1st International Round Table on Intelligent Control for Space Missions

Dr. G. Ortega, M. Grulich, D. Perz
Guidance, Navigation, and Control at ESA

2017, Nov. 24th, ESTEC, The Netherlands

…a not far future

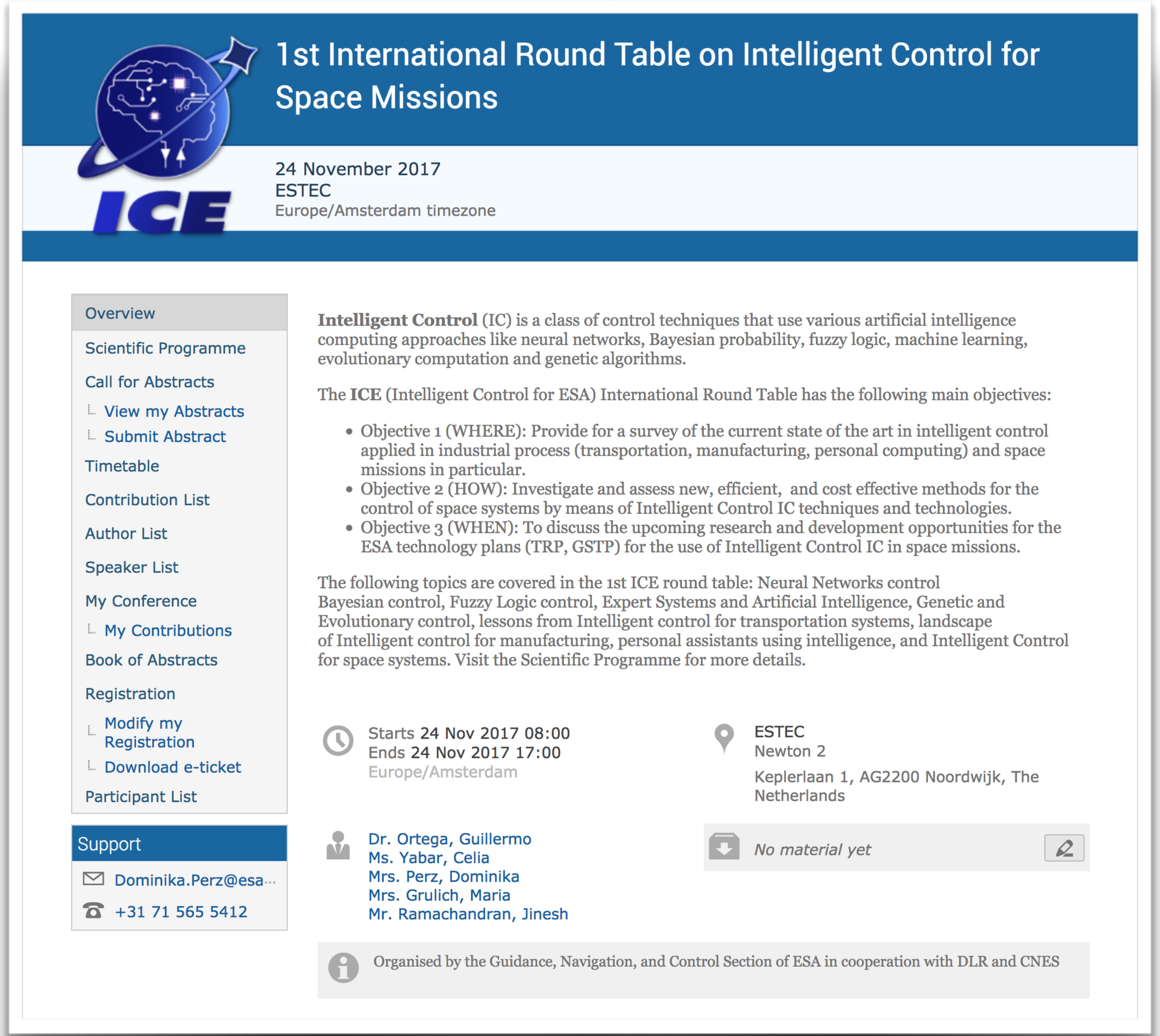
1. It will be illegal to drive
2. The language barrier disappears
3. Manned exploration of NEOs
4. Human-like AI

Welcome !

- Original **idea** of the GNC Section of ESA already in 2016 and materialised in 2017
  - Is there any **interest** on AI?
  - Can really **AI** techniques be applied for spacecraft control engineering?

Will the idea of the round table work?

- Jointly organised by:
  - **ESA**
    - Guidance, Navigation, and Control Section
    - Flight Software Systems Section
    - Advanced Mission Concepts Section of ESOC
    - Advanced Concepts & Studies Office of ESTEC
    - Automation & Robotics Section
  - **DLR**
  - **CNES**



1st International Round Table on Intelligent Control for Space Missions

24 November 2017
ESTEC
Europe/Amsterdam timezone

Overview
Scientific Programme
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Support
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Intelligent Control (IC) is a class of control techniques that use various artificial intelligence computing approaches like neural networks, Bayesian probability, fuzzy logic, machine learning, evolutionary computation and genetic algorithms.

The **ICE** (Intelligent Control for ESA) International Round Table has the following main objectives:

- Objective 1 (WHERE): Provide for a survey of the current state of the art in intelligent control applied in industrial process (transportation, manufacturing, personal computing) and space missions in particular.
- Objective 2 (HOW): Investigate and assess new, efficient, and cost effective methods for the control of space systems by means of Intelligent Control IC techniques and technologies.
- Objective 3 (WHEN): To discuss the upcoming research and development opportunities for the ESA technology plans (TRP, GSTP) for the use of Intelligent Control IC in space missions.

The following topics are covered in the 1st ICE round table: Neural Networks control Bayesian control, Fuzzy Logic control, Expert Systems and Artificial Intelligence, Genetic and Evolutionary control, lessons from Intelligent control for transportation systems, landscape of Intelligent control for manufacturing, personal assistants using intelligence, and Intelligent Control for space systems. Visit the Scientific Programme for more details.

Starts 24 Nov 2017 08:00
Ends 24 Nov 2017 17:00
Europe/Amsterdam

ESTEC
Newton 2
Keplerlaan 1, AG2200 Noordwijk, The Netherlands

Dr. Ortega, Guillermo
Ms. Yabar, Celia
Mrs. Perz, Dominika
Mrs. Grulich, Maria
Mr. Ramachandran, Jinesh

No material yet

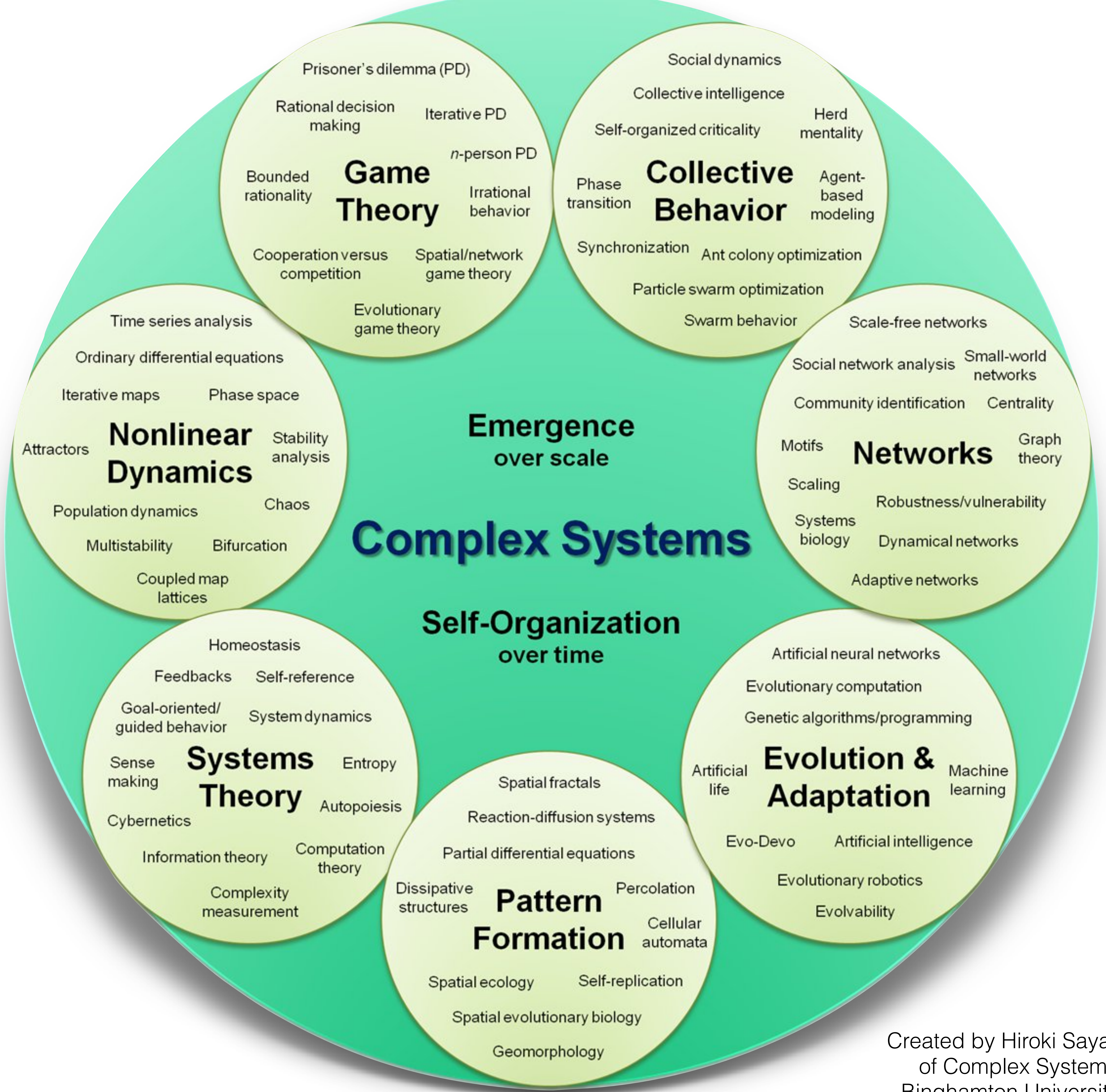
Organised by the Guidance, Navigation, and Control Section of ESA in cooperation with DLR and CNES

