Standardization training program
E-60 discipline: Control

Stars sensors terminology and performance specification standard

E-ST-60-20C Rev. 1

The ECSS E60 branch

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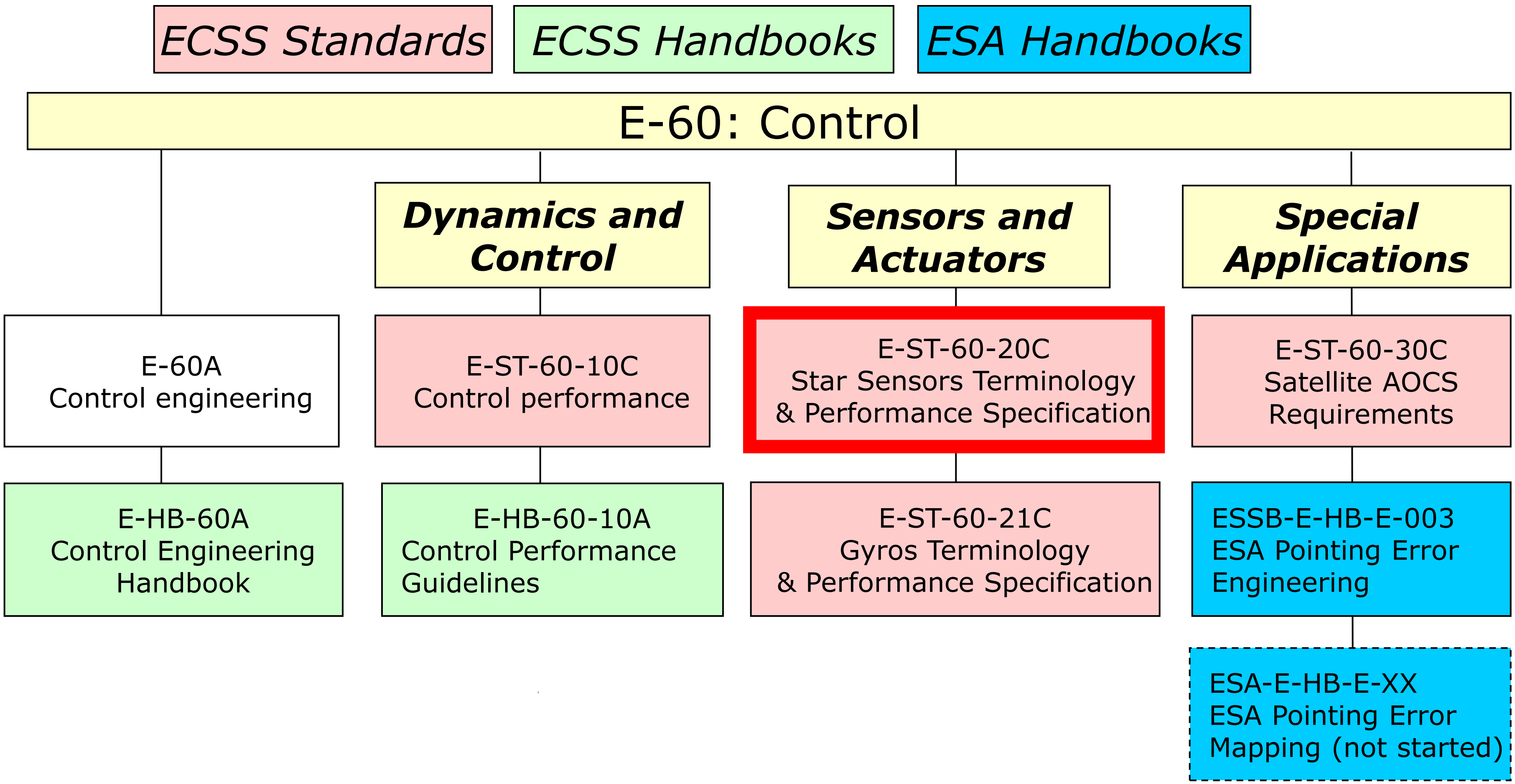

Background and motivation

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- The Star Tracker (STR) is the key sensor of all state-of-the-art AOCS
- The standard has been written to unify the naming of the terms used to specify a STR
  - Previously, major Star Tracker manufacturers were not using the same definitions for key requirements, this was leading to difficulties in comparing the products. (1σ or 3σ not mentioned, ambiguities with exclusion angles etc…).
  - Most of the satellites primes and STR suppliers were represented in the working group.
- The Standard focuses on performance specifications
  - The Standard covers all aspects of performances, including nomenclature, definitions, and performance metrics for the performance specification of star sensors.
- The Standard also specifies the verification approach
- Housekeeping data, TM/TC interface and data structures, were left outside the scope of this Standard.
- The control performance Standard WG was running in parallel, and the Pointing Error Hand book was not started
  - A difficulty for the Star Tracker working group.

