Artificial Intelligence for Space Operations

Alessandro Donati & al.
AI & Operations Innovation team @ ESOC

Phi-Week, ESRIN
12-16 Nov 2018

European Space Agency

What is Space Operations?

Similar to your daily routine

Keep you healthy

Be "productive" in your life

What is Space Operations ?

Health Caring of Spacecraft

Productive Chain: Plan + Execute + Get Payload Data & Disseminate

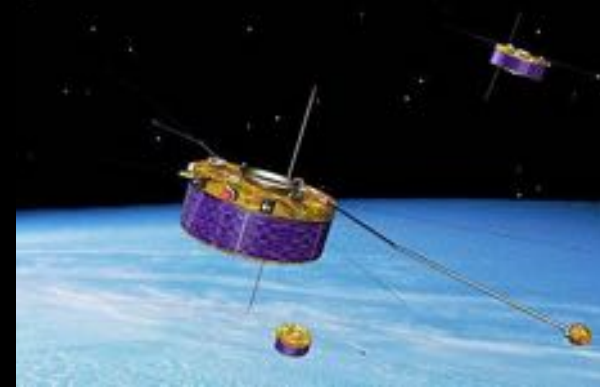European Space Agency

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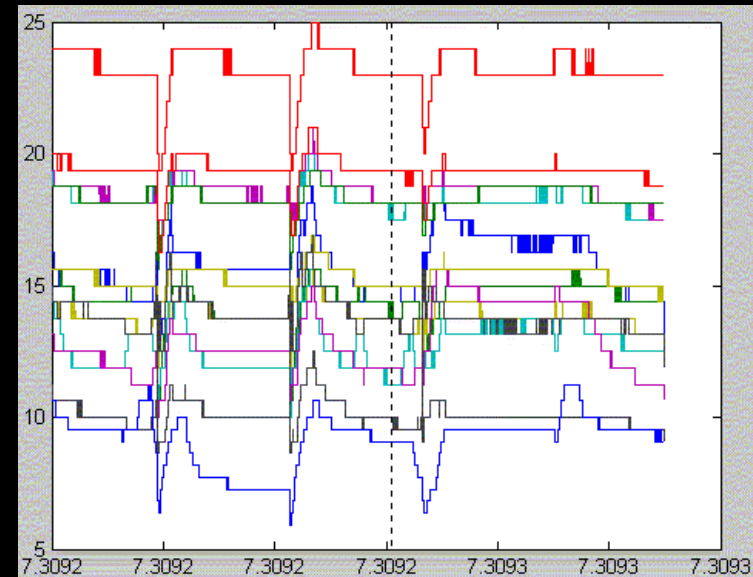
Planning
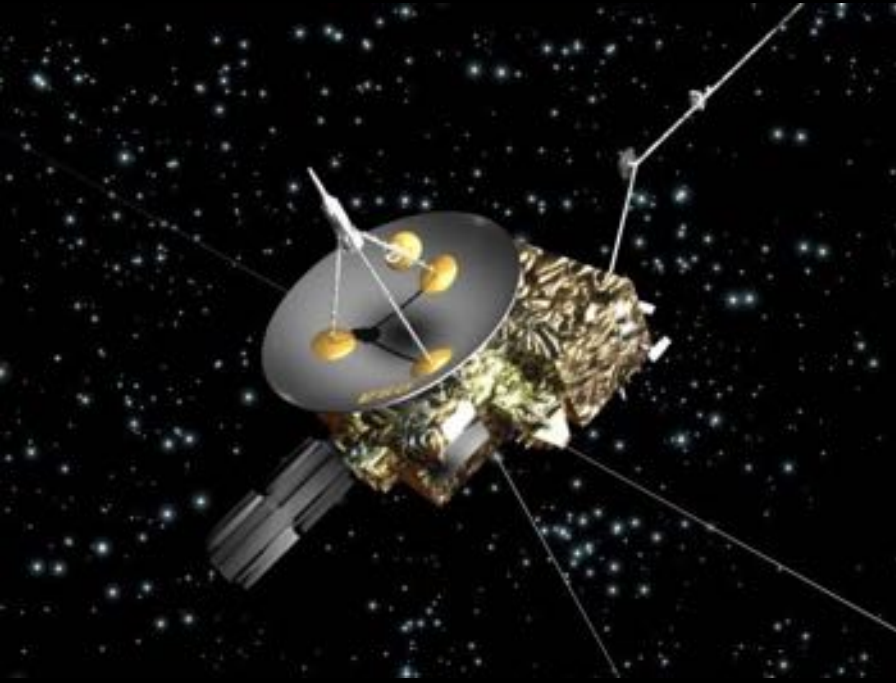Execution
Monitoring
Forecasting
Diagnostic

2002 Intuition

Space Operations @ ESOC
  is **rich** in data

We can **do more**
with these data.. If we have **easy access**.

