BepiColombo science operations modelling analysis

Liaison Scientist Team
ESAC
14/11/2011

Presentation content

1. Introduction and objectives
2. Science Operations Analysis for each experiment
3. Summary

Science Activity Plan (SAP) development
- and why this SOWG is so important…

The SAP is a document describing:

- the top-level science operations
- that all the science objectives are covered
- that operations can be performed within the (nominal) S/C resources
- experiment operations (timelines) based on current Science Operations Analysis

This SAP documents achievable science return with the current Spacecraft design.

It is going to be presented by the Project Scientist at the upcoming Spacecraft CDR

This SOWG supports and supervises the preparing and agrees on the Experiment operations timelines (and resulting data-volumes) which will be described in the SAP

Baseline Mission inputs to operations analysis on data-volume

- **Data is dumped using one Ground Station which is Cebreros which is used for a maximum of 10 hours per day**

- **Yearly data-volume return against which the spacecraft is designed: 1550 Gbit**

Important note:

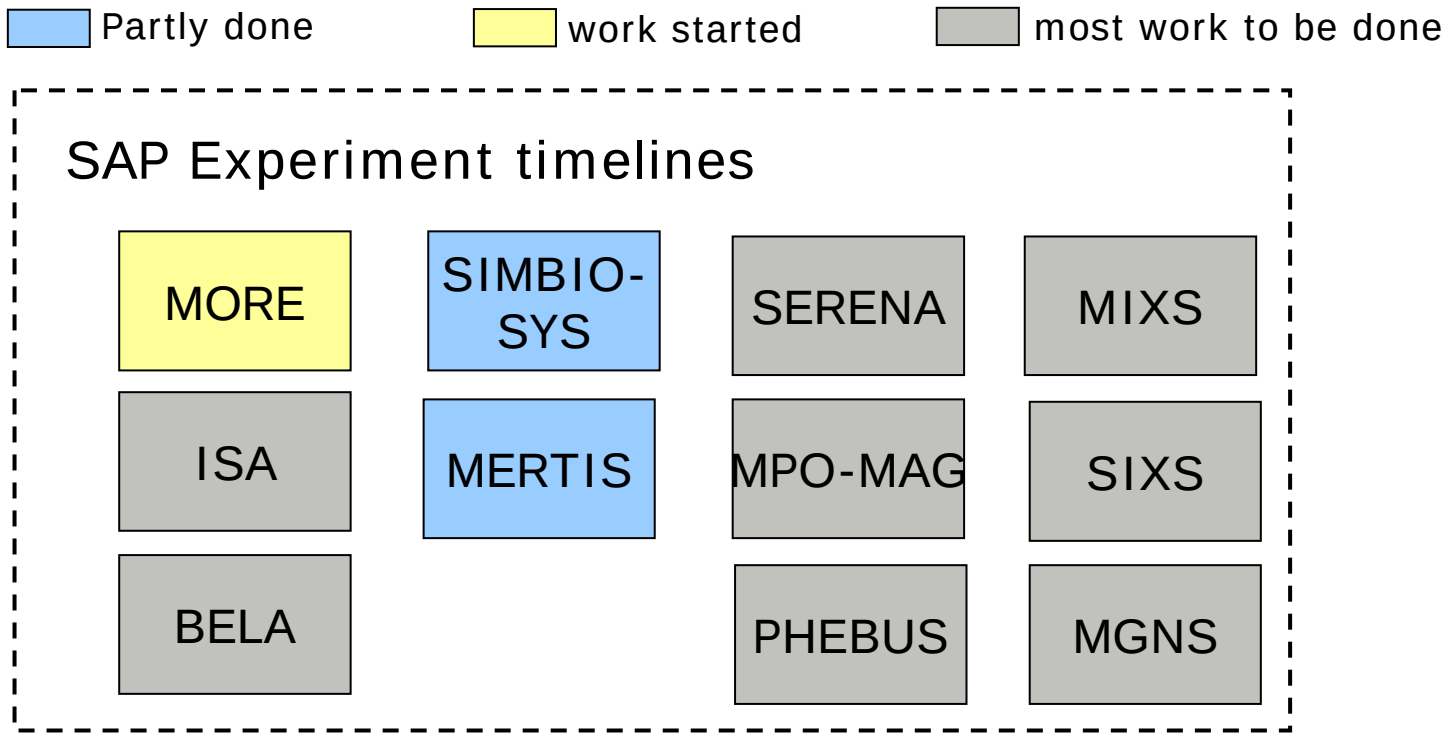
- Reports from Astrium concerning the data-volume return indicate that the requirement of 1550 Gbit is currently not met.

Objectives for this SOWG (November 2011)

The main objectives of the November 2011 SOWG:

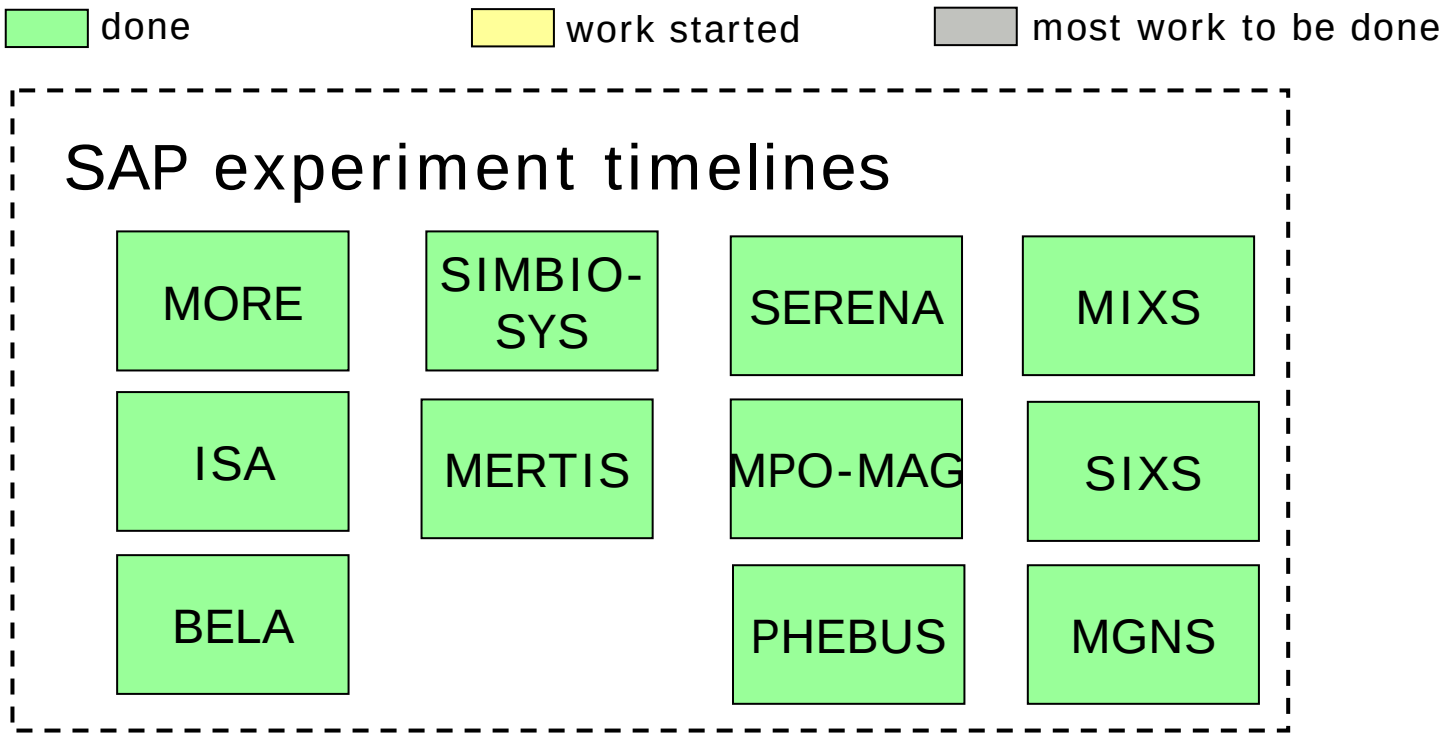
Create a timeline for the experiment operations of the complete mission with a resulting data-volume request, which is supported by all the PI teams.

SAP experiment timelines development status – after last SOWG (spring 2011)



SAP experiment timelines development status – today!