Objectives

- **Objective 1 (WHERE)**: Provide for a survey of the **current state** of the art in intelligent control applied in industrial process (transportation, manufacturing, personal computing) and space missions in particular
- **Objective 2 (HOW)**: **Investigate** and assess new, efficient, and cost effective methods for the control of space systems by means of Intelligent Control IC techniques and technologies
- **Objective 3 (WHEN)**: To **discuss** the upcoming research and development opportunities for the ESA technology plans (TRP, GSTP) for the use of Intelligent Control IC in space missions

Scope of the ICE round table

- Neural Networks Control Systems
- Bayesian Networks
- Fuzzy Logic Control
- Experts Systems
- Genetic and Evolutionary Computation
- Intelligent Control for Transportation and manufacturing
- Personal Assistants using Artificial Intelligence
- Intelligent Control for Space



Visual, organizational map of complex systems broken into seven sub-groups

Created by Hiroki Sayama, D.Sc., Collective Dynamics of Complex Systems (CoCo) Research Group at Binghamton University, State University of New York

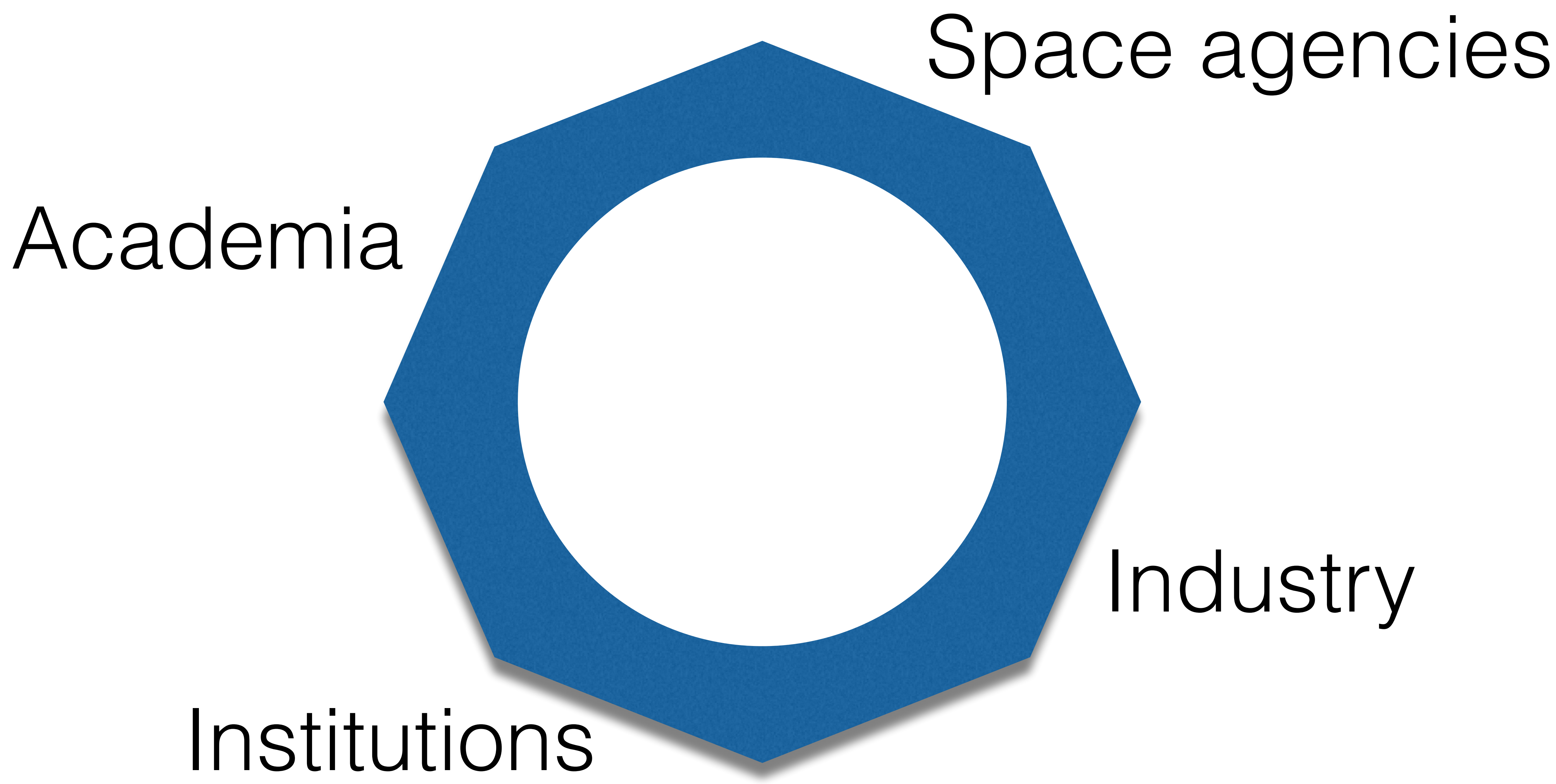
Target, objectives, process and stakeholders

Survey and analyse

Round Table

Directions

Procurements ?



White paper on Intelligent Control

Distinguished Guests and Chairs

- **20 Companies, Institutions, and Academia**: TU-Delft, ORTEC, Telespazio VEGA, Uninova-CA3, Solenix GmbH, Terma GmbH, ETH Zürich, MIT, University of Stuttgart, Knowtion, NVR, Technical University of Madrid, Technical University Munich, SISET, fortiss GmbH, EPFL-Swiss Space Centre, Strathclyde University, University of La Rioja, Thales Alenia Space, MERIS Space Technologies
- **11 Countries**: Germany, Netherlands, China, Japan, Poland, Switzerland, United Kingdom, Spain, Portugal, France, United States

- **7 chairs:**
  - Dr. J. Bals from (Director of the Institute of System Dynamics and Control at DLR)
  - Dr. M. Delpech (GNC Senior Specialist at CNES)
  - Mr. J. Fuchs (ESA, Head of the Software Division)
  - Mrs. D. Perz (ESA, GNC section)
  - Mrs. J. Ramachandran (ESA, software section)
  - Mrs. M. Grulich (ESA, GNC section)
  - Mrs. C. Yabar (ESA, GNC section)

12 Keynote speeches

- "Space Missions Model Based Control vs. Intelligent Control" by DLR
- "AI Planning & Scheduling for a new generation of Mission Planning tools" by Solenix Deutschland GmbH
- "Fuzzy logic for the control of a CubeSat" by Technical University of Madrid
- "Identification of target from image by Deep Learning" by JAXA
- "Optimisation Technology for Intelligent Control" by University of Southampton
- "Challenges and state-of-the-art of neural network verification" by fortiss GmbH
- "Applying Artificial Intelligence techniques to the orbit propagation problem" by University of La Rioja
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- "Optimisation, Uncertainty Quantification and Data Analytic at the Intelligent Computational" by the University of Strathclyde
- "On-board intelligence for small space drones" by the University of Delft
- "Applications of Intelligent Control in Industry and Adaption to Space Missions" by Knowtion
- "The expanding reach of Artificial Intelligence in Space Exploration" by JPL

