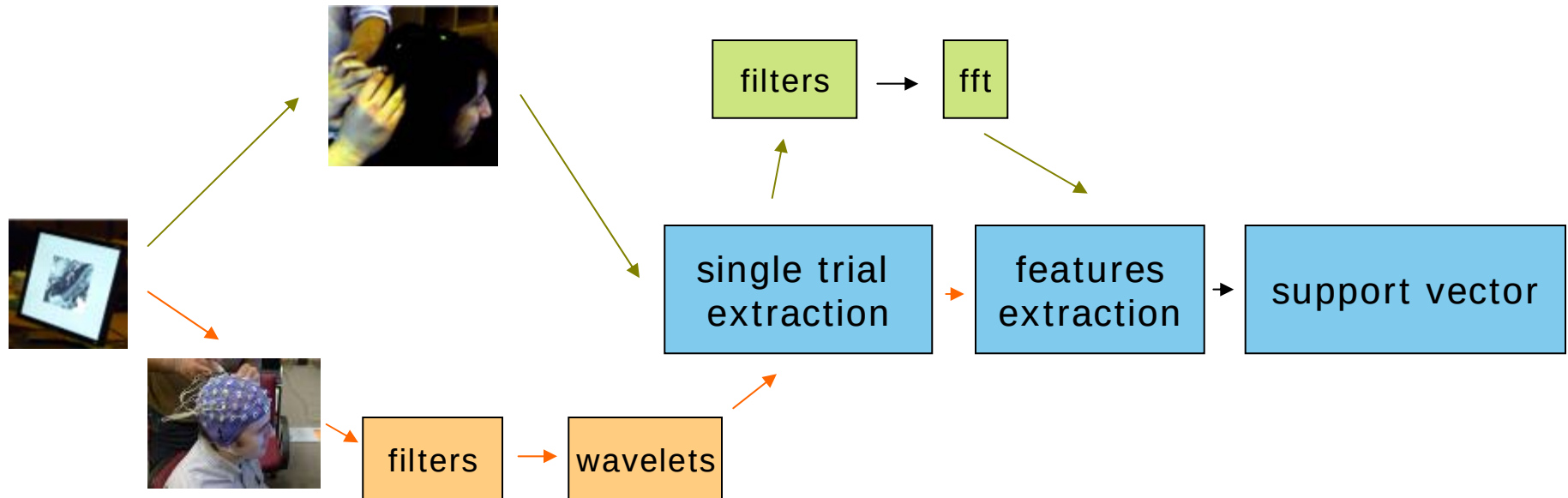
2 – Three classes

3 - Curiosity

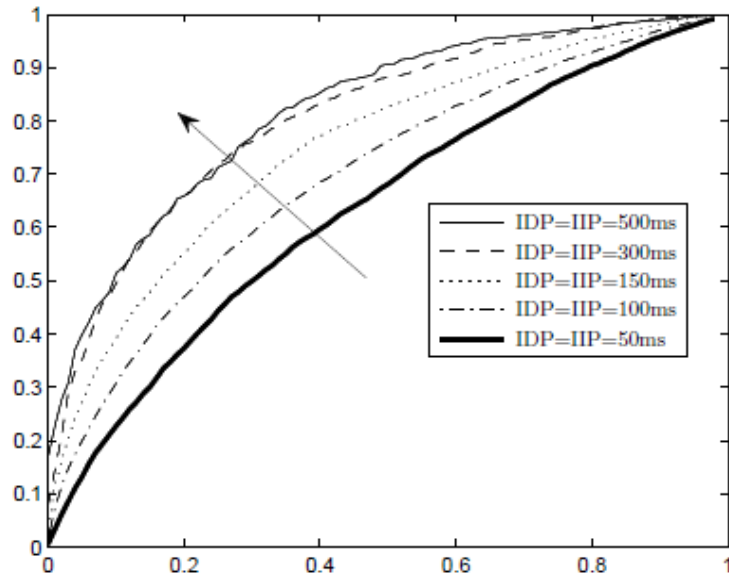


- Dublin City University (DCU) - “cheap” 4-node EEG device
- École publique Ecole Polytechnique Fédérale de Lausanne (EPFL) 32-nodes “complex” device
- subjects: students + 1 expert for experiment #1 and #2
- ESTEC Demo for experiment #3

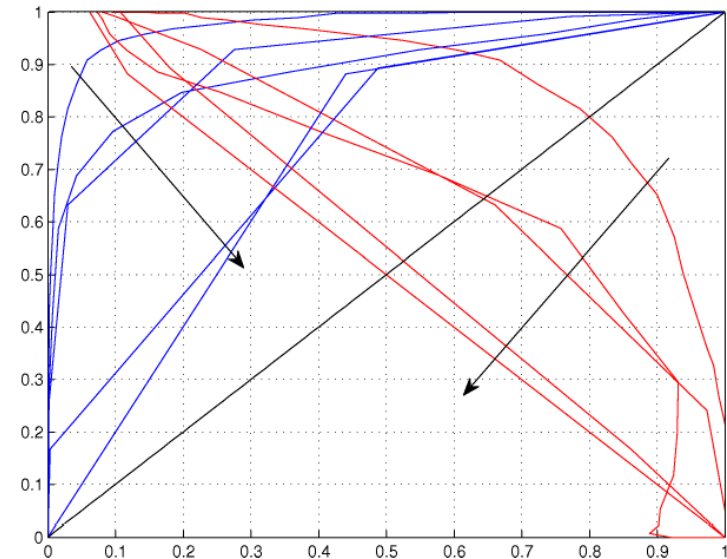




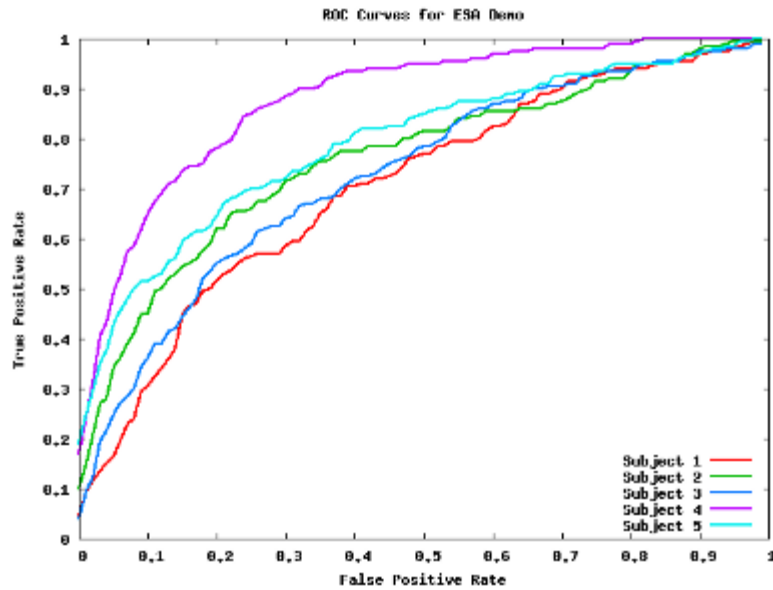
- CCviewer (sourceforge)
- Interfaces to EEGs
- Machine learning