Thermal Virtual Sensor with
Artificial Neural Network

Early AI Applications in Operations:
Fuzzy Logic for Decision Support

ENVISAT Gyroscopes Health
Monitoring Tool deployed @ ESOC

Ulysses Nutation Anomaly
Management Tool deployed @ JPL

AI in Operations

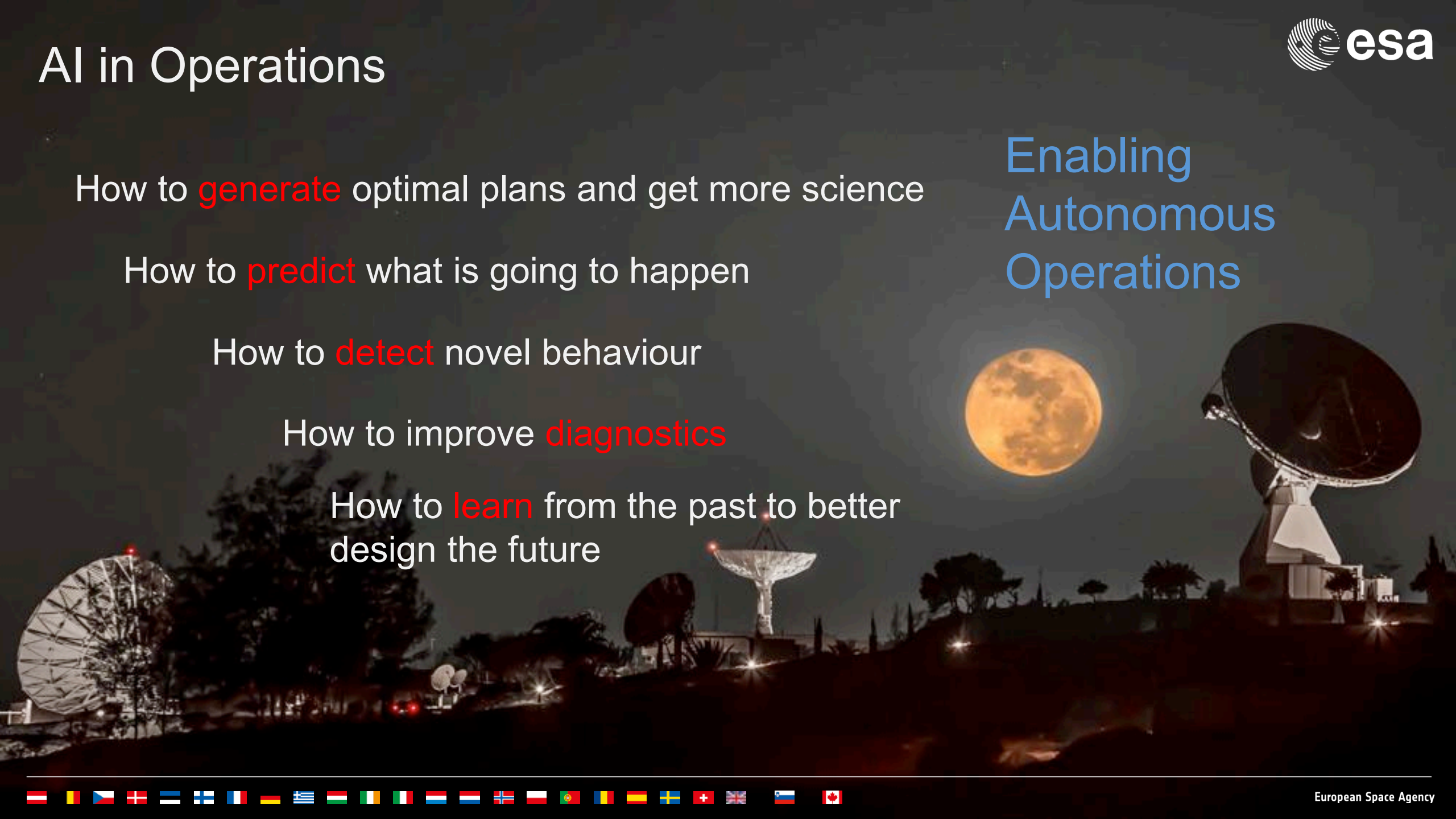How to **generate** optimal plans and get more science

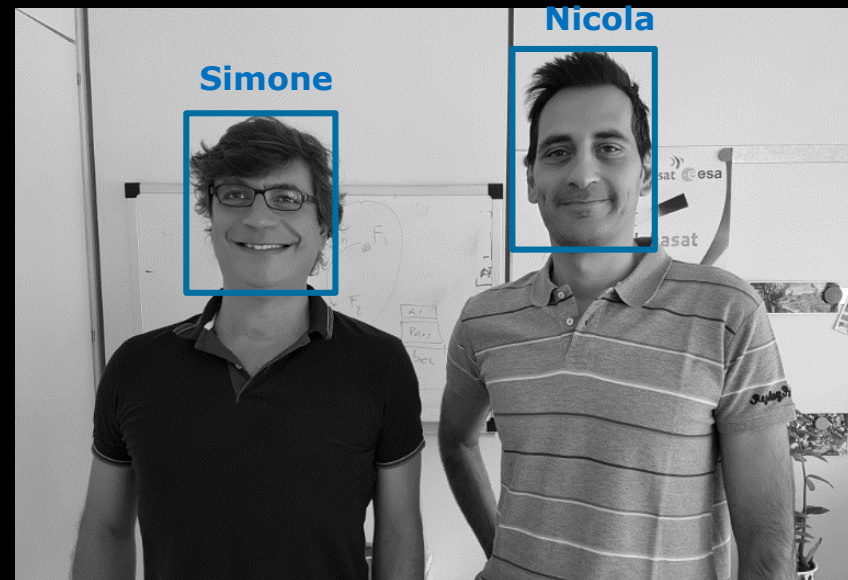How to **predict** what is going to happen