First step of SAP input finished: un-restricted timelines agreed

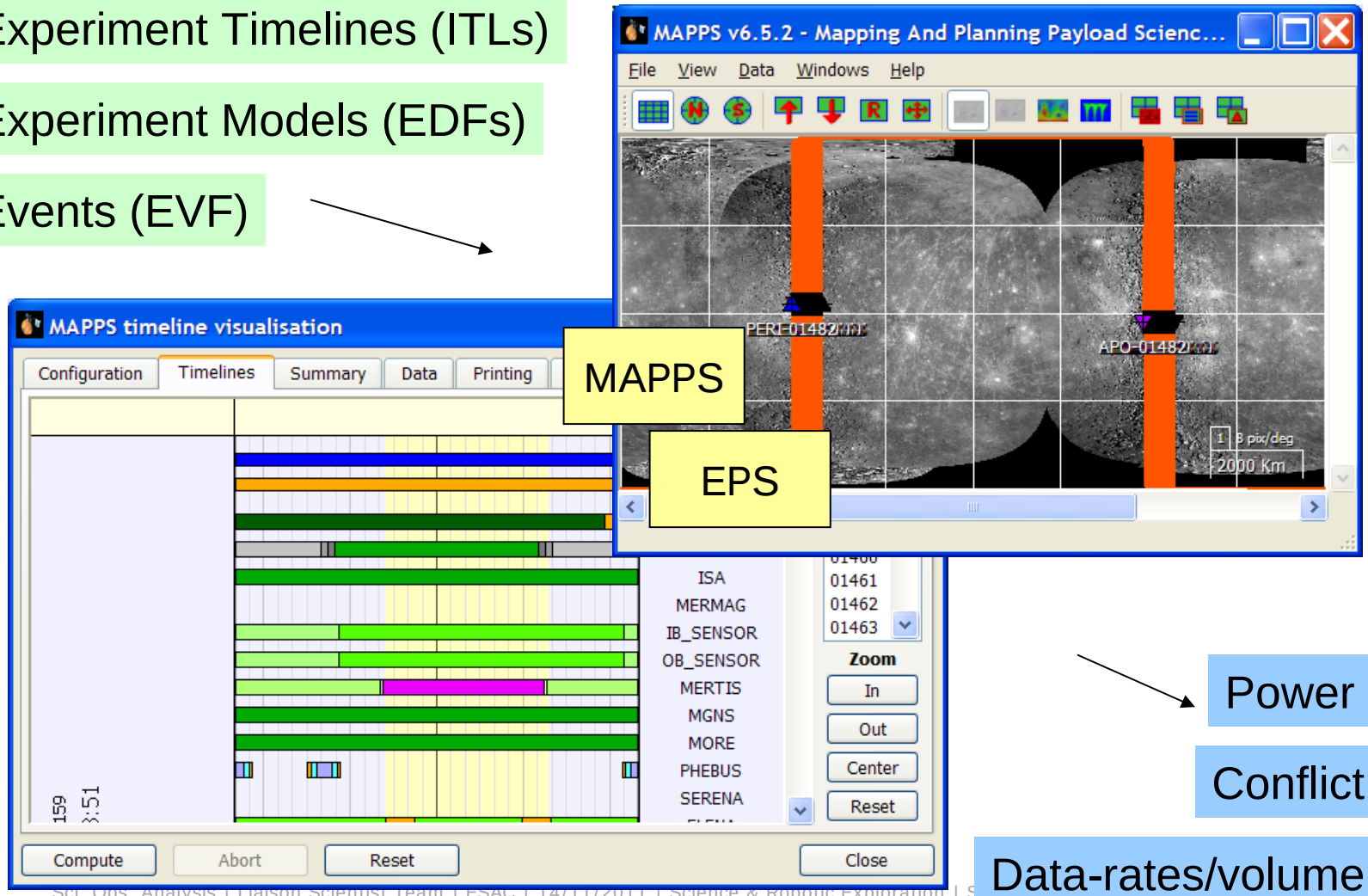


Science Operations Analysis tools?

Experiment Timelines (ITLs)

Experiment Models (EDFs)

Events (EVF)



Power results

Conflict results

Data-rates/volume results

What will be presented?

Per experiment

- overview operations used for this study
- data-rate for complete mission (unrestricted timeline)
- data-rate for complete mission
  (restricted timeline – power limitation at perihelion during GS contact)
- total data-volume requests

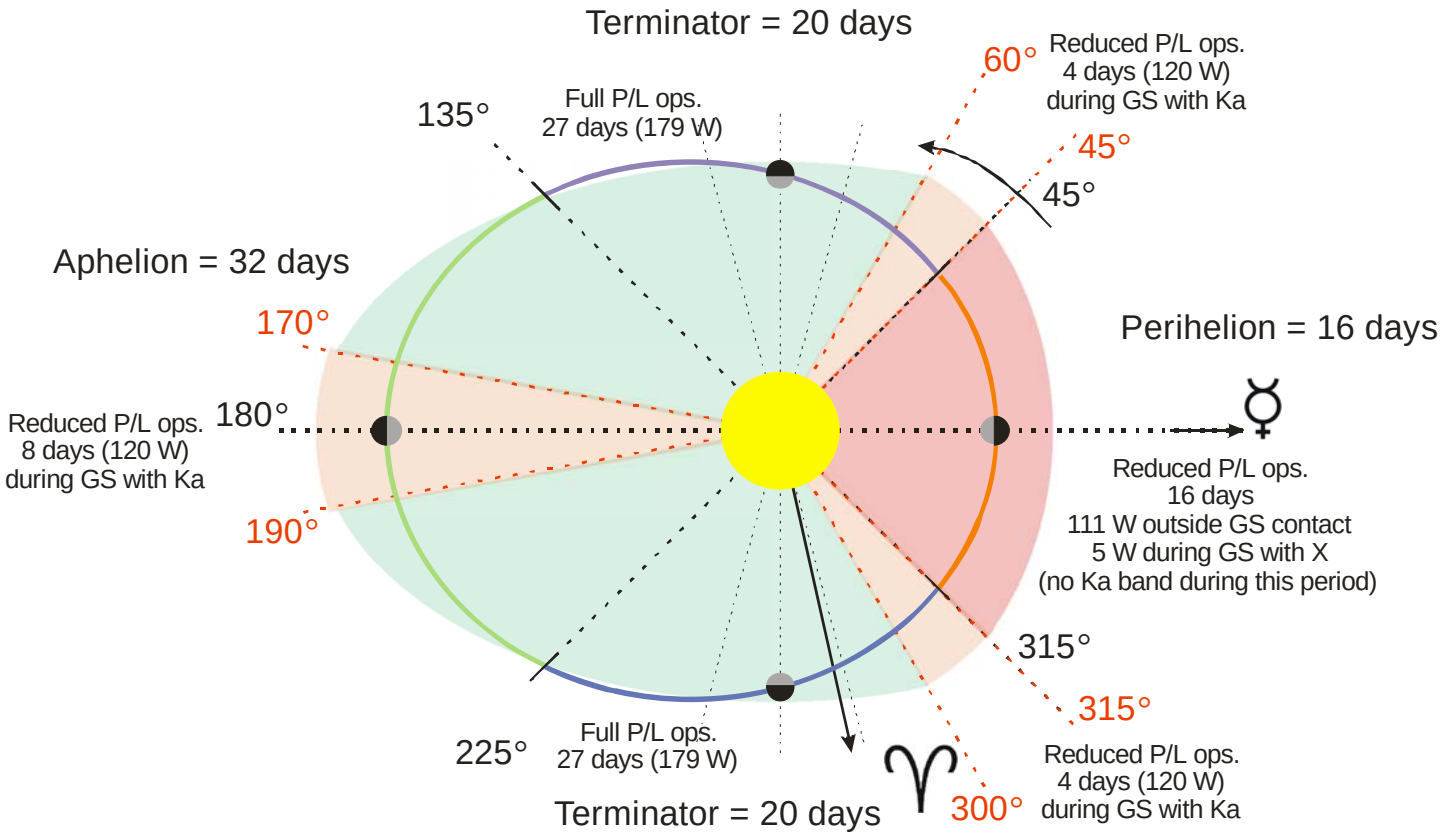
For all experiments

- total data-rate (for all experiments) for nominal mission
- total data-volume request (should be below 1550 Gbit)
- SSMM fill state and overflows for nominal mission

Power restriction explanation
- will be discussed in more detail tomorrow -

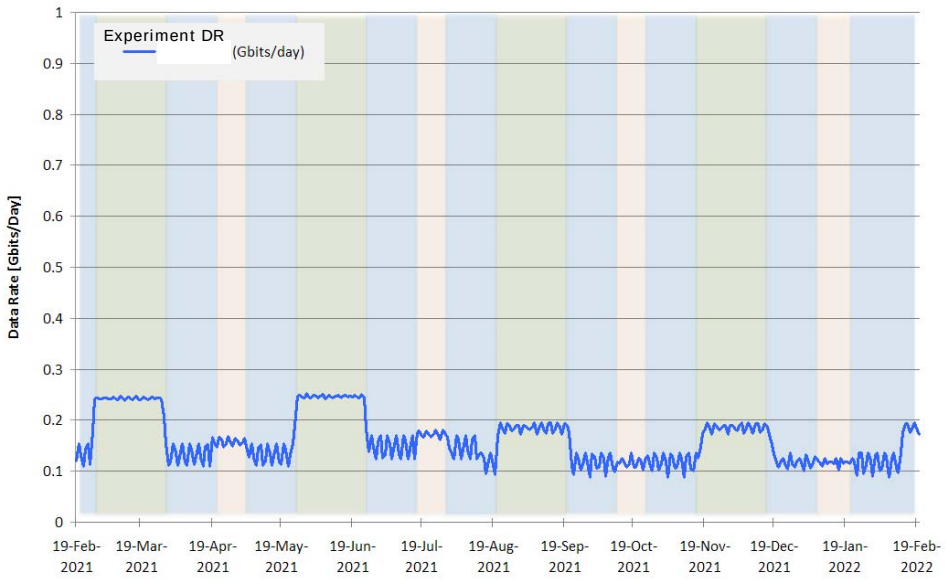
The assumption is that all instruments remain switched off during Cebreros G/S contact at perihelion phase, which lasts ~ 16 days.

The contact times vary in length between ~ 10 h and ~8 h.



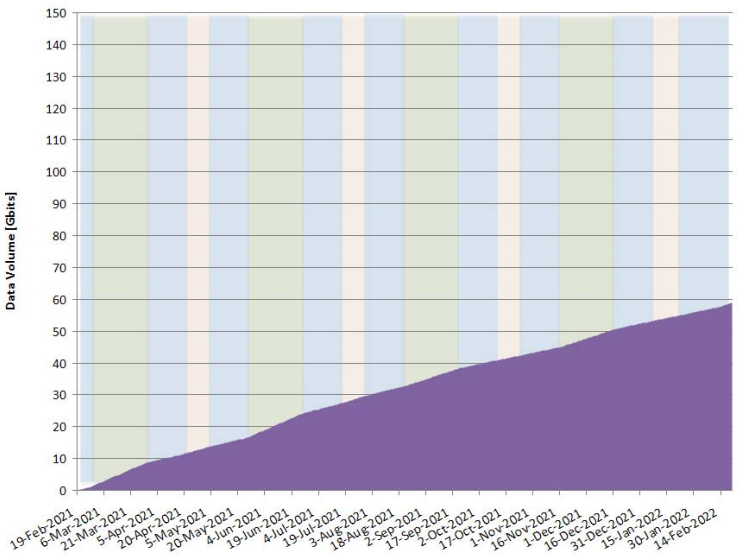
Expected result from timelines for experiments data-rates and total data-volume

<experiment> data rate



Total data-rate request is:
"XX" Gbits/day at aphelion
"YY" Gbits/day at perihelion

