Solar Wind Analyzer
The Solar Orbiter milestone towards on-board intelligent decision making systems

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On-Board Payload Data processing Workshop
ESTEC, Netherlands
25-27 February 2019

Solar Orbiter SWA

Solar Wind Analyser

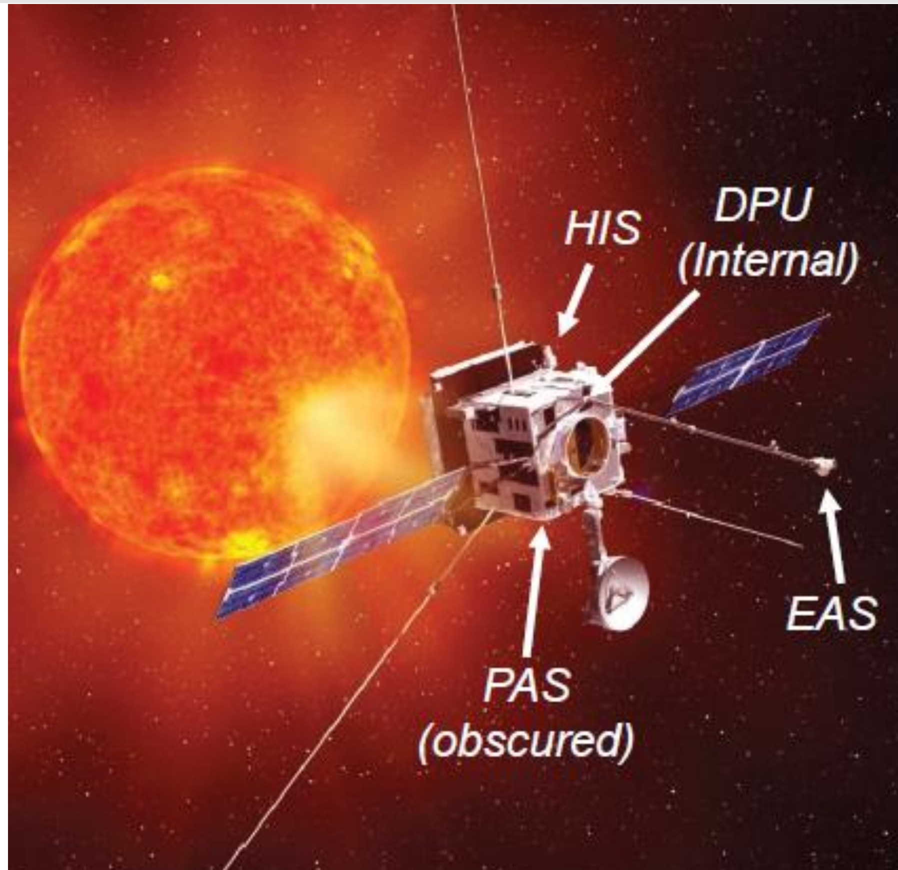
In-Situ Instrument suite
(one out of the four on-board)

composed of 4 sensors:

- EAS 1 & 2
- PAS
- HIS

and a

- Data Processing Unit

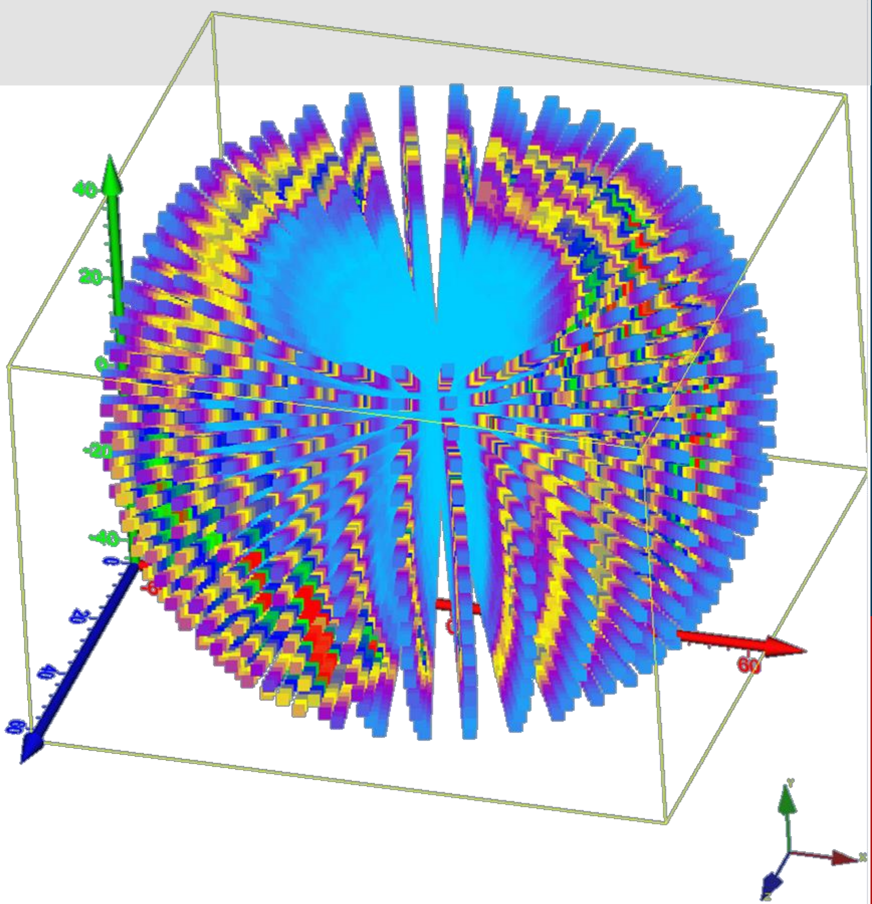


SWA Scientific Data

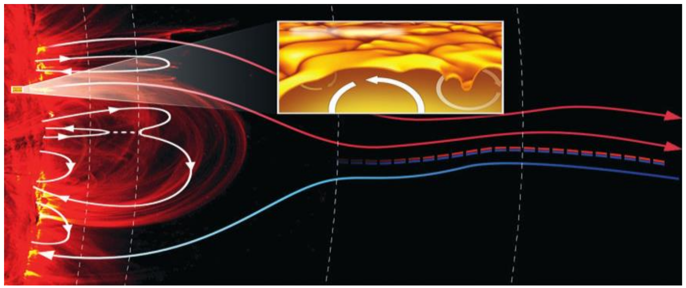
Each sensor collects (and counts) particles carried by the solar wind,

sampling a portion of the full sky per

- azimuth angles,
- elevation angles,
- energy levels

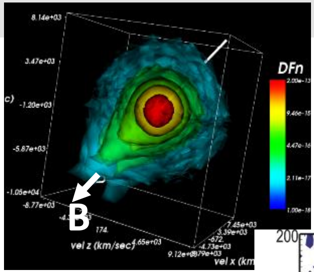


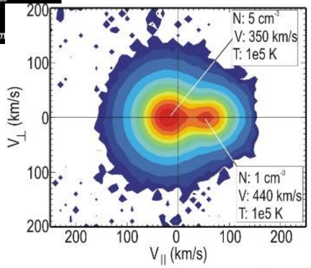
On-Board Scientific Data Processing



Solar Wind Flux Measurements

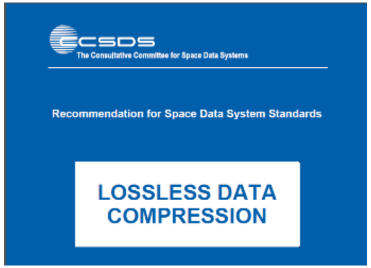
Moments computation





Meet Science Goals & Meet Telemetry allocation

Data Compression


CCSDS
The Consultative Committee for Space Data Systems
Recommendation for Space Data System Standards
LOSSLESS DATA COMPRESSION

