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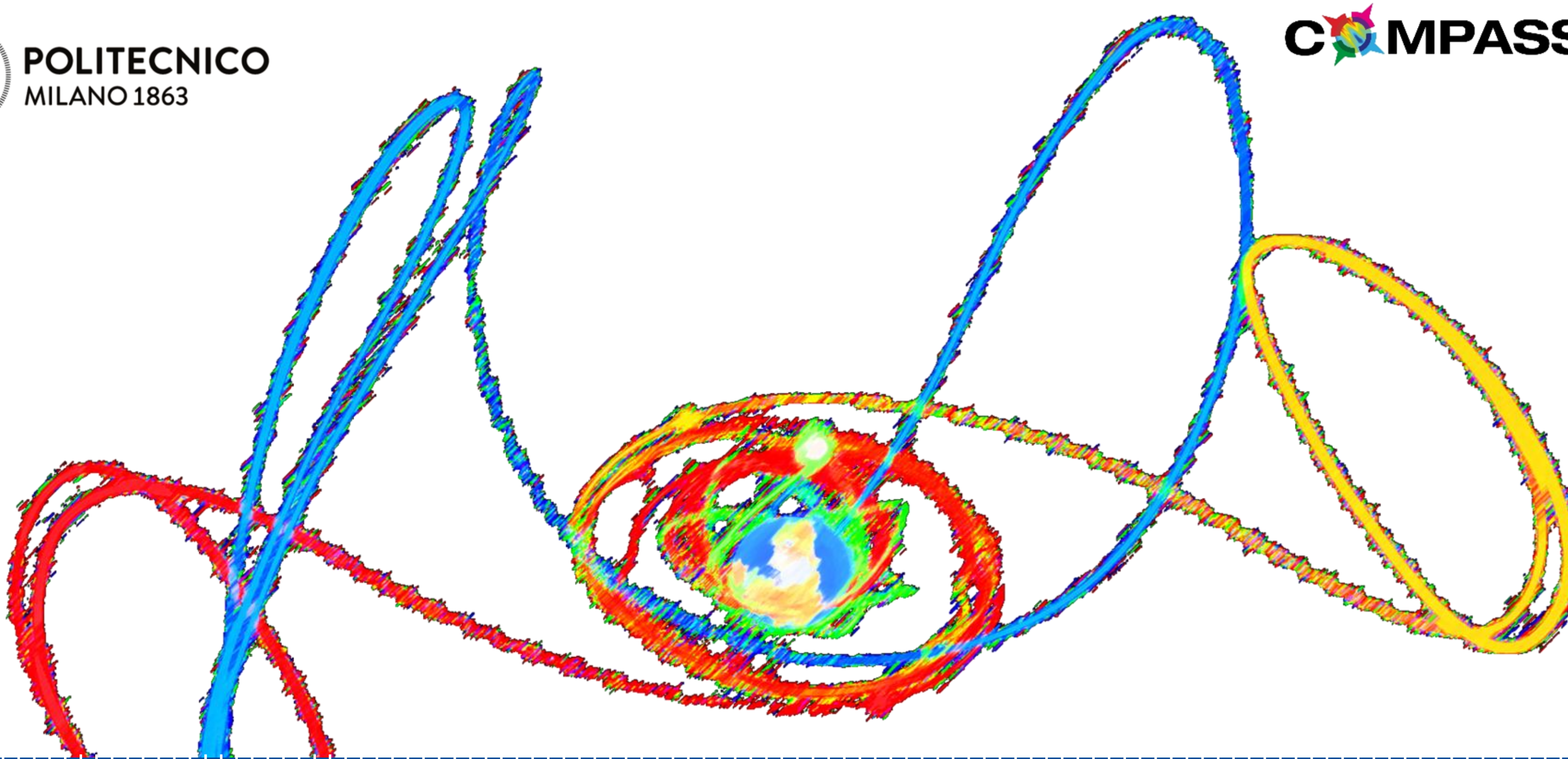


Control for Orbit Manoeuvring through Perturbations for Application to Space Systems