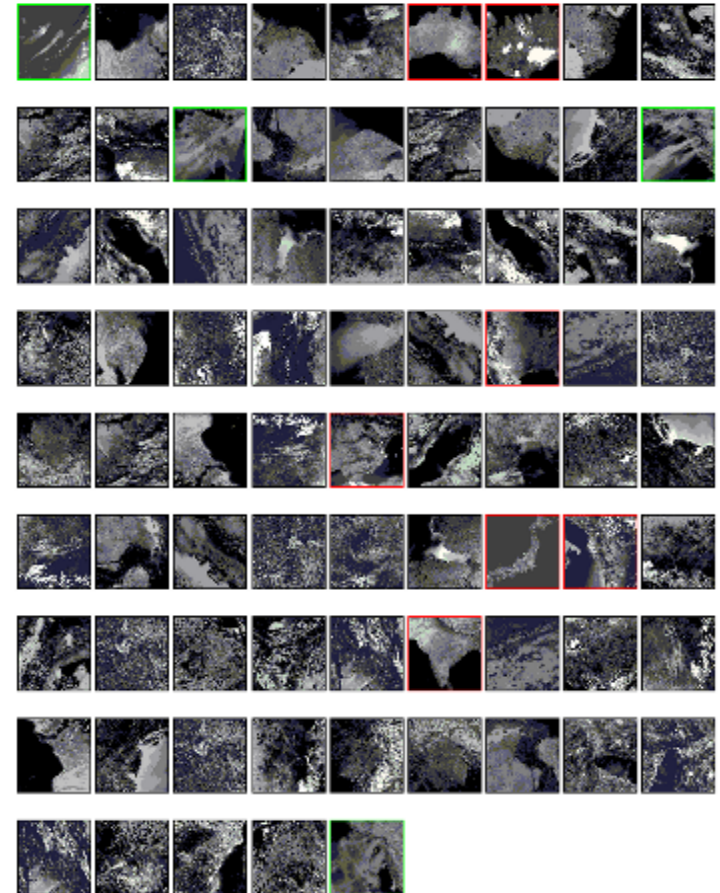
4 nodes setup
(TP-FP)



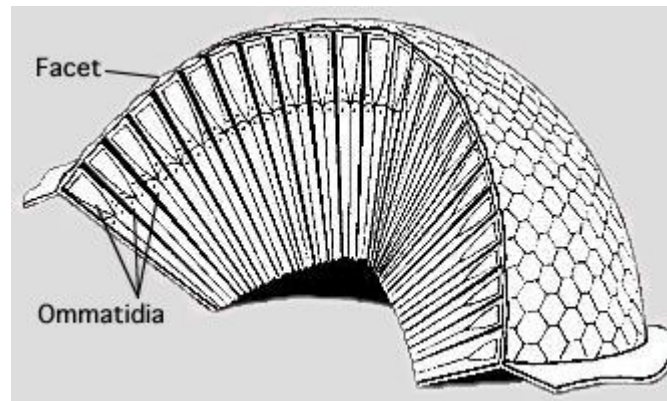
32 nodes setup
(TP-FP,
Precision, Recall
curves)