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SWA Operations

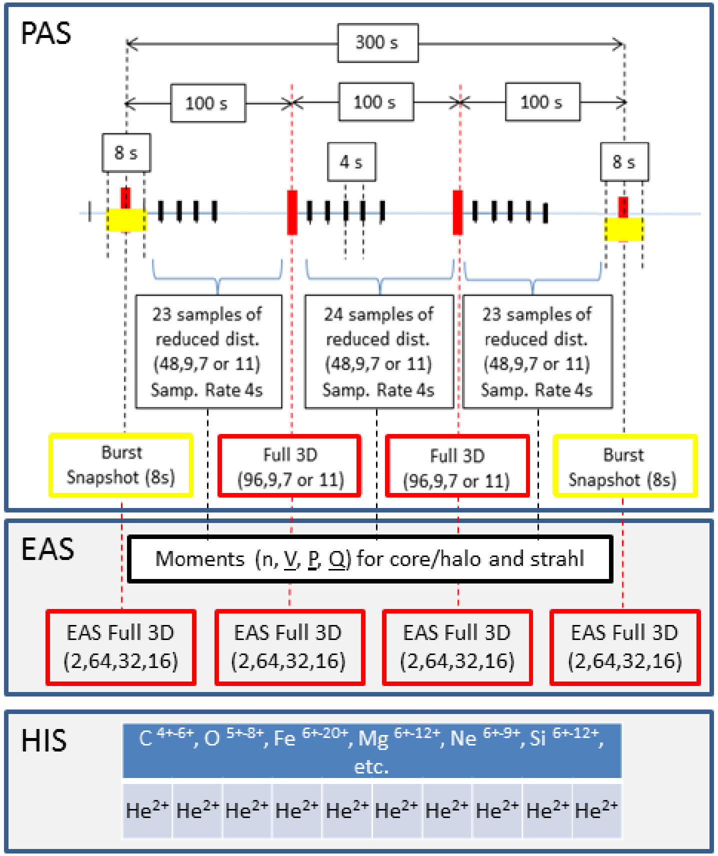
Overview

- The SWA sensors are operated in different "modes" (designed to meet the science goals), producing a wide variety of data products;

- Modes control 'raw' telemetry rates defining:
  - time resolutions,
  - on-board processing and/or
  - data compression

  (i.e. specific data products);

- Duty cycle designed to comply to **SWA suite telemetry budget limit (14,5 KiB/s)**.



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Computational Load Analysis

Test Conditions

- Hardware
  - LEON-2 ASIC board (AT697F)
    - 32KB instruction, 16KB data caches
    - Clock: 100 MHz
      - ~86 Mips & ~23 Mflops
    - SRAM: 8 MB
- Software
  - C code implementations
    +
    RTOS (VxWorks) & ASW
- Performance figures

Image Courtesy of MSSL - SWA suite configuration during FFT at MSSL

- Compression Ratio

$$CR = \frac{size\ of\ the\ input\ data\ stream\ [bytes]}{size\ of\ the\ output\ data\ stream\ [bytes]}$$

- Computational Load, estimated by means of

$$CPU\ Load = \frac{actual\ task\ computing\ time\ [ms]}{task\ cadence\ [ms]}\ \%$$

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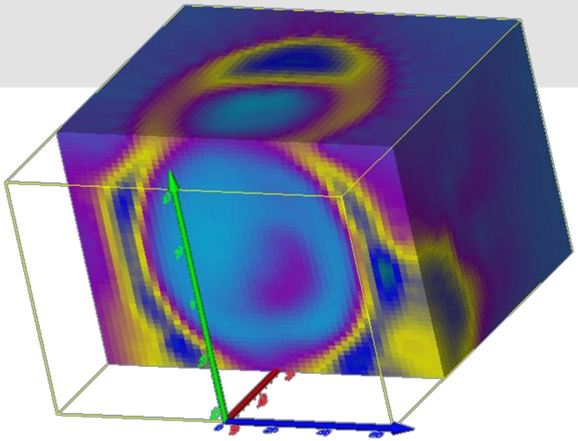
Data Compression

Overview



- Analysis
  - Select data and test cases
  - Entropy evaluation
  - “Discover” any structure in the data…
- Exploit the 3-D structure of the data [Energy, Azimuth, Elevation] groups
  - Correlation in the data
  - “preferential directions” in measurements similarity

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Algorithms Definition

Approach


CCSDS The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

LOSSLESS DATA COMPRESSION

RECOMMENDED STANDARD

CCSDS 121.0-B-2

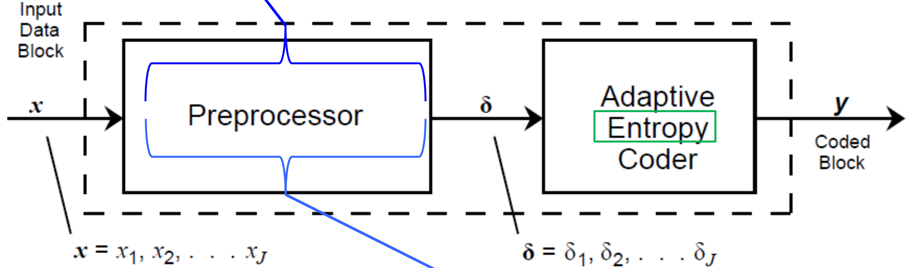
BLUE BOOK
May 2012

Perform data de-correlation by prediction-based strategies
(designed on data structure):