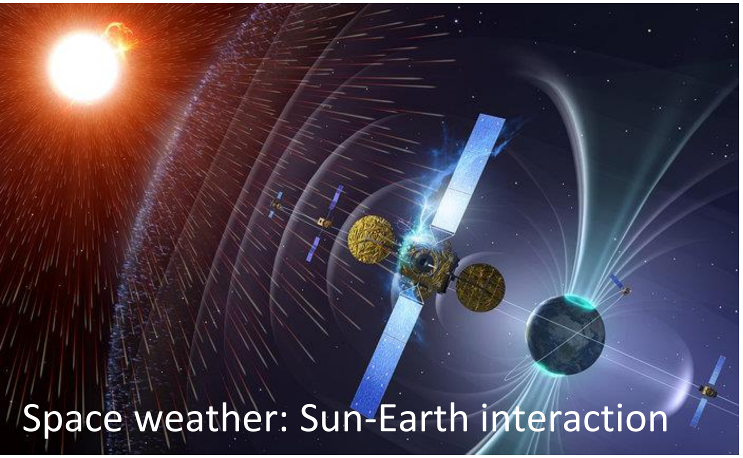
Camilla Colombo

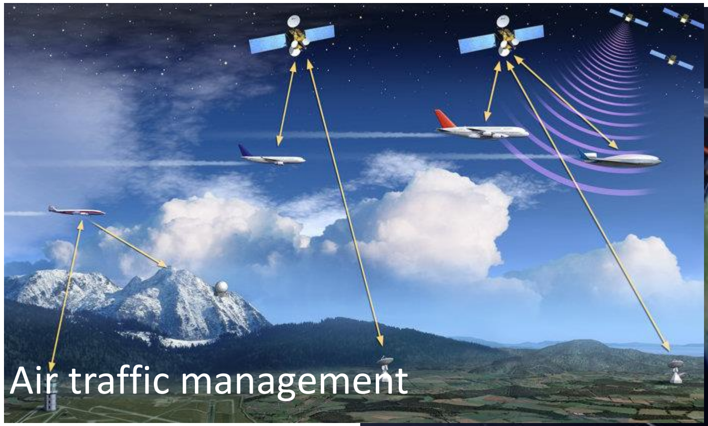
CanSat Italy 2018
Planetario di Modena

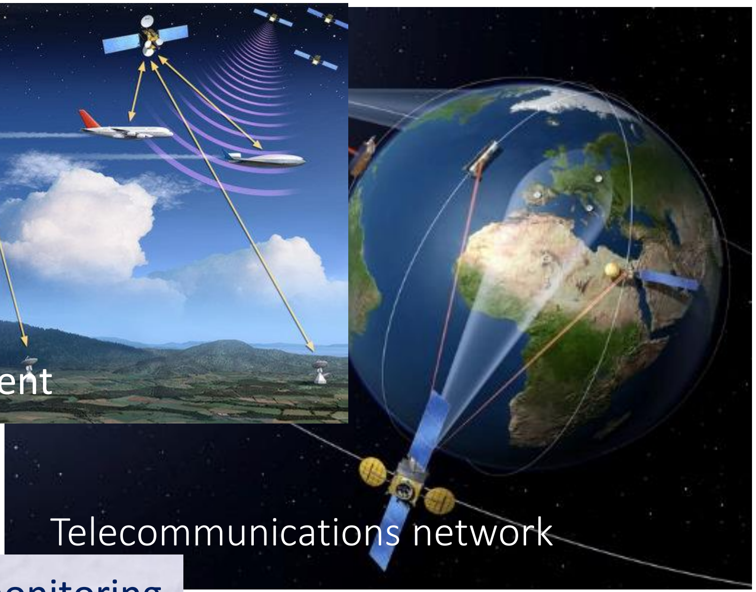
INTRODUCTION

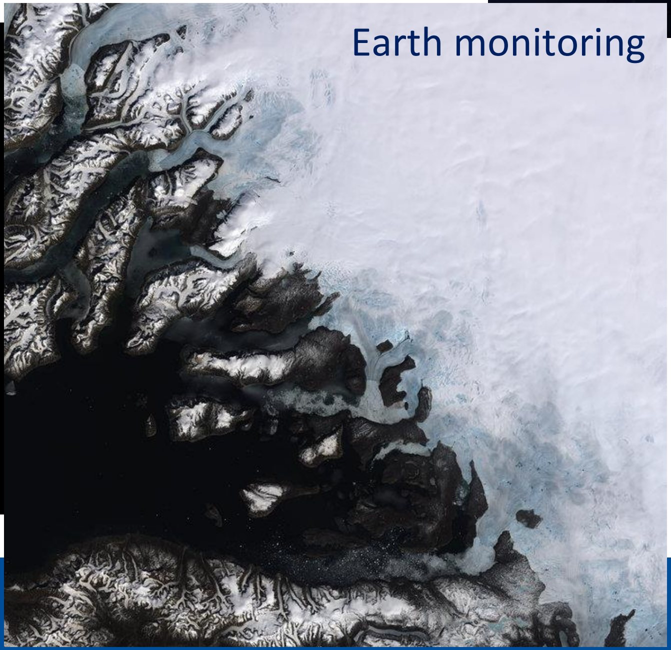
Lo spazio per noi

Perchè i satelliti?



