Machine Learning in Space Operations

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Agenda

- Machine Learning in Space Operations
    - Anomaly Detection [AD]
    - Diagnostics [Diag]
    - Prediction [Pred]

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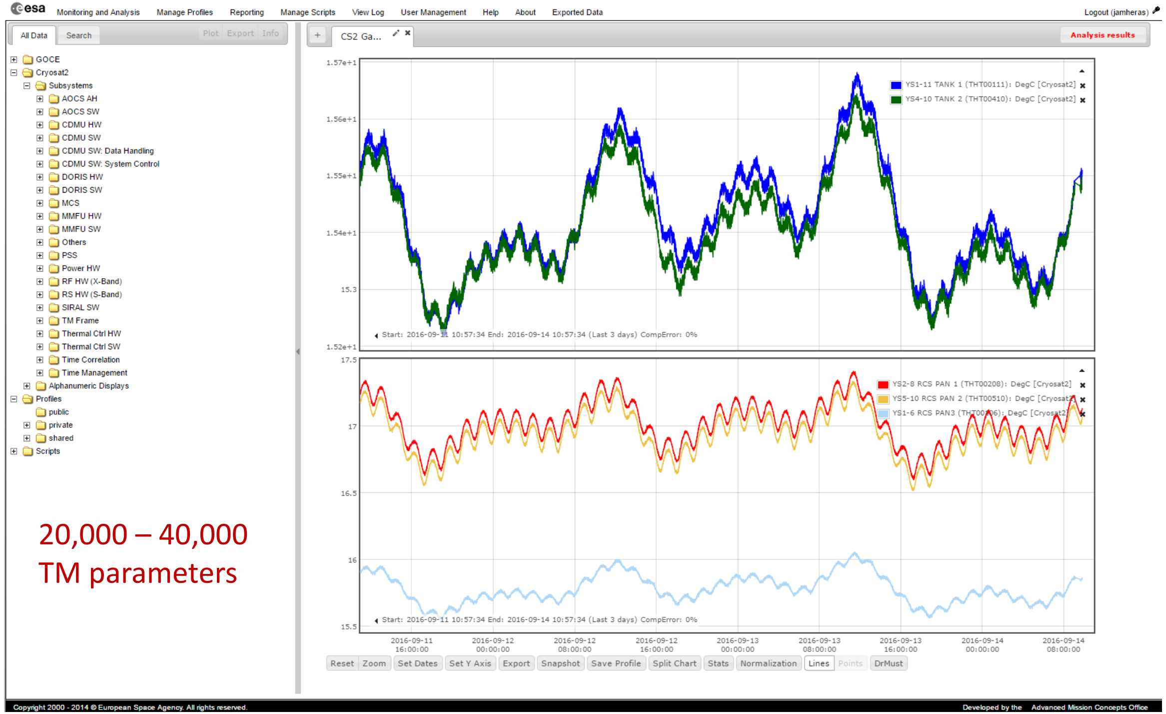
Background



20,000 – 40,000
TM parameters

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Anomaly Detection [AD]

- Challenges
- Classic Approach
- Our approach
  - Some “magic” sauce

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[AD] challenge 1: definition

- **What is** an anomaly?
  - “We didn’t want this to happen”
  - “We wanted this to happen, but it didn’t”

- Machine Learning does not know what you wanted
  - Anomaly Detection → Novelty Detection

[AD] challenge 2: First Time Anomalies

- Something in Spacecrafts will eventually break:
  - What?
  - When?

- First time anomalies impact Space Operations the most
  - Flight control engineers operate spacecraft differently after anomalies

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[AD] challenge 3: False Alarms

- False Alarms
  - It takes time to investigate each alarm
  - Engineers hate false alarms
  - May result in engineers ignoring Anomaly Detection results

- Example: 99% of the detected alarms are correct
  - In a modern spacecraft, with ~ 40,000 TM parameters
    - 400 False alarms!

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[AD] challenge 4: obviousness

- Operators need to clearly see why it is anomalous
  - Otherwise, lack of confidence in results

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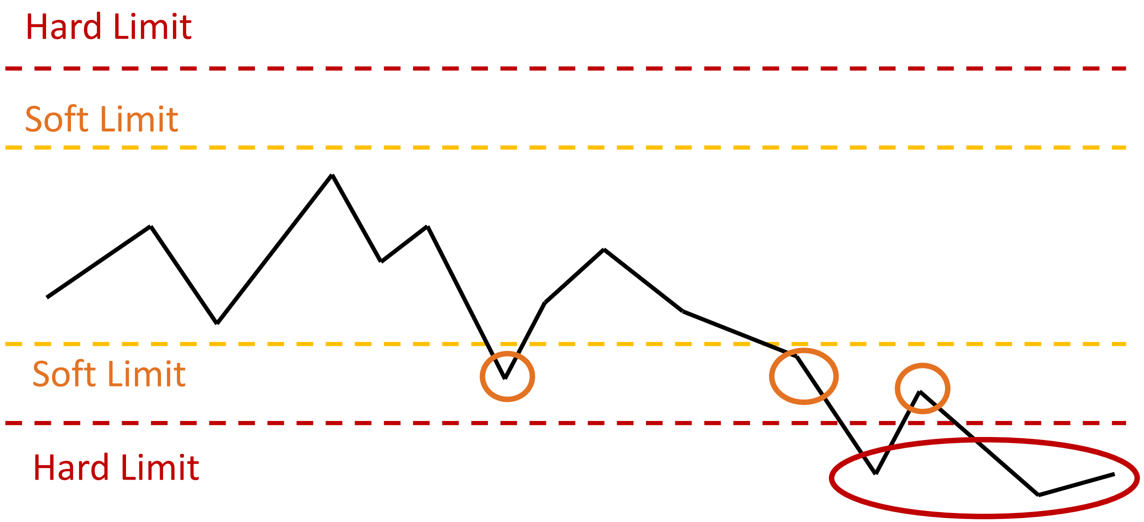
[AD] Classical approach: Out-of-Limits (OOL)