Star tracker Introduction
Main Components

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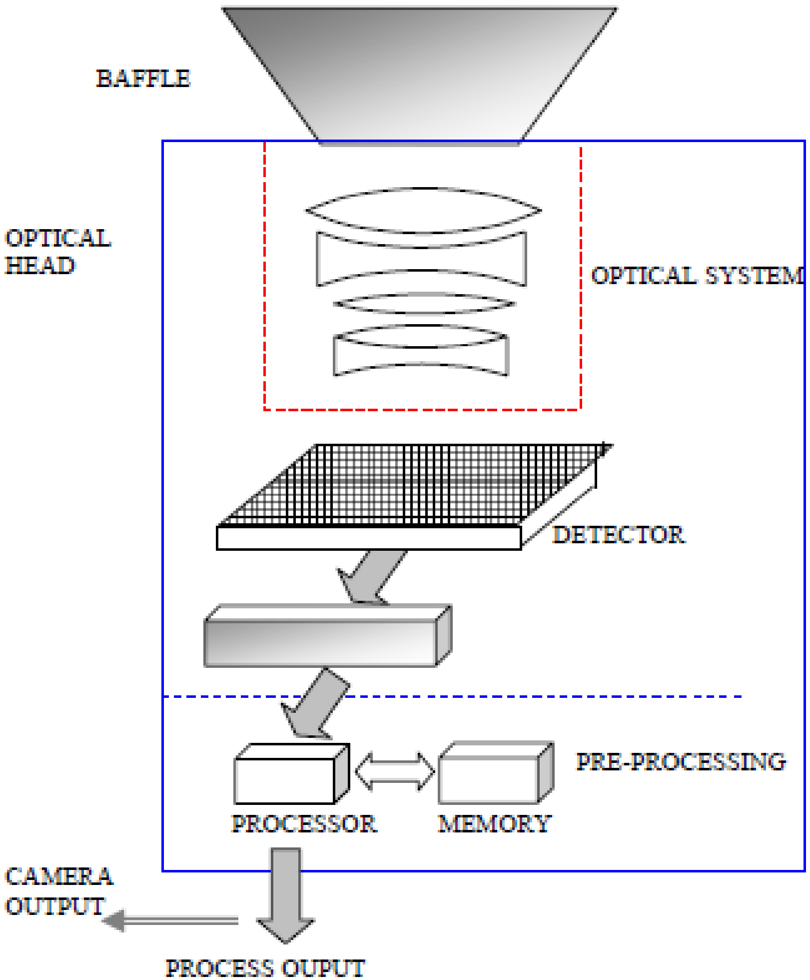
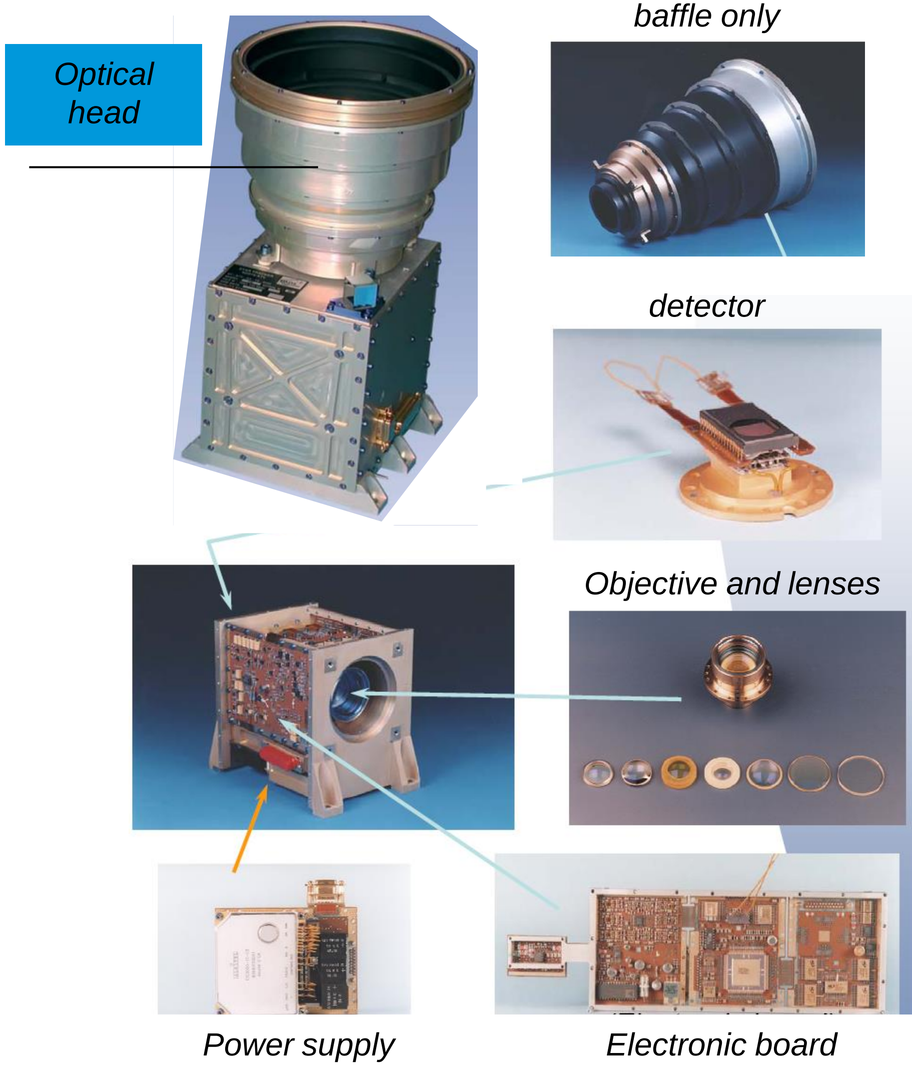