<experiment> cumulative data volume



Total data-volume request for mission is:
"ZZ" Gbits

Order of analysis results of experiments

1. MIXS
2. SIXS
3. MGNS
4. PHEBUS
5. MPO-MAG
6. SERENA
7. MERTIS
8. SIMBIO-SYS
9. BELA
10. ISA
11. MORE

MIXS

MIXS science operations analysis input

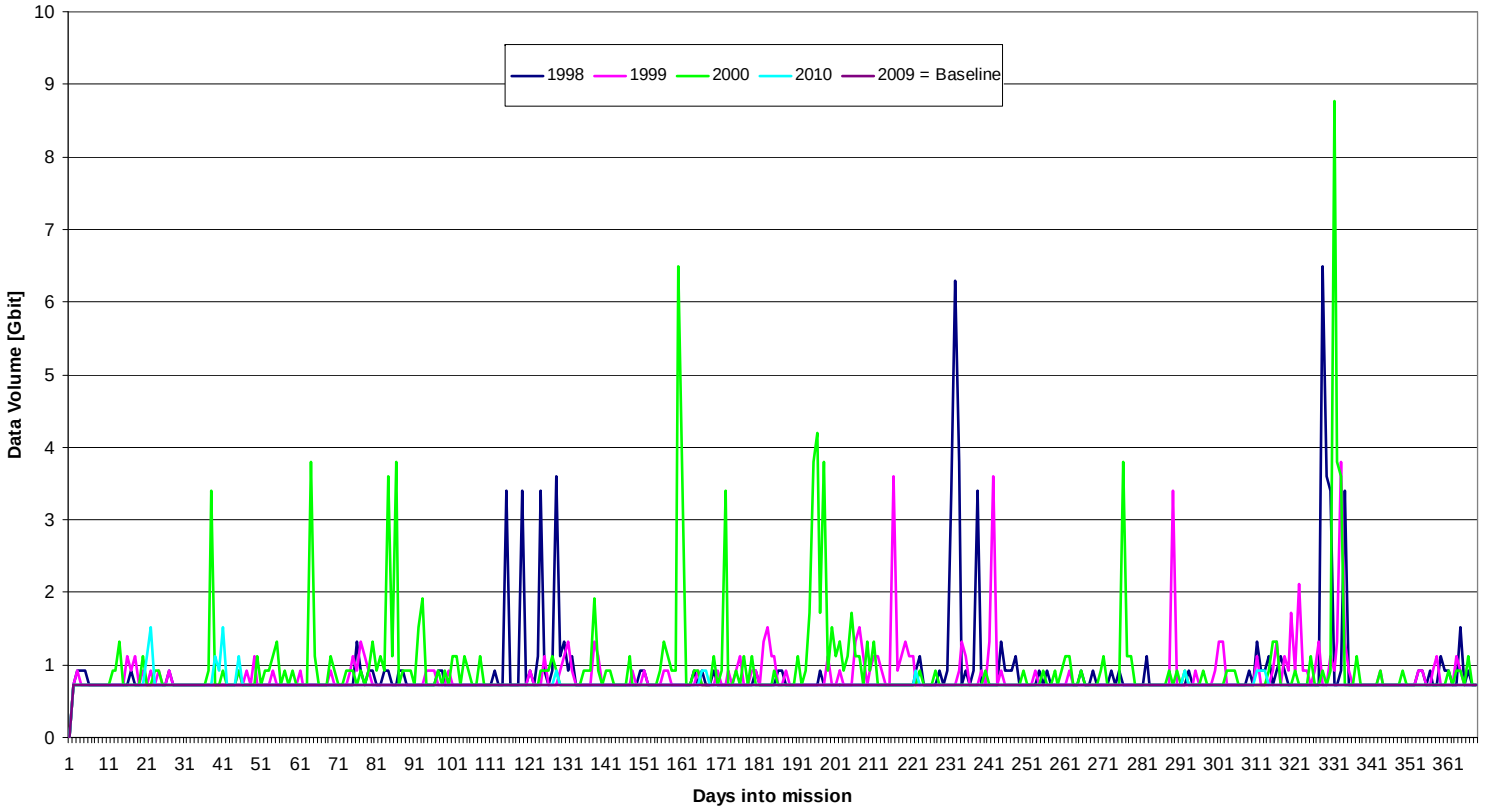
1. Input and analysis assumptions for MIXS:
    a. MIXS inputs from
        - EID-B (draft 4, 16 Jul. 2010)
        - BC-MIX-TN-126 (Data Rates and Science Operations for MIXS)
    b. Updated sensitivity and orbit-averaged data rates
    c. MIXS-T data rate increases during solar flares(~proportional to flare energy)
    d. Statistical study performed with historical data for periods representative of prime mission. Years: 1998, 1999, 2009 (no flares = baseline), 2010
    e. High flare activity during year 2000 used as upper constraint

    => The 1999 dataset is close to the statistical median value and in the following used as a case study.

MIXS data rate

Solar flares are reflected directly in the MIXS data rate, leading to a large statistic variability.

=> All presented values are to be understood with at least ±10% uncertainty!



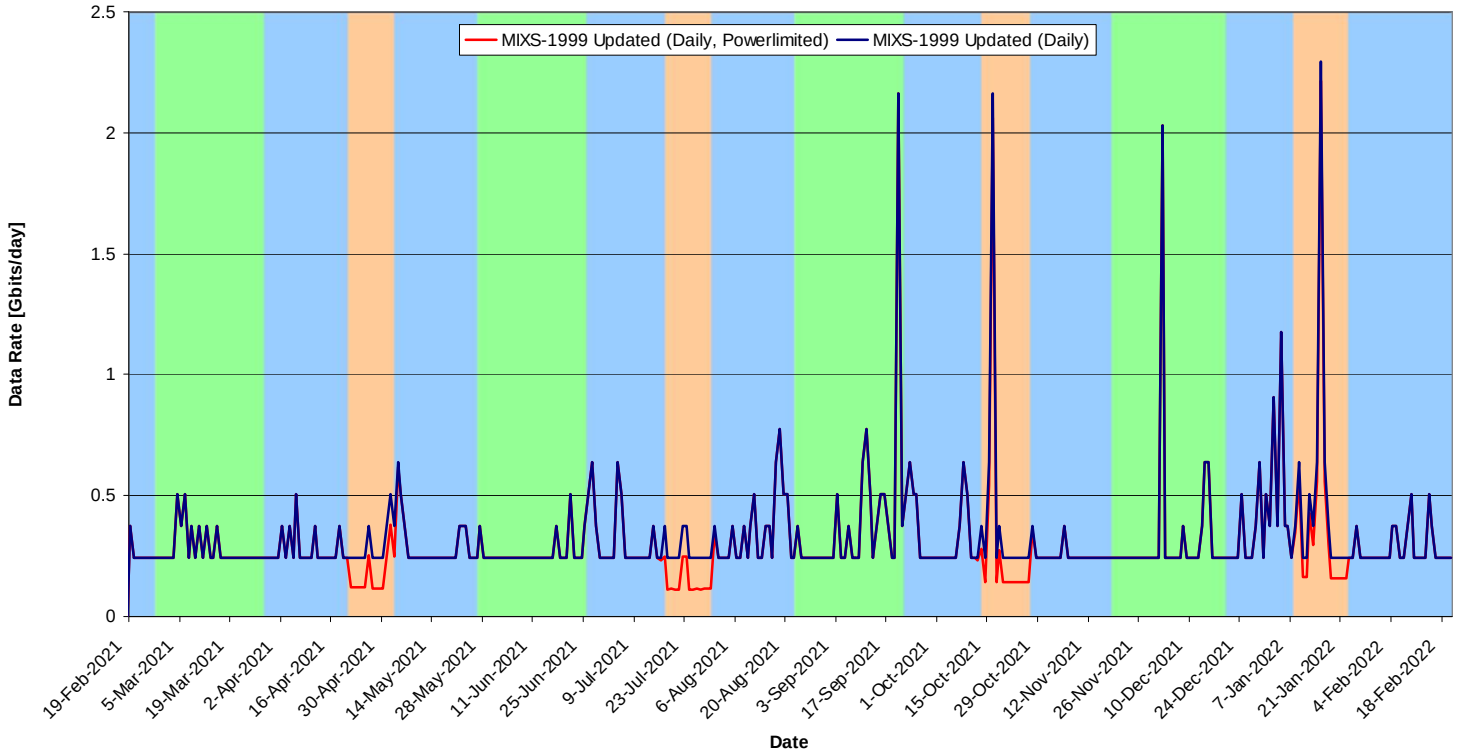
Simulations based different sets of historic flare occurrences (Data volumes not orbit averaged)

MIXS data rate

Baseline (averaged) data rate of MIXS, excluding flares:

a) **without** any restrictions: ~0.2 Gbit/day

b) **with** restrictions: ~0.1 Gbit/day @perihelion



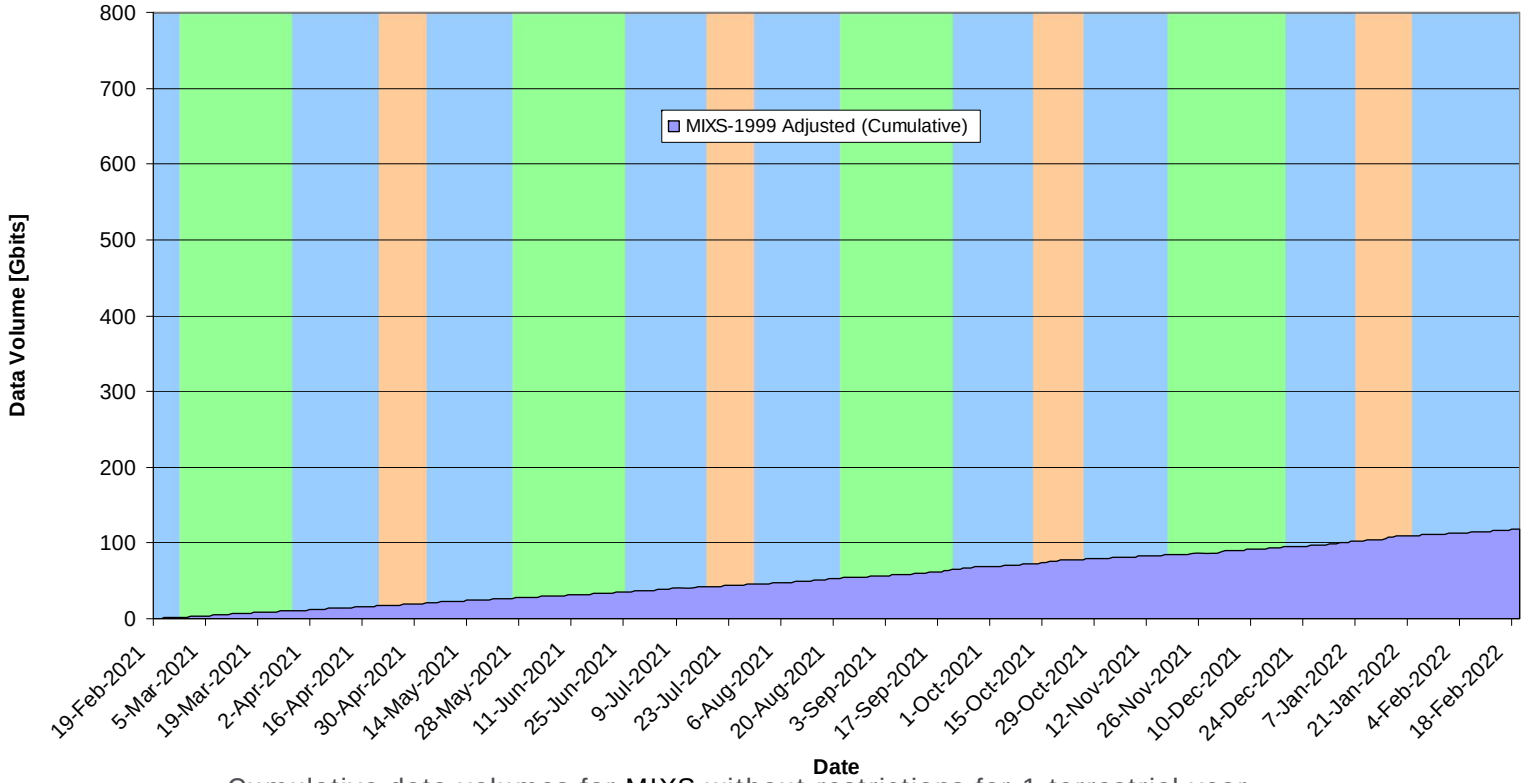
Data rates for MIXS for one terrestrial year, including simulated 1999 flare contributions

MIXS cumulative data volume

Cumulative data volume of MIXS for the 1999 solar data based simulation

a) **without** any restrictions 118 Gbit (~160 Gbit including 33% margin for statistics).

b) **with** restrictions at perihelion (off @ GS contact) 112 Gbit (~150 Gbit /w margin) .