- CSSDS 121
- CSSDS 123

(sharing the same Adaptive Entropy Coder)

Unit-Delay Predictor



Multi-Dimensional Neighborhood Predictor


CCSDS The Consultative Committee for Space Data Systems

Recommendation for Space Data System Standards

LOSSLESS MULTISPECTRAL & HYPERSPECTRAL IMAGE COMPRESSION

RECOMMENDED STANDARD

CCSDS 123.0-B-1

BLUE BOOK
May 2012

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Computational Load

Estimated Worst-Case

Operational Mode	*CCSDS 121*	*CCSDS 123*
Normal Mode + Trigger EAS + Trigger PAS *	*17,2%* (=9,6+7,5+0,13)	*39,8%* (=10,7+28,0+1,1)
Burst Mode**	*17,6%* (=14,9+2,7)	*68,7%* (=56+12,7)

* *NORMAL MODE*: the estimated load includes three components:

- overall DPU task's worst case load
- EAS additional load due to trigger event (assuming an arbitrary task cadence of 1200 sec)
- PAS additional load due to trigger event (assuming an arbitrary task cadence of 1200 sec)

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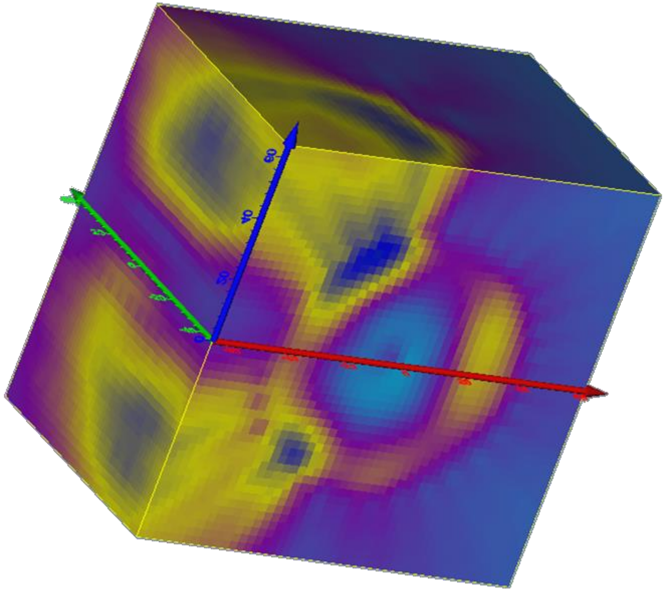
** *BURST MODE:* the estimated load for a given algorithm includes two components:

- EAS load (average over a time slot of 1 sec)
- PAS load (average over time slot of 8 sec)

Data Structure: re-ordering counts

- EAS sensor’s acquisition sequence:
  - From *slower* to *faster* variation: *Elevation-Energy-Azimuth*, hereafter shortly denoted as **El-En-Az**