Tight timing…

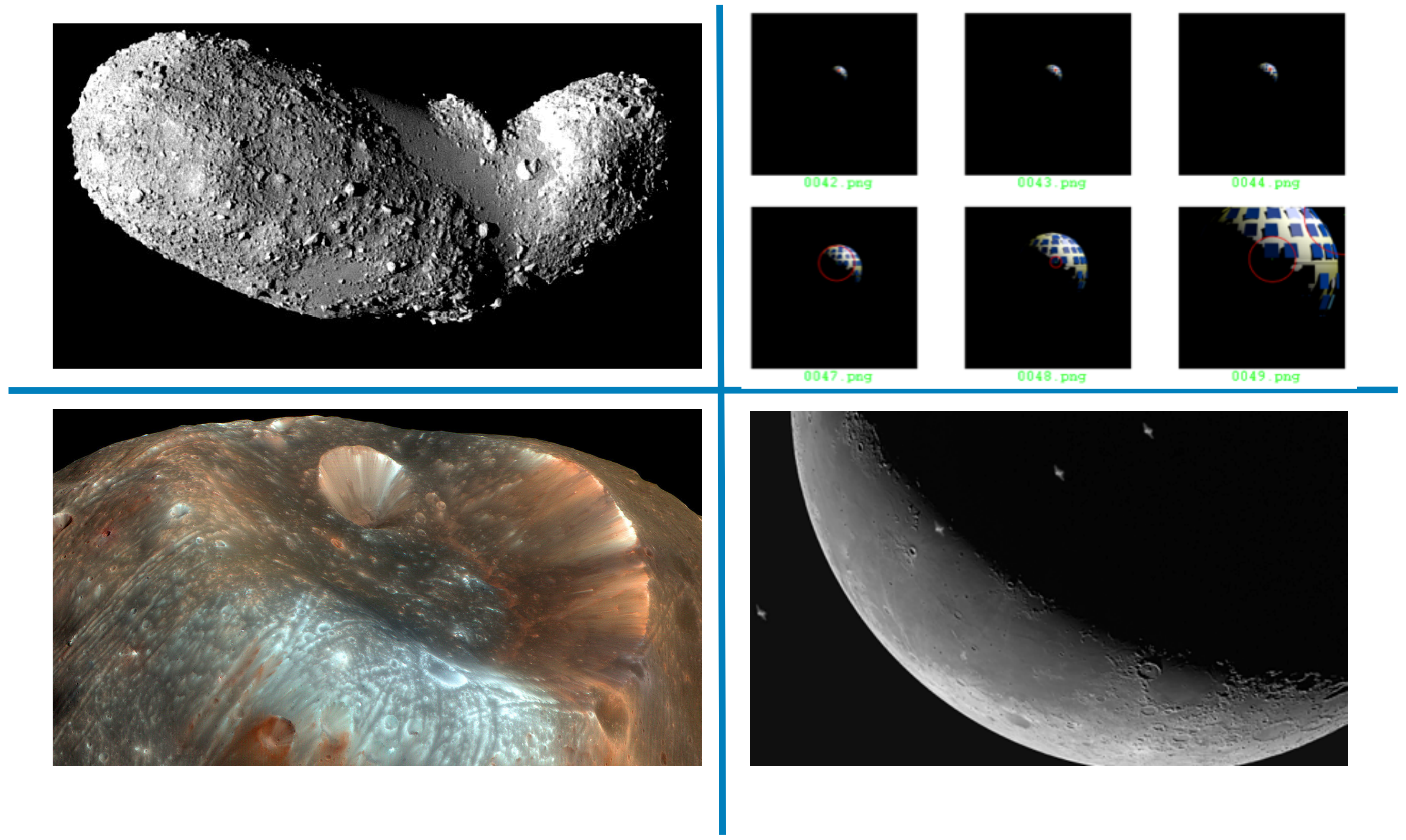
Big interests !

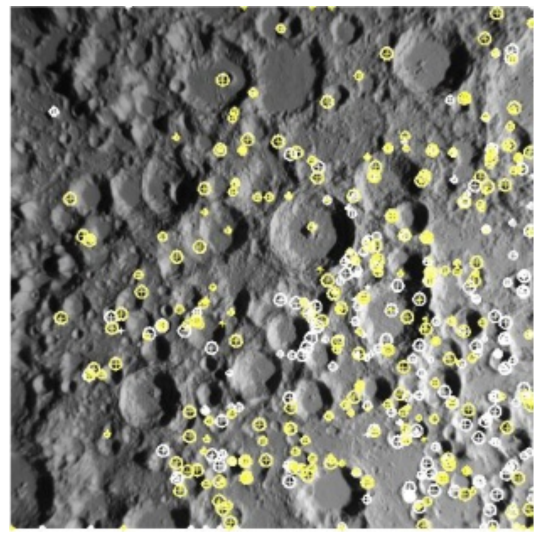
- Overwhelmed by the number of speakers wanting to make a keynote speech at the round table
  - It was necessary to keep as posters several (very) interesting presentations
- Despite of…
  - …It is only one day duration
  - …The room Newton is relative small (top capacity reached)
  - …It is rainy
  - …It is Friday

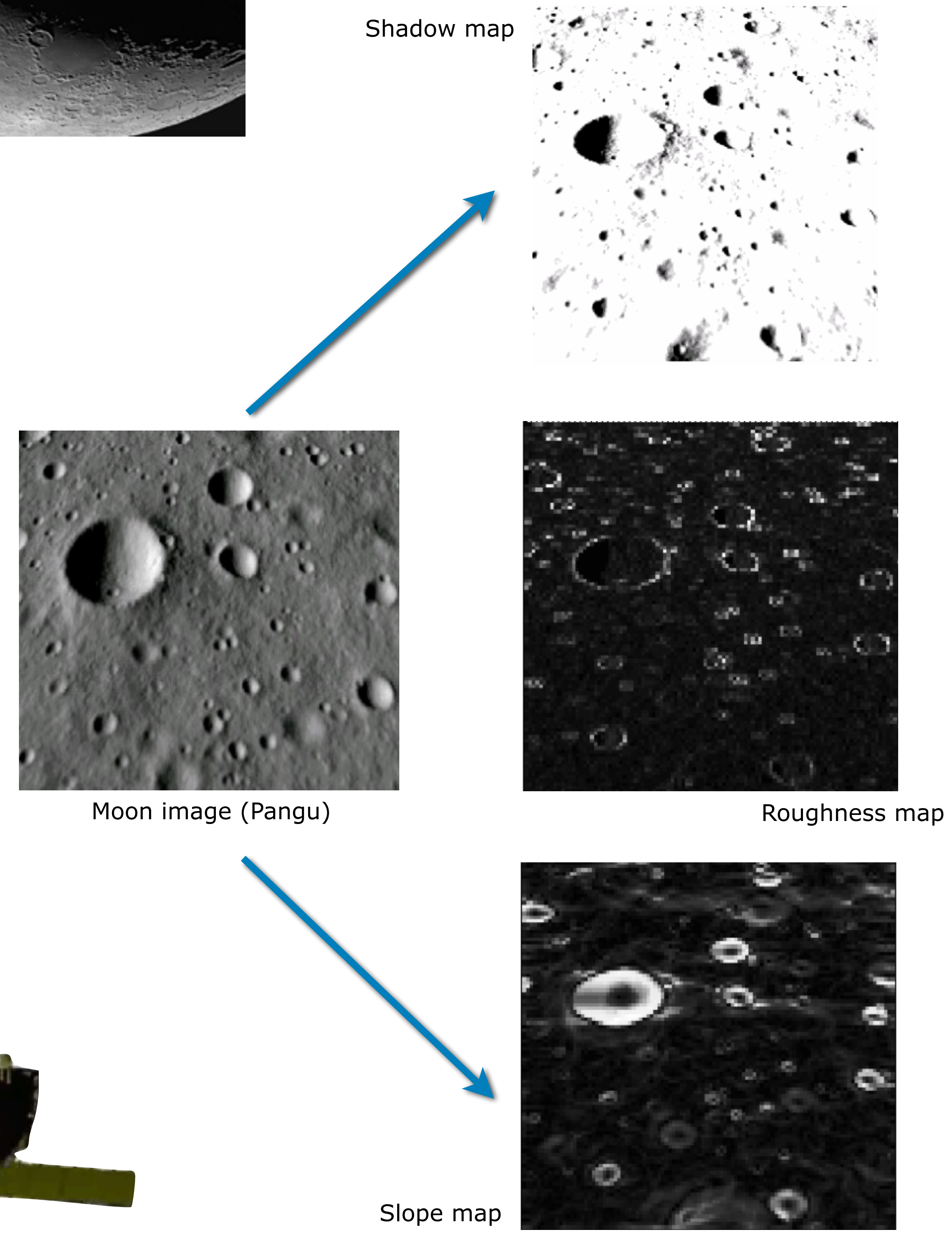
- Very high interest from very different companies and institutions
- Thanks to JAXA for its interest in being physically present delivering its keynote speech:
  - Naoki ISHIHAMA
  - Sugawara KEISUKE
- Thanks to JPL for having accepted to make the presentation from California, USA via WebEx
  - Dr. Steve CHIEN