Example shown here : SED16 from EADS SODERN



Star tracker Introduction
What is it and the place of Europe in the field

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- In recent years there have been rapid developments in star tracker technology (algorithms, detectors, optics, straylight mitigation, robustness to radiations effects), in particular with a great increase in sensor autonomy and capabilities.

- The use of Star Tracker simplifies the Attitude & Orbit Control
  - Autonomous units working from "lost-in-space"
  - Constant 3-axis measurement of the attitude
  - No dependency to altitude
    - In comparison with Earth Sensors
  - State-of-the-art STRs are now "designed-to-be" immune to radiations SEEs.

- European Star Trackers are leading the world :
  - An estimate of 75 to 80% of the market share are for Sodern (F), Selex Galileo (I) and Jena-Optronik (D).
  - Example : NASA science missions and all US telecommunication satellites are using European Star Trackers

STR terminology & performance specification overview

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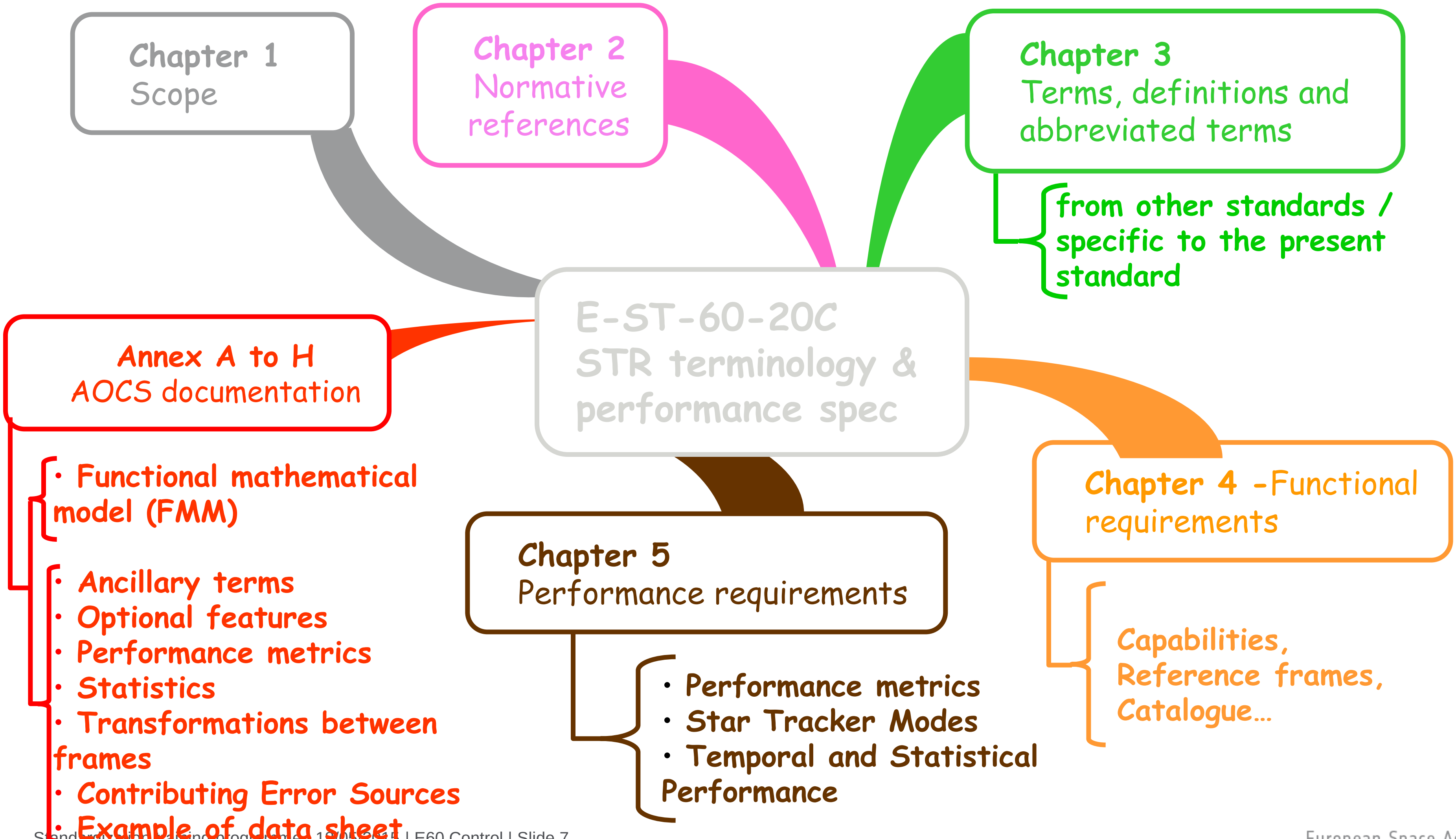

Chapter 4 : Important functional definitions of the Standard

- Hardware definitions
  - Baffle, detector, electronic processing unit, optical head, optical system
- Reference Frames
  - alignment reference frame (ARF),
  - boresight reference frame (BRF),
  - inertial reference frame (IRF),
  - mechanical reference frame (MRF),
  - stellar reference frame (SRF)
- Time and Frequency definitions.
  - integration time, measurement date, output bandwidth
- Type of sensors
  - Star Camera or Autonomous STR
- Miscellaneous
  - Field of view, Exclusions Angles
    (for Sun, Earth, Moon or other celestial bodies)