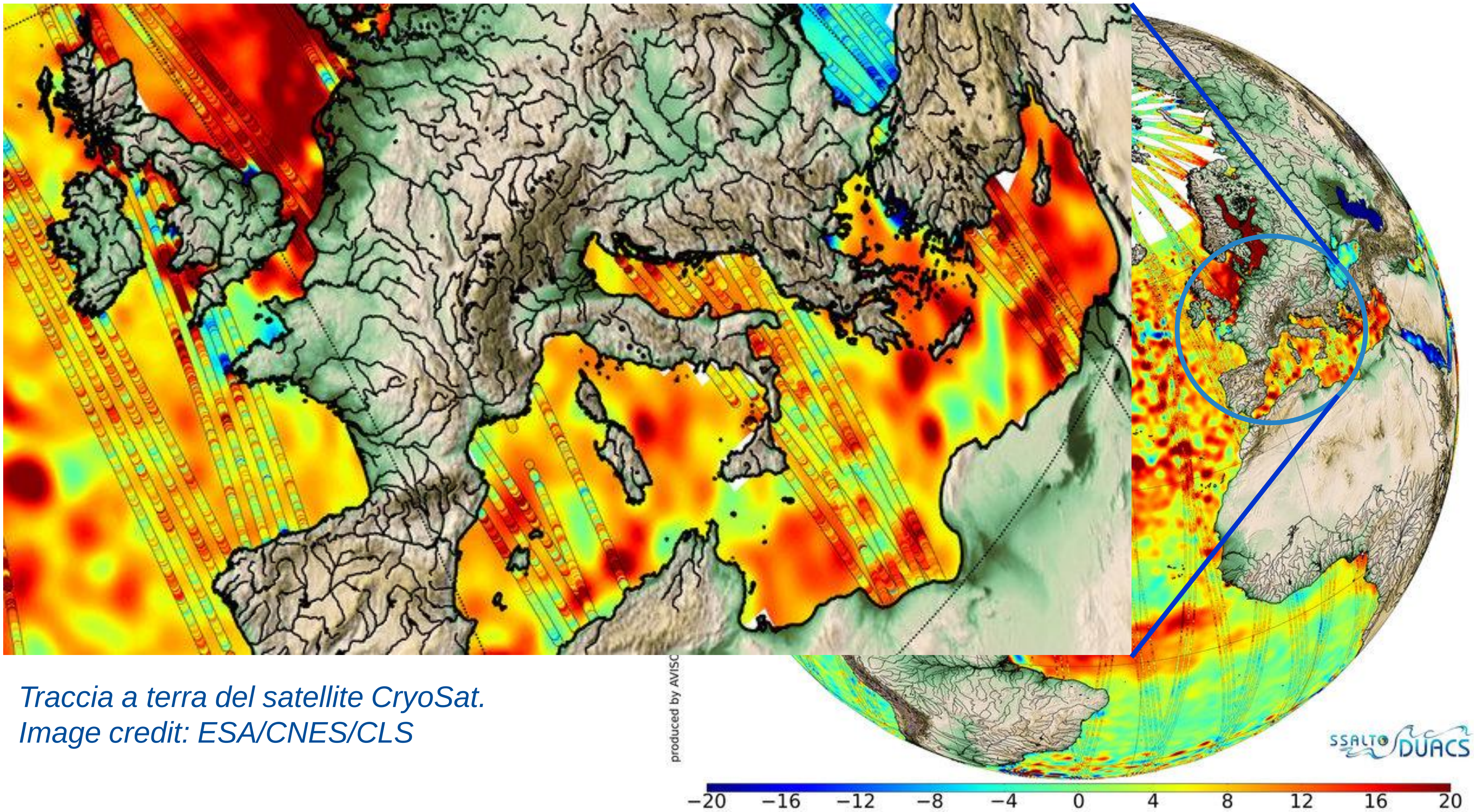






Lo spazio per noi

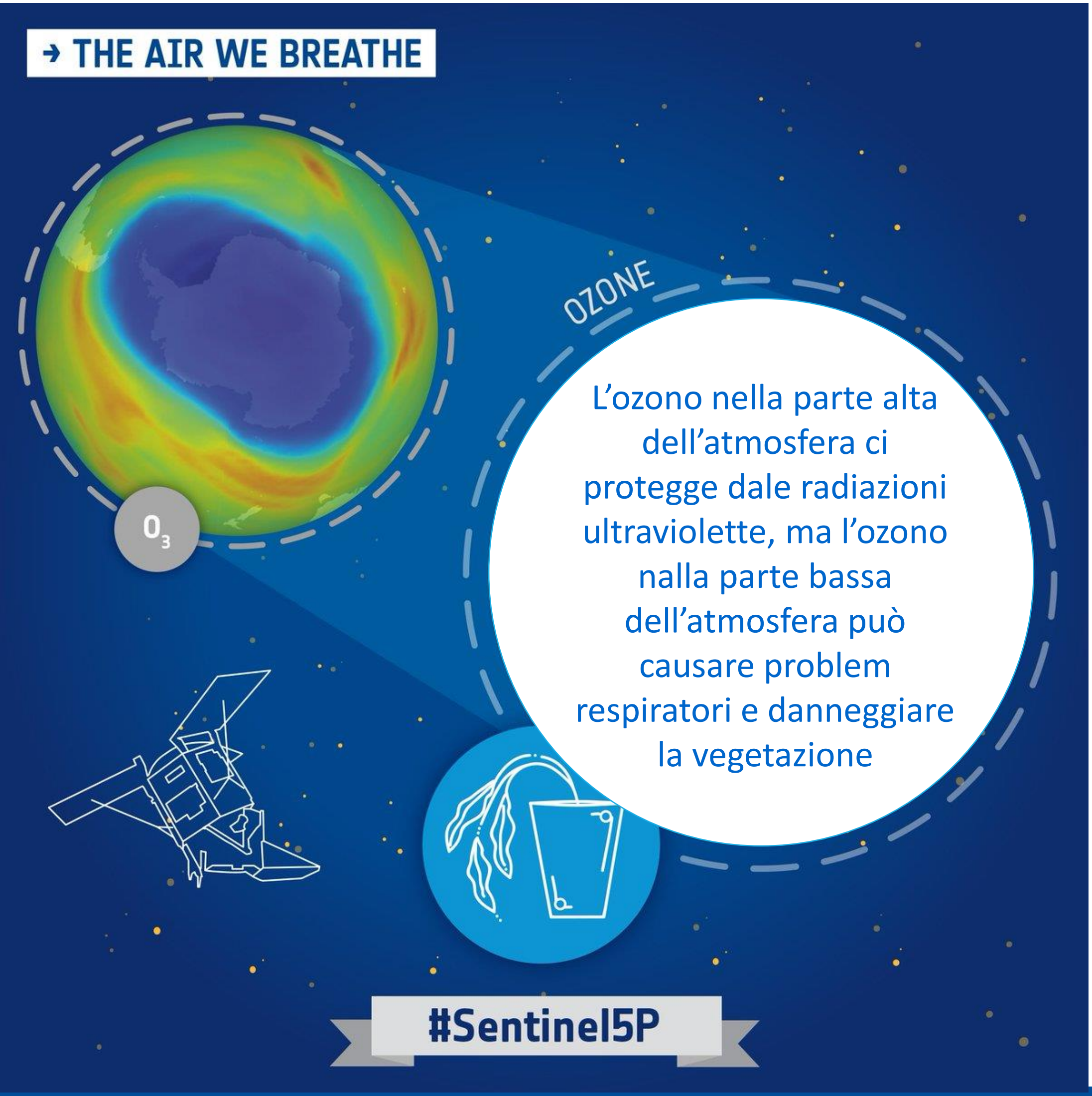
Monitoraggio remoto della terra



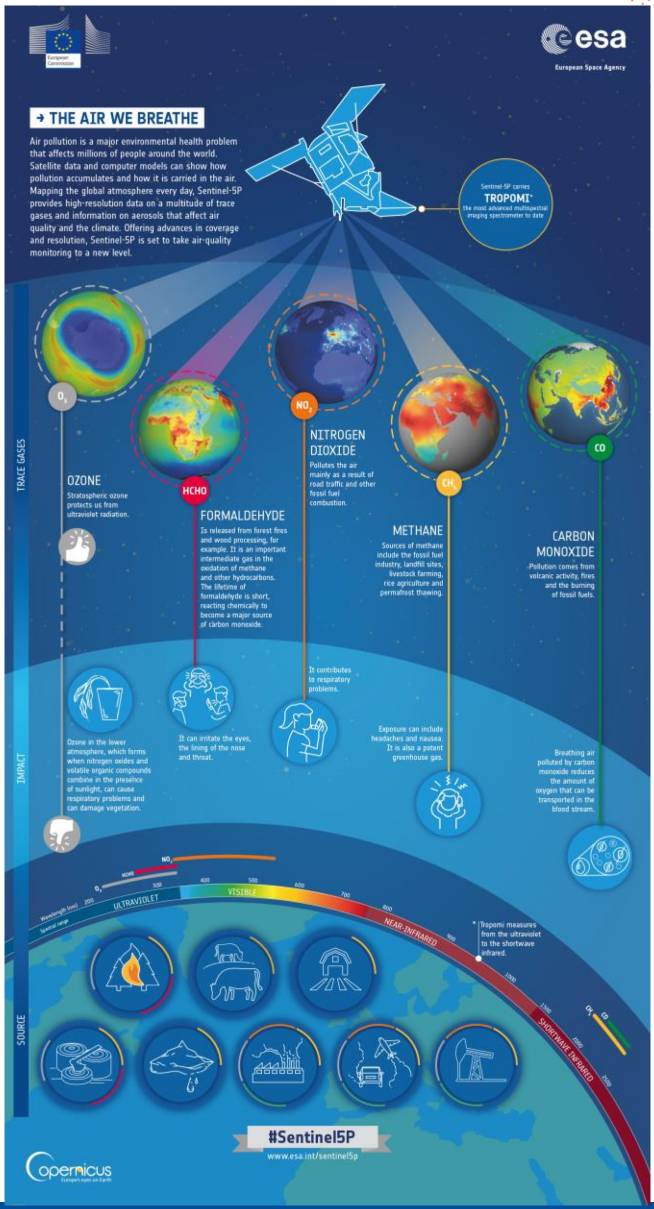
Traccia a terra del satellite CryoSat.
Image credit: ESA/CNES/CLS

Lo spazio per noi

Monitoraggio remoto della terra

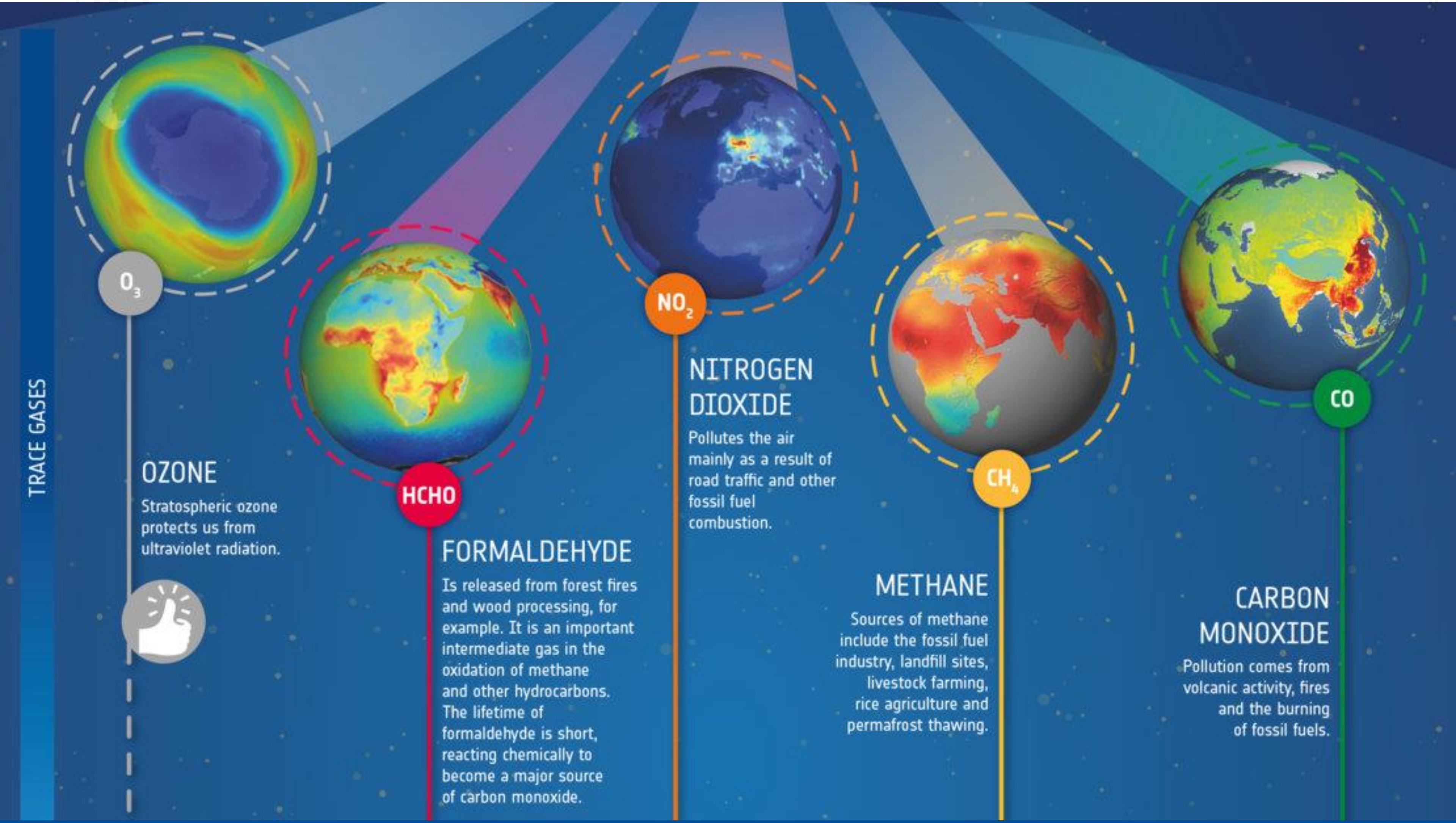


L'ozono nella parte alta dell'atmosfera ci protegge dale radiazioni ultraviolette, ma l'ozono nalla parte bassa dell'atmosfera può causare problem respiratori e danneggiare la vegetazione



Lo spazio per noi

Monitoraggio remoto della terra

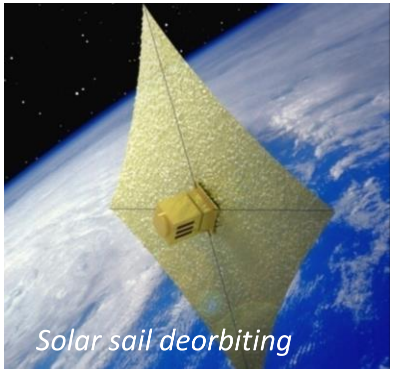


Introduction

Space transfer

Space transfer allows the colonisation of new habitats and reaching operational orbits for science missions and space services.