Cumulative data volumes for MIXS without restrictions for 1 terrestrial year.

SIXS

SIXS science operations analysis input

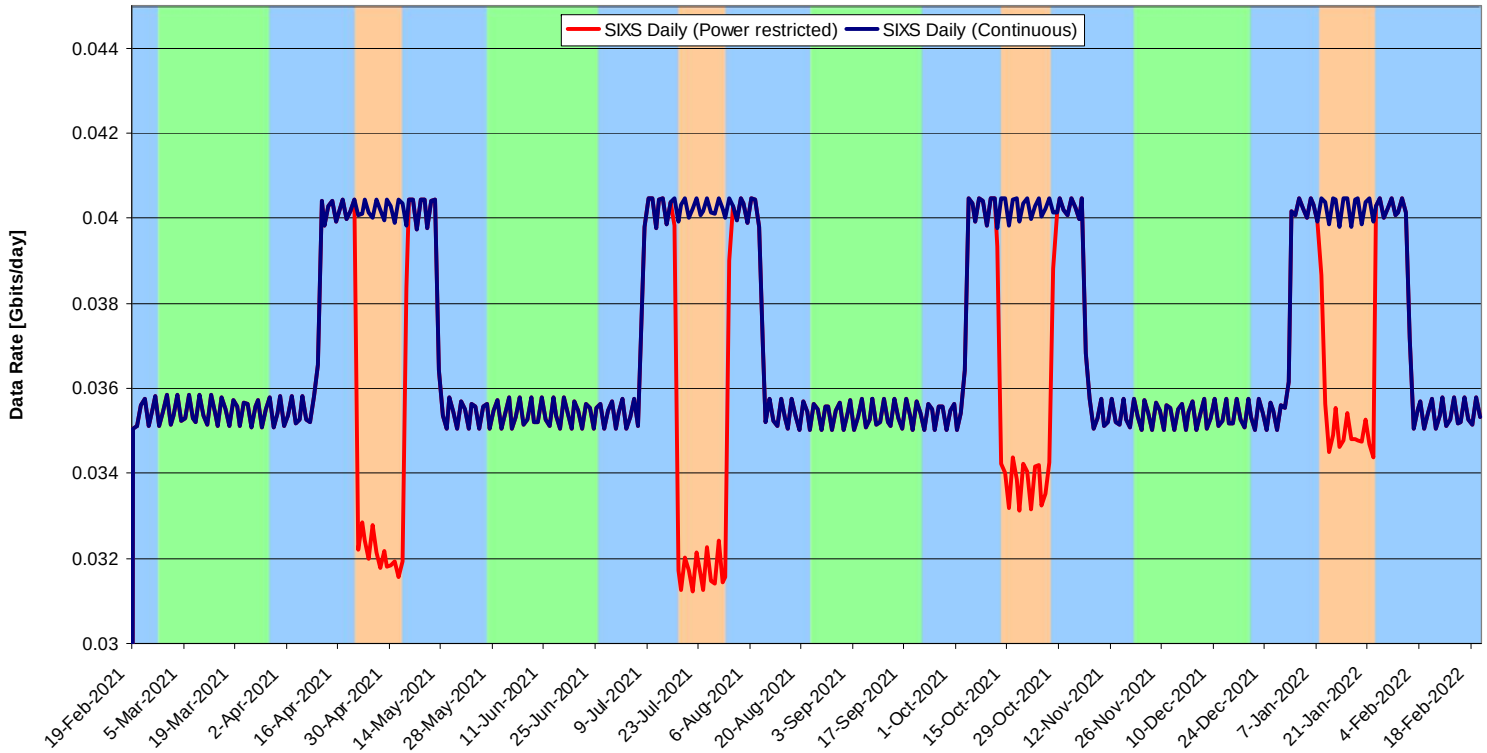
1. Input and analysis assumptions for SIXS:
    a. SIXS inputs from
        - EID-B (Issue 1 Rev. 0, 26 March 2010)
        - BC-SGS-TN-021 (IPOD)
    b. SIXS is requesting to observe whenever possible with the SIXS-P unit and with SIXS-X on the illuminated parts of each orbit.
    c. At start-up and shut down, as well as after major flare events SIXS-X will perform a short (6 min) calibration routine (included in normal operations mode). SIXS-X will perform regular annealing of each sensor, approximately ½ Orbit per sensor per hermean year during periods of good power availability (e.g. terminator orbits). SIXS-P will perform a few minutes calibration every TBD months.

SIXS data rate

Data rate of SIXS:

a) **without** any restrictions: 0.035 – 0.04 Gbit/day

b) **with** restrictions: 0.032 – 0.035 Gbit/day @perihelion



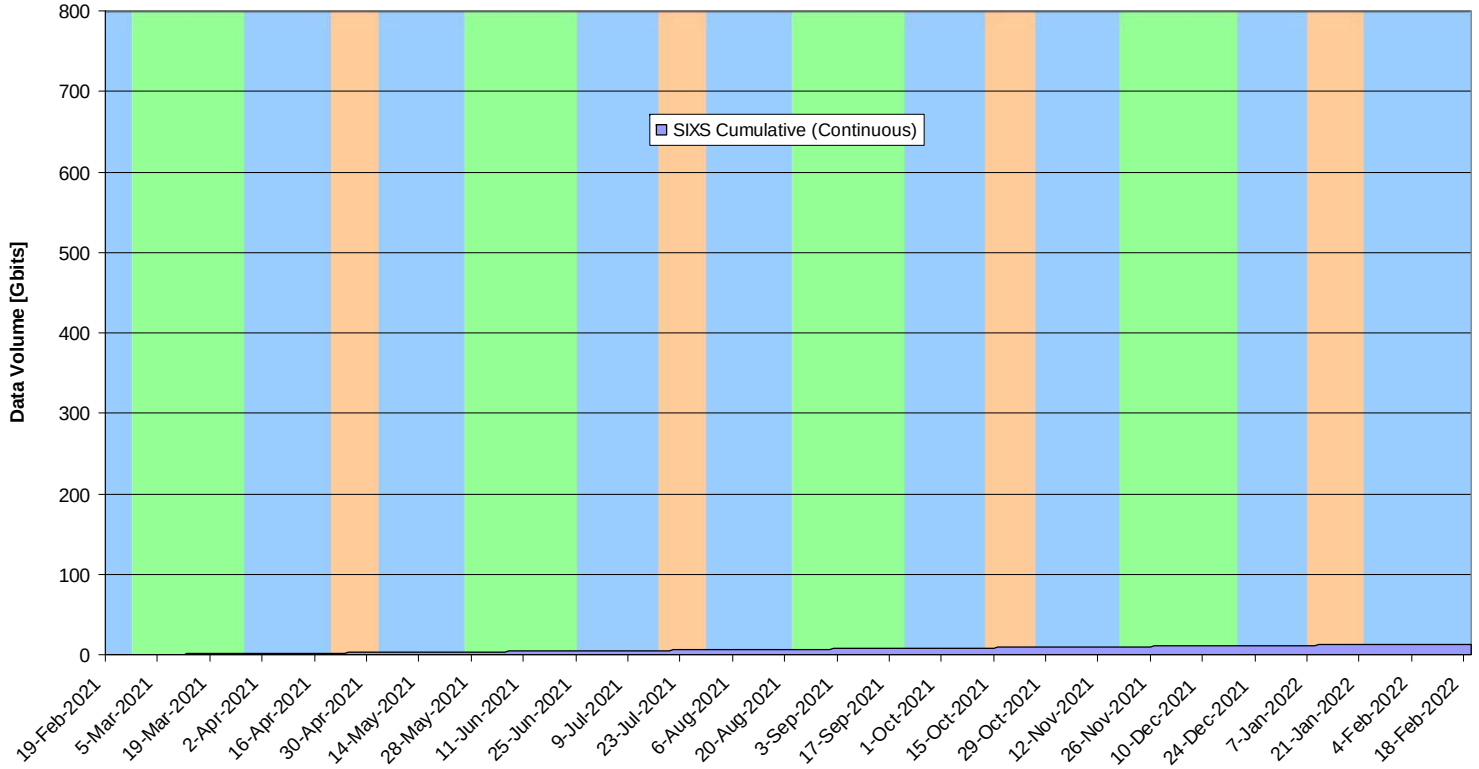
Data rate for SIXS for one terrestrial year – with and without restrictions.

SIXS cumulative data volume

Cumulative data volume of SIXS for the whole mission:

a) **without** any restrictions 13.7 Gbit.

b) **with** restrictions at perihelion (off @ GS contact) ~13.2 Gbit.



Cumulative data volume for SIXS without restrictions for 1 terrestrial year.