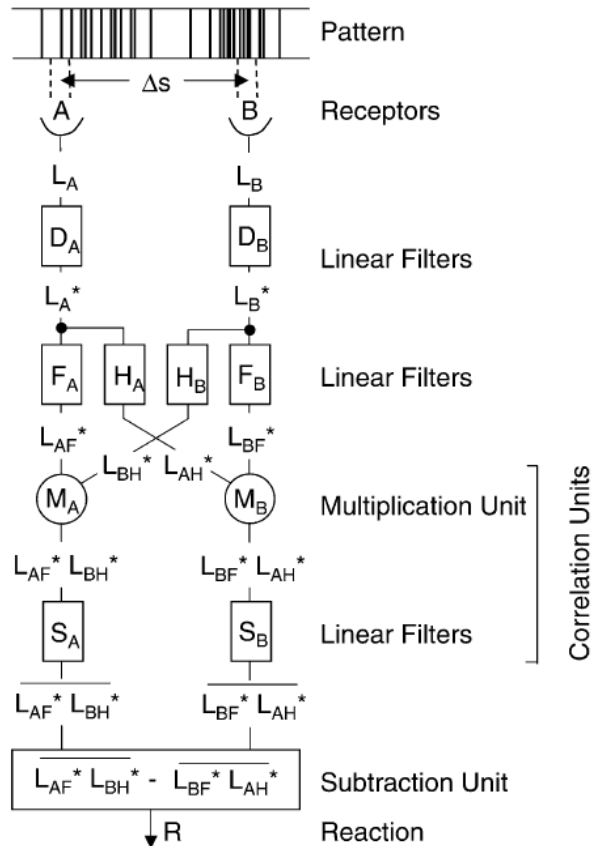
Training phase



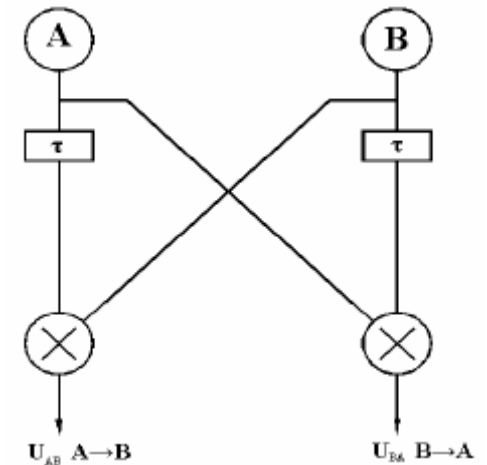
Final image rank for the best subject



e. Neuromorphic approach to planetary landing



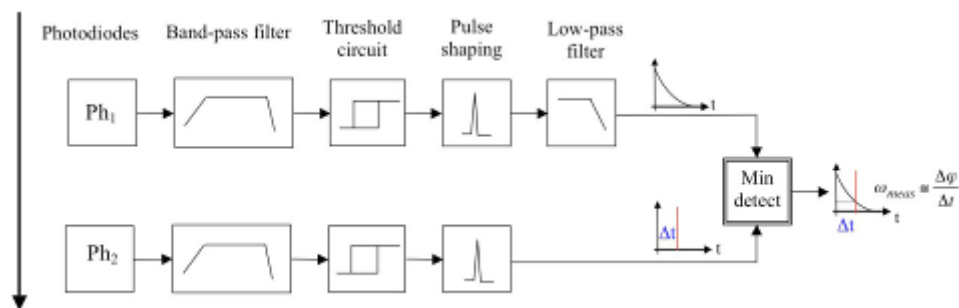
Chlorophanus beetle



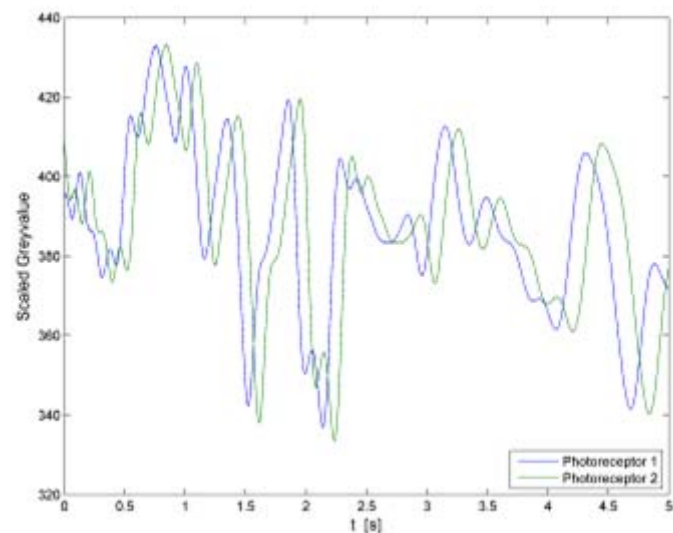
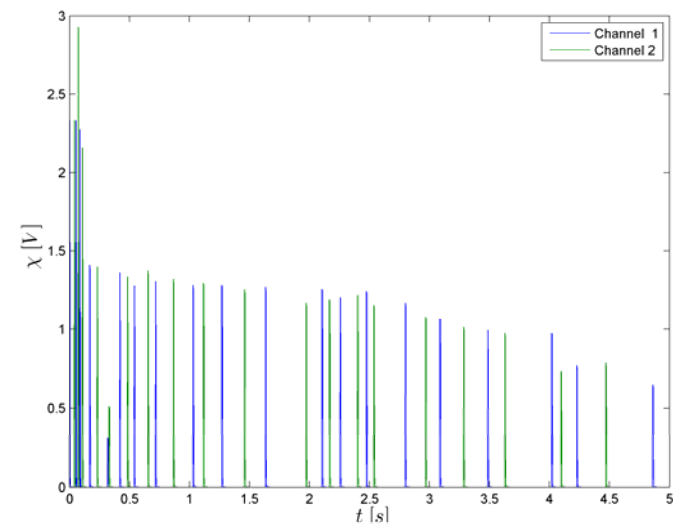
In a nutshell...

Output signal is used directly at a behavioural level,
not 'just' a velocity sensor

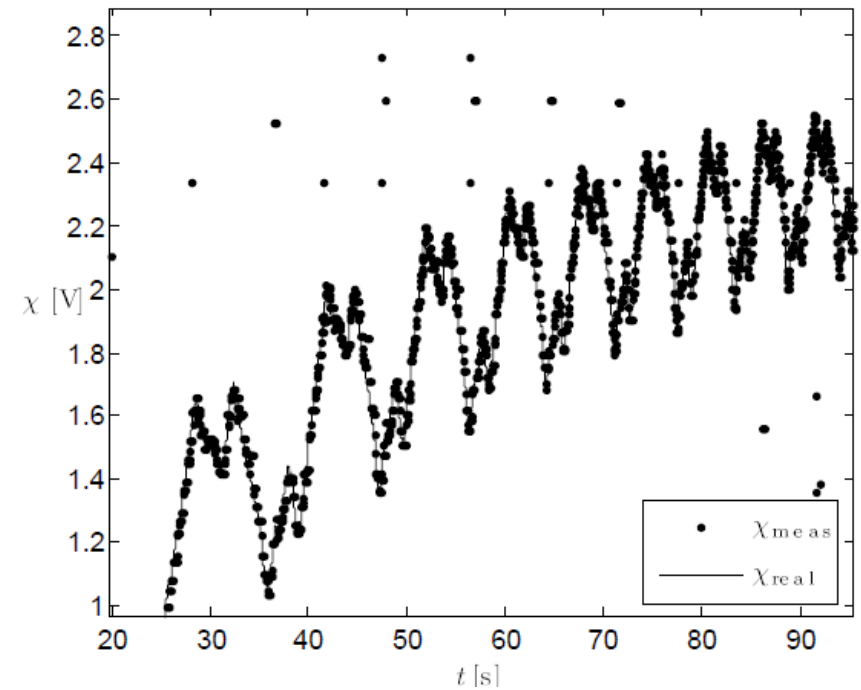
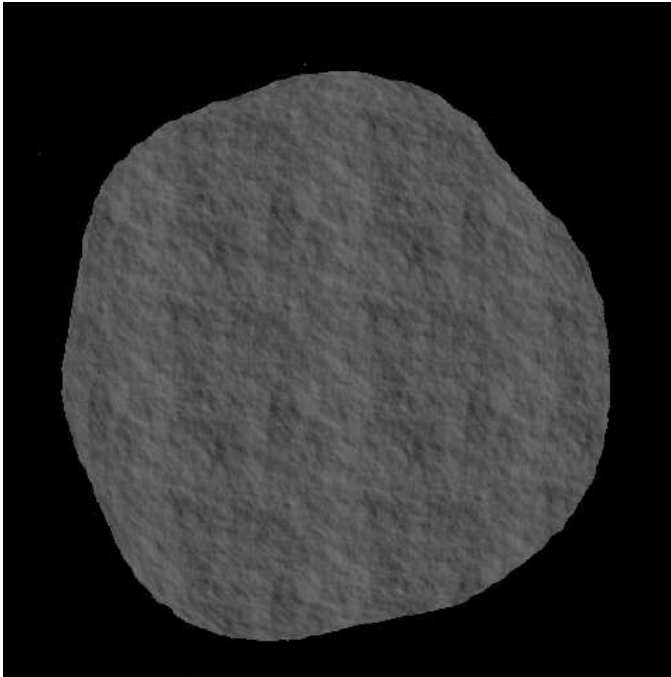
Original Reichard scheme for
motion detection



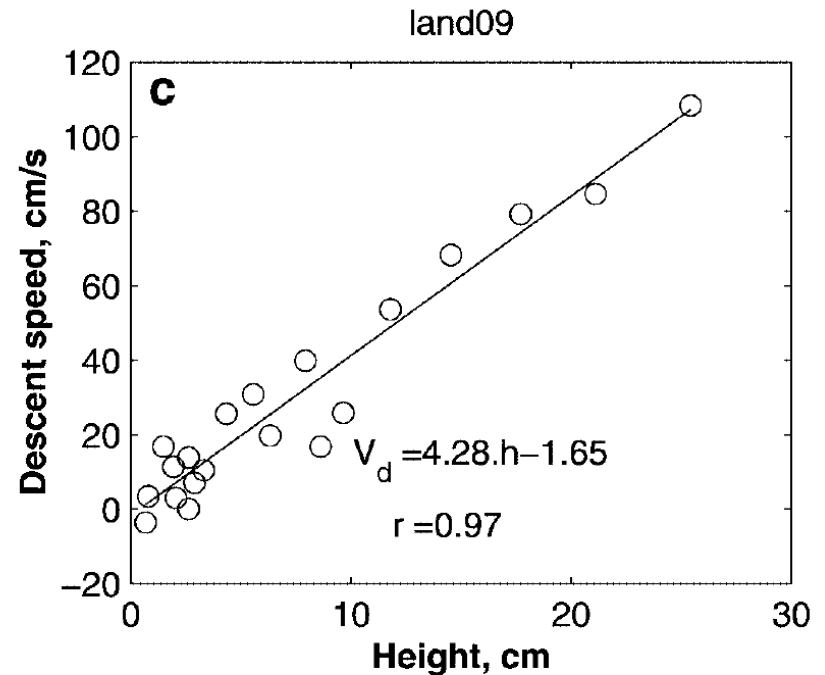
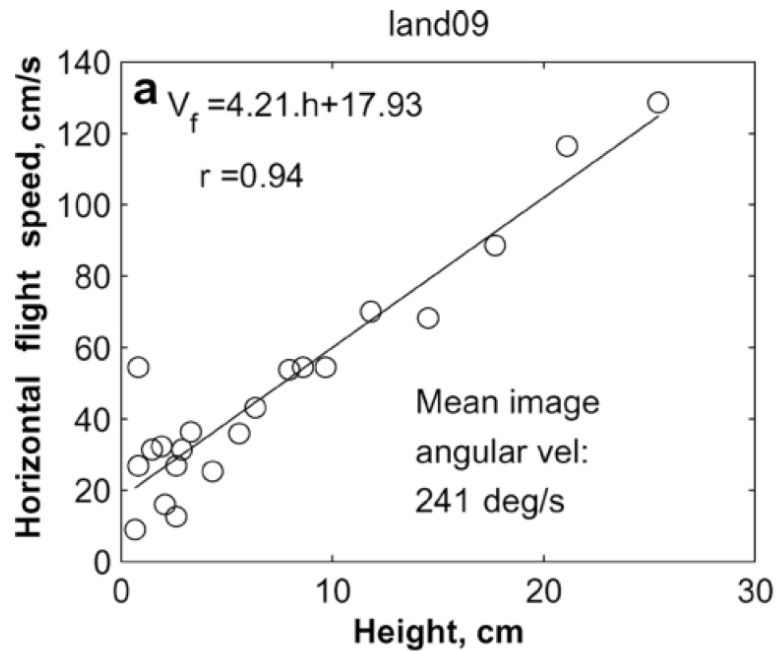
Franceschini's EMD (scheme)