- **Trajectory design** and orbit maintenance are a challenging task
- As enabling technology, **electric propulsion** is increasingly selected as the primary option for near future missions, while novel propulsion systems for de-orbiting and orbit-raising are being proposed.
- **New space system** are under development (e.g. mega-constellation, nano and CubeSat)
- The **natural dynamics can be leveraged** to reduce the current extreme high mission cost.


Solar sail deorbiting


Large constellations
Credit: Airbus video still

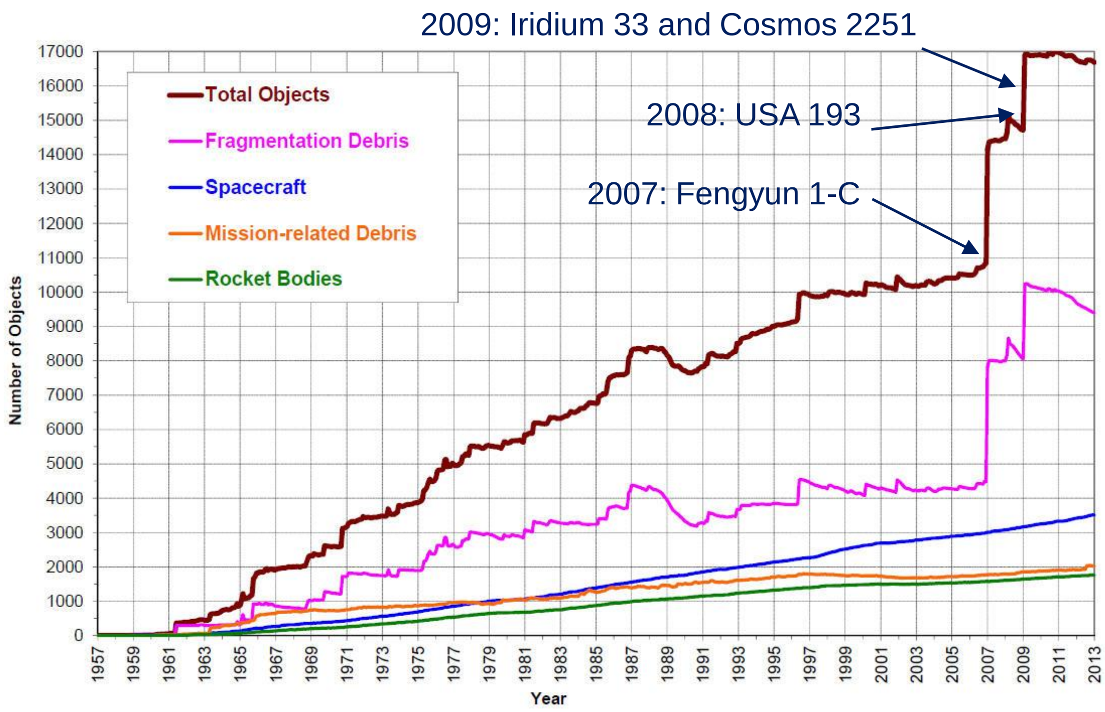

Credit: The University of Michigan

Introduction

Space situation awareness

Space debris poses a threat to current and future space activities

- Currently 22000 objects > 10 cm and 500000 objects > 1-10 cm
  Breakups generate clouds of fragments difficult to track
- Fragments can collide at very high velocity and damage operating satellites
- Need to define debris mitigation guidelines



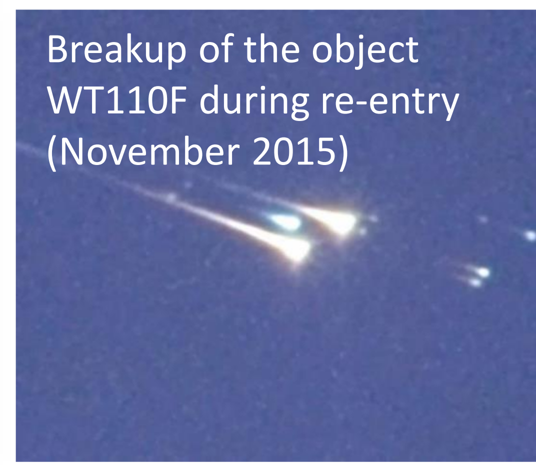
Introduction

Planetary protection

- On average a 10-km-sized asteroid strikes the Earth every 30-50 million years (Globally catastrophic effects)
- Tunguska class (100 m in size) asteroid impact every 100 years (Locally devastating effects)
- Very small asteroids are very frequent but generally burn in the atmosphere
- Spacecraft and launcher for interplanetary missions remain in resonance with the Earth and other planets

Chelyabinsk, Russia (2013), 17-30 m diameter asteroid

Tunguska, Siberia (1908), flattening 2000 km^2 of forest, 50-70 m asteroid



Breakup of the object WT110F during re-entry (November 2015)

Background and proposed approach

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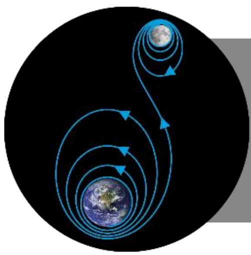
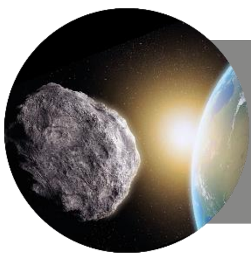
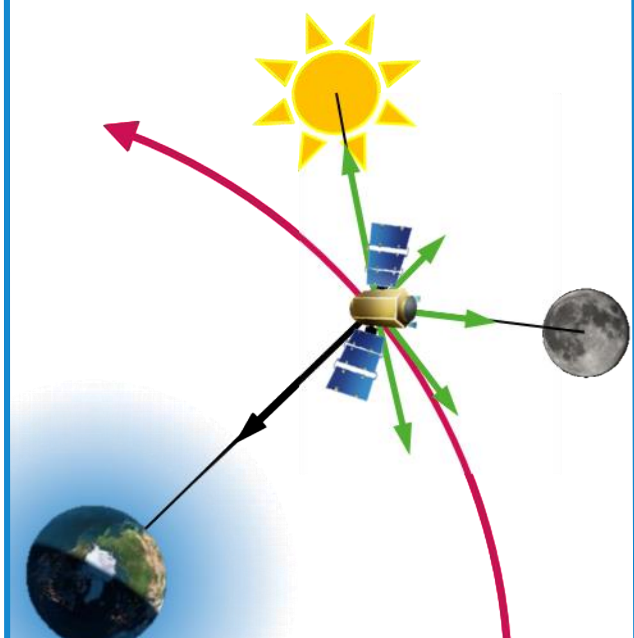
Services, technologies, science, space exploration	ORBIT PERTURBATIONS Traditional approach: counteract perturbations	COMPASS Novel approach: leverage perturbations
SPACE TRANSFER: Reach, control operational orbit	▪ Complex orbital dynamics ▪ Increase fuel requirements for orbit control	Reduce extremely high space mission costs
SPACE SITUATION AWARENESS: Asteroids. planetary protection		Create new opportunities for exploration and exploitation
SPACE SITUATION AWARENESS: Space debris		Mitigate space debris