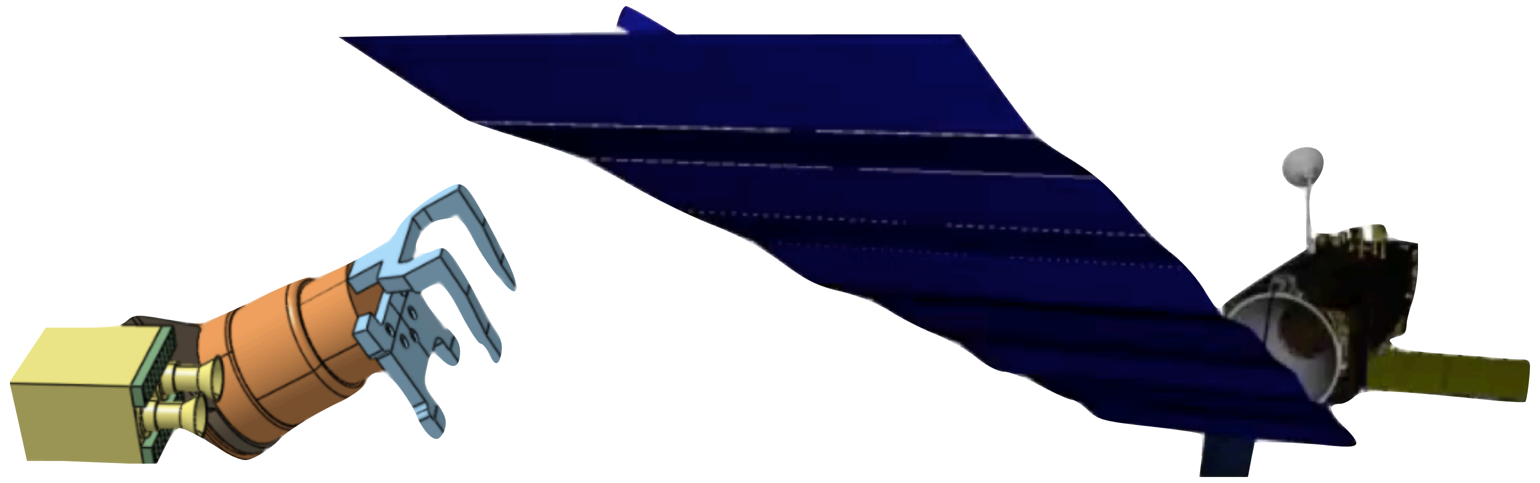
Difficult things ESA wishes to do

Mission	Needs
Solar system exploration	Tour of the the system with several flybys, and observe distant moons to explore life in the Universe
Phobos sampling	Obtain a sample from the moon of Mars Phobos
Mars Sample Return	Obtain a sample from the Martian soil
Moon Lander	Land the South pole of the Moon with an accuracy of 40m. The aim is robotics human exploration
Human Mission to Mars	Place humans on the martian surface
Debris removal	De-orbit a dead satellite safely on Earth
Asteroid mining	Mine an asteroid to obtain minerals and water









Meanwhile on the arena of AI

Applications of AI

- Games theory
- Natural language processing
- Expert systems
- Intelligent machines

Users of AI

- Military systems
- Transportation
- Domotics
- Space?

AI market size

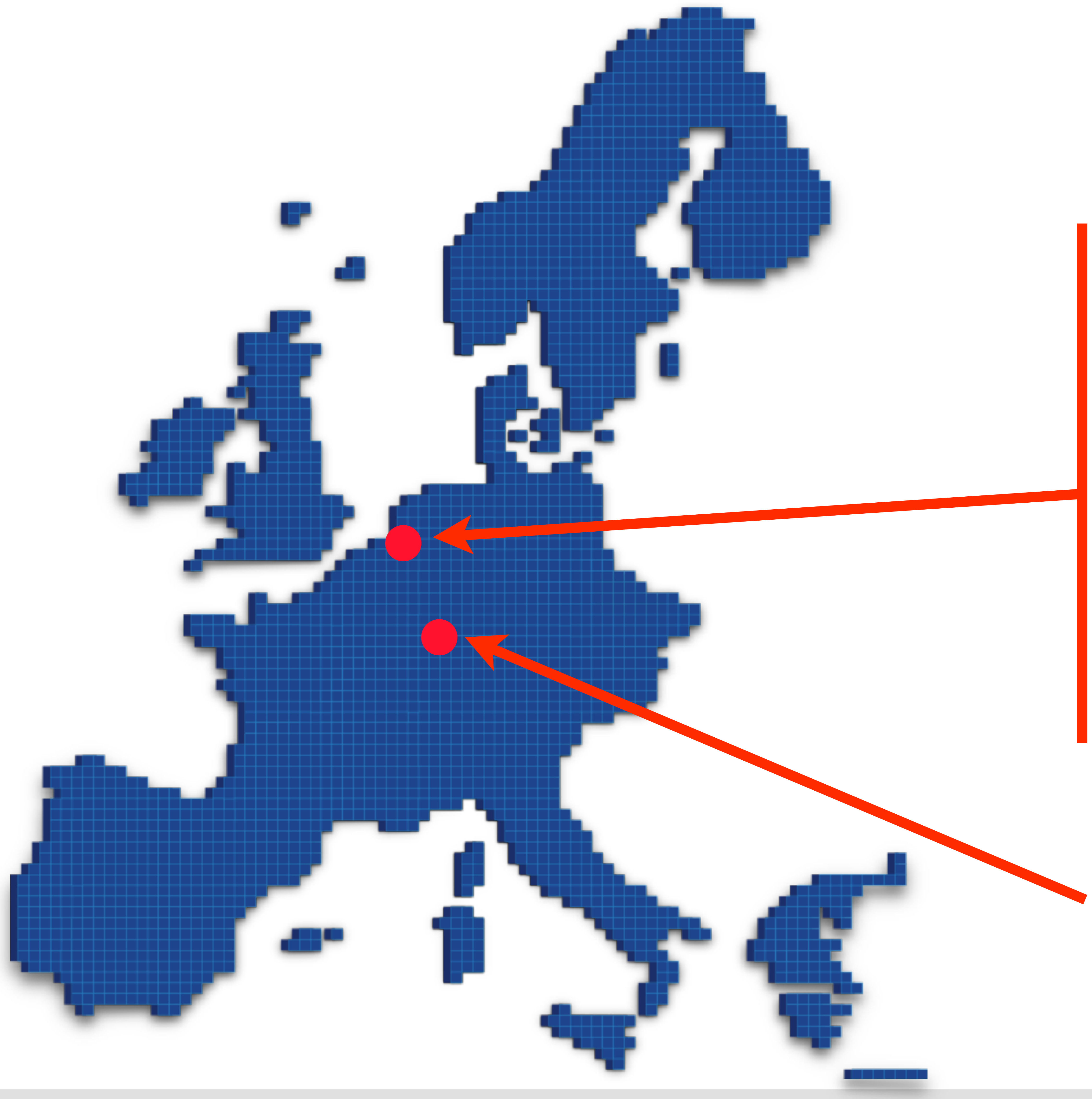
- Transparency Market Research (TMR) study:
  - **global market** for artificial intelligence estimated at 36.1% Compound Annual Growth Rate (CAGR) between 2016 and 2024
  - It will **raise** to a valuation of US$3,061.35 Bn by the end of 2024

- Elements hampering this growth:
  - Difficulties in obtaining funds for early stage research and development of prototypes and their underlying technologies
  - Lack of skill professionals
  - Maturity of the technology

- Investors:
  - Phone companies, transportation, governmental

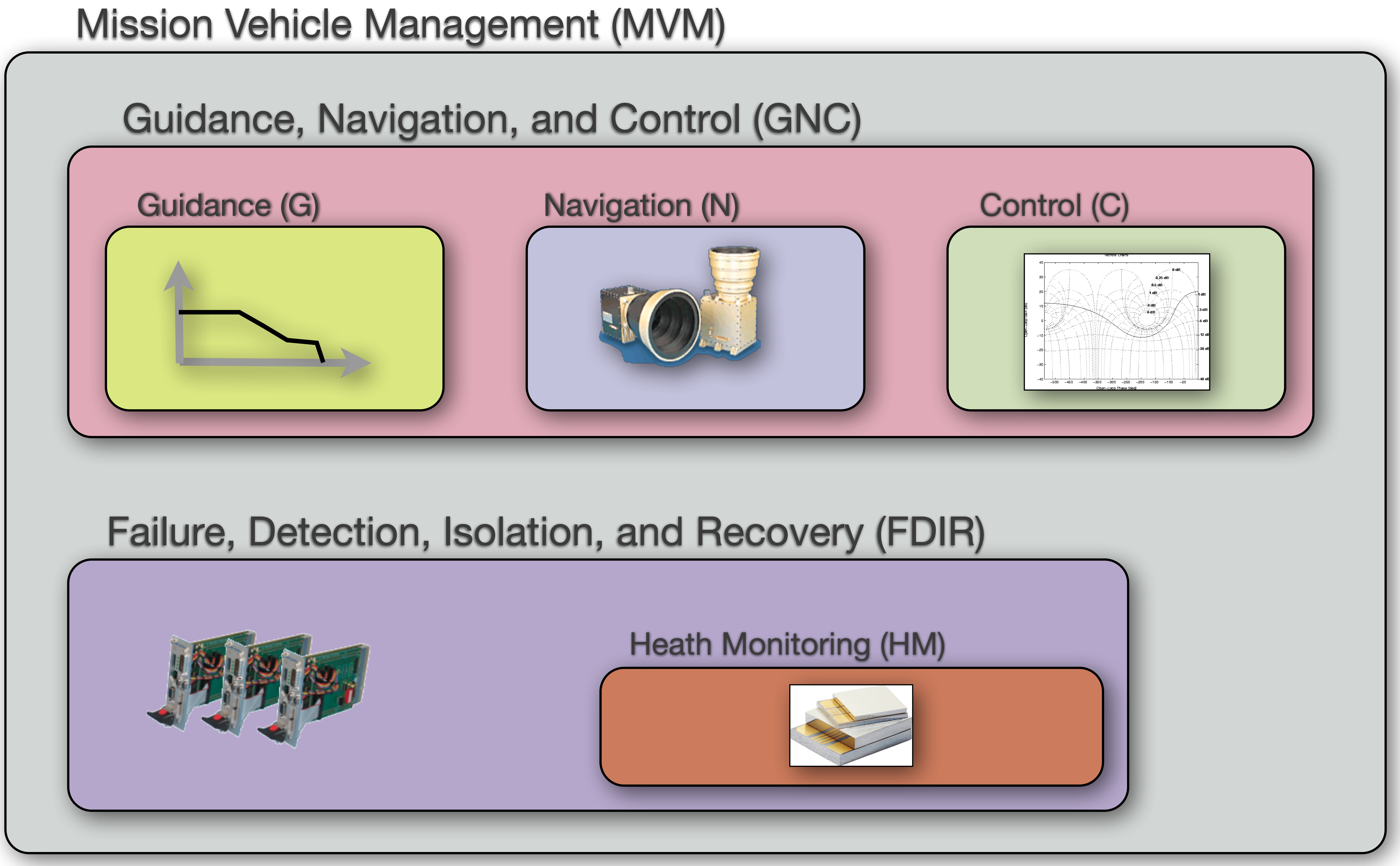
Reference: https://www.transparencymarketresearch.com/artificial-intelligence-market.html