How to **detect** novel behaviour

How to improve **diagnostics**

How to **learn** from the past to better design the future
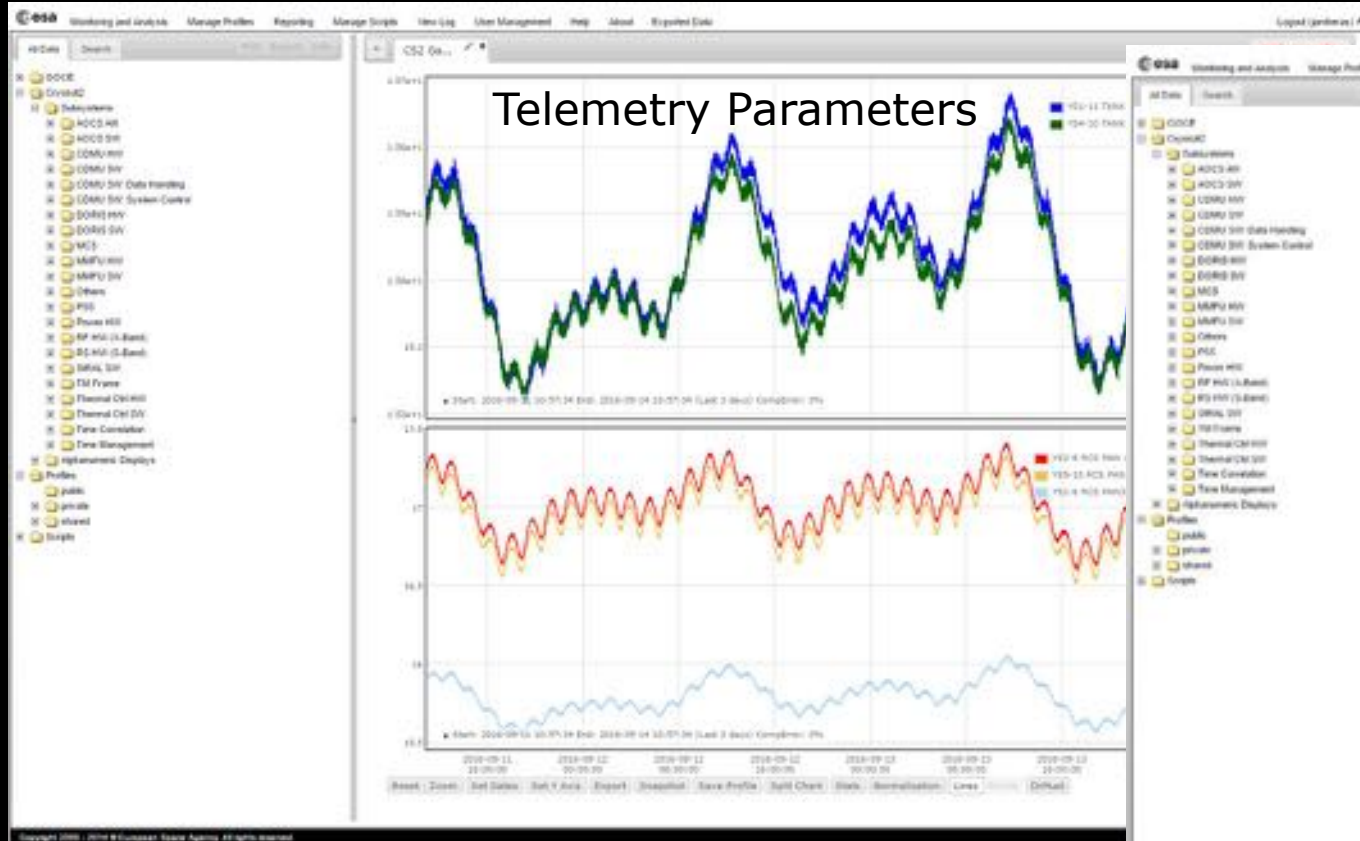
Enabling Autonomous Operations

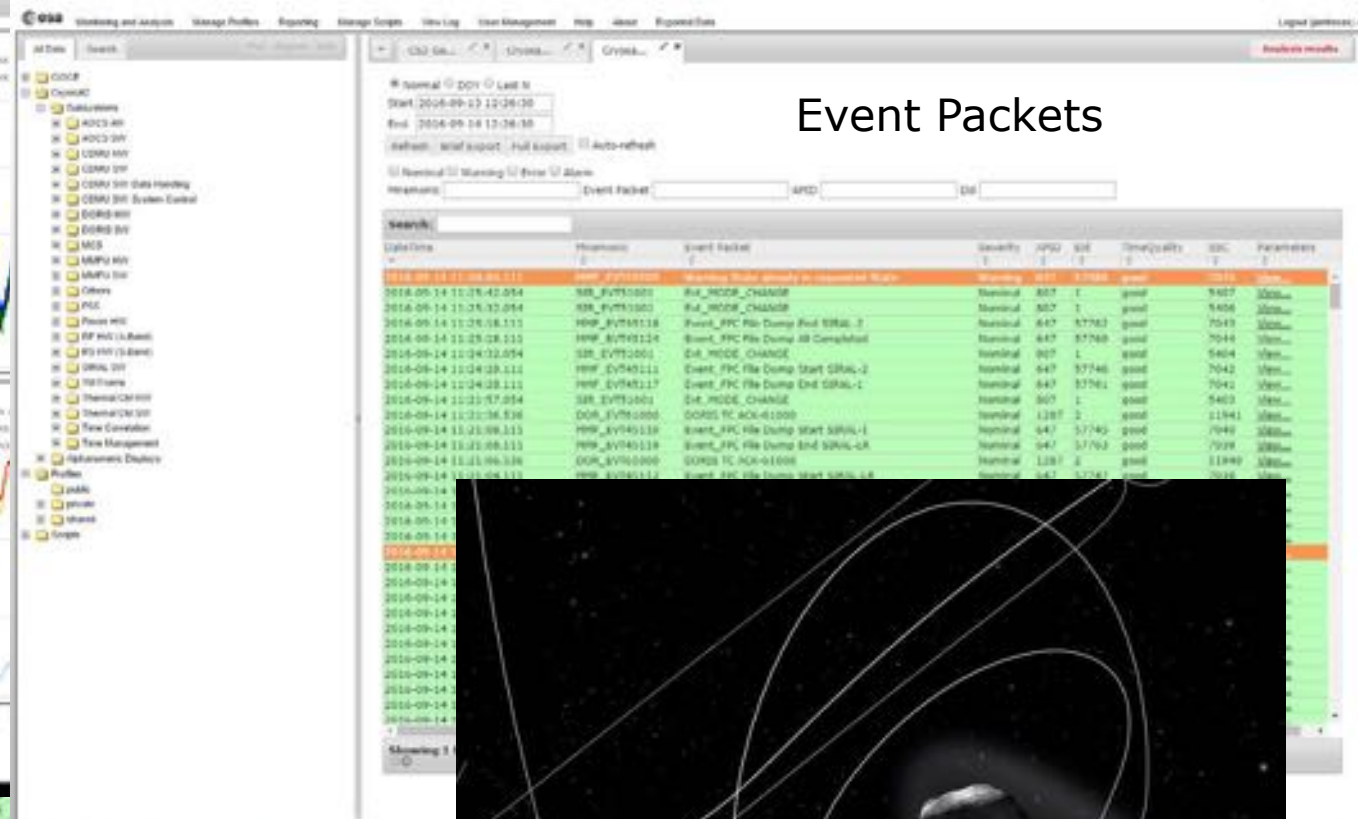# Artificial Intelligence & Operations Innovation core team @ ESOC