- Possible permutations of the acquisition sequence have been considered



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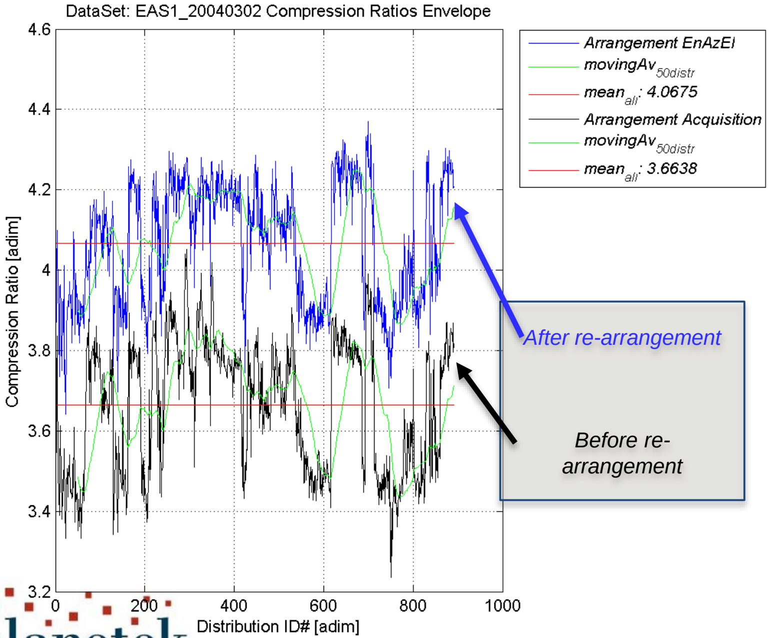
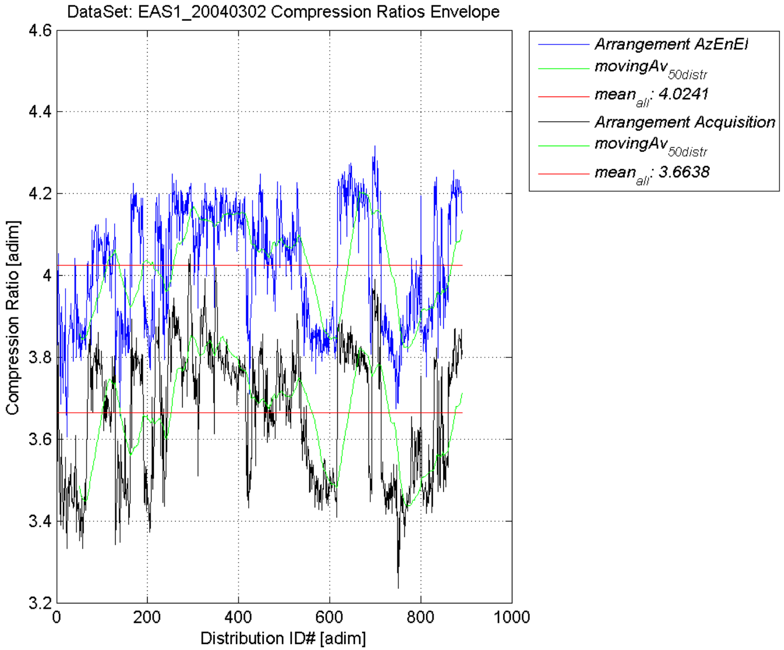
Re-ordering counts
CCSDS 121

Energy->Azimuth->Elevation
(Slower) *(Faster)*



Azimuth->Energy->Elevation
(Slower) *(Faster)*



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Target Compression Ratio: 4.3

«Complex» Re-ordering

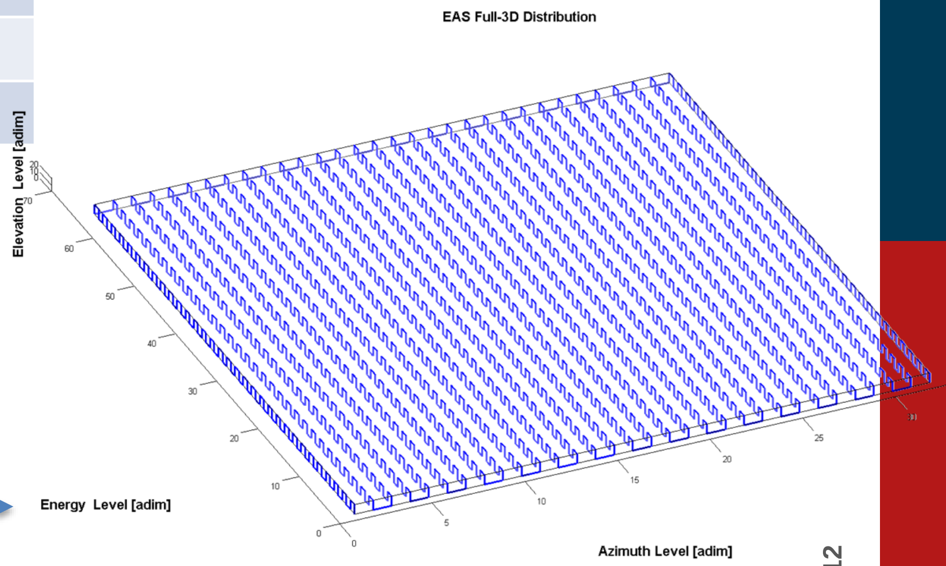
"***Simple***" re-ordering (slow to fast variations)	*CCSDS 121*
Az-En-El	109%
Az-El-En	83%
En-Az-El	111%
En-El-Az	101%
El-Az-En	83%

«***Complex***» re-ordering scheme achieved:

+***17,5% -> ~20%***

able to meet the requirement

Once Elevation as been detected as the direction showing more correlation between measured counts, it is possible to apply a ***«complex» re-ordering*** able to discover more (removeable) redundancy by avoiding «jumps» in data continuity