MGNS

MGNS science operations analysis input

1. Input and analysis assumptions for MGNS:
    a. MGNS inputs from
        - EID-B (Issue 1, Revision 2, upcoming)
        - MGNS Scientific and Technical Plan
        - Science Performance Report for MGNS

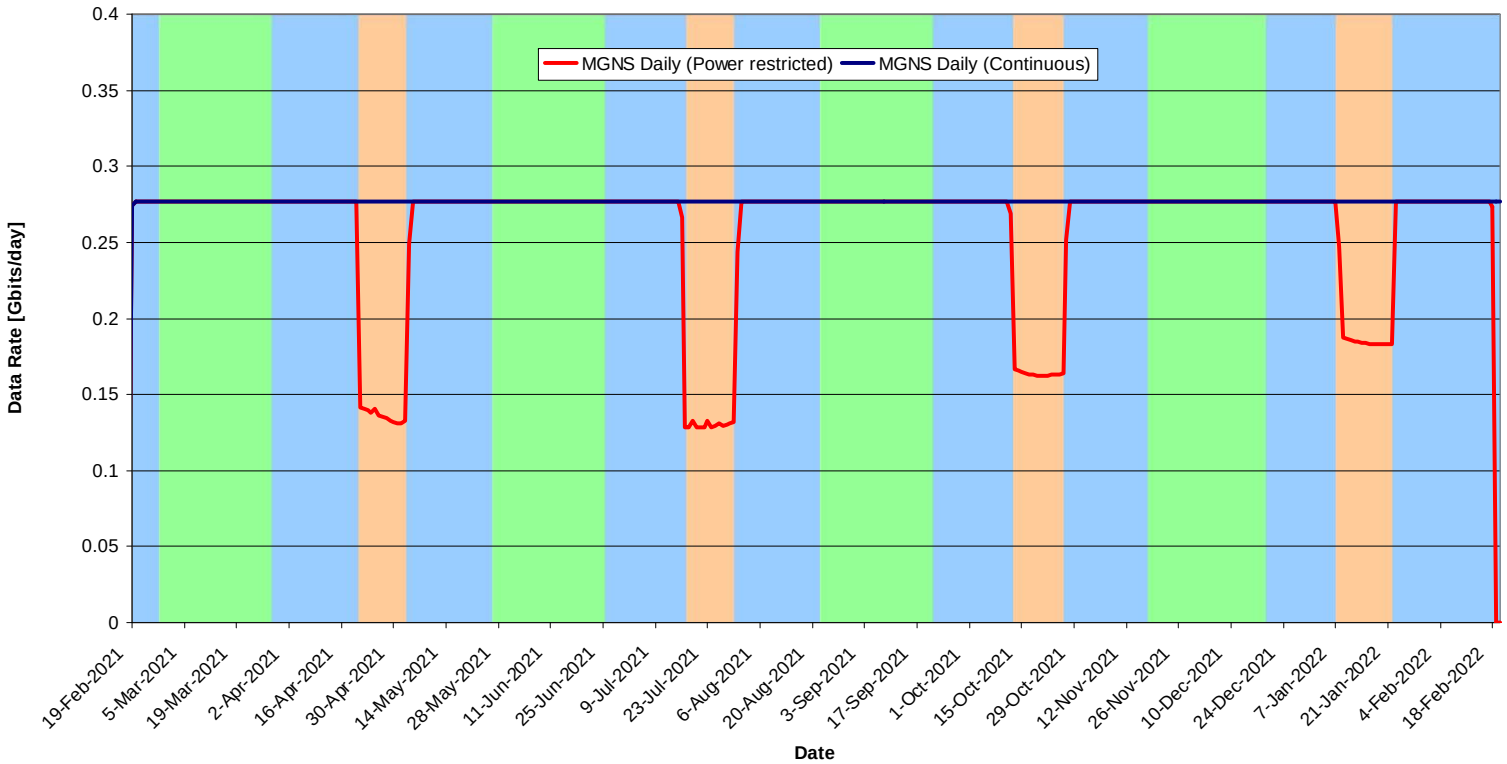
    b. MGNS has requested to operate continuously in full science mode whenever possible and with increased readout frequency during high flux events, such as solar flares.
    c. The instrument can be operated in partial science modes (Neutron or Gamma-ray) at a lower power consumption if required

MGNS data rate

Data rate of MGNS:

a) **without** any restrictions: 0.27 Gbit/day

b) **with** restrictions: 0.13 – 0.27 Gbit/day @perihelion



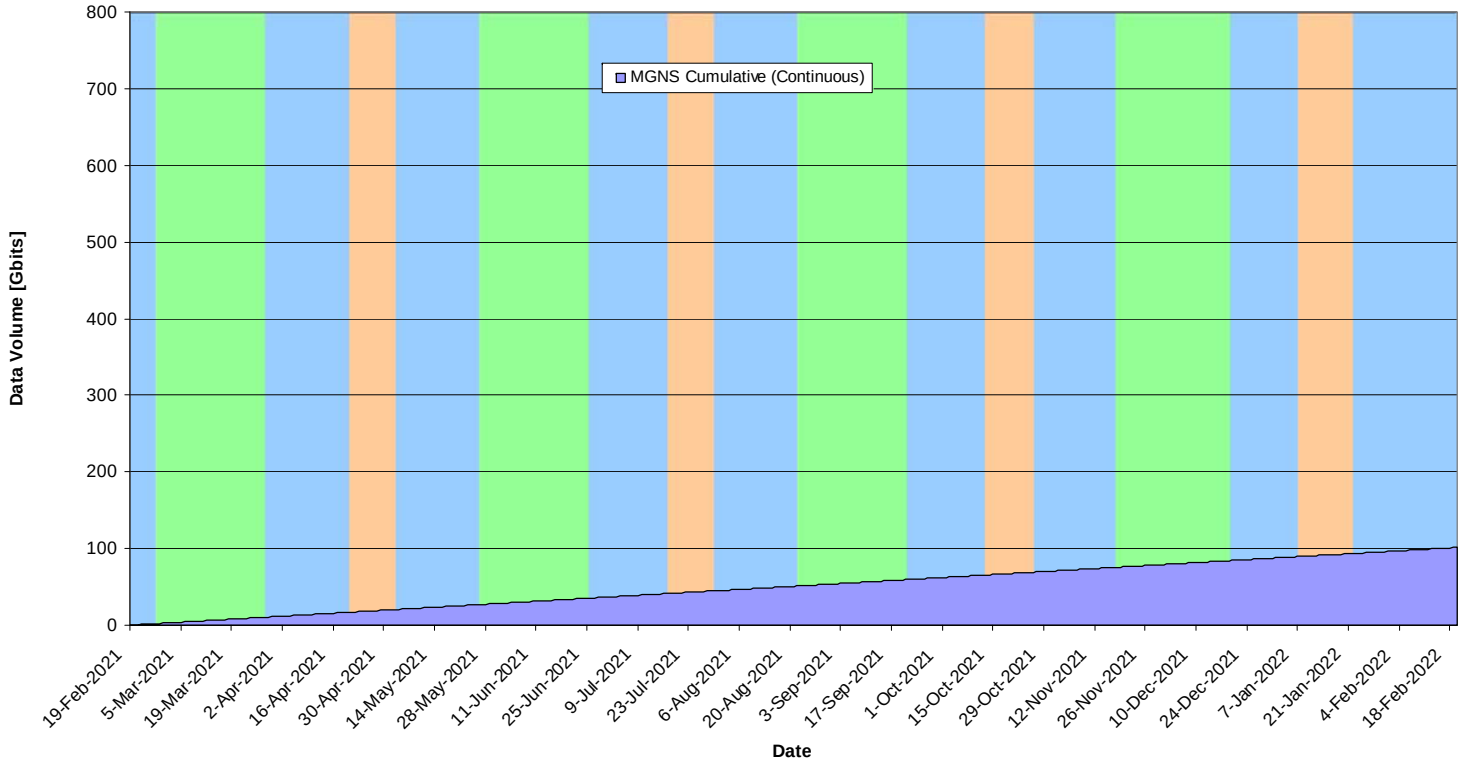
Data rate for MGNS for one terrestrial year – with and without restrictions.

MGNS cumulative data volume

Cumulative data volume of MGNS for the whole mission:

a) **without** any restrictions 101.5 Gbit.

b) **with** restrictions at perihelion (off @ GS contact) 94.1 – 101.5 Gbit.



Cumulative data volume for MGNS without restrictions for 1 terrestrial year.

PHEBUS

PHEBUS science operations analysis input

1. Inputs for PHEBUS:
    - BC-EST-RS-02513, PHEBUS EID-B, Draft 3, 19 February 2009
    - BC-PHE-TN-00002-01-00.pdf (IPDR DP/II_Technical_Package/Flight Operations)
    - BC-SGS-TN-013_D_3_PHEBUS-IPOD_2010June11.doc
    - Telecon with HRM, Angela Dietz and PHEBUS team, 20100720
    - Email from Eric Quémerais to Helen Middleton, 20111006
    - BC-SGS-MN-0149_1_0_MoM_PH_SOMA_WebEx_2011Oct10
2. Operational Modes
    a. NADIR mode every 10 orbits for 5 min after dayside end OR before dayside start.
    b. STAR calibration mode every 10 orbits for 5 min either in the centre of the eclipse OR at apoherm if no eclipse.
    c. TWILIGHT mode every orbit for 5 min after start AND before end of eclipse.

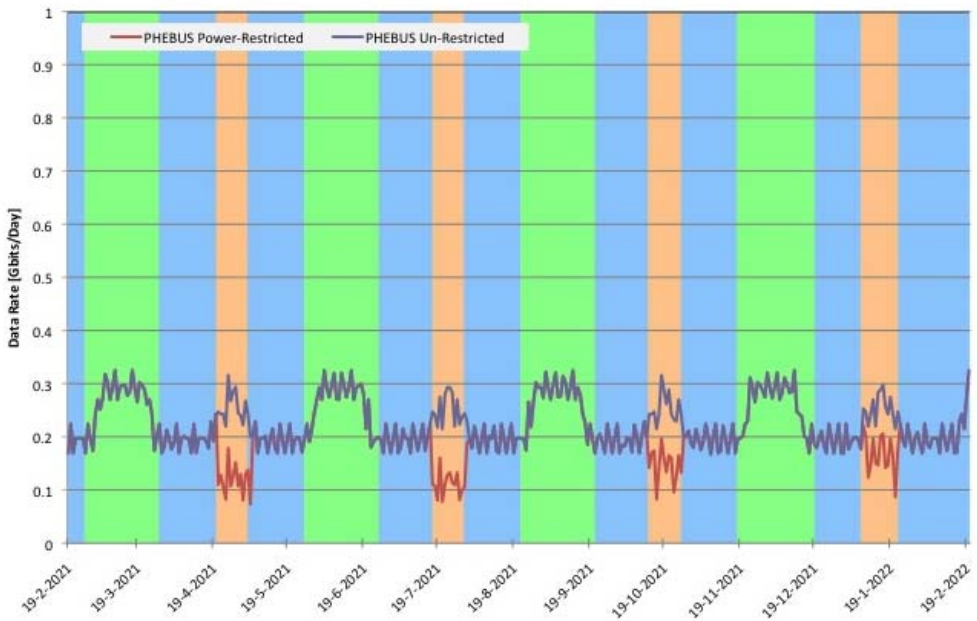
PHEBUS science operations analysis input

2. Cont.
    d. VERTSCAN mode every 3 orbits for 30 min either after start OR before end of dayside.
    e. FIXED_LOS mode every 6 orbits for 30 min after dayside end OR before dayside start.
    f. FEATURE_TRAC mode every 6 orbits for 30 min after dayside end OR before dayside start.
    g. OFF is applied when there are more than 10 min between operations.
3. Assumptions
    a. The science modes produce 16384 b/s from 3 lines of 1024 pixels in 32 bits with a possible compression factor of 3.
    b. The power applied to each mode is that from the EM and so the real numbers are TBC.