Redouane Boumghar, Jose Martinez-Heras, Jose Da Silva, Alessandro Donati, Simone Fratini, Nicola Policella

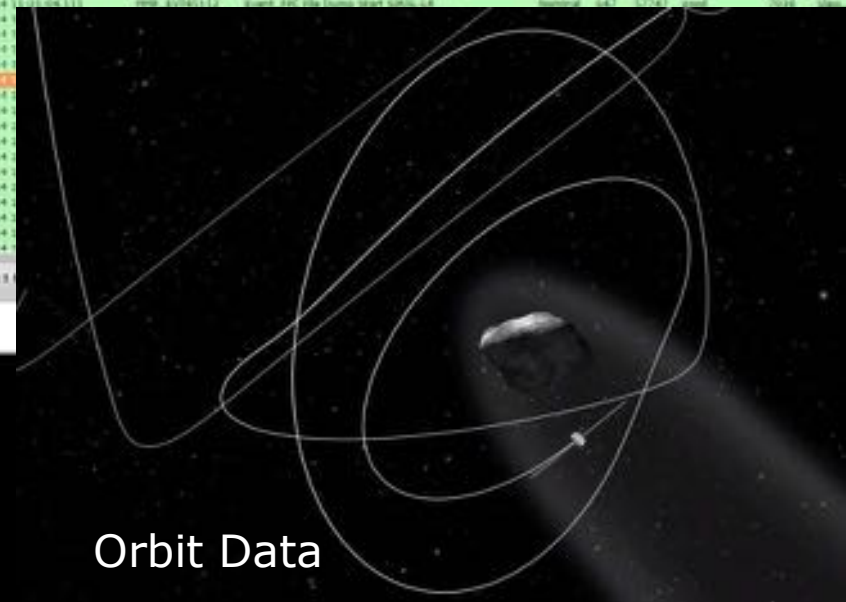# Ecosystem for **easy access** to operational data: MUST & ARES

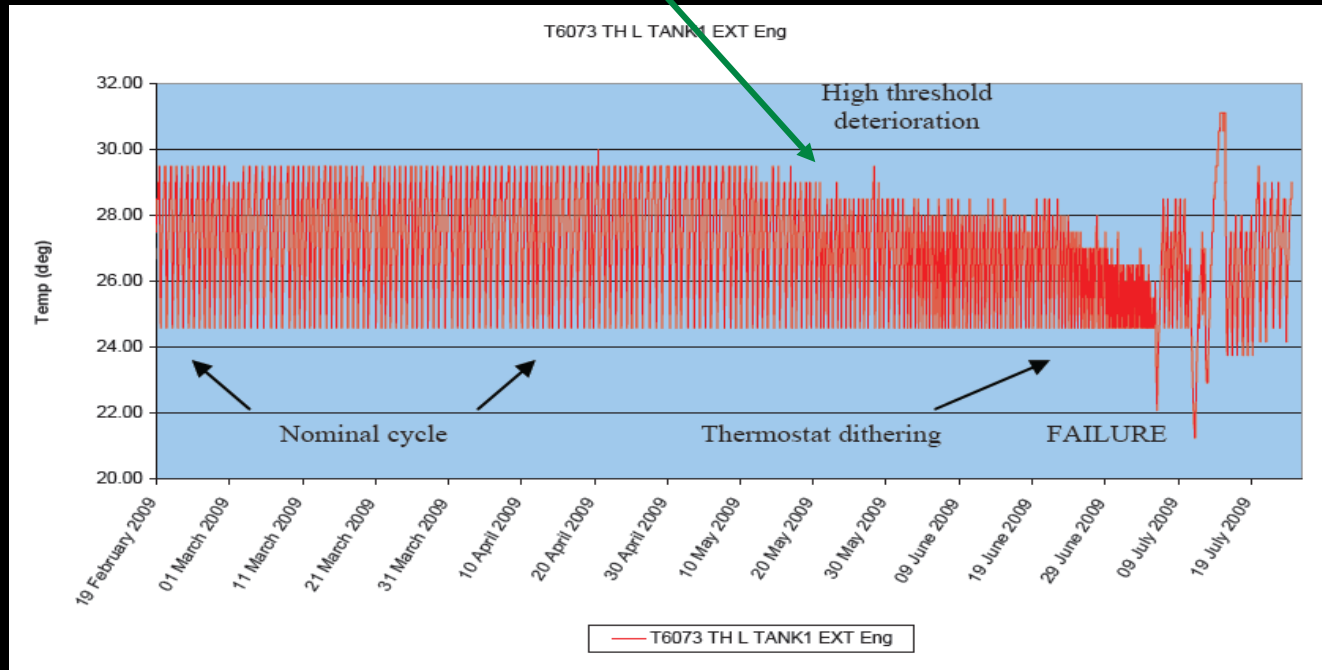Telemetry Parameters

Event Packets

Telecommand History

Orbit Data

How do we **detect** novel behaviour ahead of failures?

Predictive Maintenance: use ML and Novelty Detection

to find potential anomalies before they become serious.

How do we generate optimal plans ?

Weekly plan

Autonomous coordination and planning of payload experiments :
- Operations of 4 ESA Technology Payload on Alphasat
- AI planning & AI monitoring technology

European Space Agency

How do we **predict** the consumption of MEX thermal subsystem next year ?