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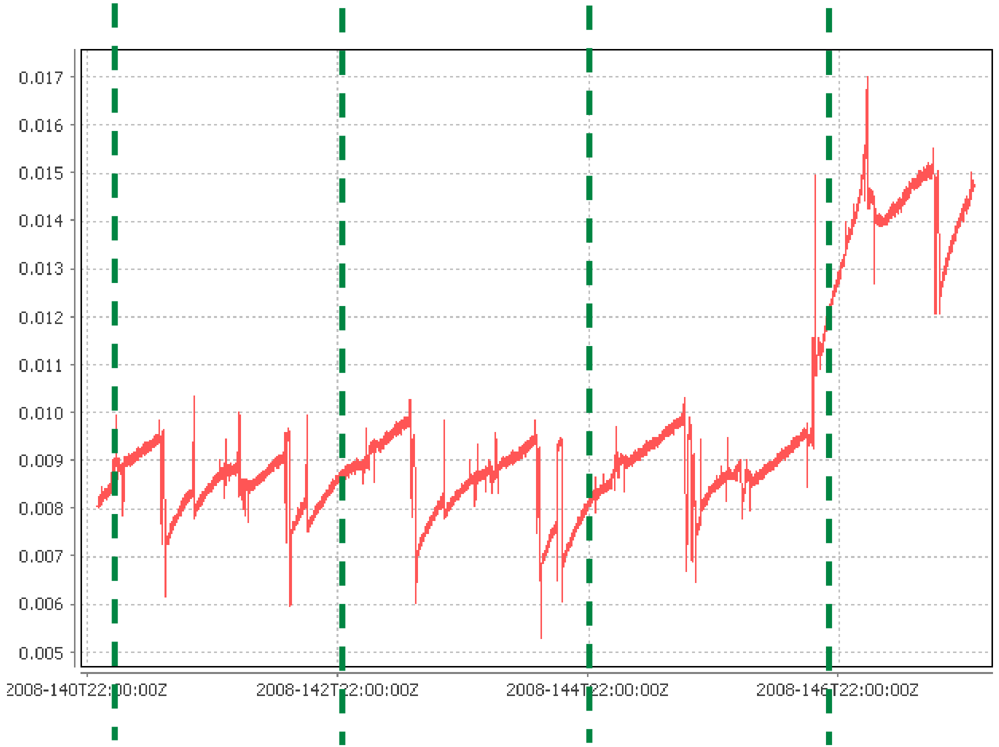
[AD] Our Solution

Split time series in periods and compute features:

- Mean
- Standard Deviation
- Maximum
- Minimum



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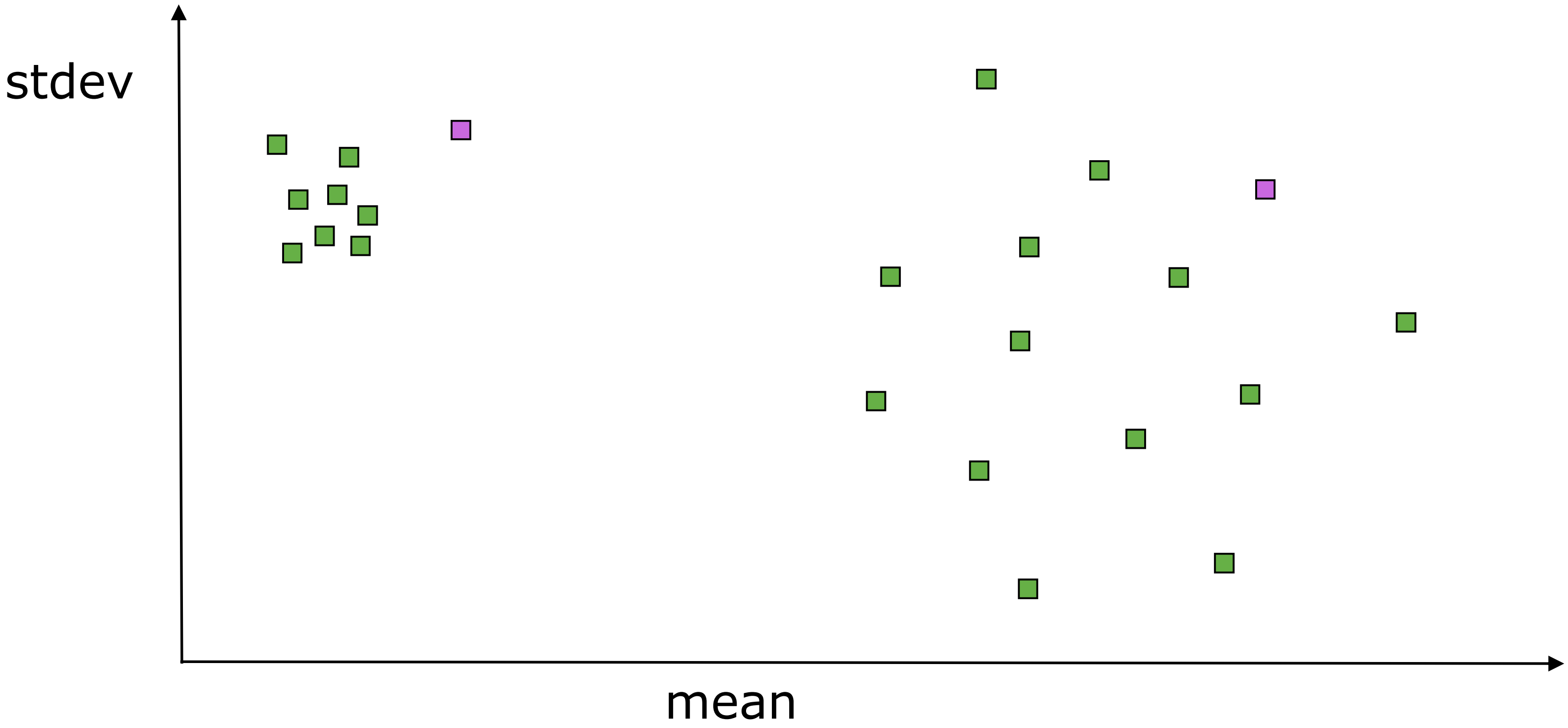
[AD] Our Solution