PHEBUS data rate

Data rate of PHEBUS:

a. **without** any restrictions (blue) over the whole mission.
b. **with** restrictions (red) over the whole mission



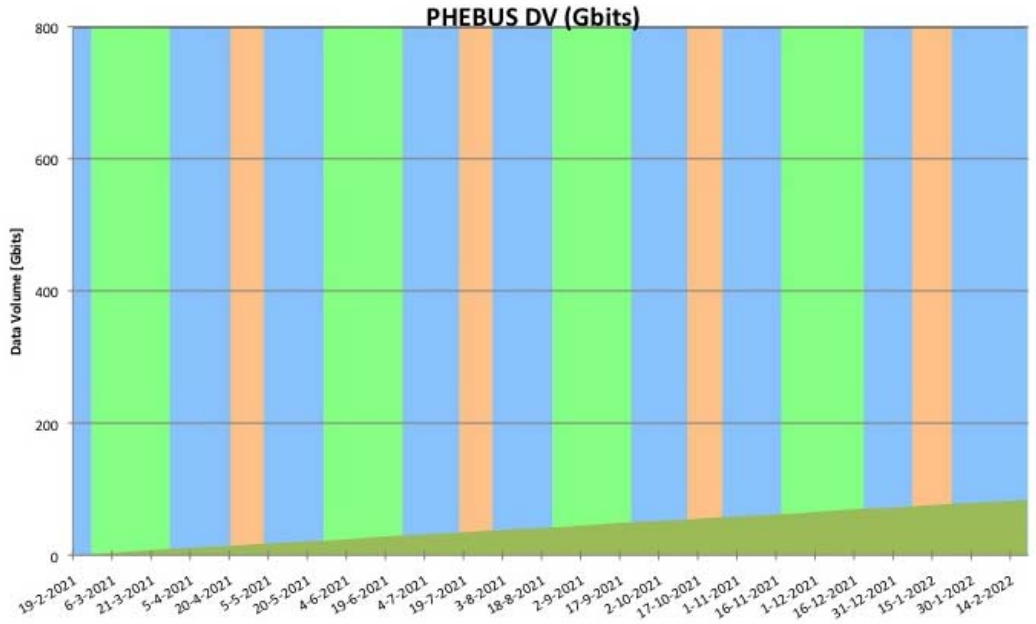
Data rate for PHEBUS for one terrestrial year – with and without restrictions.

PHEBUS cumulative data volume

Cumulative data volume of PHEBUS for the whole mission:

a. **without** any restrictions: 83.6 Gbit/year

b. **with** restrictions at perihelion (off @GS contact) amounts to 76.8 Gbit/year



Cumulative data volume for PHEBUS without restrictions for 1 terrestrial year.

MPO-MAG

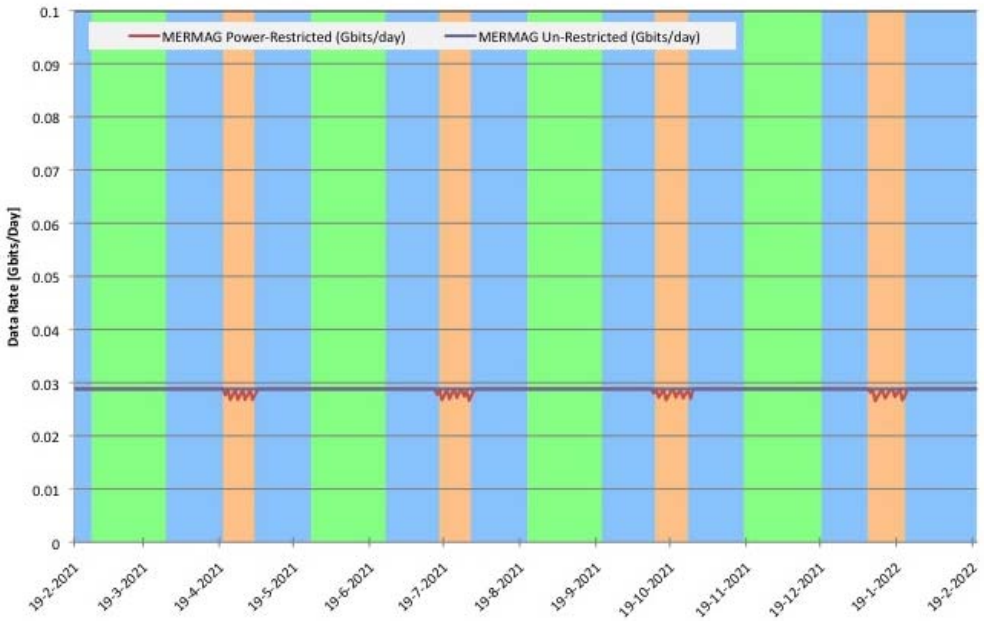
MPO-MAG science operations analysis input

1. Inputs for MPO-MAG:
    - BC-MAG-UM-00002_Instrument-User-Manual_I1R2, 20110509
    - BC-SGS-TN-008_D_2_MPOMAG_IPOD_2010Jun13
    - BC-MAG-RP-00002 Flight Operations Description Report, Issue 1, Rev. 1, 20110509
2. Operational Modes
    a. Used a non-existent but representative mode: this mode divided the typical orbit data production by the two sensors and the number of seconds in an orbit to produce a representative data rate.
3. Assumptions
    a. Heaters are activated inside eclipses
    b. No compression has been applied yet.
    c. Selective downlink will be modelled asap.

MPO-MAG data rate

Data rate of MPO-MAG:

a. **without** any restrictions (blue), 3Mbit/orbit over the whole mission.
b. **with** restrictions (red) over the whole mission



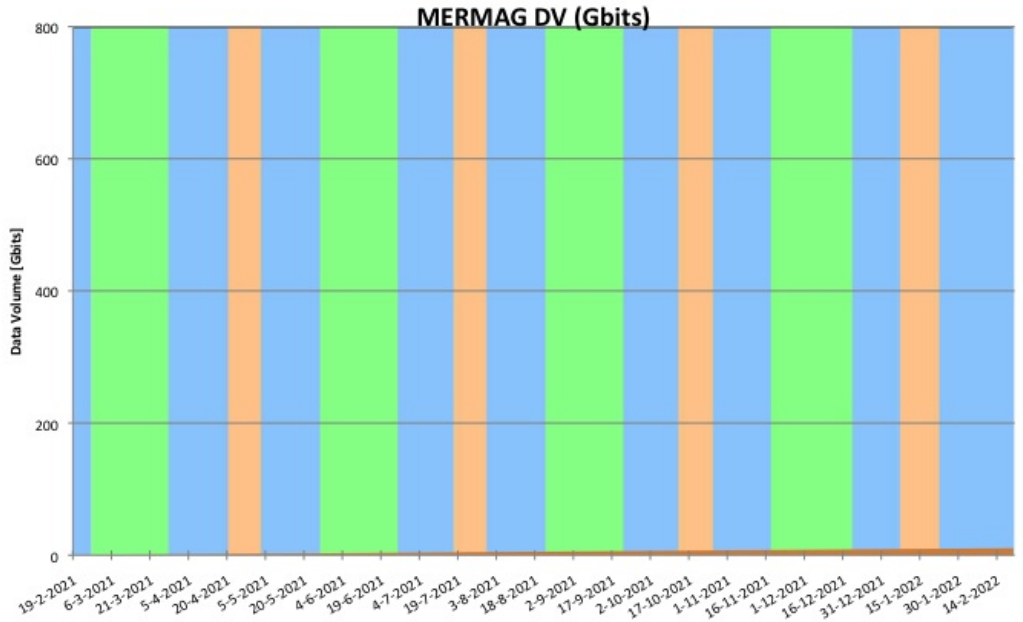
Data rate for MPO-MAG for one terrestrial year – with and without restrictions.

MPO-MAG cumulative data volume

Cumulative data volume of MPO-MAG for the whole mission:

a. **without** any restrictions: 10.57 Gbit/year

b. **with** restrictions at perihelion (off @GS contact) amounts to 10.51 Gbit/year



Cumulative data volume for MPO-MAG without restrictions for 1 terrestrial year.