Franceschini's EMD



The EMD is very robust to lighting conditions and able to function in a space scenario



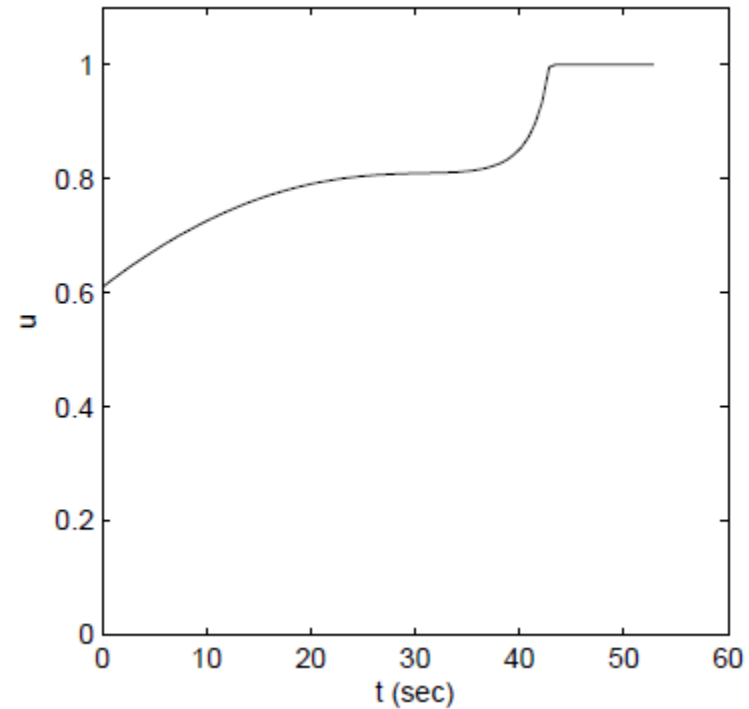
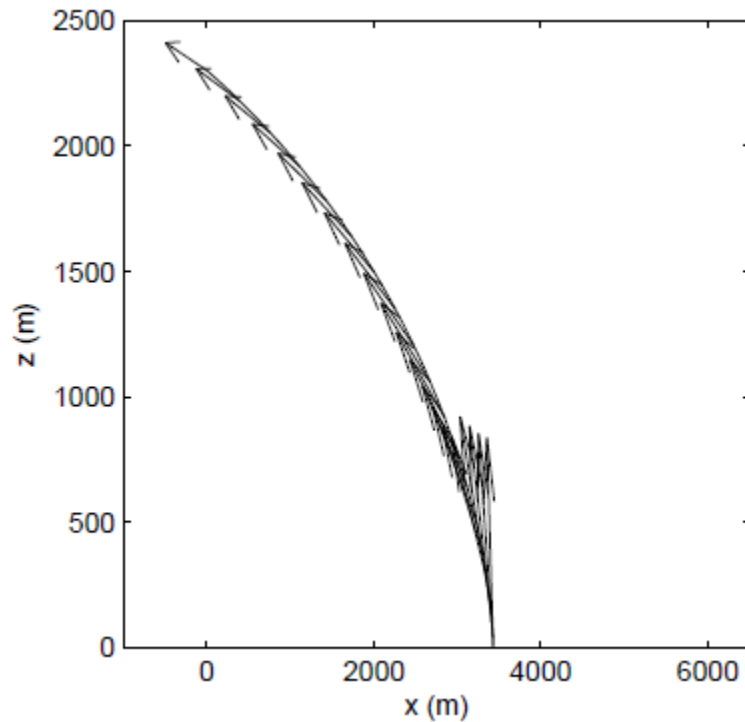
Srinivasan 2000: bees land by keeping the ventral OF constant and horizontal and vertical velocities proportional

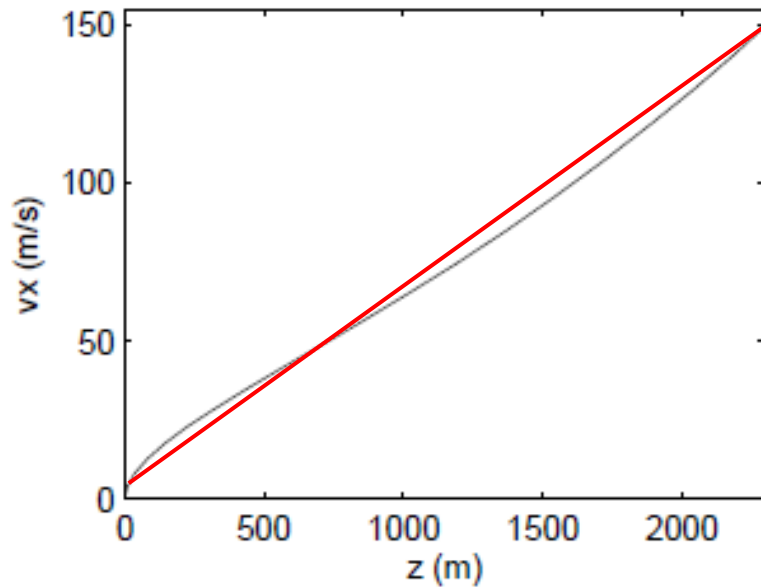


Table 1. Summary of the optimal pitch laws.