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[AD] Our Solution – Local Outlier Probabilities

1. Makes no assumptions on how nominal behaviour should be
2. Takes into account that a parameter can have different nominal behaviours
3. Takes into account density (no distance threshold required)
4. Outlier probability allows for comparison among different parameters

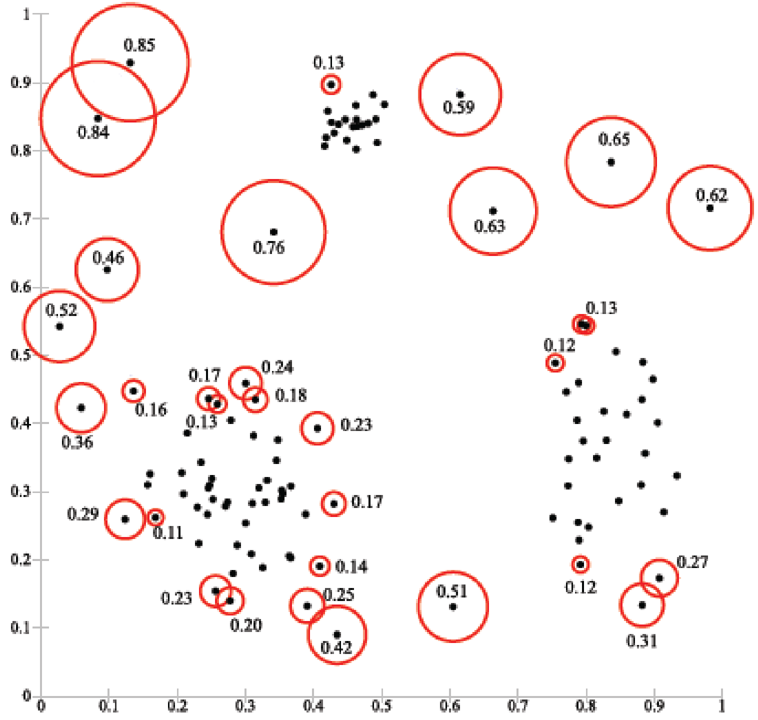

Image credit: Kriegel, Hans-Peter, Peer Kröger, Erich Schubert, and Arthur Zimek. "LoOP: local outlier probabilities." In *Proceedings of the 18th ACM conference on Information and knowledge management*, pp. 1649-1652. ACM, 2009.

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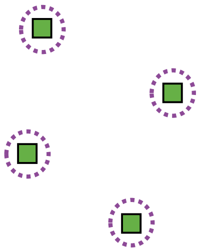
[AD] Magic Sauce

Reducing false alarms, increase obviousness

- k is arbitrary
  - k = {5, 10, 20, 30}

- Proximity filter



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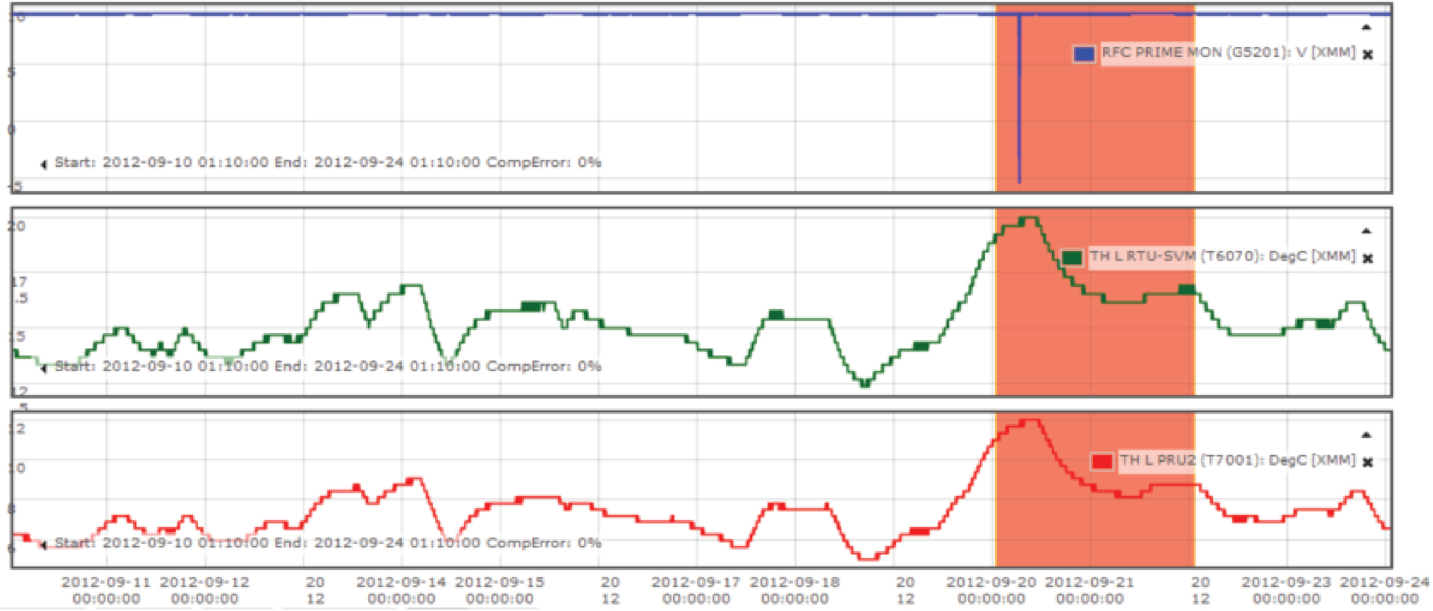
[AD] Results