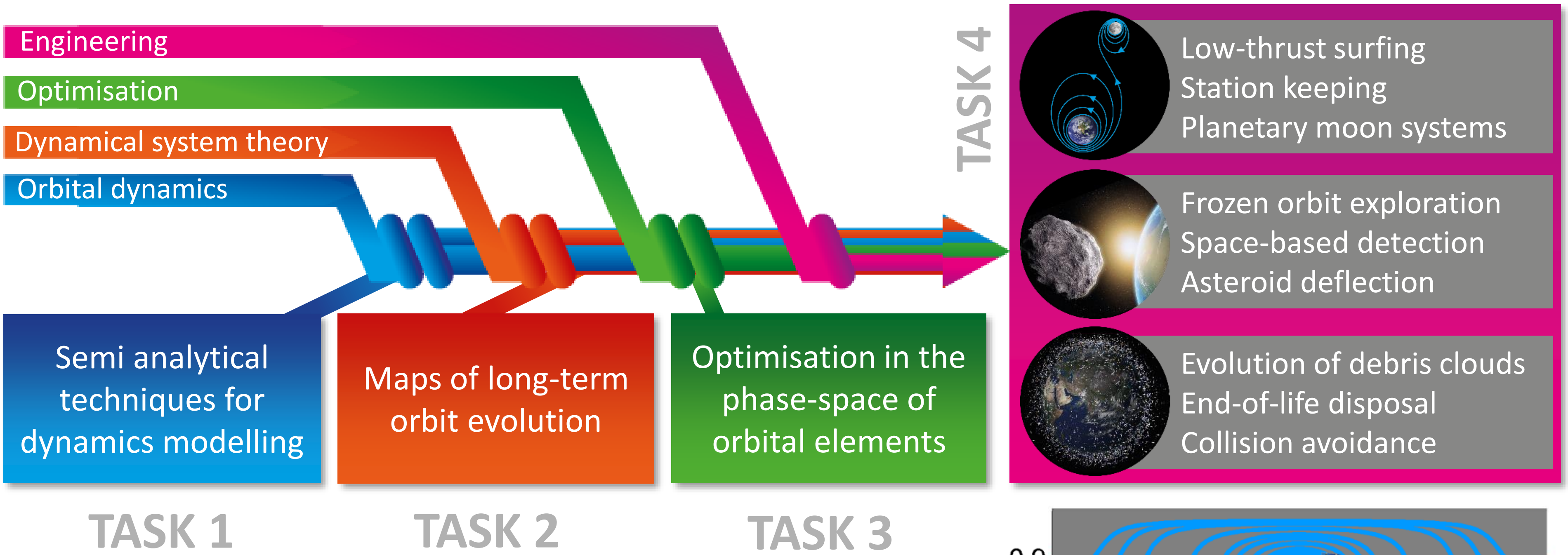




Develop novel techniques for orbit manoeuvring by surfing through orbit perturbations

METHODOLOGY

Methodology and expected results

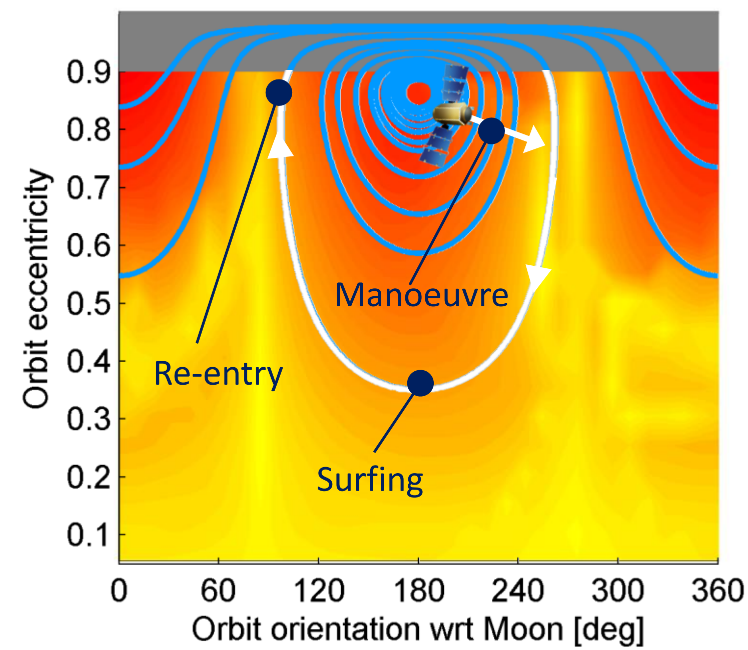


T1. Understanding of the spacecraft orbit evolution

T2. Topology of space of orbit perturbations (stability)