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Moments of a distribution

Given a velocity distribution function *f*, one can define the *n*-th order moment, in the satellite reference frame as

$$M_n = \int f(\boldsymbol{v})\boldsymbol{v}^n d\boldsymbol{v}$$

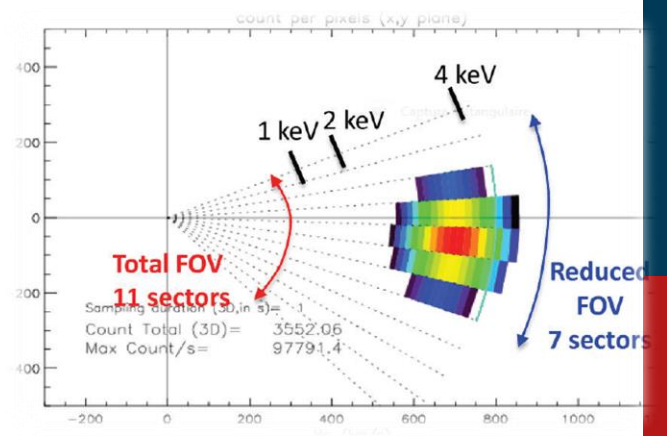
The moment of order zero is called **number density** and it is defined as:

$$n = \int f(\boldsymbol{v}) d\boldsymbol{v}$$

The first order moment is called **number flux density vector**:

$$n\boldsymbol{V} = \int \boldsymbol{v} f(\boldsymbol{v}) d\boldsymbol{v}$$

-> from which one can compute the ***flux velocity*** by dividing for *n*.



The second order moment is the **moment flux density tensor**:

$$\boldsymbol{\Pi} = m \int \boldsymbol{v}\boldsymbol{v} f(\boldsymbol{v}) d\boldsymbol{v}$$

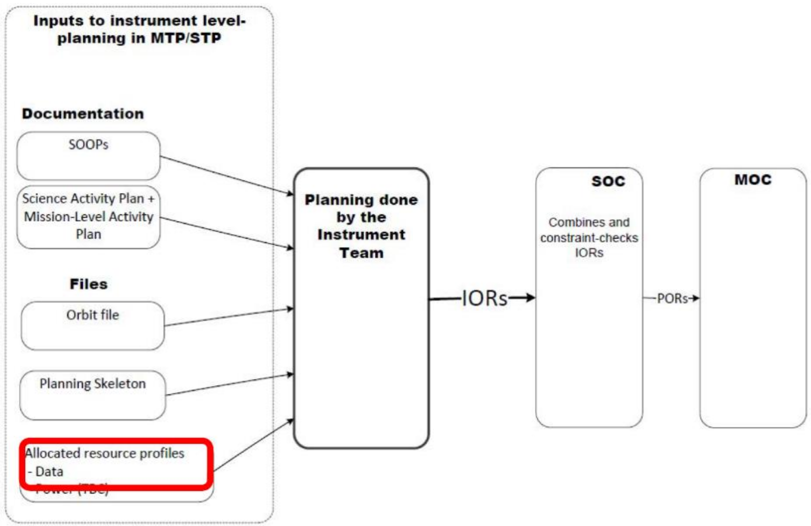
-> from which one can compute the ***temperature***

Finally, the third order moment is the **energy flux density vector**:

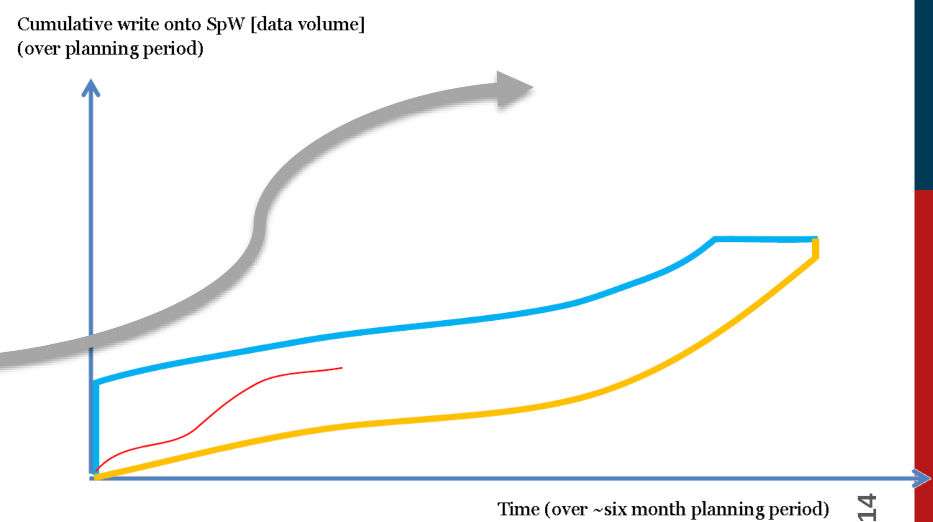
$$\boldsymbol{Q} = \frac{m}{2} \int v^2 \boldsymbol{v} f(\boldsymbol{v}) d\boldsymbol{v}$$