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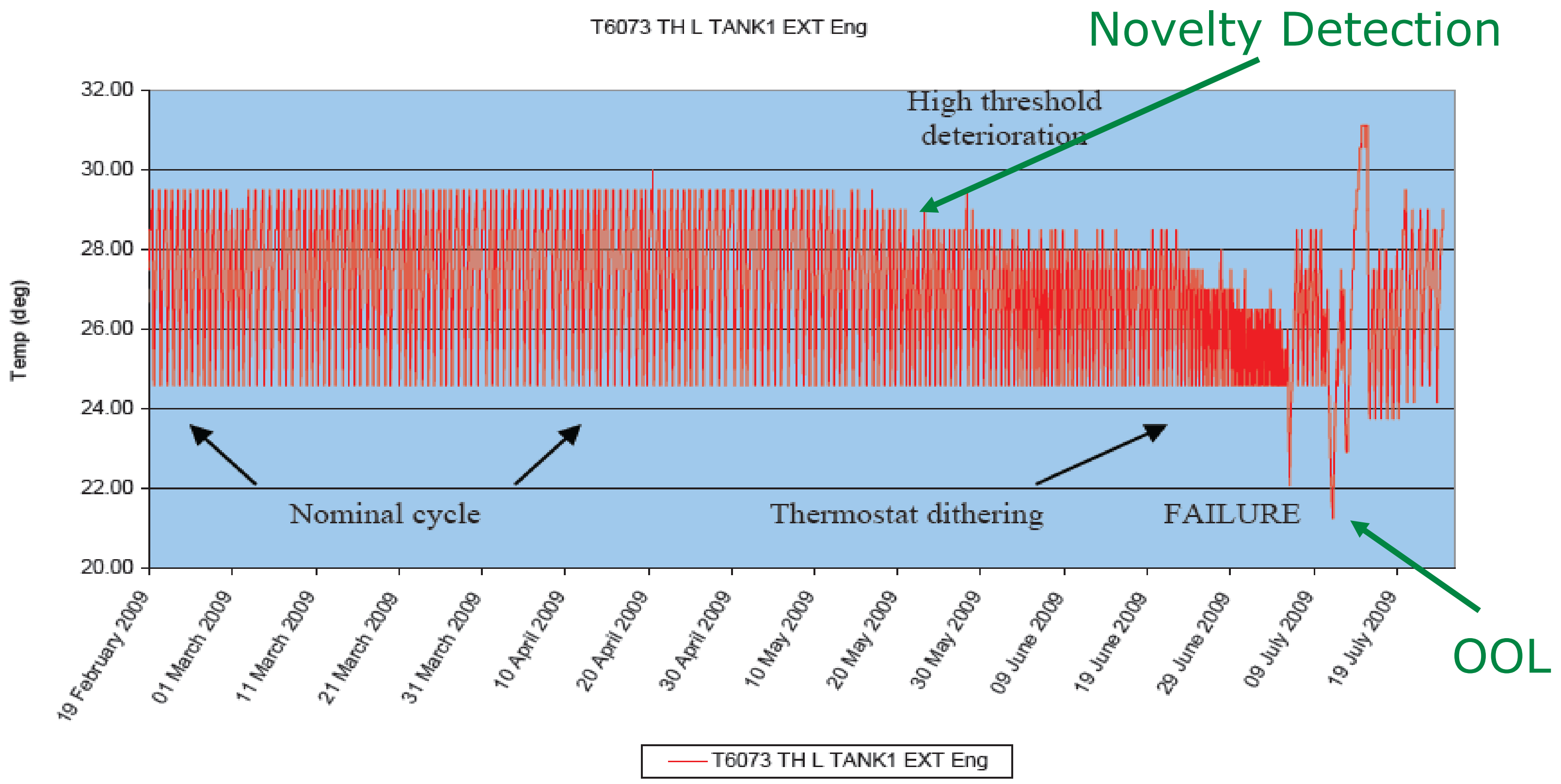
[AD] XMM Example