T3. Spacecraft surf these natural currents to the desired orbit

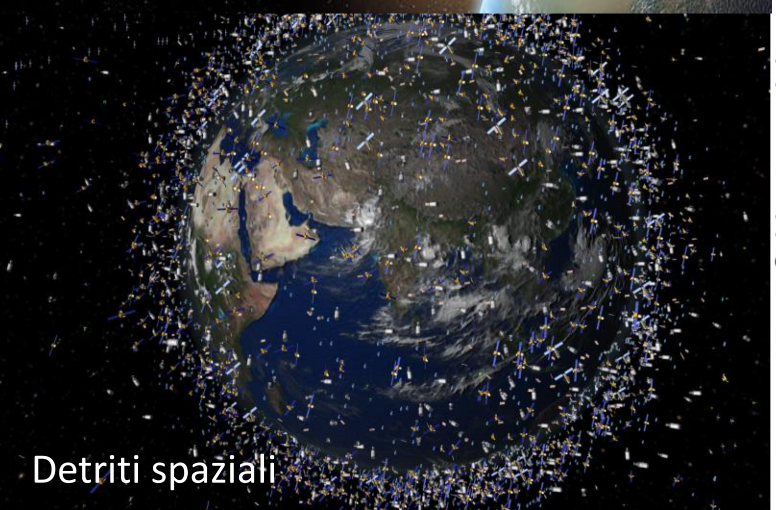
T4. Design of space missions

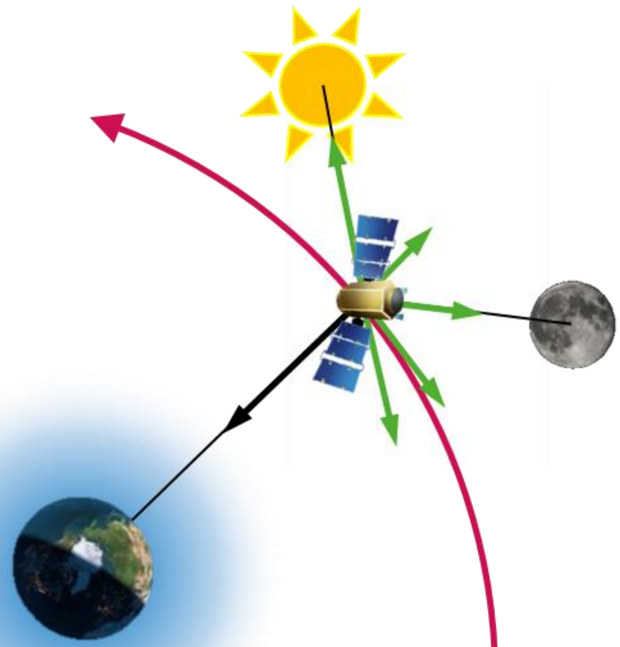


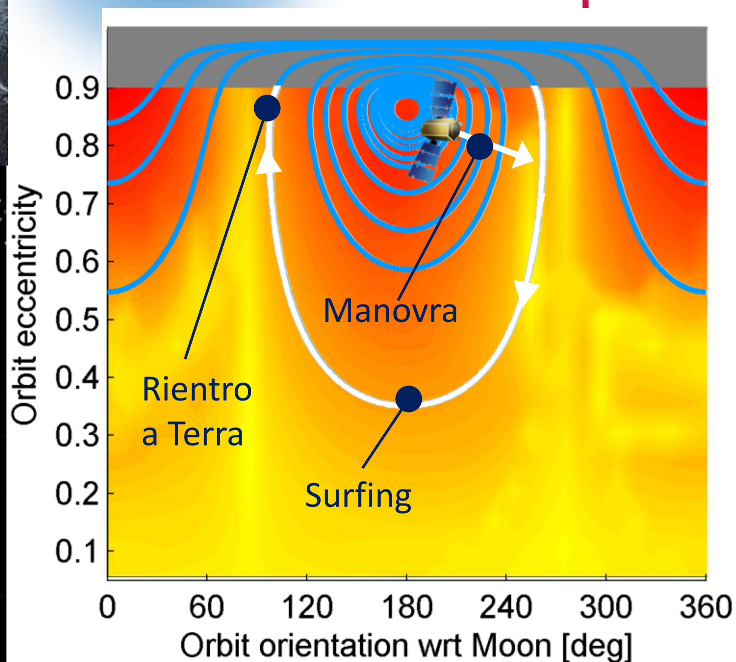
surfing nello Spazio

COMPASS

European Research Council
Established by the European Commission







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Lo Spazio per noi

Ridurre i costi delle missioni spaziali e rendere lo Spazio più accessibile

Creare nuove opportunità per l’esplorazine e lo sfruttamento delle risorse spaziali

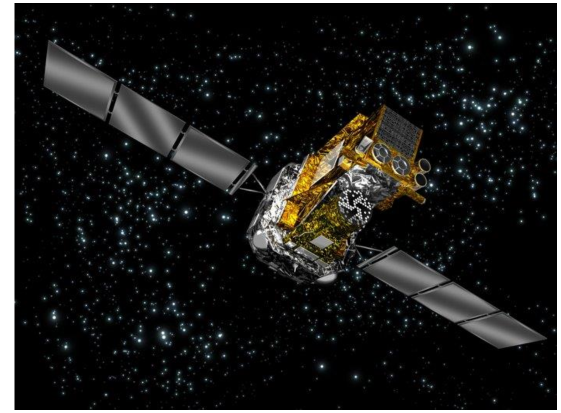
Ridurre e controllare i detriti spaziali

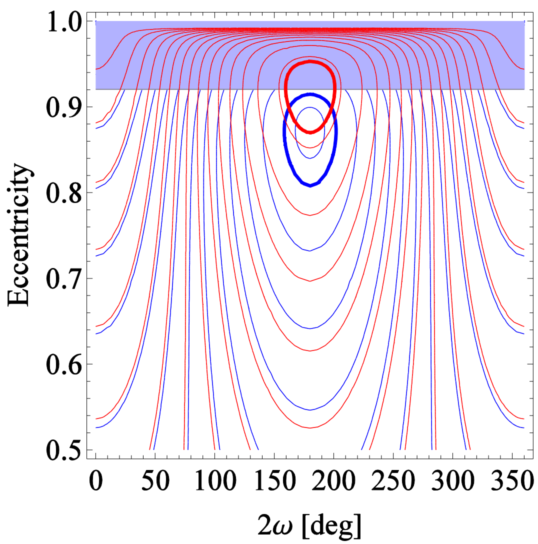
MISSION APPLICATIONS

Concept demonstration

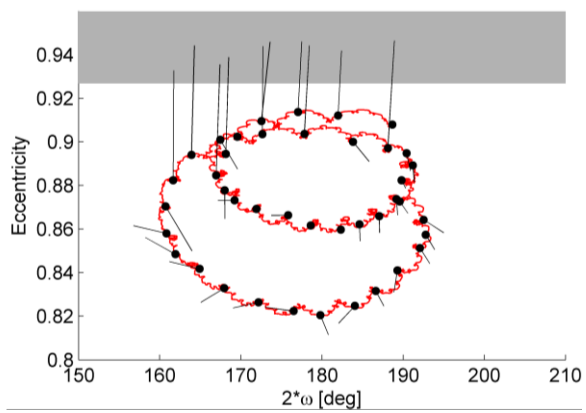
Perturbation enhanced end-of-life design of INTEGRAL mission

- Astrophysics and astronomy missions (e.g., INTEGRAL and XMM-Newton)
- Very complex dynamics under the effects of Moon and Sun perturbation and Earth's oblateness
- No end-of-life disposal



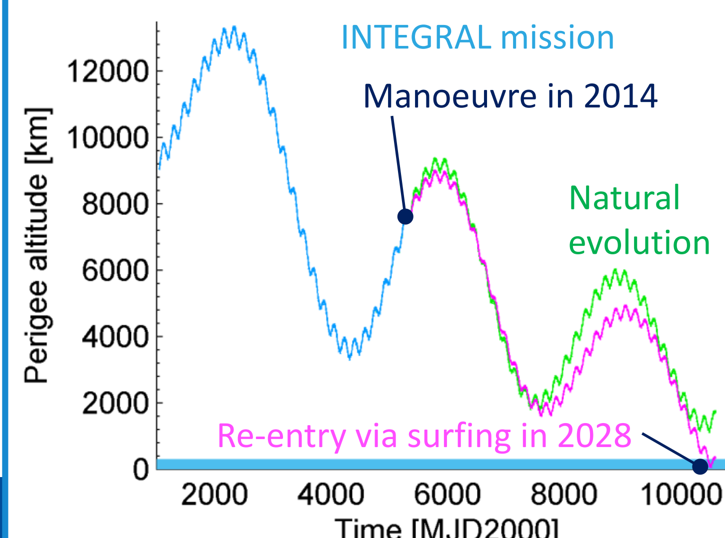


Orbit phase-space evolution



Trajectory design in the phase space

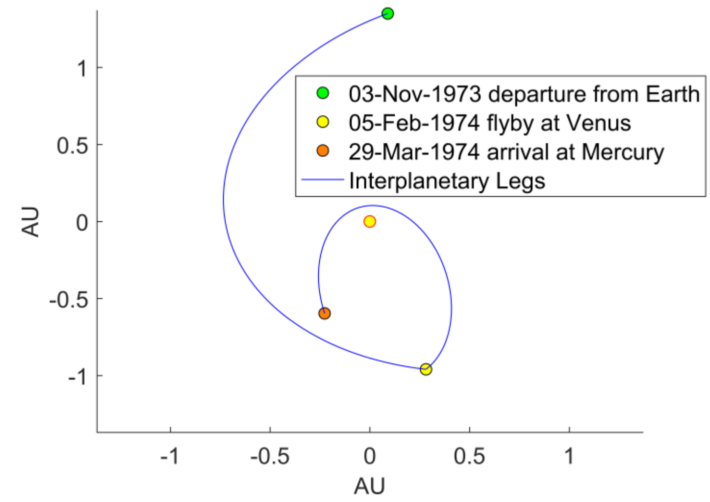
Luni-solar perturbation surfing made re-entry of INTEGRAL mission possible