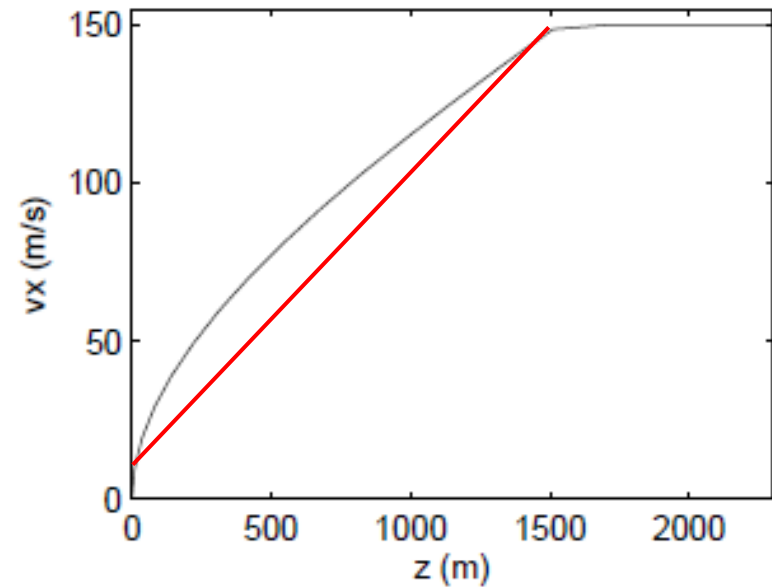
Case	Optimal Pitch Law	m_f [kg]	t_f [s]
minimum time	$\tan \beta^* = a + bt$	8798.77	44.88
maximum mass	$\tan \beta^* = a + bt$	8869.44	54.07
minimum time (OF=const)	$\cos \beta^* = \frac{m\omega v_z^*}{T}$	8789.01	45.54
maximum mass (OF=const)	$\cos \beta^* = \frac{m\omega v_z^*}{Tu^*}$	8824.74	52.91

High-gate low-gate
Apollo like landing



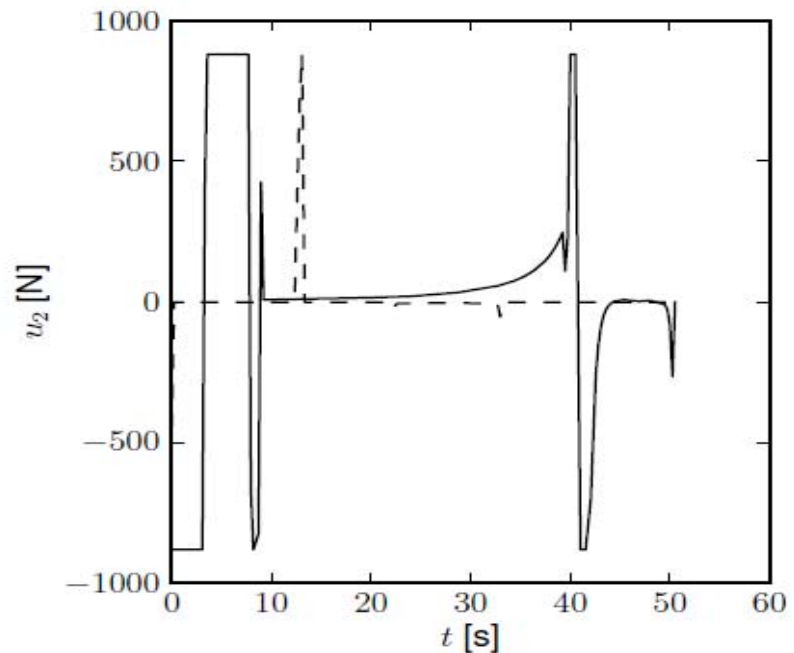
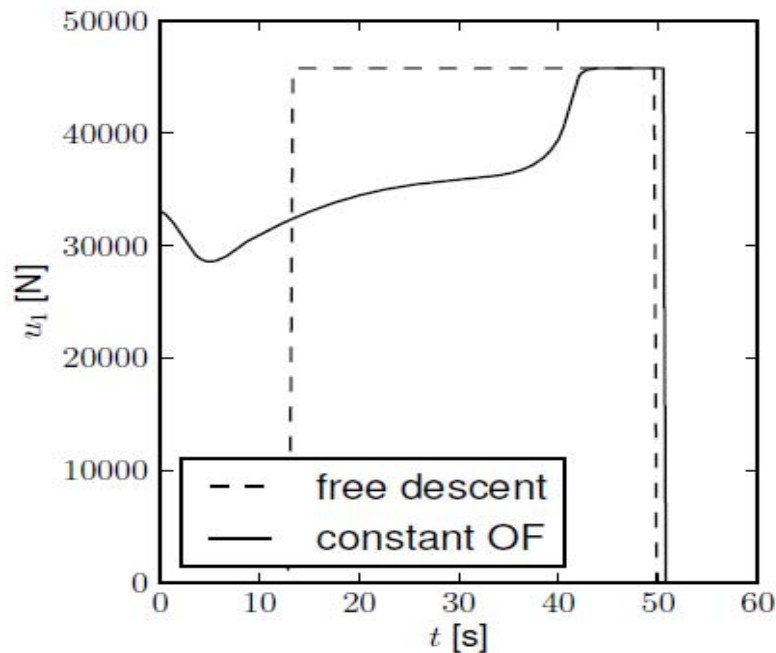


Minimum time



Maximum mass

...m m m m



Parameter	Range	ΔP_{max}	ΔP_{mean}	ΔP_{min}
$v_{x0} \left[\frac{m}{s} \right]$	170...120	11.39%	8.66%	6.71%
$v_{z0} \left[\frac{m}{s} \right]$	-22... - 65	9.65%	8.53%	7.13%
z_0 [m]	3300...2300	11.66%	10.02%	8.49%

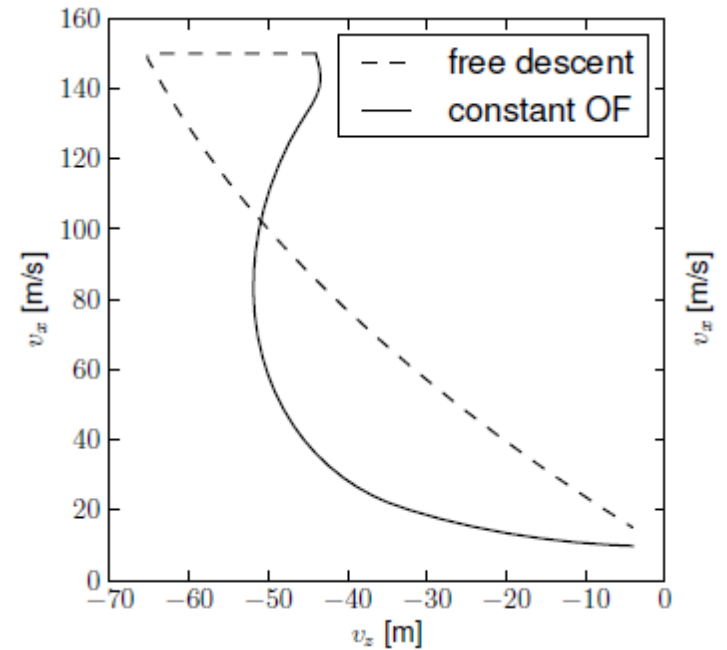
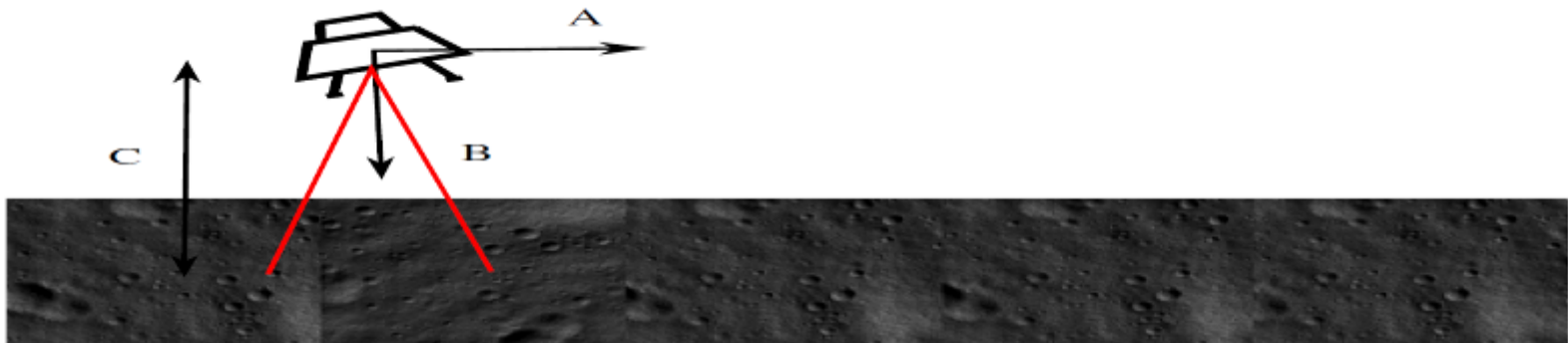