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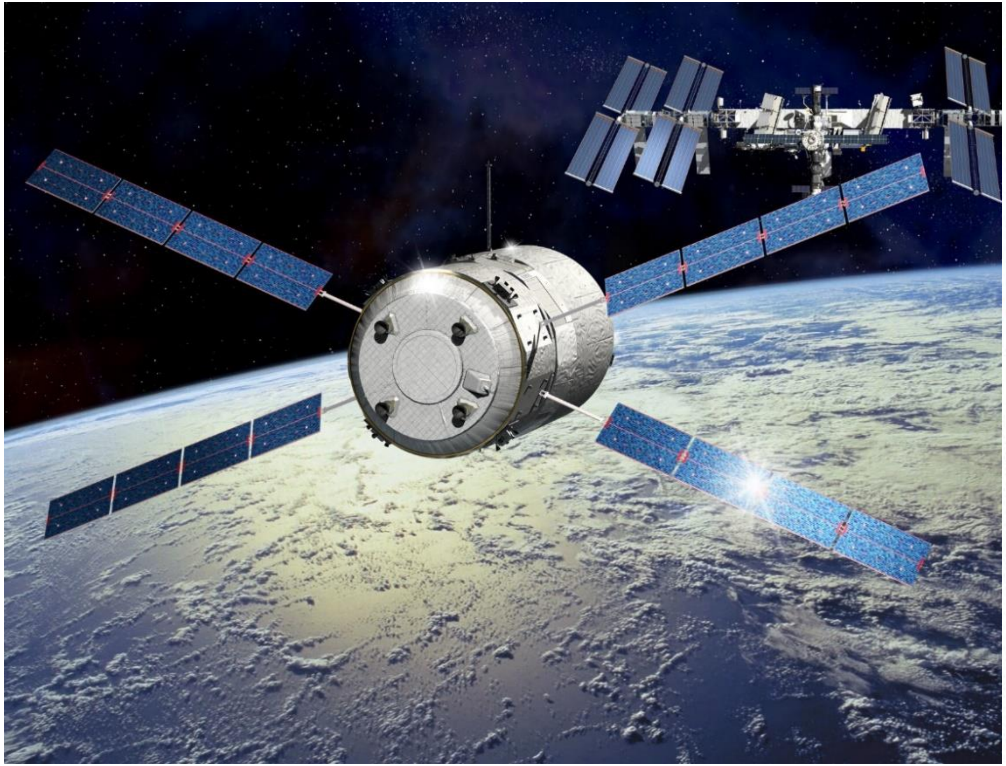
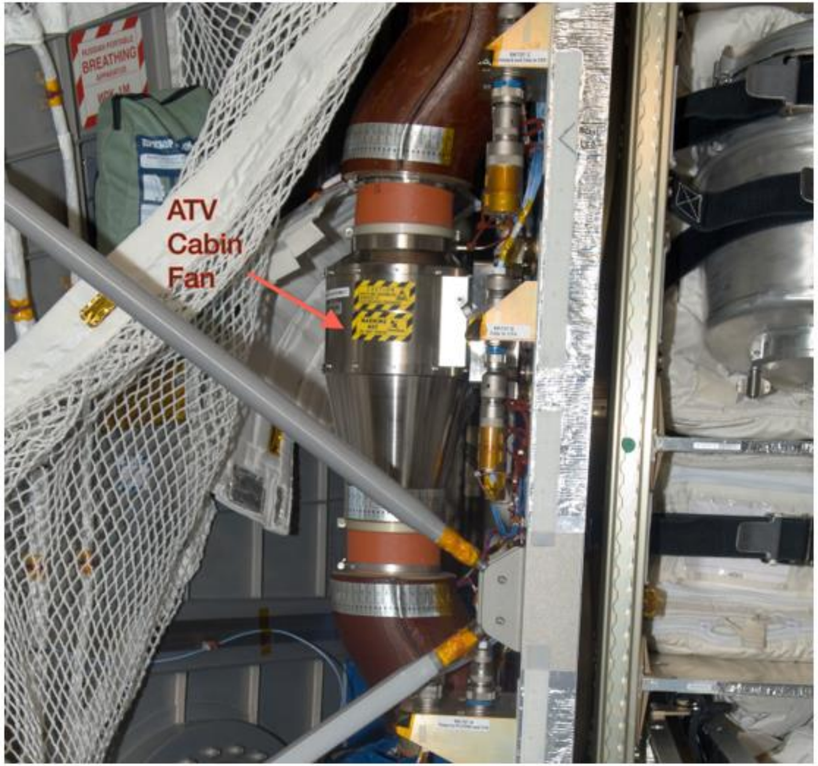
[AD] ISS ATV fan example





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[Diag] Diagnostics

- Support operators in finding out why the anomaly happened
  - Other parameters may hold the key to understand why the anomaly happened
  - Check all 30,000+ TM parameters (and TCs and Events) for insights

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[Diag] Dr. MUST

- Assumption:
  - Parameters involved in the anomaly behave differently during nominal and anomaly periods

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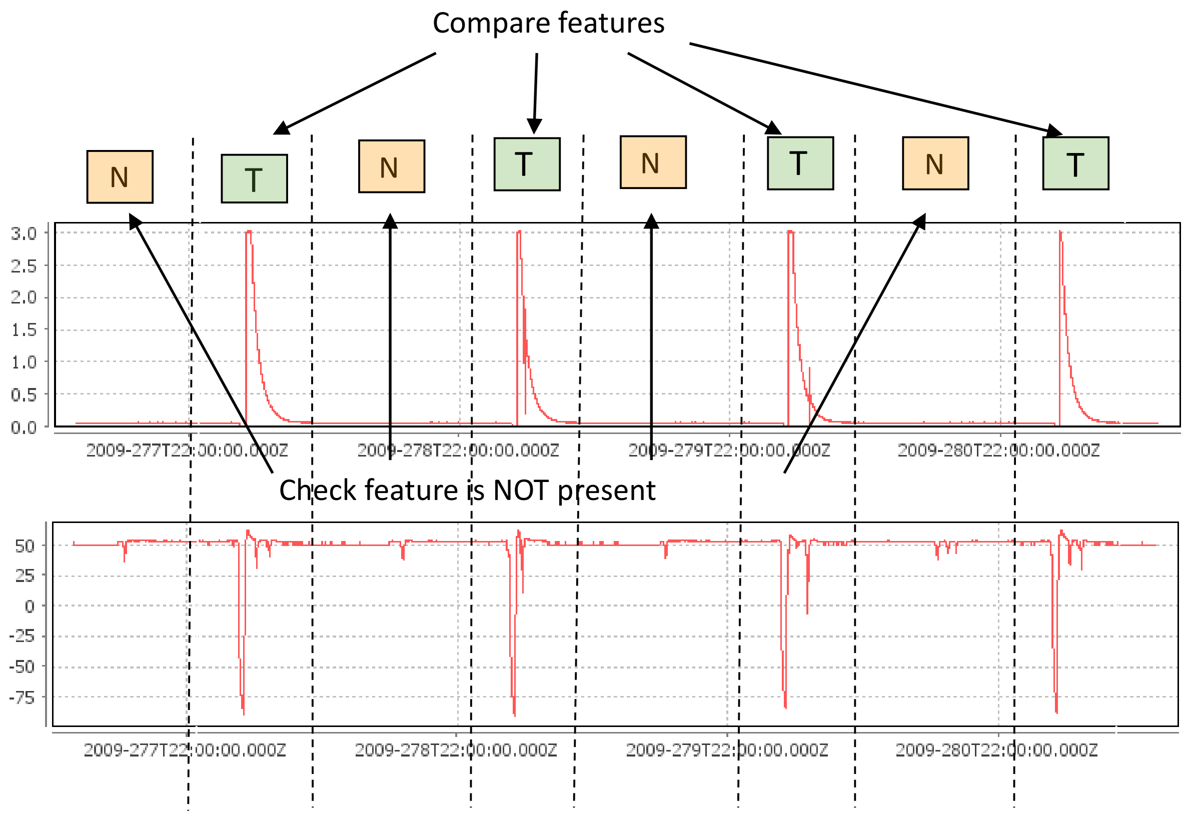
[Diag] Dr. MUST