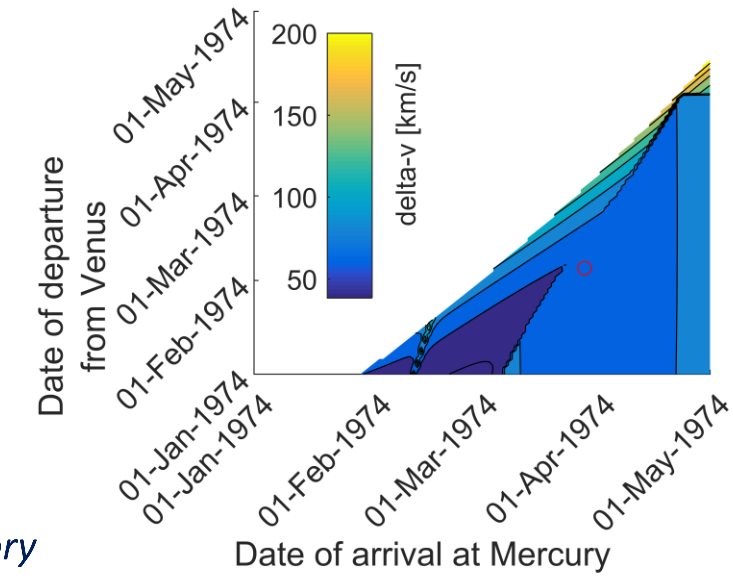


Space transfer

Interplanetary fly-by design through maps

- Solution of interplanetary trajectory optimisation problem
- Orbital phase design through well-known Lambert problem
- Tisserand energetic manner method to identify reachable bodies and encounter conditions
- Combined Lambert-Tisserand solution applied to the single flyby problem



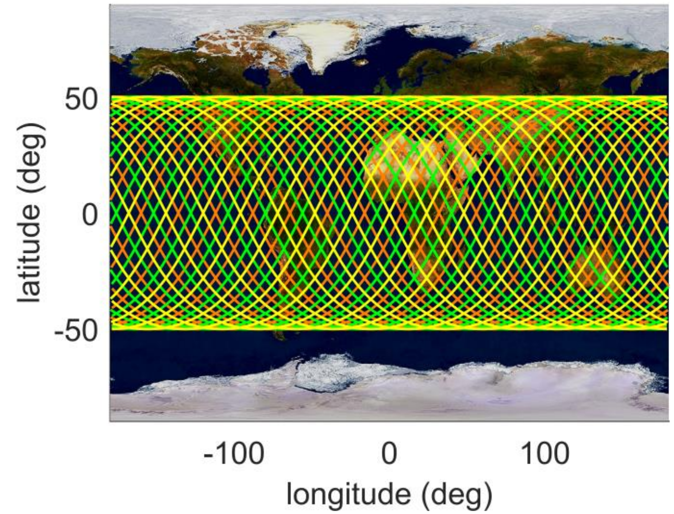


Mariner 4 trajectory

Space transfer

Design of spacecraft mega-constellations for space-based services

- Comparative assessment of different constellation geometries for space-based applications
- Optimisation of constellation design
- Debris interaction and end-of-life
- Perturbation enhanced frozen orbits



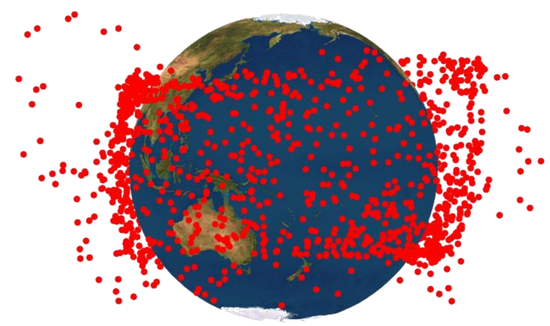
Constellation design in LEO and MEO

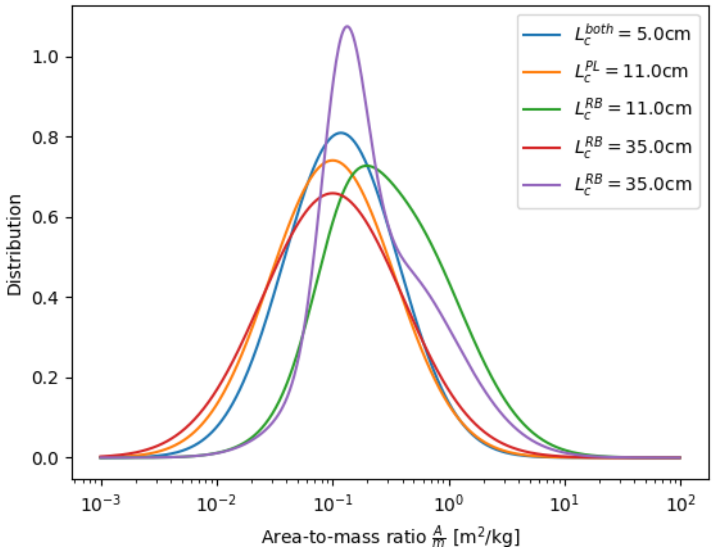
Space debris

Evolution and collision risk of space debris clouds

- Semi-analytical models to study the evolution of space debris in orbit
- Continuity equation approach: follow he evolution of the spatial density rather than each single object
- Challenging as dynamical problem is very complex
- Interaction of fragmentation clouds in highly elliptical orbit with the ow earth orbit environment

Distribution of debris fragments following a collision event





Space debris

End of life trajectory design

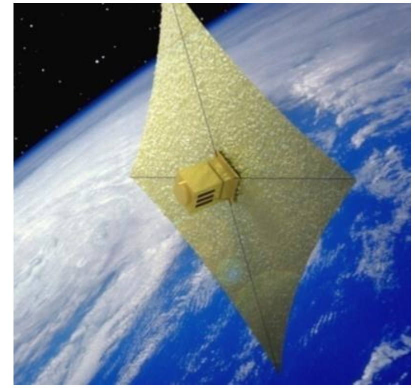
Solar sail deorbiting

- Solar sail for end-of life deorbiting in Earth centred orbit
- Novel technique for solar sailing to maximise deorbiting effect

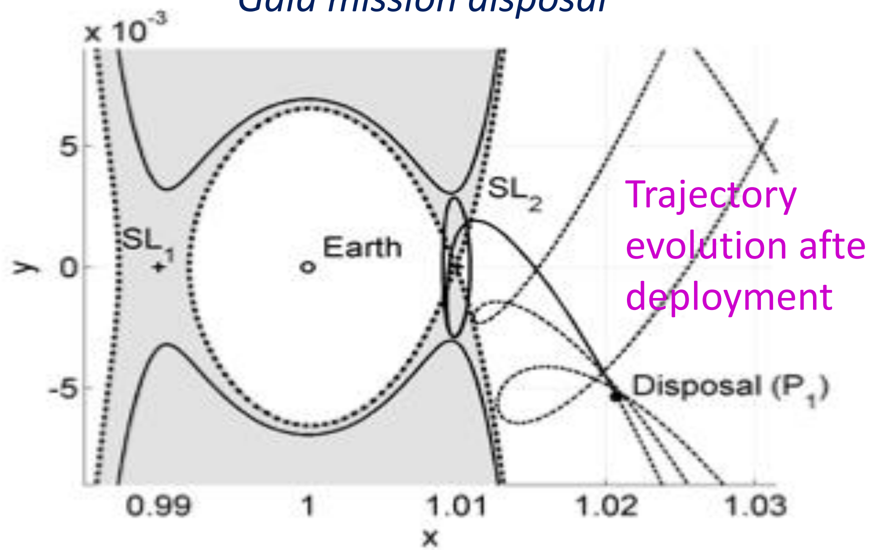
End-of-life for Lagrangian point missions

- End-of-life trajectory design for missions at the Lagrangian point
- Study of re-entry conditions
- Study of resonances
- Mission application to Gaia and Lisa Pathfinder missions