  - other common terms used to specify or read Star Tracker documentation.

Chapter 4:
Examples of key aspects of the STR for AOCS

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- STRs provide attitude measurements
    - E.g. quaternions
- Accuracy
    - E.g. 10 arcsec at EOL (95% confidence level)
- Output rate
    - E.g. 2 Hz or more
- Integrity
    - Quaternions flagged as valid have to be valid
- Autonomy (Current state-of-the-art in Europe)
    - E.g. capability to:
        - **Autonomously determine the attitude**
        - **Autonomously track the attitude**
- Sun / Earth / Moon blinding
    - Exclusion angles

Chapter 5.1, 5.2, 5.3: Performance Requirements - General

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- Performance budget is not purely temporal :
  - Performances have a statistical nature and the standard presents the knowledge required to build performances up : Only an envelope of the actual performances can be provided.
  - Different statistical interpretations can be taken to handle the statistical ensemble (See PEEH for details)
- Performance is to be verified in two steps:
  - **Single star performances** : These shall be validated (at zero body rates) against on-ground tests using artificial stellar sources.
  - **Attitude/Quaternion performances** : These shall be validated against on-ground tests using artificial stellar sources or night-sky-tests.
- For each type of errors, the standard defines :
  - If the error is to be represented in the statistical or pure temporal domain.
  - The exhaustive list of contributors to be used in the budget.
  - And the verification method to be used (Analysis, Simulation or Test).
- Confidence level is to be agreed with the customer for each of the error source (1σ, 2σ or 3σ)