→ **Mars Express Power Challenge**

Get the data, model and predict the thermal power consumption.
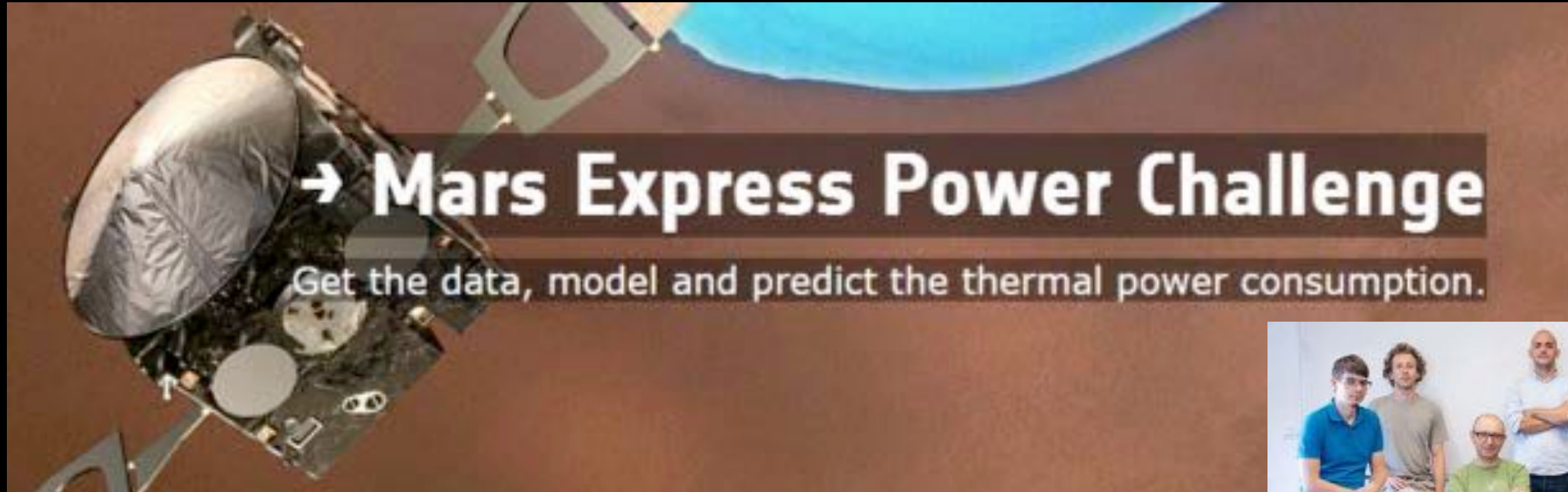
Added value: Accurate power consumption

prediction enables more resources for science

Winning team from Jožef Stefan
Institute in Ljubljana, Slovenia

How do we learn from the from the past to better design the future?

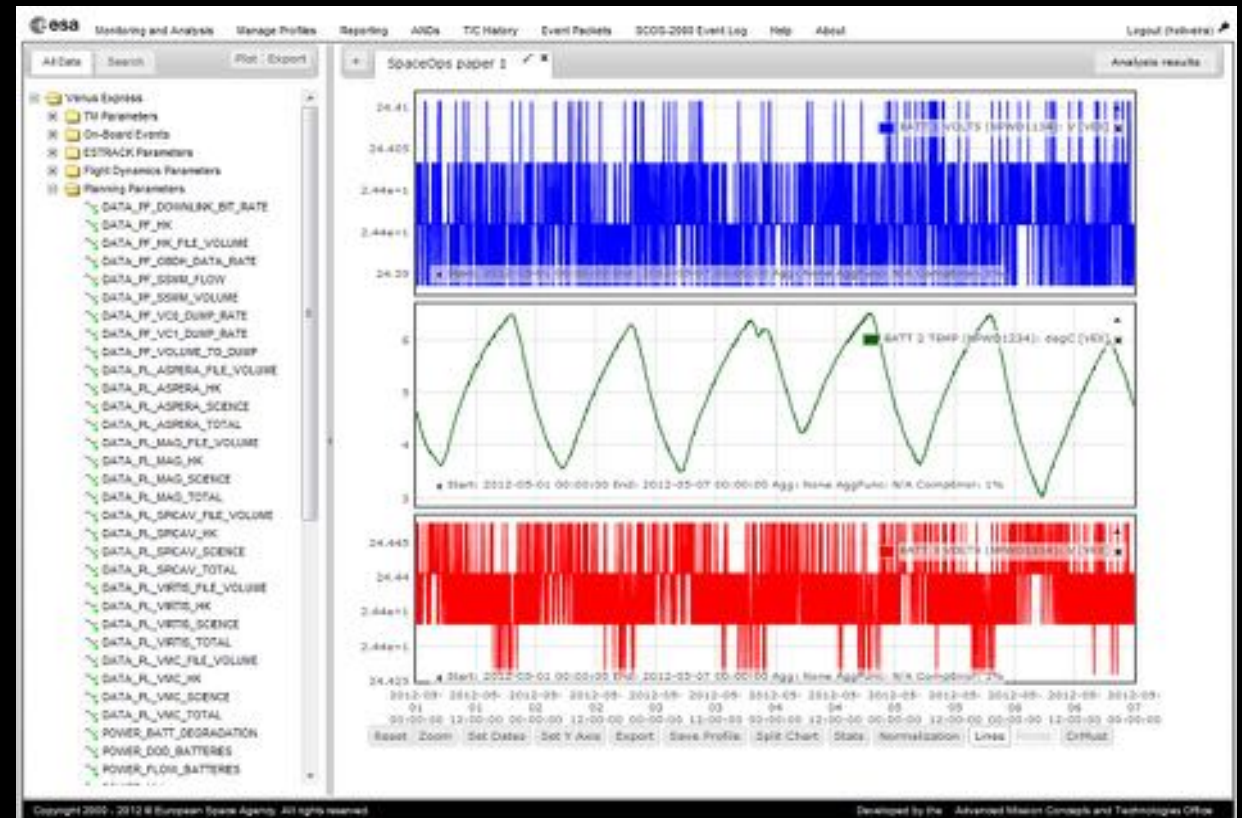TEC-MUST, a data analytics platform and service to support inter-directorate:
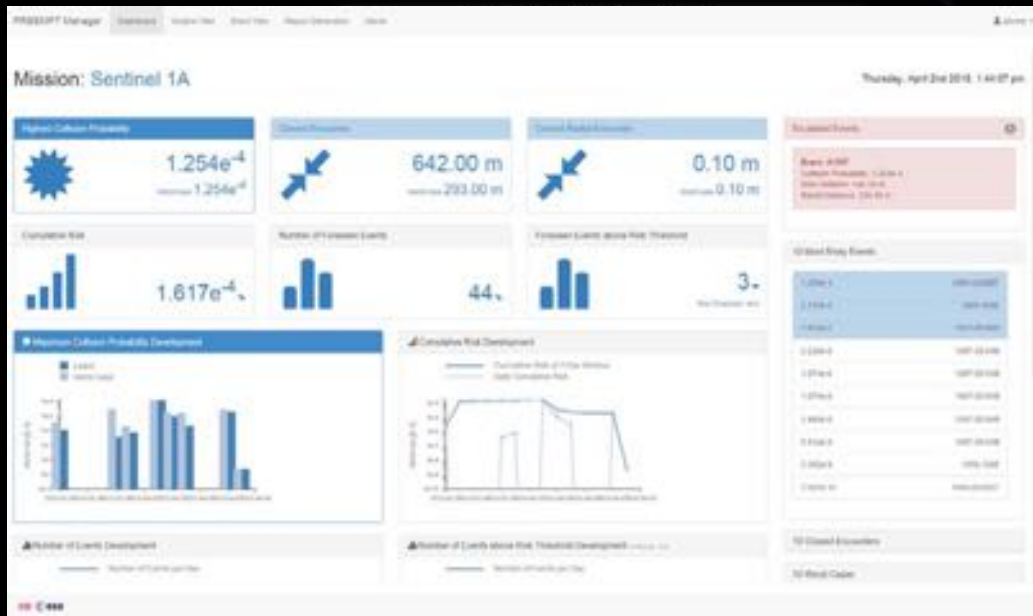
- Multi-Spacecraft performance assessment