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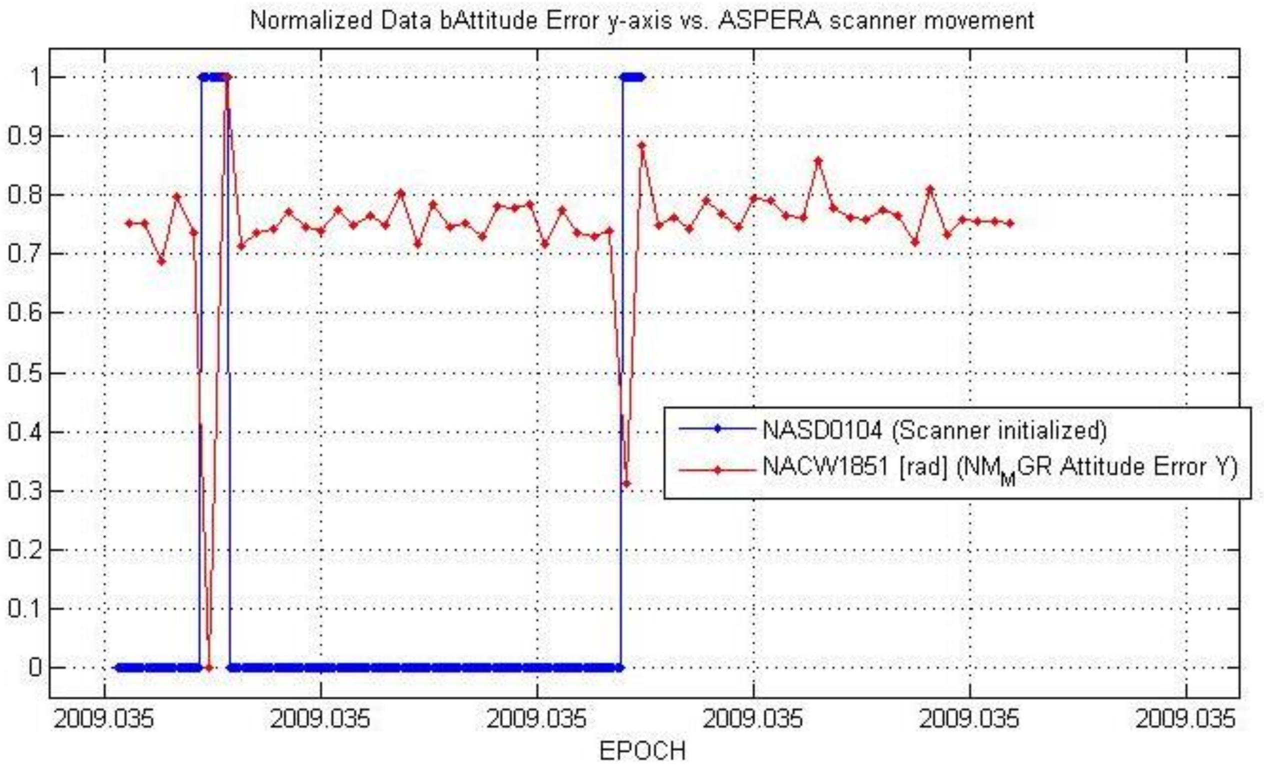
[Diag] Dr. MUST example