Detected work on AI techniques at ESA (to be updated)



ESA area	Field of Work	Link (probably old)
GNC	Trajectory optimisation Fuzzy Logic Control Neural Networks Navigation	https://web.fe.up.pt/~asousa/sbld/scilab/FISLAB-man.pdf
ESTEC Advanced Team	Game theory Trajectory optimisation Probabilistic computing …	http://www.esa.int/gsp/ACT/ai/index.html
Robotics	Rover planning and operations	http://www.esa.int/About_Us/ESOC/Artificial_intelligence_for_robotic_exploration_Q_A_with_Ari_Kristinn_Jonsson
ESOC Advanced Office	Operations planning Failure forecasting	http://www.esa.int/About_Us/ESOC/Artificial_intelligence_for_robotic_exploration_Q_A_with_Ari_Kristinn_Jonsson

Applicability of AI techniques to GNC engineering



- AI techniques are being applied to
  - **GUIDANCE**: optimal trajectories
  - **NAVIGATION**: image processing
  - **CONTROL**: supervisors
  - **FDIR**: reconfiguration

Objectives of GNC engineering techniques at ESA

GUIDANCE

- Ob1) Find the **optimal** reference **trajectory** that satisfies a set of path constrains and boundary constraints
- Ob2) **Reduce** the **elapsed** flight time
- Ob3) **Reduce** the amount of **energy** needed to move the space vehicle to the next desired point
- Ob4) Facilitate the generation of optimal trajectories, hence reducing mission cost

NAVIGATION

- Ob1) **Simplify** the **estimation** and **prediction** processes
- Ob2) Reduce the potential partial unavailability of sensors
- Ob3) **Reduce** the number of **sensors** needed, the sensors errors sources, and the sensors operation complexity and initialisation processes
- Ob4) Augment the dynamics range for sensing, field of view, while optimising the lay-out

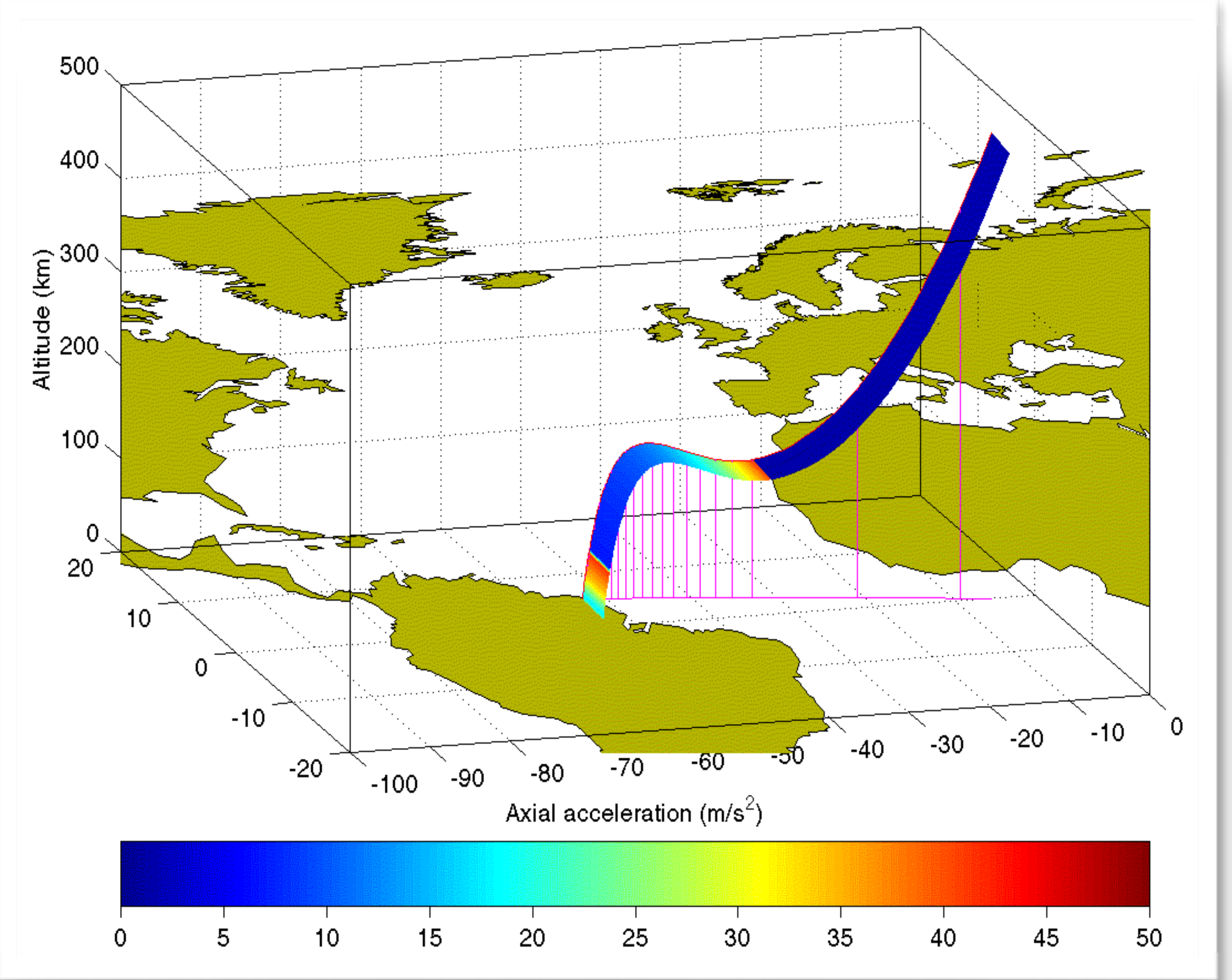
CONTROL

- Ob1) **Minimise** the spacecraft **propellant** mass or overall mass, hence reducing mission cost
- Ob2) **Increase** the **accuracy** of the control when tracking or regulating the plant
- Ob3) Increase the agility of the spacecraft manoeuvres
- Ob4) Facilitate the overall design process of the GNC subsystem, hence **reducing** mission **cost**

Guidance Techniques Used and to be Used at ESA

- **Classic**
  - Proportional guidance, two-phases optimal guidance, Optimal Feedback Guidance
  - Collocation and shooting methods guidance
  - Mixed Integer Optimisation guidance
  - Low thrust optimal guidance
- **Advanced**
  - Genetic algorithms
  - Ant colony optimisation
  - Hybrid optimisation

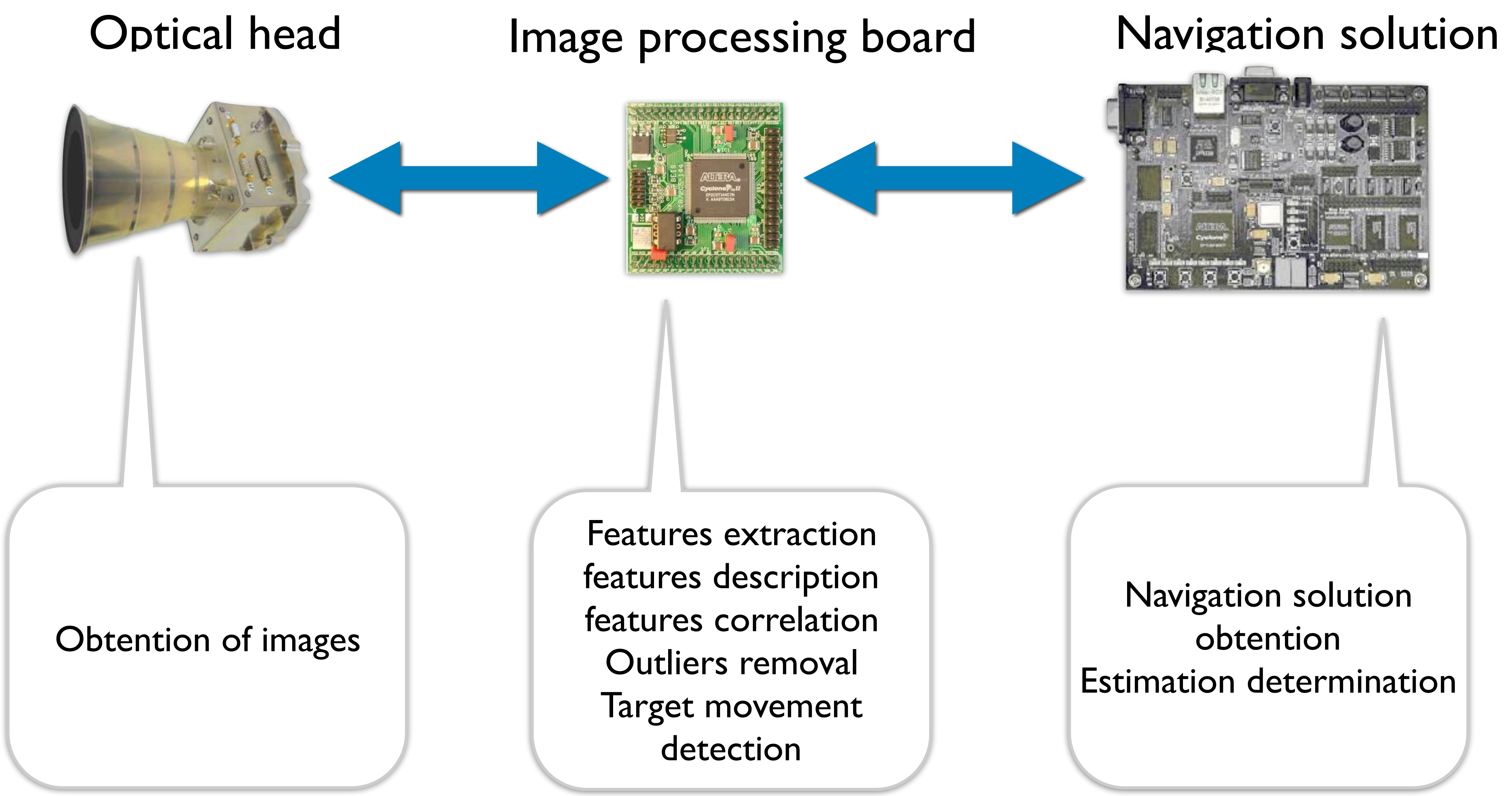
- **Boundary conditions:** initial conditions (launch pad), target orbit, return of rocket stages, staging conditions, visibility of ground stations, ...
- **Path constraints:** max. dynamic pressure, max. heat load, bending moment, max. acceleration, constraints on flight path...
- **Performance Indices/ Cost Functions:** maximise payload, minimise fuel consumption, minimise cost ...