SERENA

SERENA science operations analysis input

1. Inputs for SERENA:
   - SERENA EID-B
   - Science Operations meeting on 28-29 September 2011 at IFSI
2. Operational modes

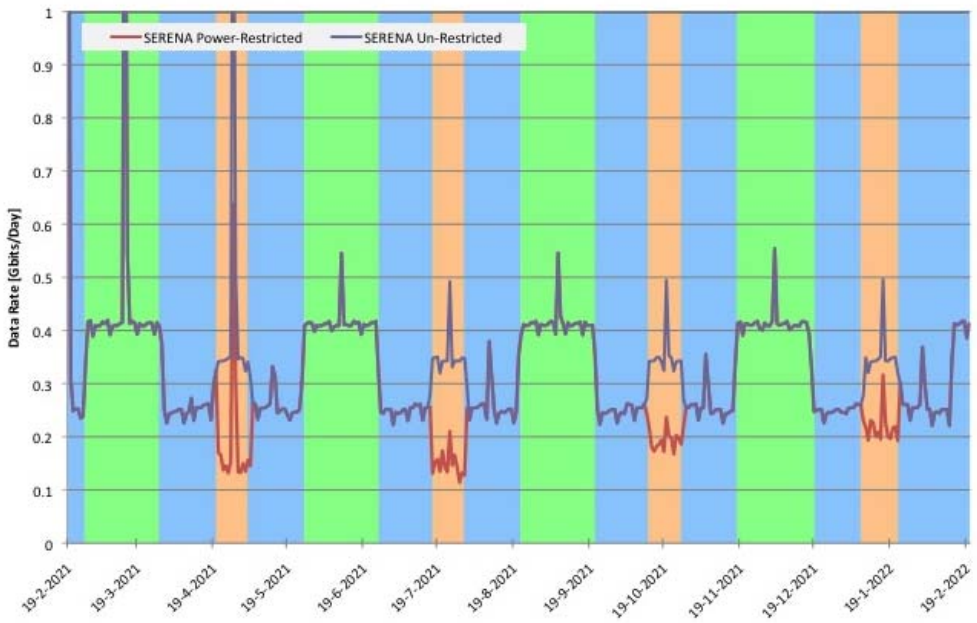
	AA		AP		EBA		LBA		EBP		LBP	
	Orbits	Mode	Orbits	Mode	Orbits	Mode	Orbits	Mode	Orbits	Mode	Orbits	Mode
STROFIO	all	N	all	N	all	N	all	N	all	N	all	N
ELENA	all	H	all	N	all	N	all	low	all	low	all	N
PICAM	all	IM_HT31_HR	5/12 5/12 1/12 1/12	MC_HR511_LE_S MC_HR511_LE_H MD_NR128_HE_S MD_NR128_HE_H	all	IM_HT31_HR	all	IM_HT31_HR	5/12 5/12 1/12 1/12	MC_HR511_LE_S MC_HR511_LE_H MD_NR128_HE_S MD_NR128_HE_H	5/12 5/12 1/12 1/12	MC_HR511_LE_S MC_HR511_LE_H MD_NR128_HE_S MD_NR128_HE_H
MIPA	all	5 (occasional "full mode" - TBD by MIPA)	all	6	all	5	all	5	all	5	all	5

	CA		CP		EDA		LDA		EDP		LDP	
	Orbits	Mode	Orbits	Mode	Orbits	Mode	Orbits	Mode	Orbits	Mode	Orbits	Mode
STROFIO	all	N	all	N	all	N	all	N	all	N	all	N
ELENA	all	H	all	H	all	low	all	N	all	N	all	low
PICAM	1/12 1/12 10/12	IM_HR31_HT MC_HR511_LE_S MC_HR511_LE_H	5/12 5/12 1/12 1/12	MC_HR511_LE_S MC_HR511_LE_H MD_NR128_HE_S MD_NR128_HE_H	all	IM_HT31_HR	all	IM_HT31_HR	5/12 5/12 1/12 1/12	MC_HR511_LE_S MC_HR511_LE_H MD_NR128_HE_S MD_NR128_HE_H	5/12 5/12 1/12 1/12	MC_HR511_LE_S MC_HR511_LE_H MD_NR128_HE_S MD_NR128_HE_H
MIPA	all	6	all	5 (occasional "full mode" - TBD by MIPA)	all	5	all	5	all	5	all	5

SERENA data rate

Data rate of SERENA:

a. **without** any restrictions (blue) over the whole mission.
b. **with** restrictions (red) over the whole mission



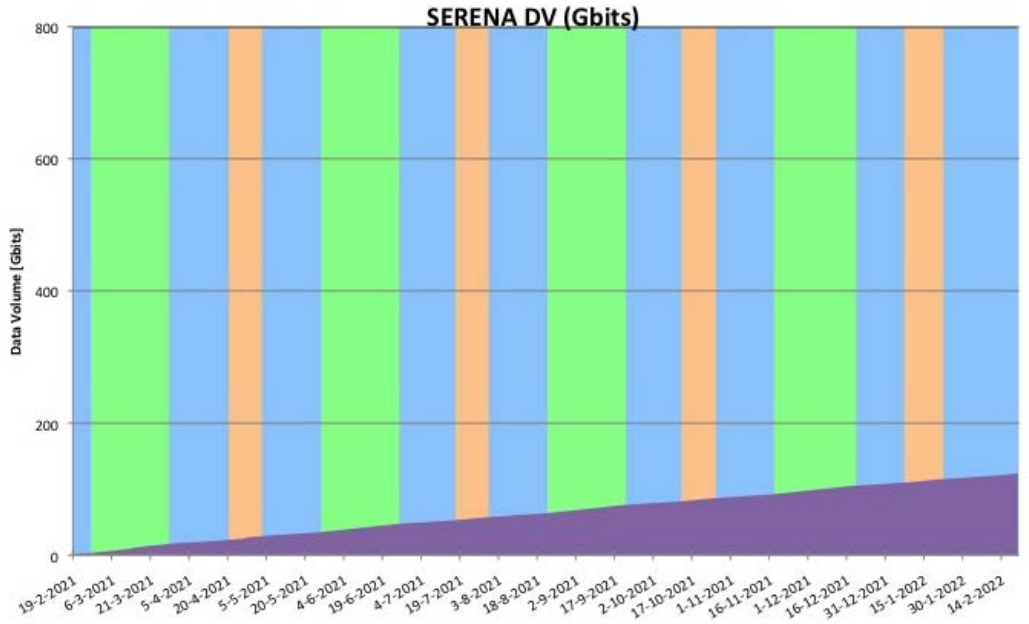
Data rate for SERENA for one terrestrial year – with and without restrictions.

SERENA cumulative data volume

Cumulative data volume of SERENA for the whole mission:

a. **without** any restrictions: 123.76 Gbit/year

b. **with** restrictions at perihelion (off @GS contact) amounts to 113.1 Gbit/year



Cumulative data volume for SERENA without restrictions for 1 terrestrial year.

MERTIS

MERTIS Science Operations Analysis Input

Analysis Input for **MERTIS**:

a. MERTIS EID-B (Issue 1. 1 April, 2010).

b. MERTIS ICDR Presentation on Flight Operations (8 June, 2011)

Operations Assumptions:

a. Hi-Res Global Mapping performed during Aphelion seasons.
   - Major reduction in overlap via complex commanding strategy.

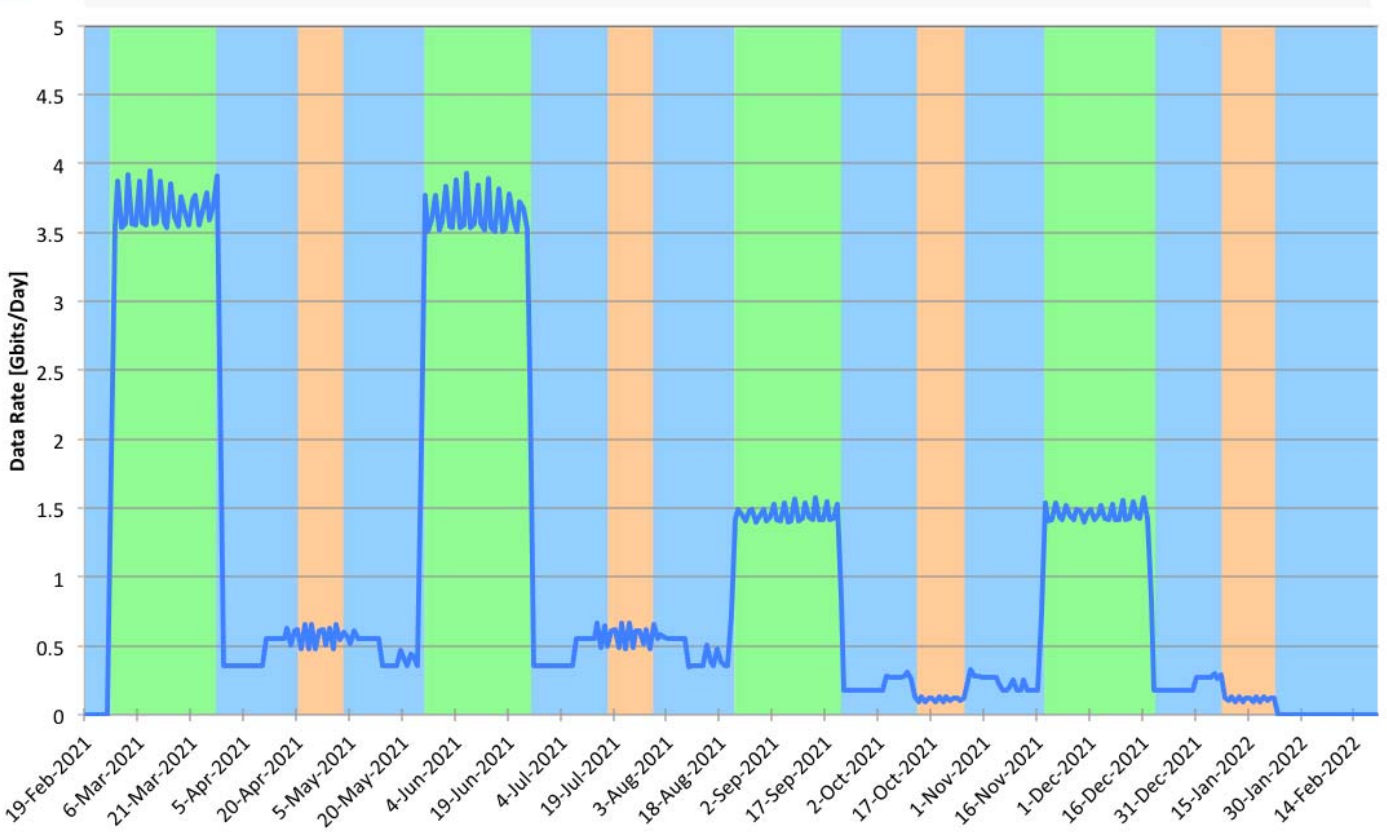
b. Survey Mapping performed during Extended Perihelion seasons.
   - Similar reduction strategy as at Aphelion.

c. Thermophysical and Polar Mapping performed during Terminator seasons.
   - Once every c. 10th orbit, reduced to every c. 20th orbit in 2nd six months.

d. Radiometer is “always” on.
   - Highest Res opportunities during Perihelion season.