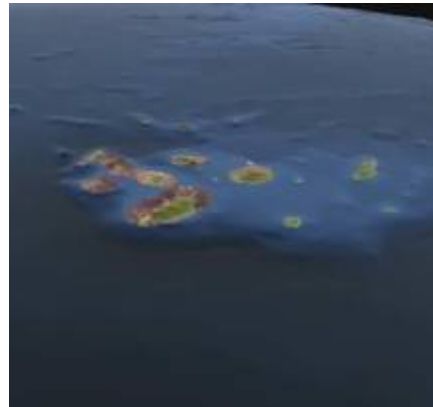
→ constant optic flow

$$\dot{v}_x = a_{x_{cmd}} = c_1 + c_2 t$$

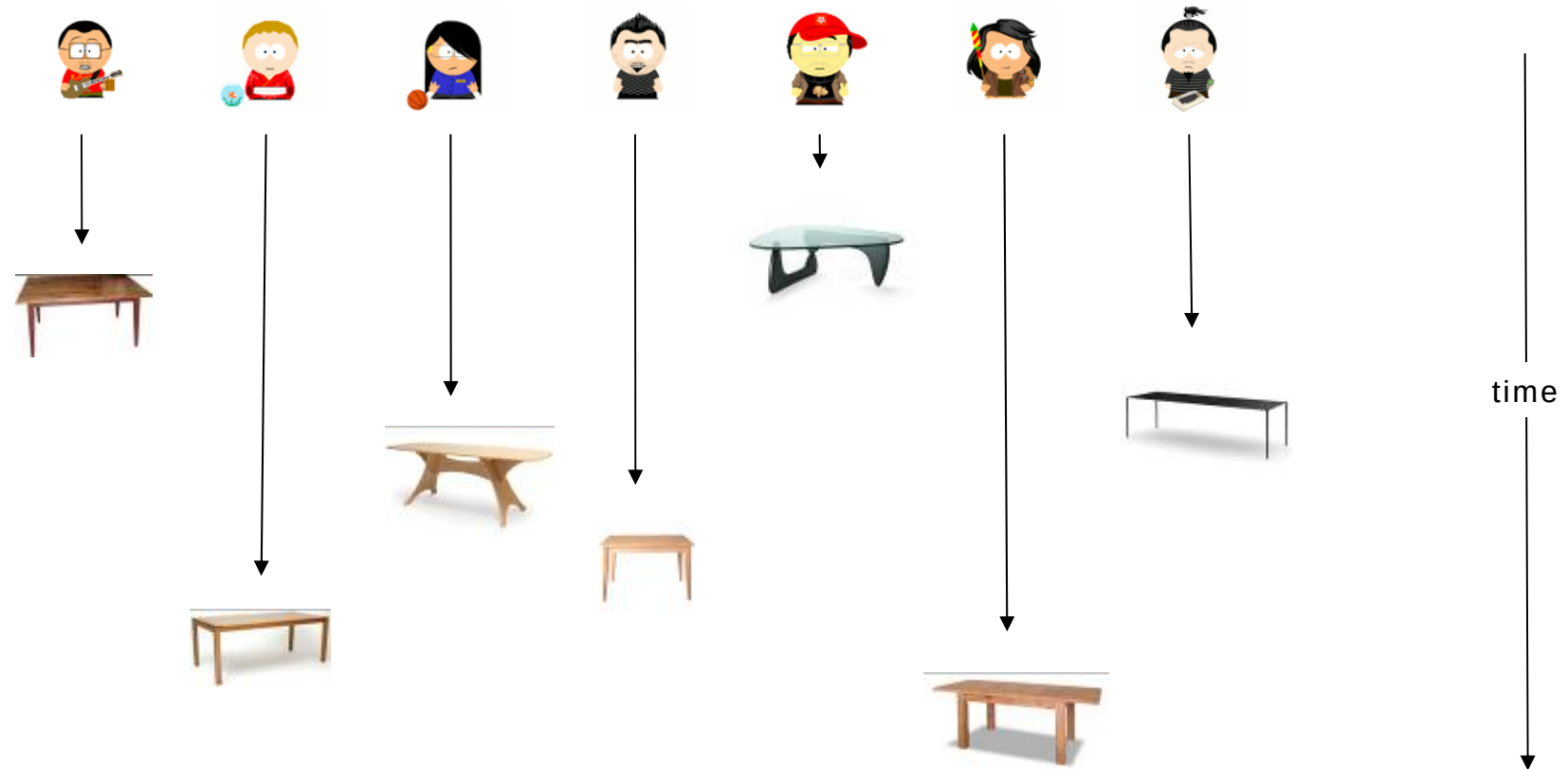
$$c_1 = \frac{-2(v_t + 2v_0)}{t_t} + \frac{6(x_t - x_0)}{t_t^2}$$