Used In its way To be Used

Estimation Techniques Used and to be Used at ESA

- **Deterministic**
  - Kalman-like estimation: Extended Kalman (EKF), Unscented Kalman (UKF), Ensemble Kalman (EnKF)
  - Wiener estimator (WE)
  - Particle filter estimators (PF)
  - Method of moments (MoM)
  - Minimum-variance unbiased estimator (MVUE)
- **Stochastic**
  - Maximum likelihood estimators (ML)
  - Bayes estimator (BE)
  - Minimum mean squared error estimator (MMSE)
  - Maximum a posteriori estimation (MPE)
  - Markov chain Monte Carlo (MCMC)



- **Non-linear**
  - Neural networks

Used | In its way | To be Used

Control Techniques Used and to be Used at ESA

- **Multivariable Linear-Time-Invariant systems**
  - H-infinity, Structured Singular Value (SSV), Quantitative Feedback Theory (QFT), Model-Based Predictive Control (MPC), Linear Parameter Varying (LPV)
- **Multivariable Non-Linear systems**
  - Non-Linear Dynamics Inversion (NDI), Feedback Linearization (FL), Sliding Mode Control (SMC), Numerical Optimization (NO), Fuzzy Logic Control and Neural Networks Control
- Control of Distributed Parameters Systems
- Human Control Systems

Used   In its way   To be Used

Control and Estimation Theories Time-Line till date

1950's ➡ 1960's ➡ 1970's ➡ 1980's ➡ 1990's ➡ 2000's ➡ 2010's

Classic
Shannon's theorem
LQR
Youla parameterisation
Gain scheduling
Kalman filter
Robust multivariable control
Phase plane
Frequency domain
Multivariable systems
Digital control
Lyapunov stability

Adaptive
Self-optimize control
Model reference adaptive control
Flight control for aircraft
Self tuning regulator

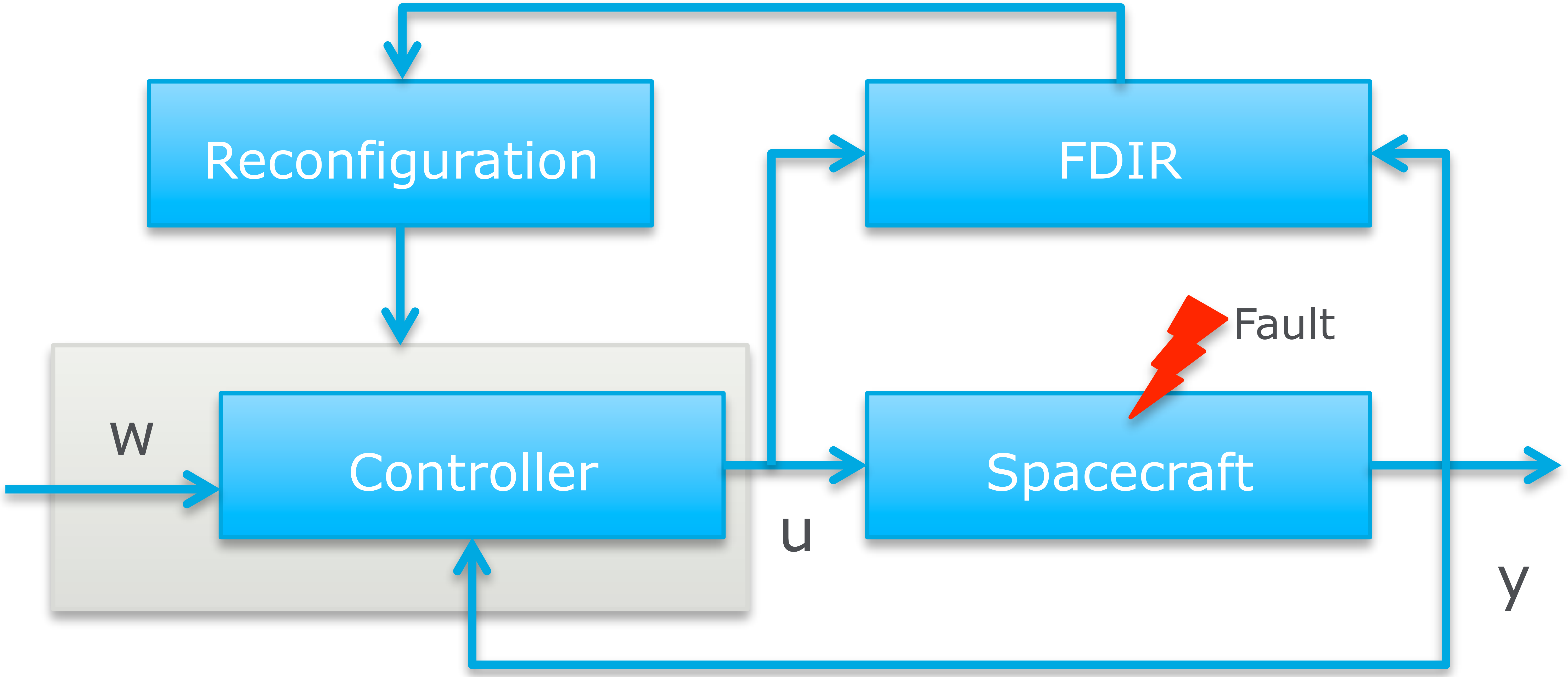
Stochastic
Optimal stochastic control
Mean squared error
Quadratic optimal control
Liner quadratic Gaussian control
Non-linear filtering

Robust
LMI for control
SISO H-infinity
MIMO H-infinity

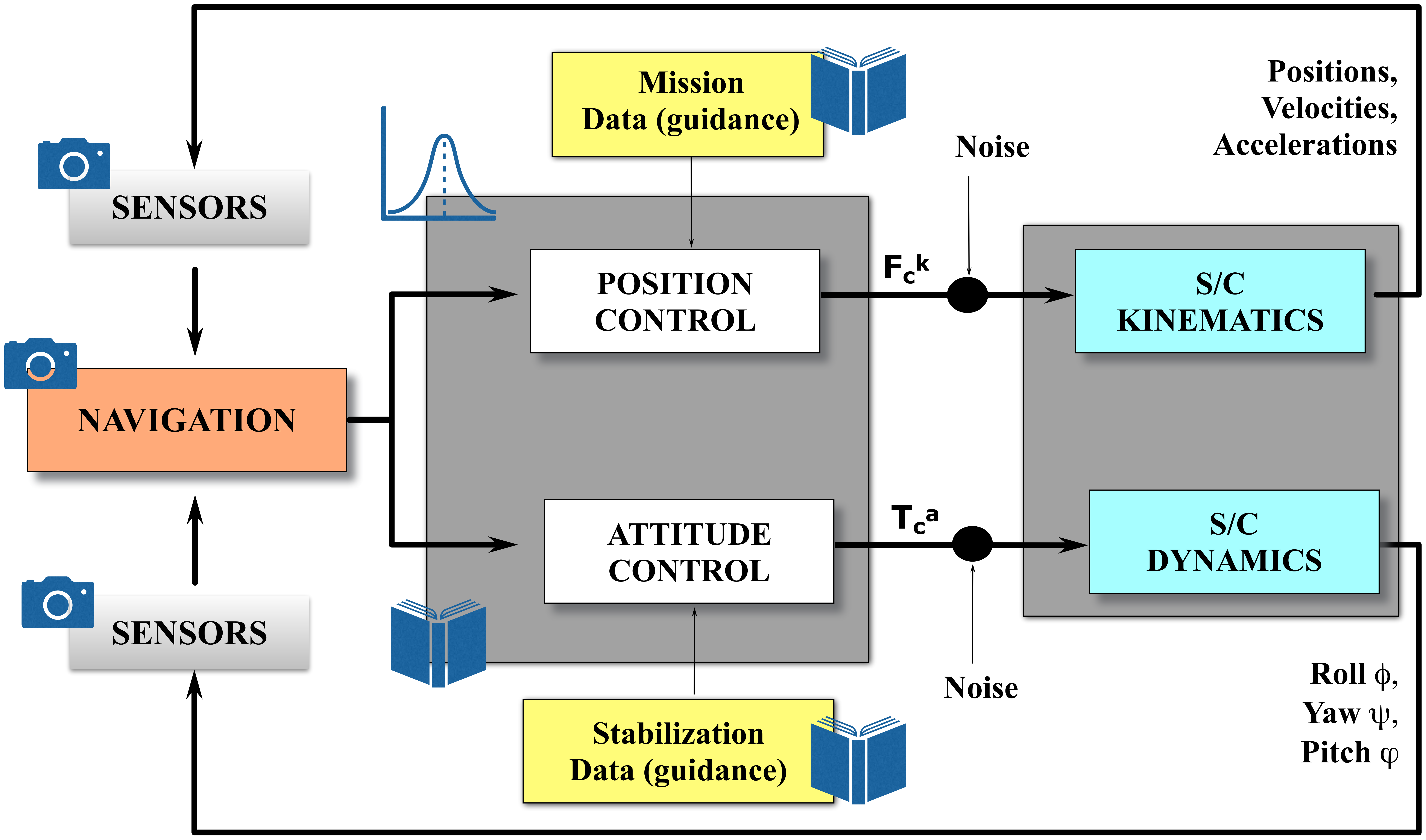
Non-linear
Describing function
SSV framework
LPV
Fuzzy logic control
FL
NLDI
Numerical Optimisation
Averaging control
SMC
QFT
Neural Networks control