Solar sailing deorbiting



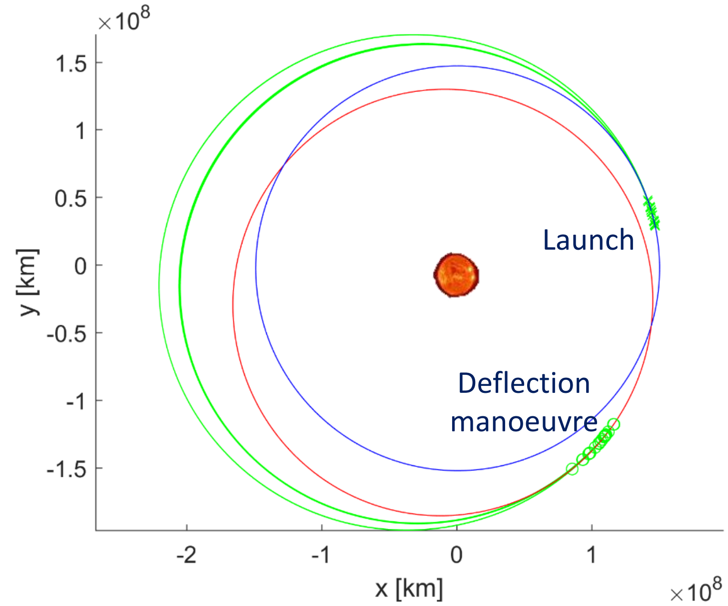
Gaia mission disposal



Planetary protection

Reference missions for different NEA threat scenarios

- Prepare a response to an Near Earth Asteroid (NEA) impact threat scenario
- Study mission design for NEA deflection mission
- Consider a diversity of cases: asteroids have different orbit and physical properties
- Study of selected case for direct and resonant encounter
- Design of robust deflection manoeuvre
  - Uncertainties on asteroid characteristics
  - Uncertainties on orbit determination and manoeuvre error

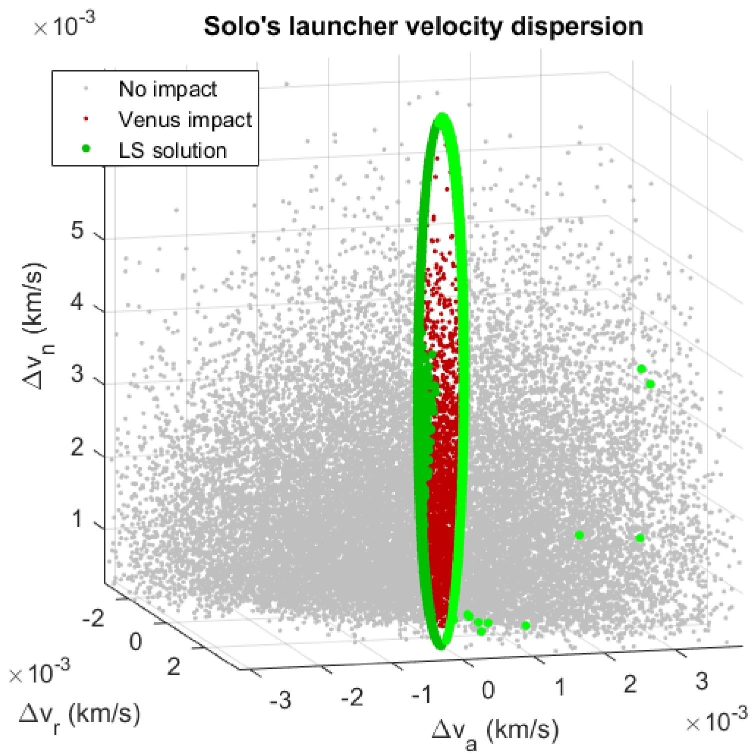


Direct deflection mission to 2010RF12

Planetary protection

Analysis of planetary protection requirements

- Spacecraft and launchers used for interplanetary missions and missions to the Lagrangian points may come back to the Earth or impact with other planets
- Planetary protection requirements: avoid the risk of contamination = check maximum impact probability with planets over 50-100 years
- Development of a tool for the verification of the compliance using a Monte Carlo approach and the b-plane representation



Solo launcher velocity dispersion: impact condition with Venus

RESEARCH TEAM

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Scientific Advisory Board

esa — European Space Agency	cnes — Centre National d'Études Spatiales
NASA	JAXA — Japan Aerospace Exploration Agency
UK Space Agency	

Conclusions

Contributions

- Beauty: Understanding of perturbations dynamics
- Novelty: Surf by exploiting natural disturbances
  (Problem into opportunity)
- Impact: Perturbation-enhanced mission design

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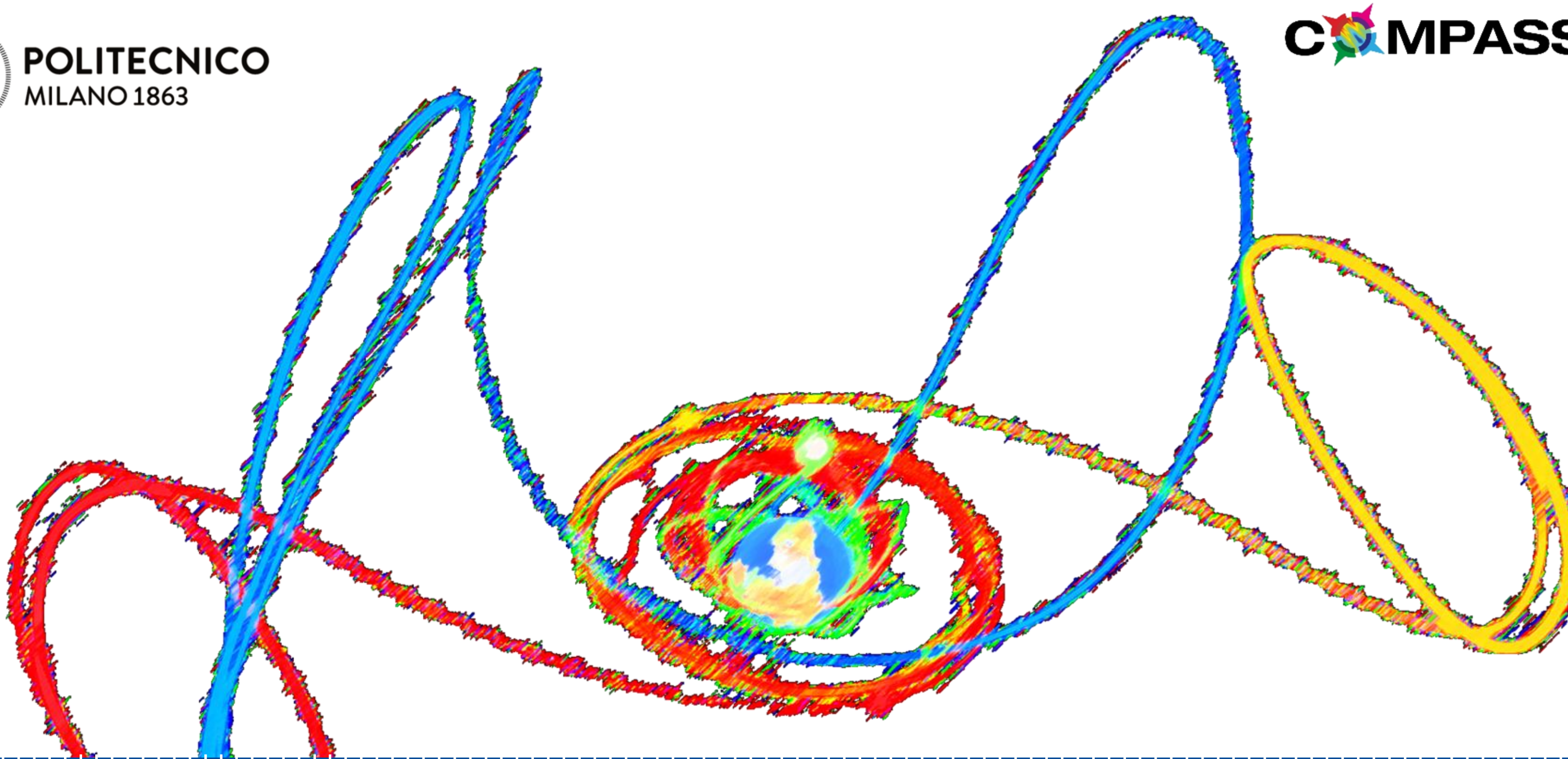

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