Operations Telemetry Corridor (OTC)

An input to instrument planning at ***medium-/short-term*** planning cycles.

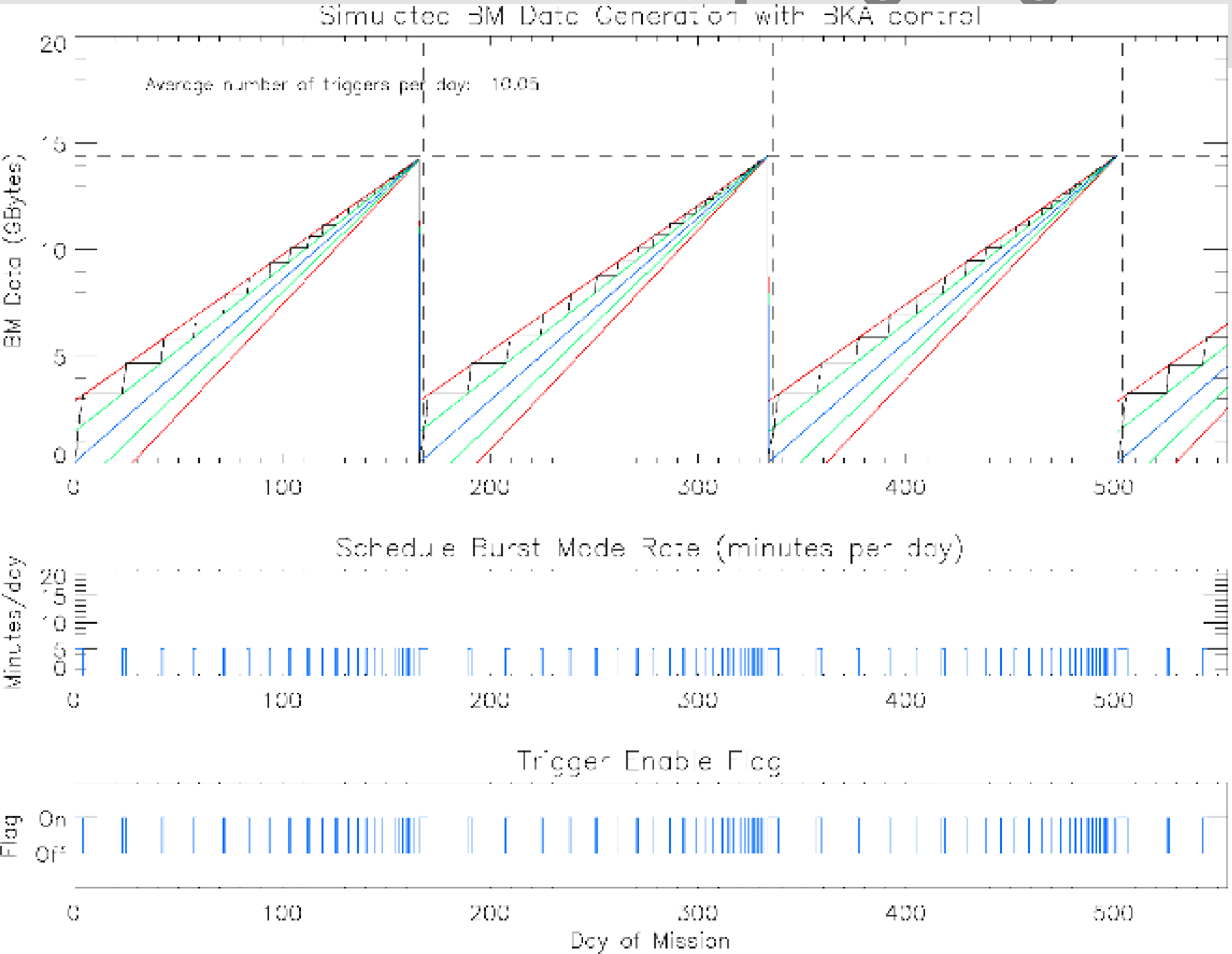


It is a type of ***resource profile for planning*** since it indicates to the instrument teams the ***allowable rates, as a function of the mission timeline***, at which they can send science data to the spacecraft's SSMM via SpaceWire



(*) Image Credits: ESAC

SWA Book-Keeping Algorithm



To impose data collection and/or mode use and telemetry generation restrictions on each of the 3 SWA sensors separately in order to keep each of them within the respective allocations rate.