Chapter 5.4: Performance Requirements - Conditions

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- The performance conditions of the 'statistical ensemble' shall be used to encompass the following conditions for EOL:
  - worst-case baseplate temperature within specified range;
  - worst-case radiation flux within specified range;
  - worst-case stray light from solar, lunar, Earth, planetary or other sources.
- The maximum magnitude of body rate and acceleration shall be used.
- Single star position measurement performance within the verification simulations shall be:
  - validated against on-ground test data for fixed pointing conditions, and
  - able to predict metric performance under these conditions with an accuracy of 10 %.
- Detector error sources in the simulation shall also be validated using direct data injection into the electronics and analysis of the test outputs.
- The simulation allows the verification to cover the full range of conditions, including stray light, finite rates/accelerations, full range of instrument magnitudes, and the worst-case radiation exposure.
- EOL simulations used to predict EOL performance shall be verified by test cases verifiable against measurable BOL data.
- Impact of individual star errors on the overall rate accuracy shall be provided via simulation.

Chapter 5.5: Performance Requirements – Definition of error contributors

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- The Standard defines the different type of errors and their origin or frequency :
  - Static bias
    - Driven by on-ground calibration residuals, launch misalignment
  - FOV spatial error
    - Driven by optics distortion, star shape over the field of view, focal length over temperature,
    - Aberration and catalogue errors
  - Pixel spatial error
    - Driven by detector non uniformities
    - Lead to bias error in the case of inertial pointing, while they contribute to random noise for high angular rate missions.
  - Temporal noise
    - White noise,
    - Driven by star signal shot noise, background signal shot noise (straylight level, detector temperature…), read-out noise, quantification noise, datation noise
  - Thermo elastic error
  - Aberration of light or residual of aberration is also addressed to help the future user to chose which type of compensation is the most suitable.

Chapter 5.5
Examples of requirements

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- *The Star Sensor shall have a temporal noise of less than 10 arcsec around any axis up to 10 deg/s at EOL and for accelerations up to 1,0 deg/s²*
- *The Measurement date error shall be less than 0,1 ms*
- *The probability of correct attitude determination within 10 s shall be greater than 99,99 % for random initial pointings within the entire celestial sphere, for rates around any axis of up to 100 arcsec/s at EOL and for accelerations up to 10 arcsec/s²*
- *The probability of false attitude determination within 10 s shall be less than 0,1 % for random initial pointings within the entire celestial sphere, for rates around any axis of up to 100 arcsec/s at EOL and for accelerations up to 10 arcsec/s².*
- *The Star Sensor shall be capable of performing a full image download of the entire Field of View at 12 bit resolution. The image output time shall be less than 10 seconds*

Conclusions and way forward

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- The same definitions are now shared between all STR manufacturers (In Europe)
- Performance budgets are now based on the same structure.
  However a frequential characterisation of the performance is desirable e.g. to analyse gyrostellar hybridisation
  - The ESA Pointing Error Engineering Handbook now provides the theoretical background
- An harmonisation of functional interfaces for future Star Trackers is desirable
  - Under SAVOIR initiative, a SAVOIR SAFI WG has been created between satellite primes and all four main Star Trackers manufacturers to agree on a common core of data and commands. This could be added as an Appendix of the Standard.
  - See next slide the initial mapping done by SAVOIR SAFI WG
- Additional requirements on the verification of Star Trackers robustness to solar flares is desirable (solar flares are not mentioned in the current version)
  - Lessons learnt from an ESA launch with interplanetary cruise where the Star Tracker was on the list of the go/no go criteria, depending on space weather. See next slide.
- For these 3 topics, Change Requests will be raised mid 2015 (new Working Group?)
- Contact points:
  - Steeve.Kowaltschek@esa.int (document focal point)
  - Alain.Benoit@esa.int (ESA CESB chairman)