- Collaborative diagnostics

- Design models fine tunes

- Close-loop btw development
  and operations

Dependency Finder plus Visual Analytics

Mars Express Dependency Network
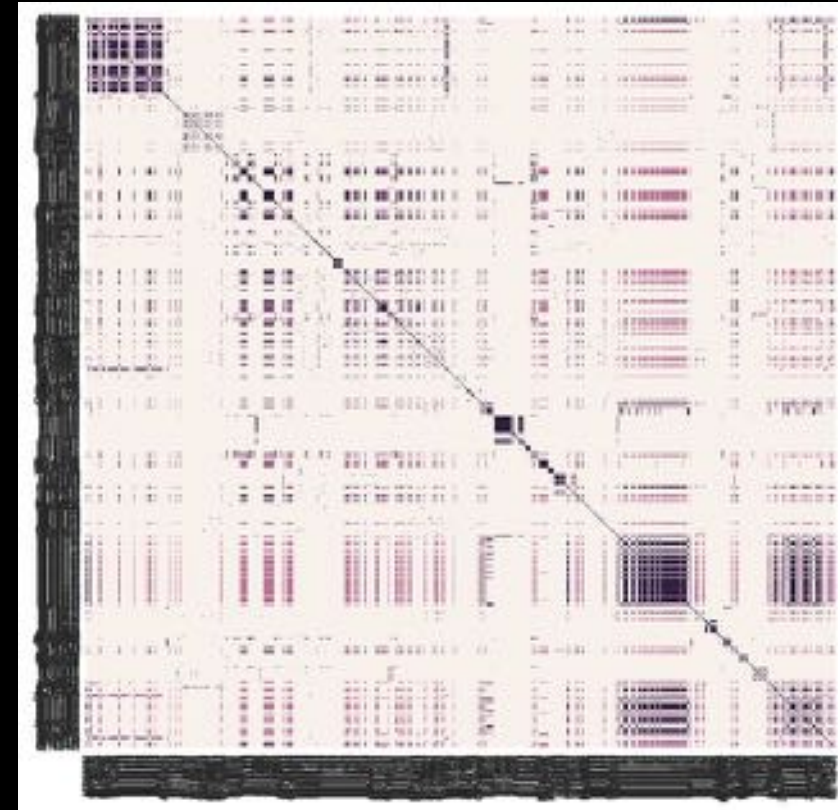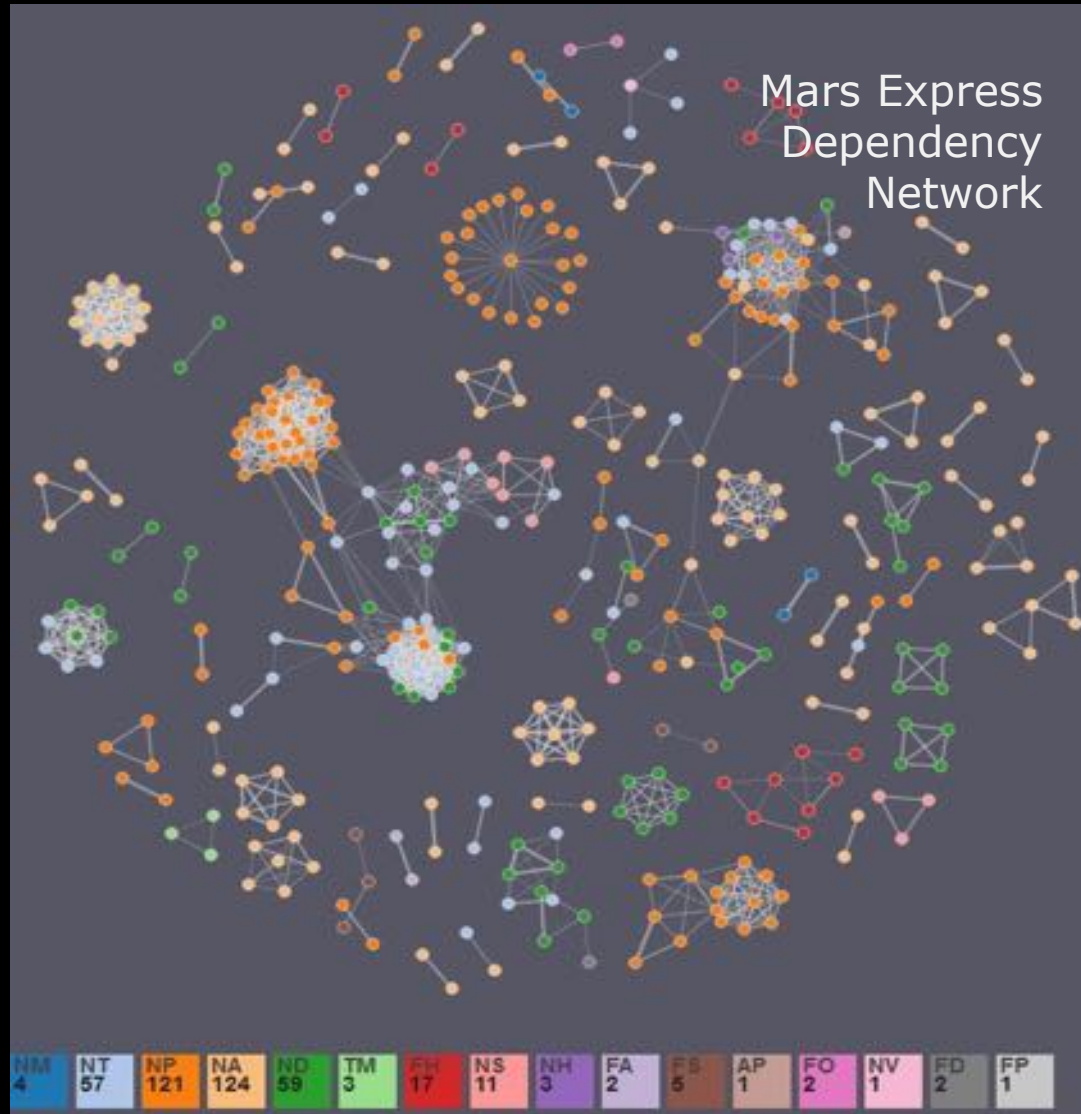
Spotting of unexpected coupling:
- update of ops procedure
- feedback to design