$$c_2 = \frac{6(v_t + v_0)}{t_t^2} - \frac{12(x_t - x_0)}{t_t^3}$$

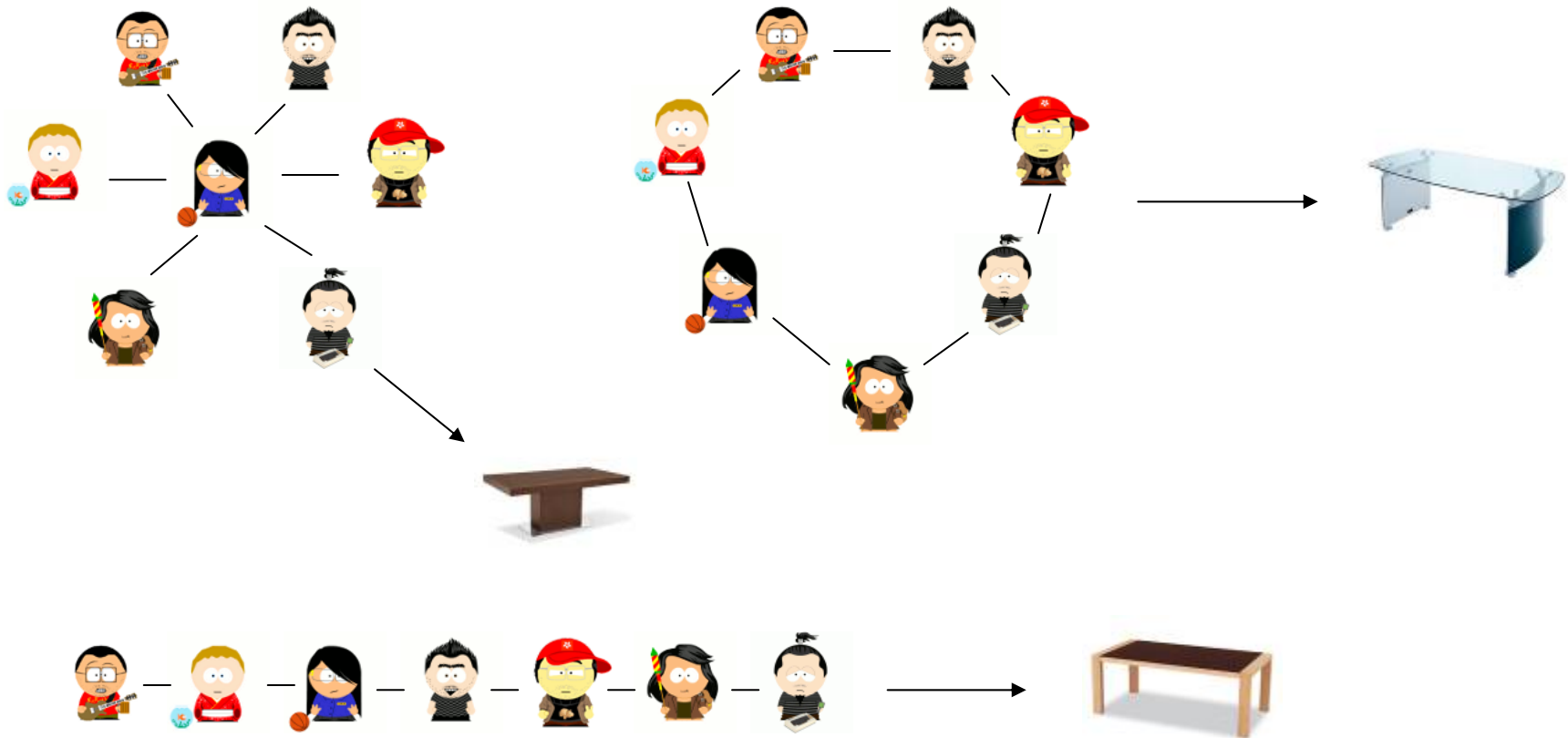




f. PaGMO: A swarm of algorithms for massively parallel engineering optimization



Ask different people to design a table, as individuals ...



or put them together



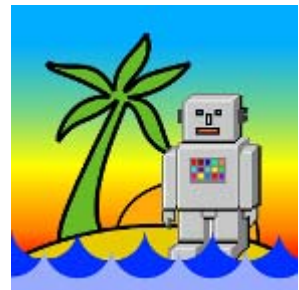
No free lunch in global optimisation,
same paradigm applies: **algorithm** = **South Park** character

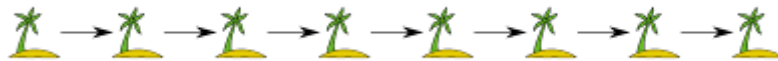
Questions:

- **How often** information should be exchanged?
- **How much** information should be exchanged each time?
- **Who** should exchange information **with who**?
- **What** is the problem we are solving?



- First DiGMO, then SeGMO, then PaGMO
- Open source on sourceforge
- Engineers worry only to define its problem, efficient parallelization and problem solution demanded to PaGMO
- Archieplago, island, population, migration topology
- Algorithm:
 - **Coded in PaGMO:** adaptive neighbourhood simulated annealing, improved harmony search, compass search, monotonic basin hopping, multistart, monte-Carlo, ant-colony, bee-colony, genetic, differential evolution, nsga-II, firefly, cross-entropy
 - **Interfaced to PaGMO:** gsl library (nelder mead, bfgs, ...), nlopt library (bobyqa, cobyla, ...), IPOPT library, SNOPT library, scipy optimization algorithms
- Problem:
 - **Standard tests:** Paraboloid, Ackley, Rastrigin, Rosenbrock, Branin, Schwefel, Griewank, Lennard-Jones, Levy5, HimmelBlau, Luksan-Vlcek, Golomb Ruler, Knapsack Problem, Travelling salesman, SCH, FON
 - **Engineering optimization:** MGA, MGA-DSM, MGA-LT

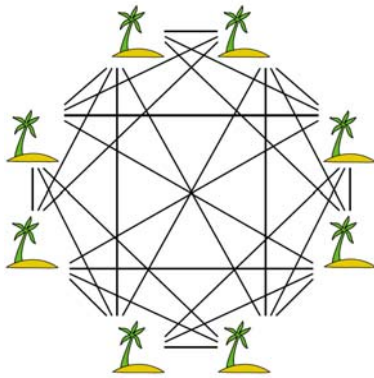




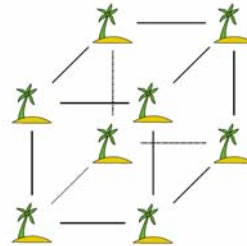
chain



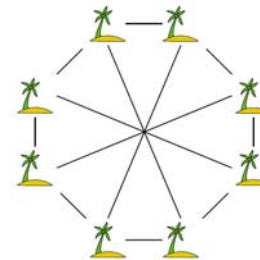
**Erdos Renyi, Watts Strogatz
Barabasi Albert**



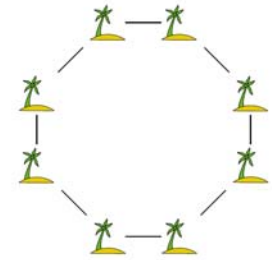
full



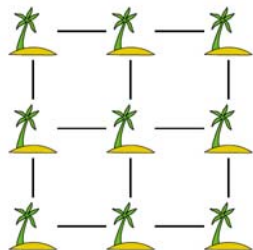
hypercube



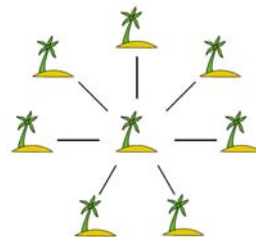
cartwheel



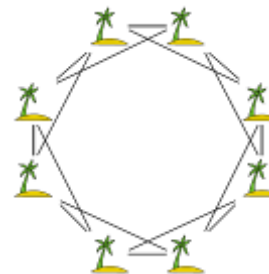
ring



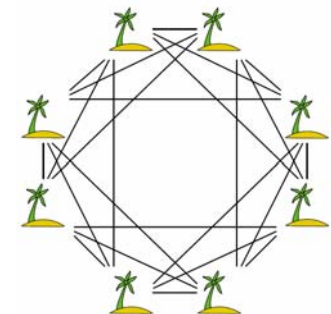
lattice



broadcast

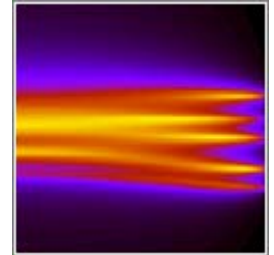


Ring 12

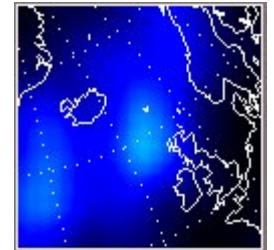


Ring 123

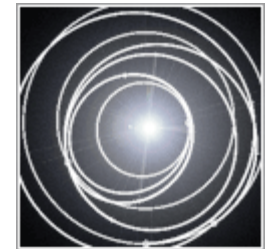
Full parameter study of multilayer coating
for thermal applications