Initial mapping of Star Trackers functional I/F

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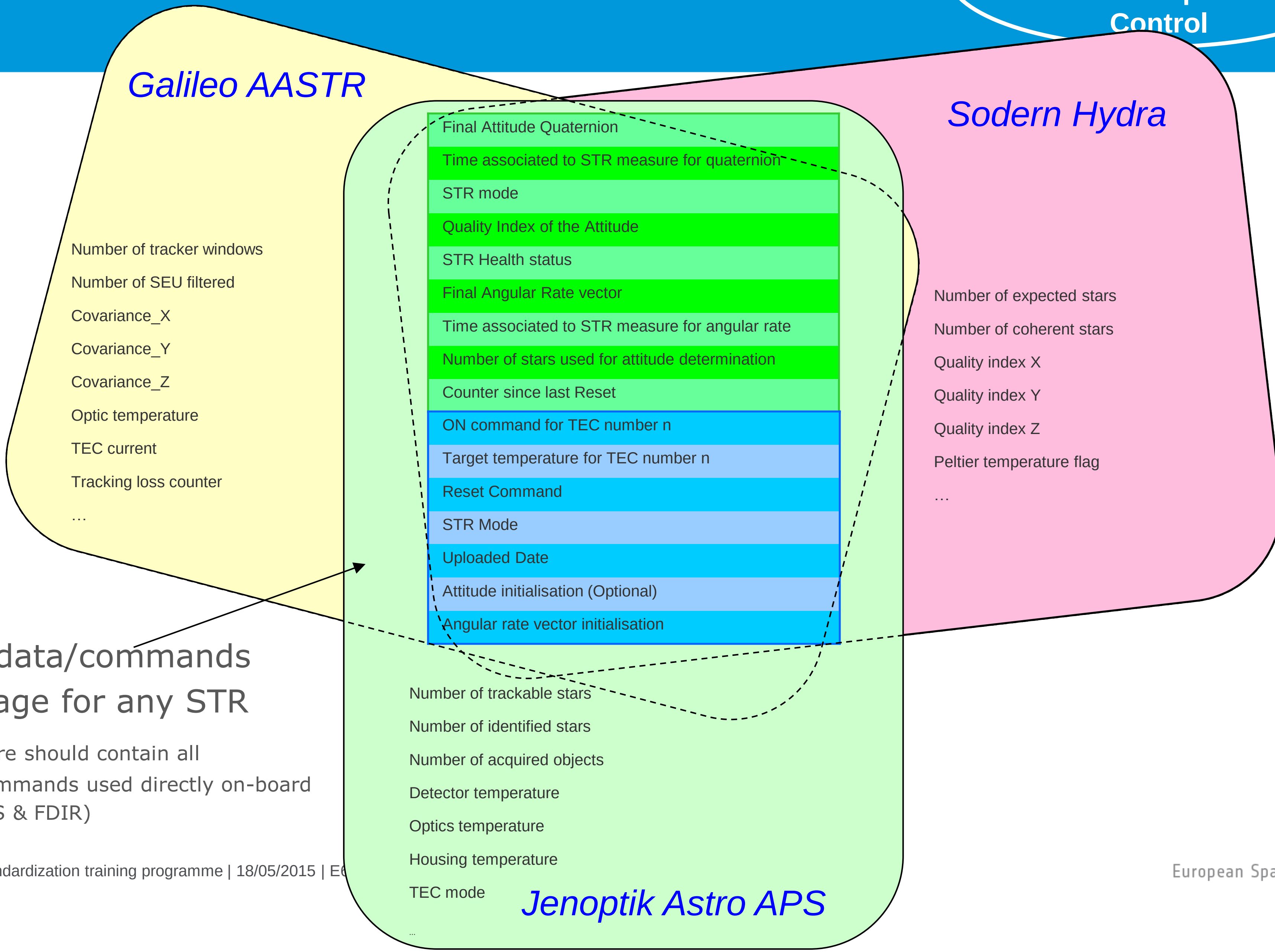

Core data/commands package for any STR

(This core should contain all data/commands used directly on-board by AOCS & FDIR)

Draft requirements related to Star Tracker robustness to solar flares

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- Proposed clauses

  " In case of time-critical attitude acquisition relying on star sensing, the Star Tracker specification
  - shall mention the case of solar flare,
  - shall define the appropriate environment specifications for the mission, comprising of reference solar flare including time period (worst day, worst week, …,) and margin (e.g. factor of 2), customising the acquisition and tracking requirements (allowed duration and probability of success and of loss of track)
  - and shall specify the verification method."

- Example of requirement:

  "The probability of correct autonomous attitude determination of the STR within 10 s with no a priori knowledge of the attitude and motion rate for the different dynamics conditions xxx shall be greater than 99% for the worst combination of conditions cited in section 3.7 taking into account 30 false stars and Single Event Upset rate derived from the maximum average flux (worst week) as defined in yyy."