use mouse to look around and wheel to zoom in/out
press 'q' to cycle through camera views

COLLISION_PROBABILITY	0.0001575
COLLISION_PROBABILITY_METHOD	KLINKRAD
MAX_COLLISION_PROBABILITY	0.0002982
MISS_DISTANCE	292 m
RELATIVE_SPEED	14910 m/s
TCA	2015-01-17T06:08:22+00:00
SCREEN_ENTRY_TIME	2015-05-07T12:52:11+00:00
SCREEN_EXIT_TIME	2015-05-07T12:52:11+00:00
START_SCREEN_PERIOD	2015-05-07T12:52:11+00:00
STOP_SCREEN_PERIOD	2015-05-07T12:52:11+00:00

CRYOSAT 2 : 36508
Event: 36854
CDM: 36508

How to identify critical conjunctions autonomously?

e.g. Oneweb:
- 720 spacecraft
- Up to 100 collision alerts per spacecraft every day
- 30 parameters per alert to be analysed by human experts
- => more than a million data points to be considered for collision avoidance action day and night!
- => planned ARTES study on autonomous decision taking

AREA_PC	2.927 m**2
CD_AREA_OVER_MASS	0.010239 m**2/kg
CR_AREA_OVER_MASS	0.00755 m**2/kg
SEDR	0.0000846139 W/kg
THRUST_ACCELERATION	0 m/s**2

CNDOT_TDOT	0 m**2/s**2
CN_N	772.3028 m**2
CN_R	307.7216 m**2
CN_T	4066.6 m**2
CRDOT_N	0 m**2/s

2015-01-17T06:08:22+00:00

PREEMPT v0.1.0
CGI

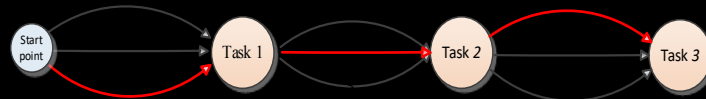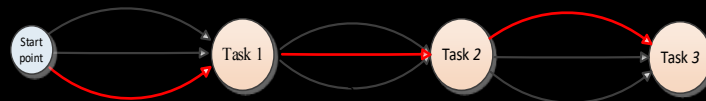| 08:18 | 08:19 | 08:20 | 08:21 | 08:22 | 08:23 | 08:24 | 08:25 | 08:26 | 08:27 |

AI Planning & Scheduling: Self-organizing EO Constellation using Ant Colony Optimization Paradigm

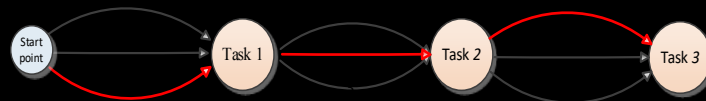**Coordination mechanism:** **3** DMC3 spacecraft**, Multiple** GEO spacecraft

Self Organization → Ants community

→ Spacecraft community!