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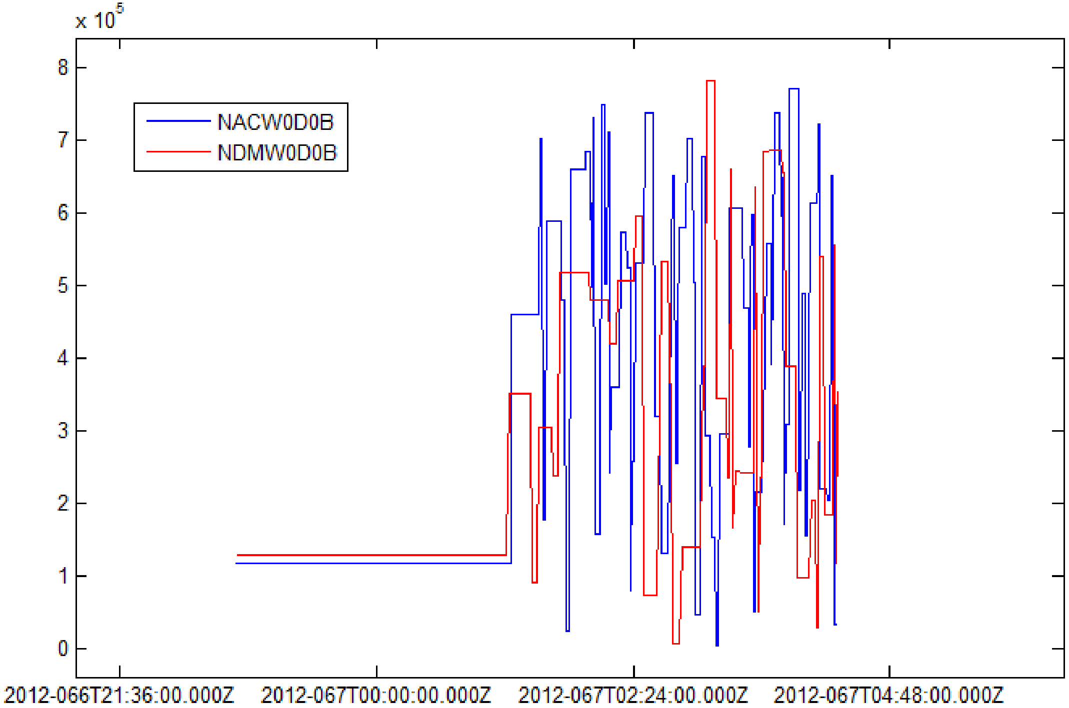
[Diag] Dr. MUST example



Number of bit errors detected & corrected during a Solar Flare

In addition of some star tracker parameters affected

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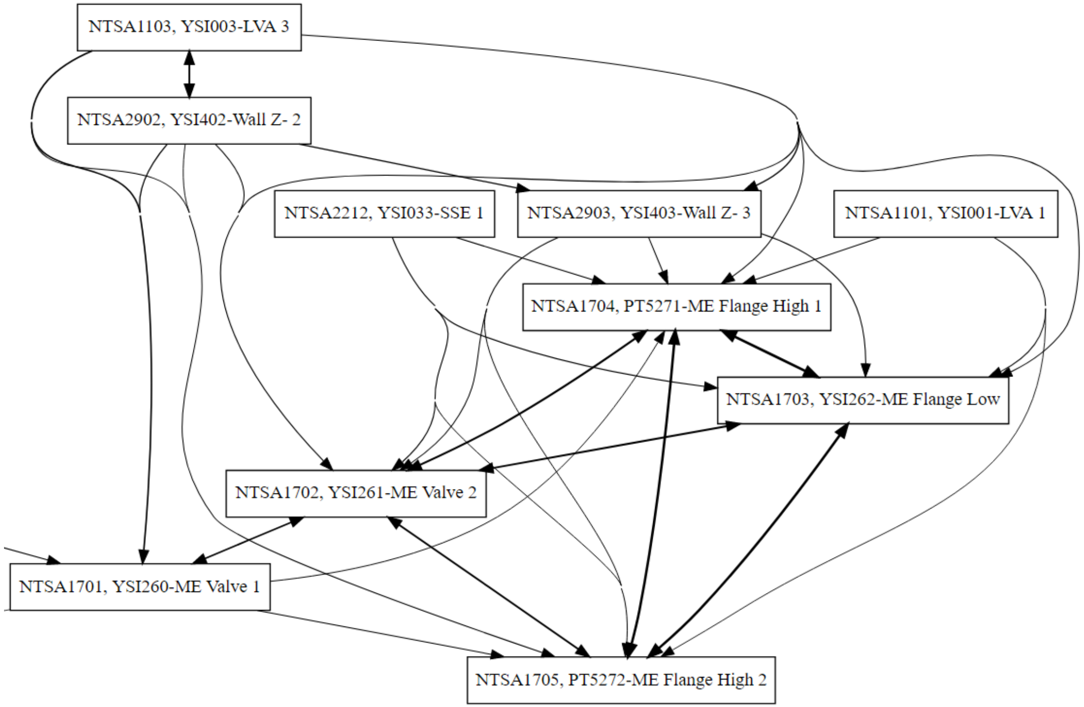
[Diag] Dependencies from TM data



Graph representation of the Mars Express dependencies (only a small section is shown)

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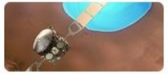
[Pred] - Prediction

- Let’s see some examples about prediction in the Space Domain

[Pred] – Thermal Power Consumption

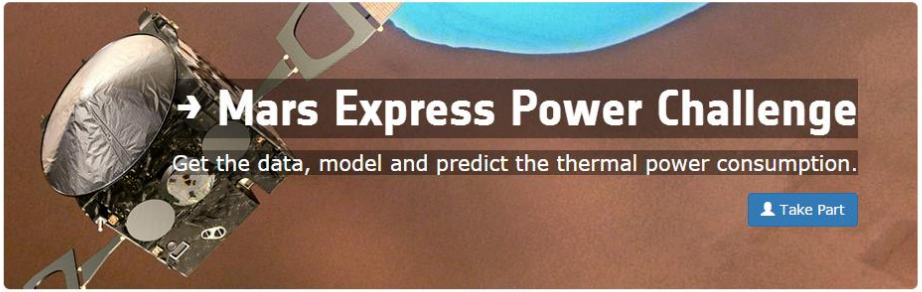
Kelvins | About | Competitions | Mars Express Power Challenge | jose



- Home
- Challenge
- Data
- Evaluation
- Rules
- Results
- Leaderboard
- Submission
- Discussion

March 31, 2016, 10 p.m. UTC | Timeline | July 31, 2016, 10 p.m. UTC

The competition is over.