Distributed Computing for Ionospheric
Data Processing



Interplanetary trajectory optimisation

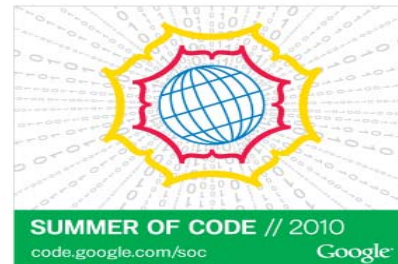


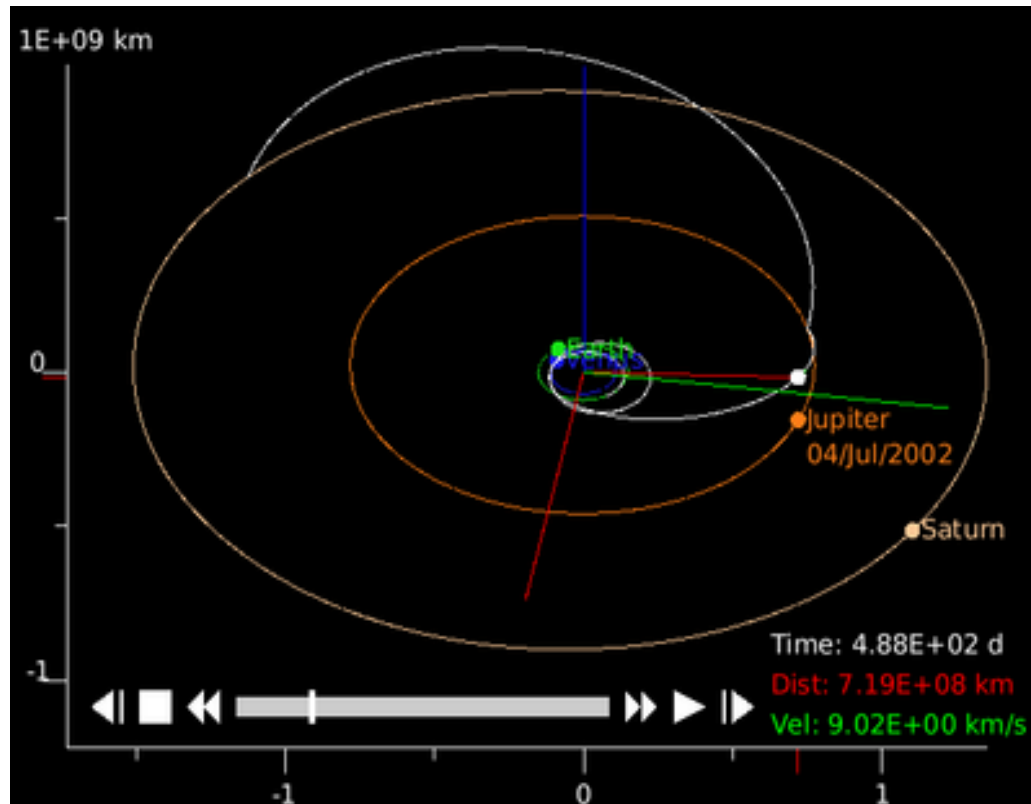
Parallel artificial evolution



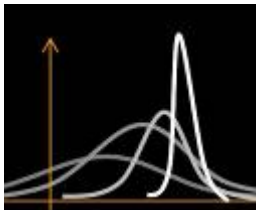


**PaGMO was selected for the Google
summer of code 2010**

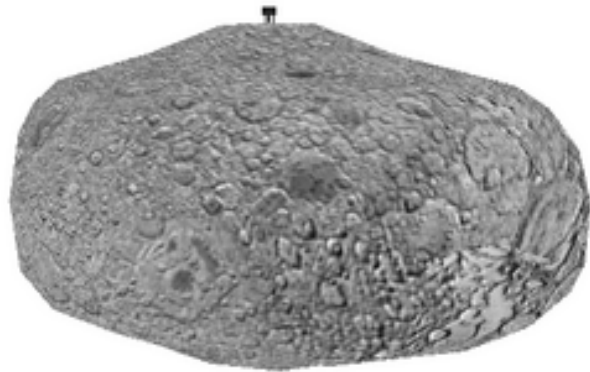




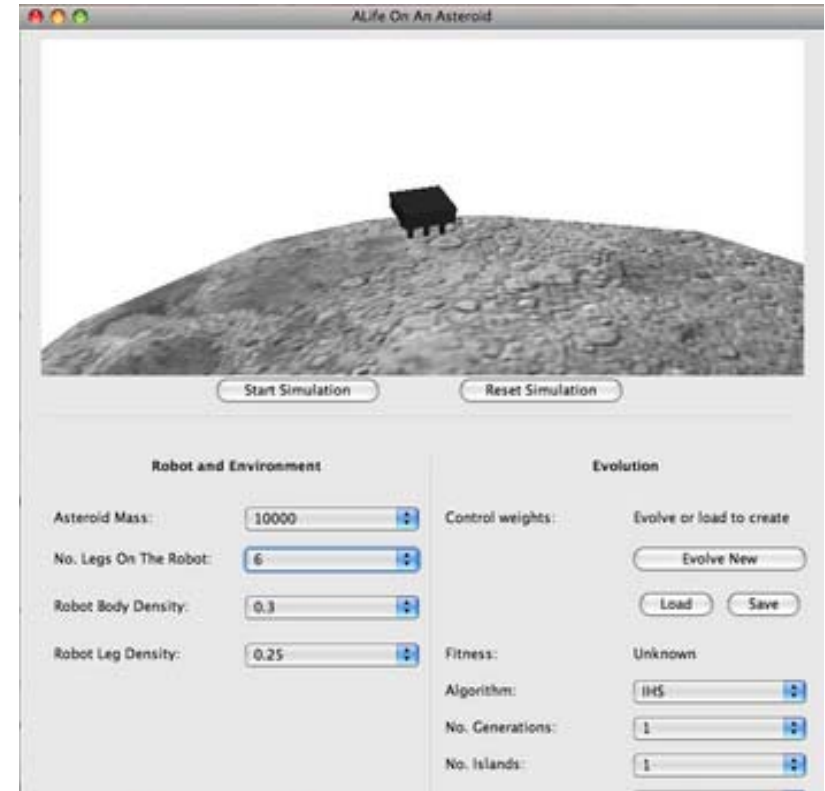
MGA, MGA-DSM and
MGA-LT visualization
interfaced to PyGMO

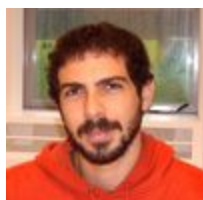
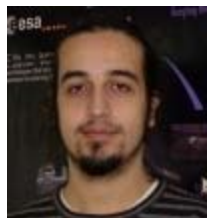


Study of the generalized migration operator for
bio-inspired optimisation algorithms



Experimenting with artificial life
on asteroids





Thanks!!