Evaluation of how well **all s/c** performed

Objective function = f (S/C 1, S/C 2, …)

European Space Agency

Coordination mechanism: **3** DMC3 spacecraft**, Multiple** GEO spacecraft

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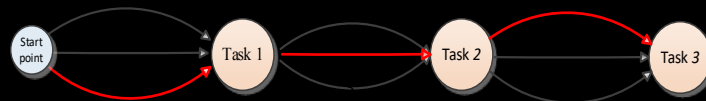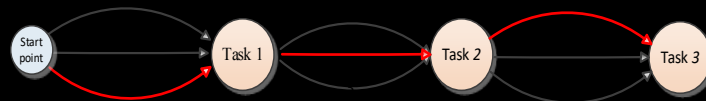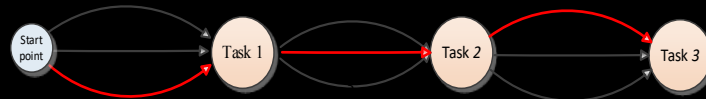
Amount of pheromone decided based on the performance of the **group**

*Act as a **unit**, not separate S/C*

OPS-SAT experiment: AI for Autonomy Operations

Demonstrate the capability and maturity of AI planning and scheduling

- to **autonomously schedule and re-schedule onboard activities**

- based on

  - awareness of **current situation**

  - on pre-loaded **operations goals**

Built on "Advanced Planning Scheduling Initiative" (APSI)

ESA Open Source Platform

Random Forests to predict the ESA News #views

http://www.esa.int/Our_Activities/Space_News

Random Forest provides accurate predictions

but …

The ESOC Communication Office is looking forward to **understanding** what engages the public

Dissemination of Experience: Machine Learning Lectures

https://github.com/jmartinezheras/2018-MachineLearning-Lectures-ESA

Spin-off of AI in Operations

Health Caring of Spacecraft
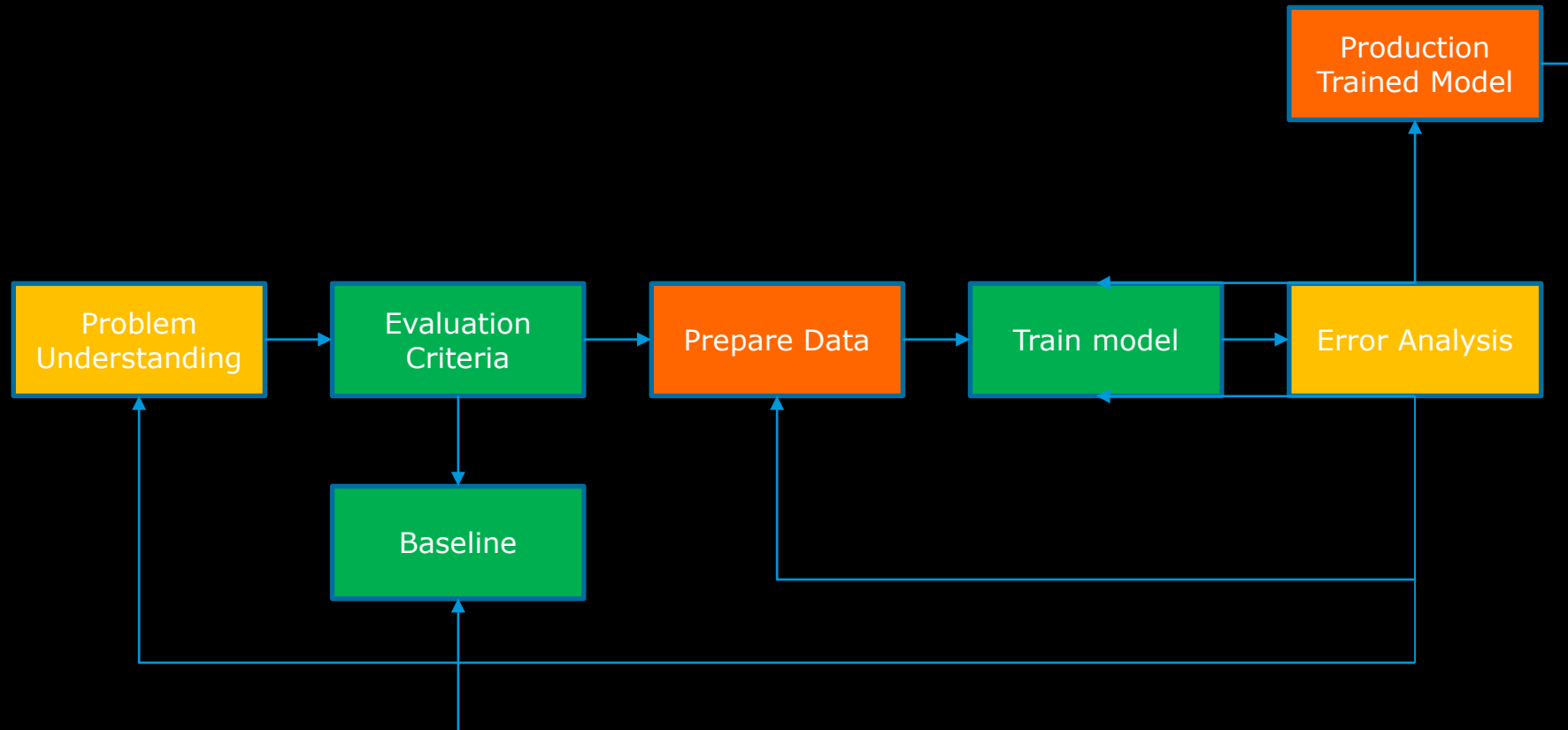
Health Caring of Humans

Collaboration with ESA Astronauts Medical Team

Collaboration with Merck

Machine Learning Workflow: where the effort goes

AI for Space Operations: Way forward

- Share experiences to help & sustain AI potential exploitation in
    - Spacecraft operation
    - Spacecraft design
    - Payload products & services

- Next Themes for Space Operations:
    - Explainable AI
    - AI for Autonomy
        - On ground (e.g. ground stations)
        - Space + Ground (one entity)

Artificial Intelligence in Operations

Spin-off: dissemination, consultancy

D/OPS experience & perspectives

- **15 served missions, incl. Galileo**

- **10 AI applications in operations, incl. 2 patents and 1 invention**

- **4 in-house AI specialists with deep operations knowledge**

- **Cooperation with other directorates, national & int. space agencies & int. organizations**

- **Networking and support with Academia and Industry to spread AI for space applications**

AI for Space Operations and more - Take Away

- AI is now an integrated part of Space Operations

- From ground   to onboard as a new space-ground unified asset

- **Collaborative AI** is becoming a field for Data Scientists across Spacecraft & Mission lifecycle (concept, design, production, operations, dissemination)

- *Easy access to "good" data is imperative*

Thank you for your time

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