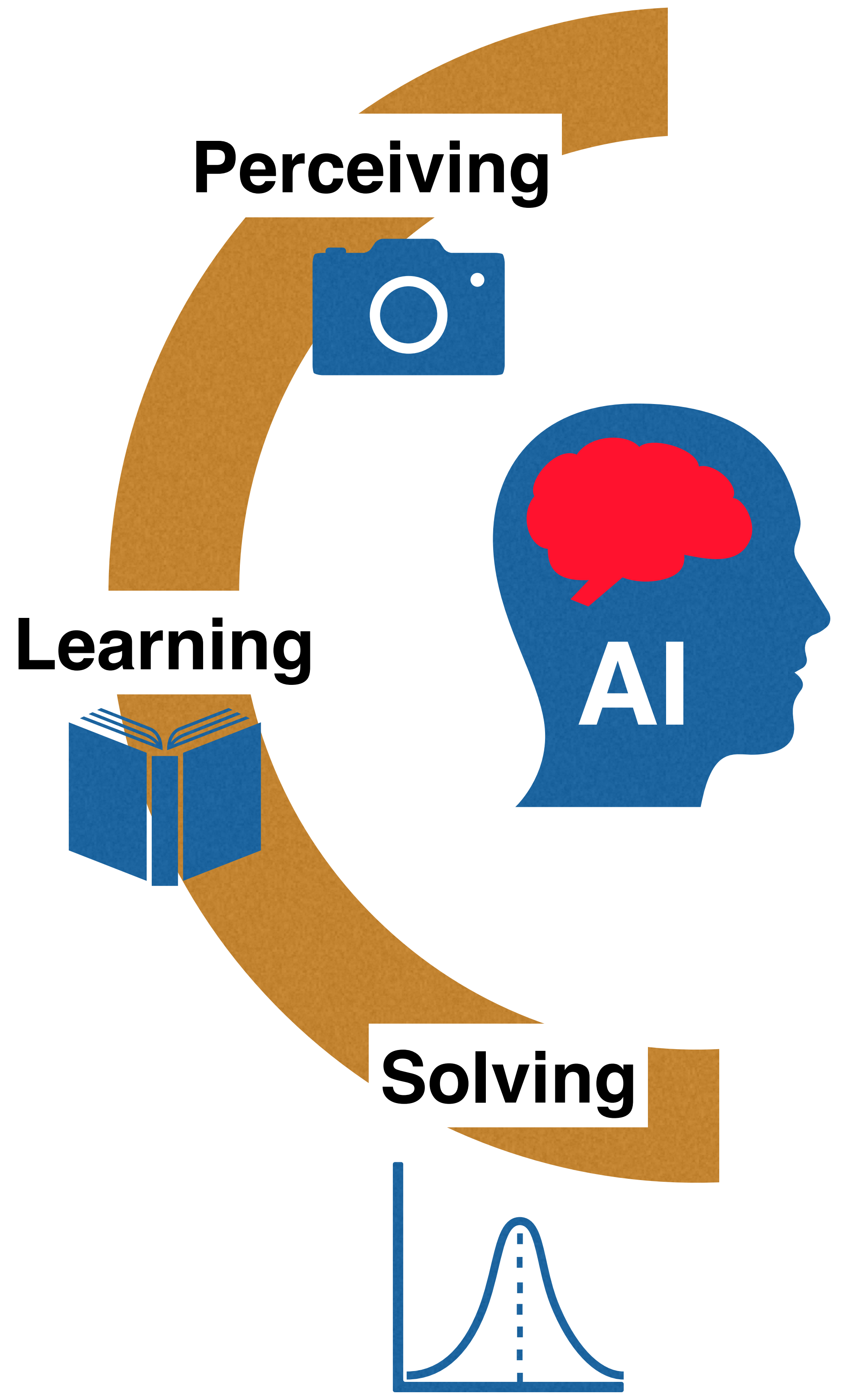
Reconfiguration and FDIR

- Used when faults occur, such as actuator or sensor outages, cause a break-up of the control loop, which must be restructured to prevent failure at the system level
- In addition to loop restructuring, the controller parameters must be adjusted to accommodate changed plant dynamics
- Control reconfiguration increases the dependability of systems under feedback control