It has now been more than 12 years that the Mars Express Orbiter (MEX) provides science data from Mars about its ionosphere and ground subsurface composition. The 3D imagery of Mars has provided the community with unprecedented information about the planet. Today, thanks to the work of careful and expert operators, Mars Express Orbiter still provides information that supports ground exploration missions on Mars (Curiosity, Opportunity, ...) and a lot of other research.

The Mars Express Orbiter is operated by the European Space Agency from its operations centre (Darmstadt, Germany) where all the telemetry is analysed. The health status of the spacecraft is carefully monitored to plan future science observations and to avoid power shortages.

Operators of Mars Express keep track of the thermal power consumption thanks to the telemetry data. The spacecraft uses electric power coming from the solar arrays (or batteries, during eclipses) not only to supply power to the platform units, but also to the thermal subsystem, which keeps the entire spacecraft within its operating temperature range. The remaining available power can be used by the payloads to do science operations:

Science Power = Produced Power - Platform Power - Thermal Power

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[Pred] – Collision Risk with Space Debris

- **Home**
- Challenge
- Data
- Submission Rules
- Rules
- Scoring
- Leaderboard
- Submission
- Discussion

Oct. 16, 2019, 5:03 p.m. UTC | Timeline | Dec. 16, 2019, 1:35 p.m. UTC

3 weeks 29 minutes and 24 seconds remaining

Today, active **collision avoidance** among orbiting satellites has become a routine task in space operations, relying on validated, accurate and timely space surveillance data. For a typical satellite in Low Earth Orbit, hundreds of alerts are issued every week corresponding to possible close encounters between a satellite and another space object (in the form of **conjunction data messages CDMs**). After automatic processing and filtering, there remain about 2 actionable alerts per spacecraft and week, requiring detailed follow-up by an analyst. On average, at the European Space Agency, more than one collision avoidance manoeuvre is performed per satellite and year.

In this challenge, you are tasked to build a model to predict the final collision risk estimate between a given satellite and a space object (e.g. another satellite, space debris, etc). To do so, you will have access to a database of real-world conjunction data messages (CDMs) carefully prepared at ESA. Learn more about the challenge and the data.

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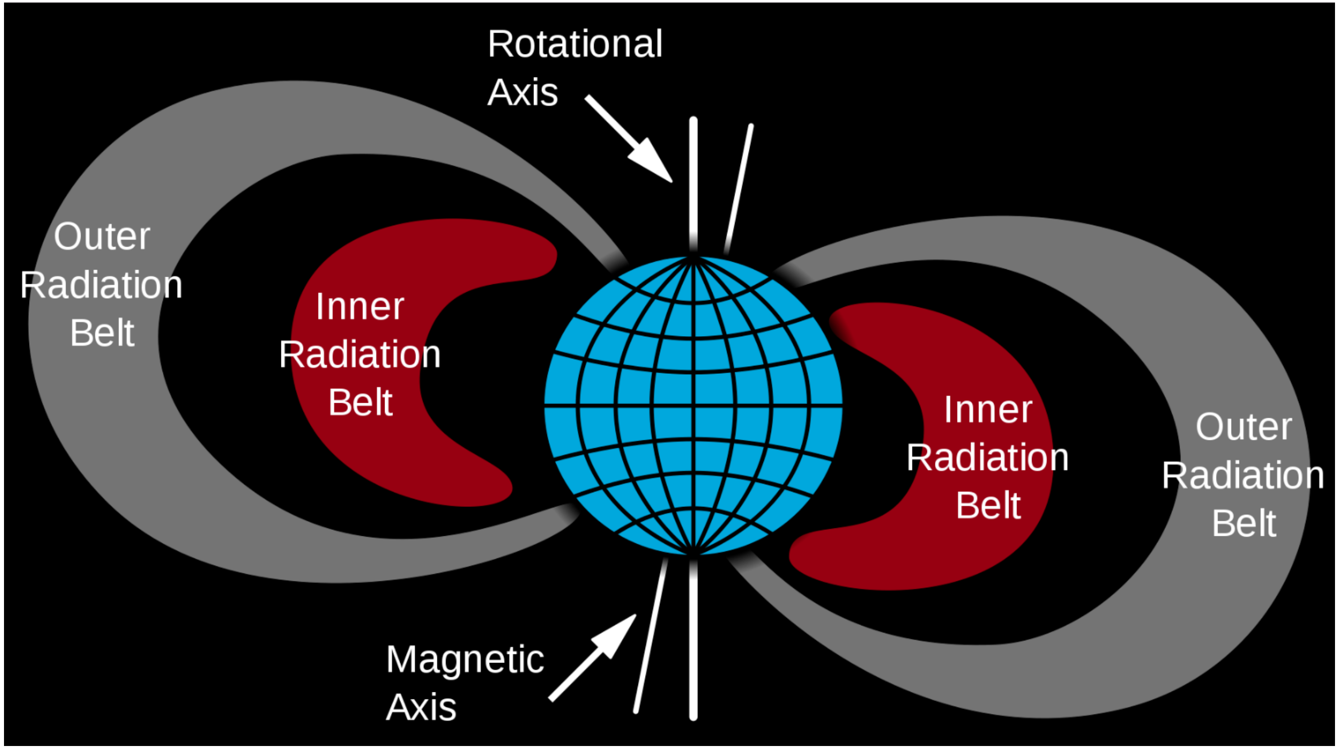
[Pred] Radiation Belts crossing



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[Pred] Wind impact in Deep Space antennas

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[Pred] ESA News number of views

[esa.int] Predict which articles will receive a high number of views

High: Rosetta, comet, surface, lander, image, crater, mars, stars, galaxy, black holes

Low: ESA, company, technology

Let’s stay in touch

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Discussion

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Thank You

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