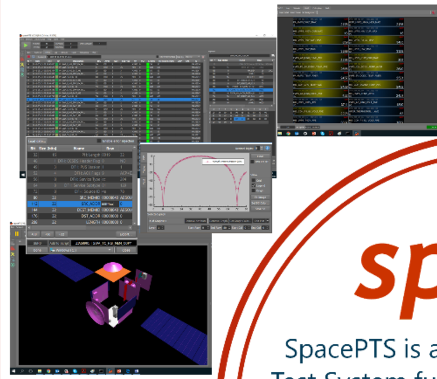
(*) Image Credits: MSSL

From EGSE SW to* Continuous *Integration in Space

***SpacePTS* Payload Test System**

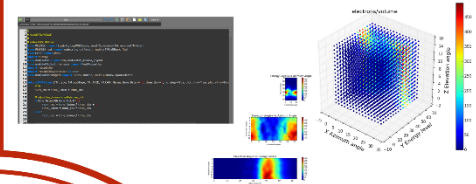
The User Interface

- Modern Qt based UI
- Fully dockable widgets
- Multimonitor
- Customizable application layout.



Data Analysis

- Python based data analysis scripts
- Data processing and visualization with spacepy, numpy, scipy, matplotlib.

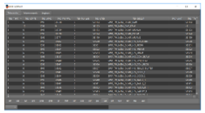


spacePTS

SpacePTS is a Payload Test System fully implementing EGSE business logic for on-board sensors, designed and developed with a special attention to data analysis and scientific users' needs. Its functionalities also fit to Ground Segment operations.

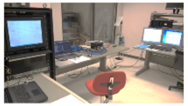
I/O Databases

- SCOS2000 MIB compliant
- Postgres, SQLite, MySQL drivers availability.



Features

- TM/TC real-time traffic monitoring
- Archived data browsing
- Session statistics
- HK parameters monitoring
- SCOS2000 IDB explorer
- Data export for off-line analysis
- Python based scripting for automation
- Assisted TC editing
- Source data protocol selection (Serial, SpW, C&C, EDEN, CFDP, etc.)
- Full packet inspection (bytewise/bitwise included)
- Plug-in based architecture
- HW devices control

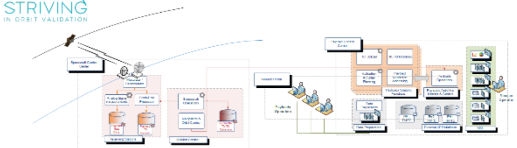


Application

- Payload Development Kit for Solar Orbiter Solar Wind Analyzer (SWA)
- Scientific Ground Segment SW for SWA
- Payload Development Kit for STRIVING IoD/IoV
- Payload Control Center SW for STRIVING IoD/IoV

solar orbiter

STRIVING IN ORBIT VALIDATION



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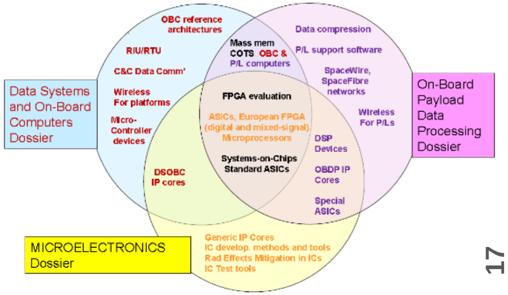
Conclusions

1. The increased level of ***autonomous scientific data assessment*** presents a possible solution to classical issues like bandwidth limitations, which can be conflated into the problem of data modeling

2. Onboard science data analysis will improve the capabilities of existing sensors and enable ***transformative new operational modes*** to address novel science issues thus relieving constraints on time, bandwidth and power, and by ***responding automatically to events on short time scales***

3. Unprecedented opportunities to ***downstream*** data from Space to Earth

4. The technologies/methods designed for the SWA's on-board science data processing chain, in line with the ***ESA OBPDP roadmap***



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