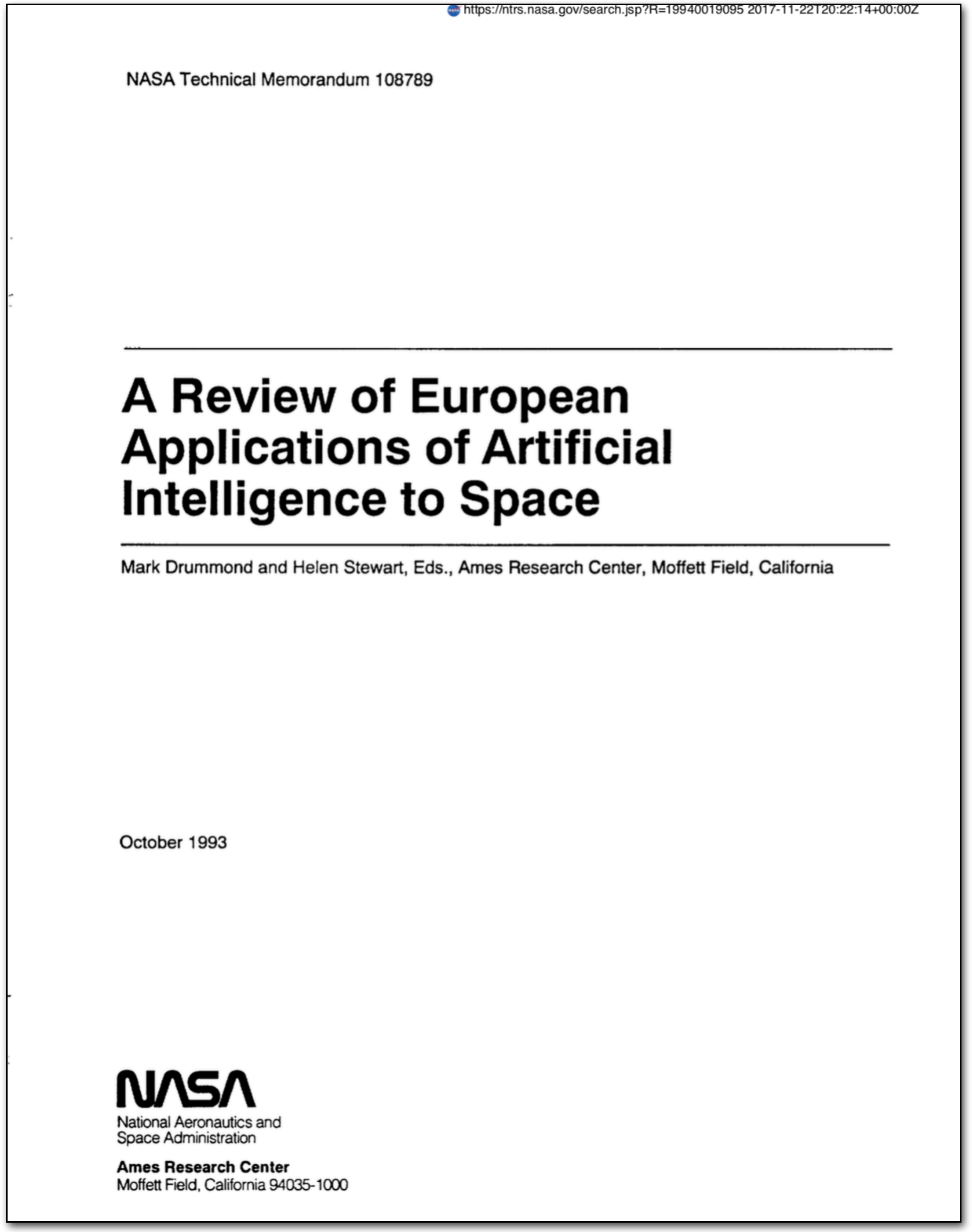


Intelligence inside the GNC blocks





Other views on AI



https://ntrs.nasa.gov/search.jsp?R=19940019095 2017-11-22T20:22:14+00:00Z

NASA Technical Memorandum 108789

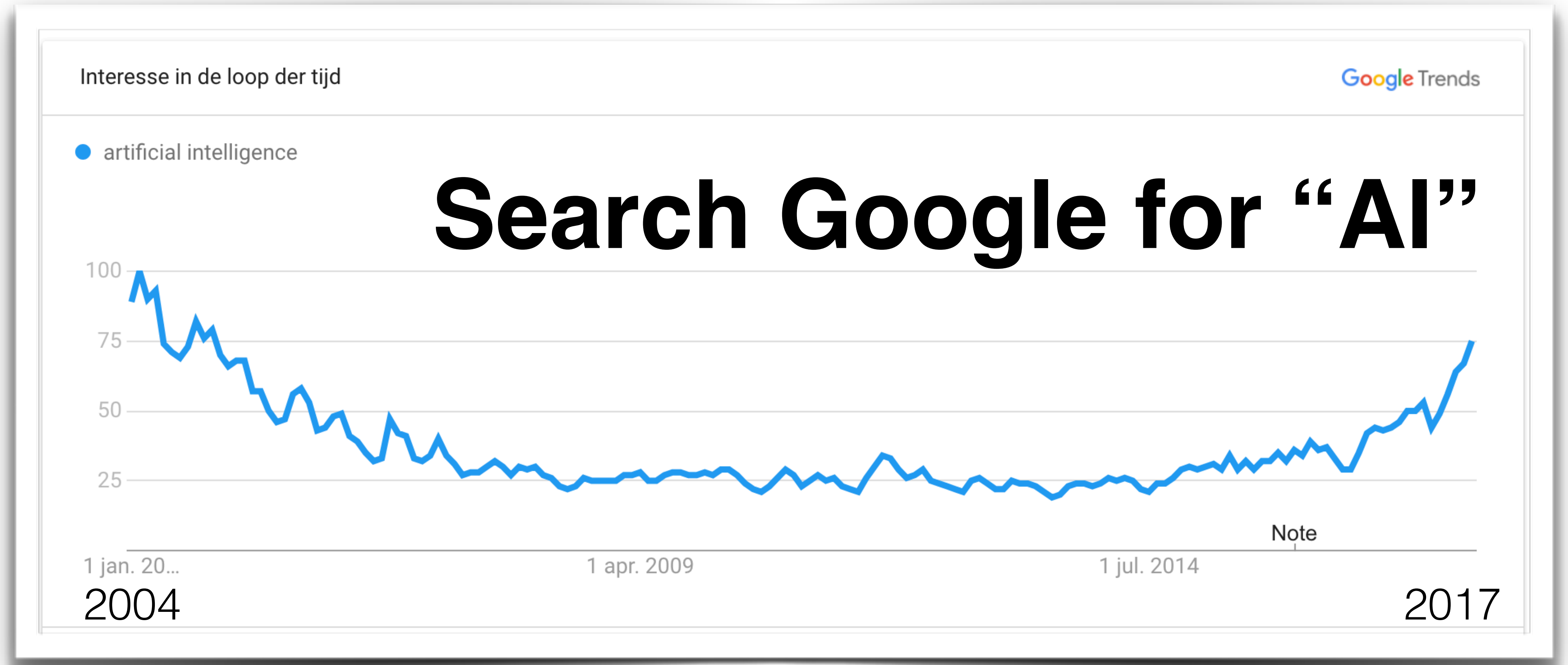
A Review of European Applications of Artificial Intelligence to Space

Mark Drummond and Helen Stewart, Eds., Ames Research Center, Moffett Field, California

October 1993

NASA
National Aeronautics and Space Administration

Ames Research Center
Moffett Field, California 94035-1000



5 Very Smart People Who Think Artificial Intelligence Could Bring the Apocalypse

Time article:

http://time.com/3614349/artificial-intelligence-singularity-stephen-hawking-elon-musk/

ESA current points of contact (to be expanded)

- **Contact** the following ESA managers in case of more ideas or questions:
  - Guidance, Navigation, and Control Section: G. Ortega
  - ESTEC Advanced Concepts: D. Izzo
  - Flight Software Systems Section: M. Hernek
  - ESOC Advanced Mission Concepts Section: A. Donati
  - Automation and Robotics Section: G. Visentin

The program

time	[id] title	presenter
09:00	[15] Introduction to the ICE round table (00h25')	Dr. ORTEGA, Guillermo (ESA)
09:25	[6] "Space Missions Model-Based Control vs. Intelligent Control" by DLR (00h25')	Dr. BALS, Johann (DLR)
09:50	[7] "AI Planning & Scheduling for a new generation of Mission Planning tools" by Solenix Deutschland GmbH (00h25')	Dr. FRATINI, Simone (Solenix Deutschland GmbH) Dr. POLICELLA, Nicola (Solenix Deutschland GmbH)
10:15	[8] "Fuzzy logic for the control of a CubeSat" by Technical University of Madrid (00h25')	Prof. LAPUERTA GONZÁLEZ, María Victoria (Technical University of Madrid)
10:40	[20] "Identification of target from image by Deep Learning" by JAXA (00h25')	SUGAWARA, Keisuke (Japan Aerospace Exploration Agency)

Coffee Break 1 - Newton 2 (11:05-11:20)

time	[id] title	presenter
11:20	[23] "Optimisation Technology for Intelligent Control" by University of Southampton (00h25')	Prof. FLIEGE, Joerg (University of Southampton)
11:45	[9] "Challenges and state-of-the-art of neural network verification" by fortiss GmbH (00h25')	NÜHRENBERG, Georg (fortiss GmbH)
12:10	[10] "Applying Artificial Intelligence techniques to the orbit propagation problem" by University of La Rioja (00h25')	Dr. SAN-JUAN, Juan Félix (Scientific Computing Group (GRUCACI), University of La Rioja)
12:35	[11] "Deep Reinforcement Learning for Control" by the University of Stuttgart (00h25')	Prof. HENNES, Daniel (University of Stuttgart)

Lunch - Canteen (13:00-14:00)

time	[id] title	presenter
14:00	[12] "Optimisation, Uncertainty Quantification and Data Analytic at the Intelligent Computational" by the University of Strathclyde (00h25')	Dr. RICCARDI, Annalisa (Strathclyde University)
14:25	[13] "On-board intelligence for small space drones" by the University of Delft (00h25')	Dr. ALONSO-MORA, Javier (Delft University of Technology) Dr. DE CROON, Guido (TU Delft)
14:50	[14] "Applications of Intelligent Control in Industry and Adaption to Space Missions" by Knowtion (00h25')	Mr. KLUMPP, Vesa (Knowtion UG)

Coffee Break 2 - Newton 2 (15:15-15:35)

time	[id] title	presenter
15:35	[21] "The expanding reach of Artificial Intelligence in Space Exploration" by JPL (00h25')	Dr. CHIEN, Steve (Jet Propulsion Laboratory, California Institute of Technology)

Round Table - Newton 2 (16:00-17:00)

- Conveners: Mr. Ramachandran, Jinesh (ESA); Mrs. Grulich, Maria (ESA); Mrs. Perz, Dominika (ESA)

Thank you to the organisers

Maria Grulich
(GNC)

- Program
- Keynote speeches
- Registration
- Web site
- Call for participation

Dominika Perz
(GNC)

- Contacts with authors
- Abstracts and affiliations
- Sessions and tracks
- Logos and icons
- Mailing lists

Dr. Dario Izzo
(ESTEC Advanced Concepts)

Jinesh Ramachandran
(Flight Software)

Announcing 007th ICATT


7th International Conference on Astrodynamics Tools and Techniques (ICATT)

3-6 July 2018
DLR Oberpfaffenhofen
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"To the Moon and Beyond - New Ways of Astrodynamics"

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ICATT aims at providing agencies, companies, organizations, universities and research institutes with a forum of excellence in the area of astrodynamics and space flight mechanics. Participants are invited to showcase their latest tools and techniques so as to promote the creation and exchange of ideas and the identification of new trends and required developments: challenges in the field of astrodynamics and orbital mechanics, current status of tools, their pros and cons, visions for the future, etc.

In addition to the latest theoretical advances in the field of astrodynamics, **ICATT** is especially devoted to astrodynamics software tools. Demonstrations and short tutorials are welcome. Furthermore, as in previous editions, **ICATT** offers a series of keynote lectures. These lectures are delivered by experts from specific astrodynamics fields.

Starts 3 Jul 2018 08:00
Ends 6 Jul 2018 13:00
Europe/Amsterdam

DLR Oberpfaffenhofen
Münchener Straße 20
82234 Weßling

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Ms. Yabar, Celia
Mr. Martinez Barrio, Alvaro
Dr. Jehn, Ruediger
Mrs. Perz, Dominika
Mrs. Grulich, Maria
Mr. Reinthal, Eric
Mr. Steindorf, Lukas
Mr. Muresan, Tudor

No material yet

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July 3rd – July 6th 2018

Have a great round table !

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