MERTIS Daily Data Rates

Nominal Scenario, “Unrestricted” at Perihelion



MERTIS Cumulative Data Volume

Cumulative Data Volume for Nominal Mission: 390 Gbits

SIMBIO-SYS

SIMBIO-SYS Science Operations Analysis Input

Analysis Input for **SIMBIO-SYS**:

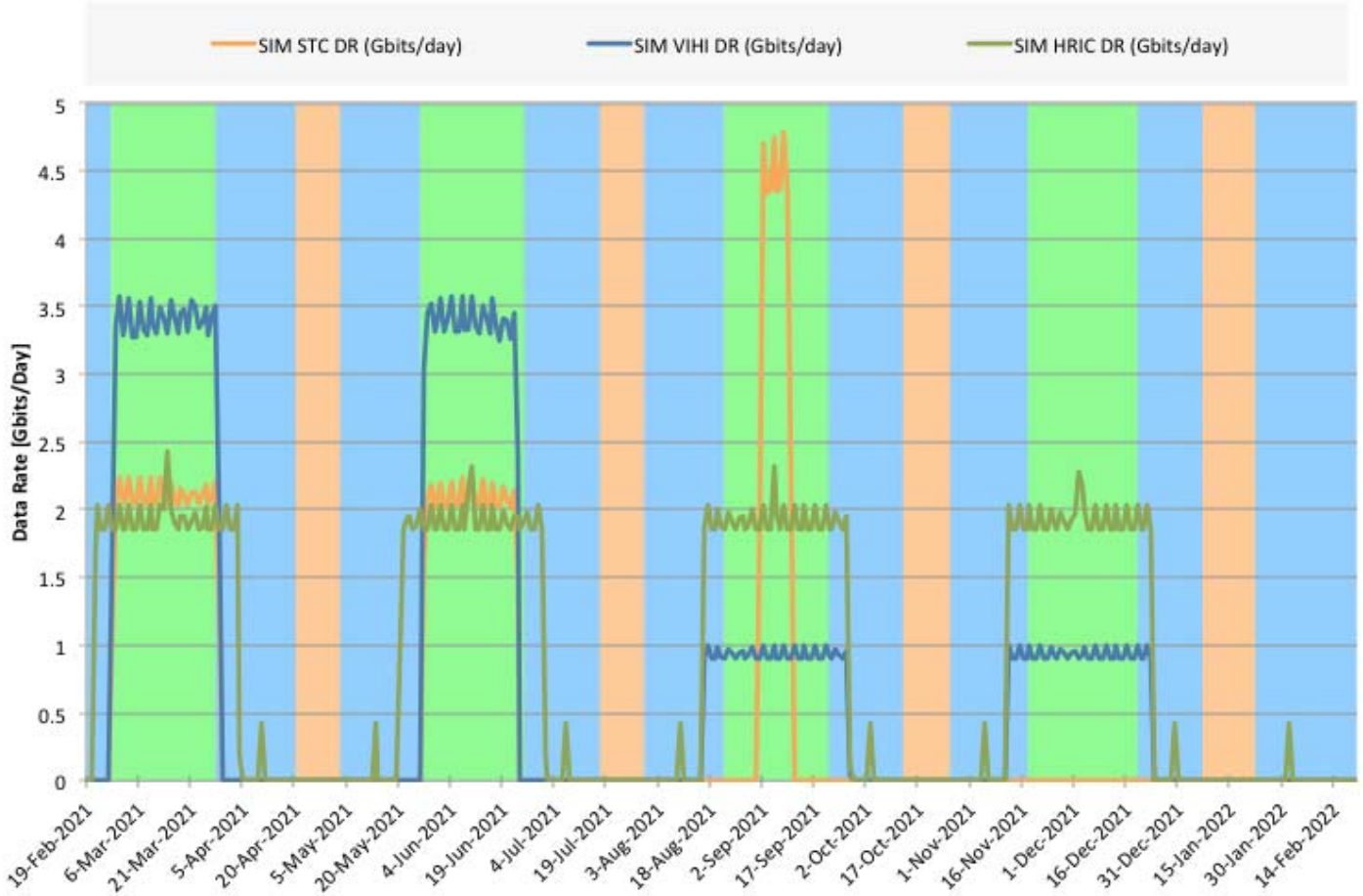
a. SIMBIO-SYS **EID-B** (BC-EST-RS-02523, Iss. D.4).
b. SIMBIO-SYS **Science Performance Report** (BC-SIM-PI-RP-001, Iss. 1.3)
c. SIMBIO-SYS **FM User Manual** (BC-SIM-GAF-MA-002, Iss. D.2)
d. SIMBIO-SYS **Flight Operations** (BC-SIM-PI-TN-001, Iss. 1.0)
e. SIMBIO-SYS **VIHI Flight Operations** (BC-SIM-TN-007, Iss. 3.1)
f. SIMBIO-SYS **STC Observation Strategy** (BC-SIM-OPD-TN-005, Iss. 2.1)
g. SIMBIO-SYS **HRIC Expected Values of Power and SNR** (BC-SIM-OACUPA-TN-019, Iss. 2.0)
h. SIMBIO-SYS **HRIC Operations Along the SC Orbit** (BC-SIM-OACUPA-TN-019, Iss. 2.0)
i. SIMBIO-SYS **HRIC Science Themes Operative Modes** (BC-SIM-OACUPA-TN-074, Iss. 2.0)
j. SIMBIO-SYS **HRIC Data Production Simulation** (BC-SIM-OACUPA-TN-108, Iss. 1.0)

SIMBIO-SYS Science Operations Assumptions

Mandatory Objectives	Criteria
STC	
Stereo Global Mapping	100% in 1st/2nd Aphelions
Colour Coverage	15% in 3rd Aphelion (could be spread-out)
Calibration	1 Gbit stellar calibration (not-modeled)
HRIC	
High Resolution (Mode 1)	7% coverage, wavelet compression
Colour Imaging (Mode 4)	2% coverage, wavelet compression, binned at low altitude
Calibration	c. 6.5 Gbit night side & stellar (modeled)
VIHI	
Global Mineralogy mapping	100% in 1st/2nd Aphelions
High Resolution target imaging	4% coverage full spectral and spatial resolution
Calibration	1 Gbit internal and stellar calibration (not-modeled)

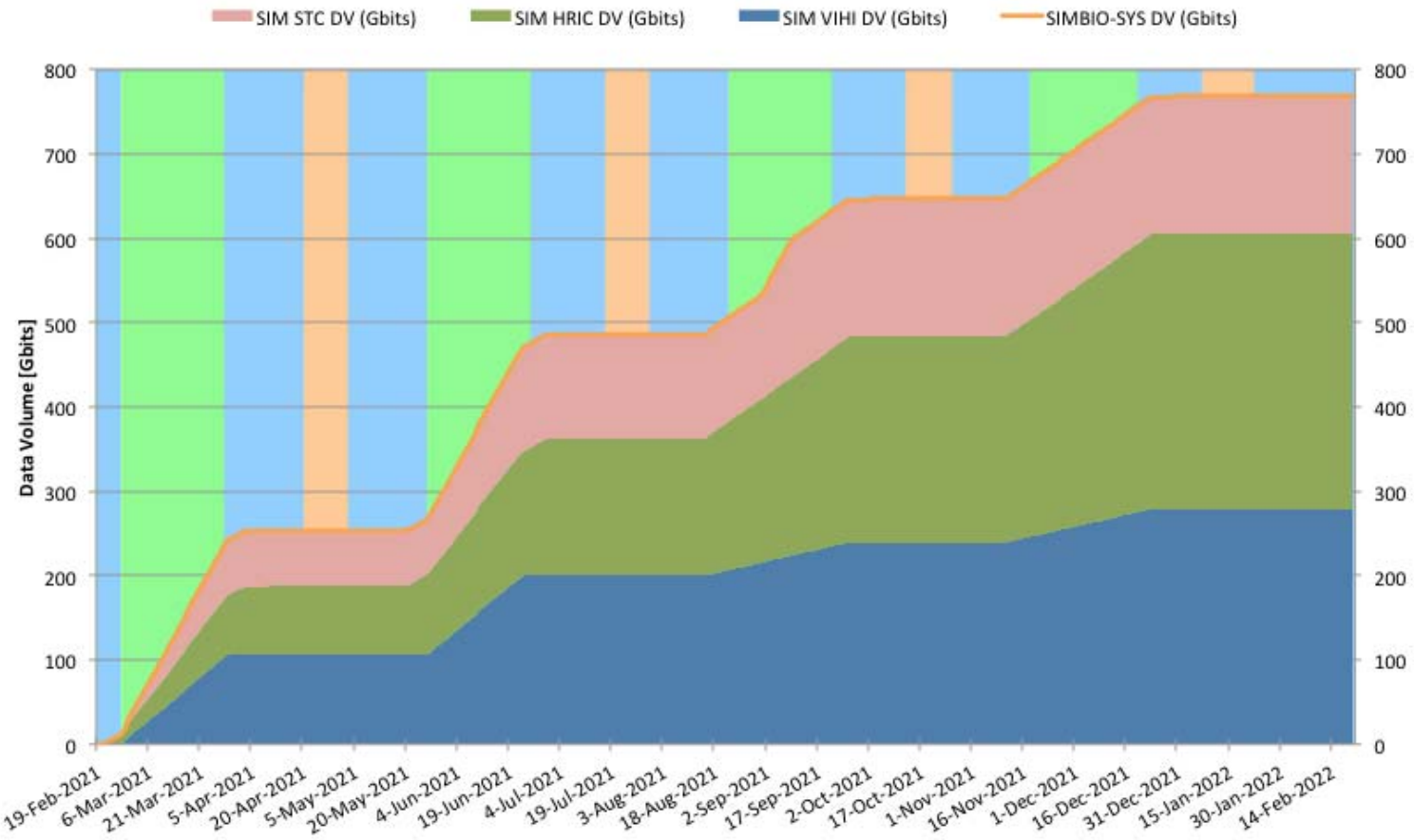
SIMBIO-SYS Daily Data Rates

Nominal Scenario, Mandatory Science Objectives



SIMBIO-SYS Cumulative Data Volume

Cumulative Data Volume for Nominal Mission: 770 Gbits



SIMBIO-SYS Data Volumes

Mandatory Objectives	Data Volume (Gbits)
STC	**163**
Stereo Global Mapping	123
Colour Coverage (15%)	40
Calibration	1
HRIC	**327**
Mode 1 (High-Res, wavelet compression, 7%)	
Mode 4 (Colour, wavelet compression, binned, low altitude, 2%)	
Calibration	
VIHI	**278**
Global Mineralogy (1st/2nd Aphelions)	106
High Spectral / Spatial Res (4%)	176
Internal Calibration and Stellar Calibration	1
Total	**770**

BELA

BELA science operations analysis input

Input and analysis assumptions for **BELA**:

a. BELA inputs from

- BELA EID-B (draft 4, 18 Feb. 2011)
- Recent updates in ICDR documentation
- Science Operations meeting on 28/01/2011 at DLR
- Communications with BELA team on 11/10, 19/10, and 21/102011

b. Modes:

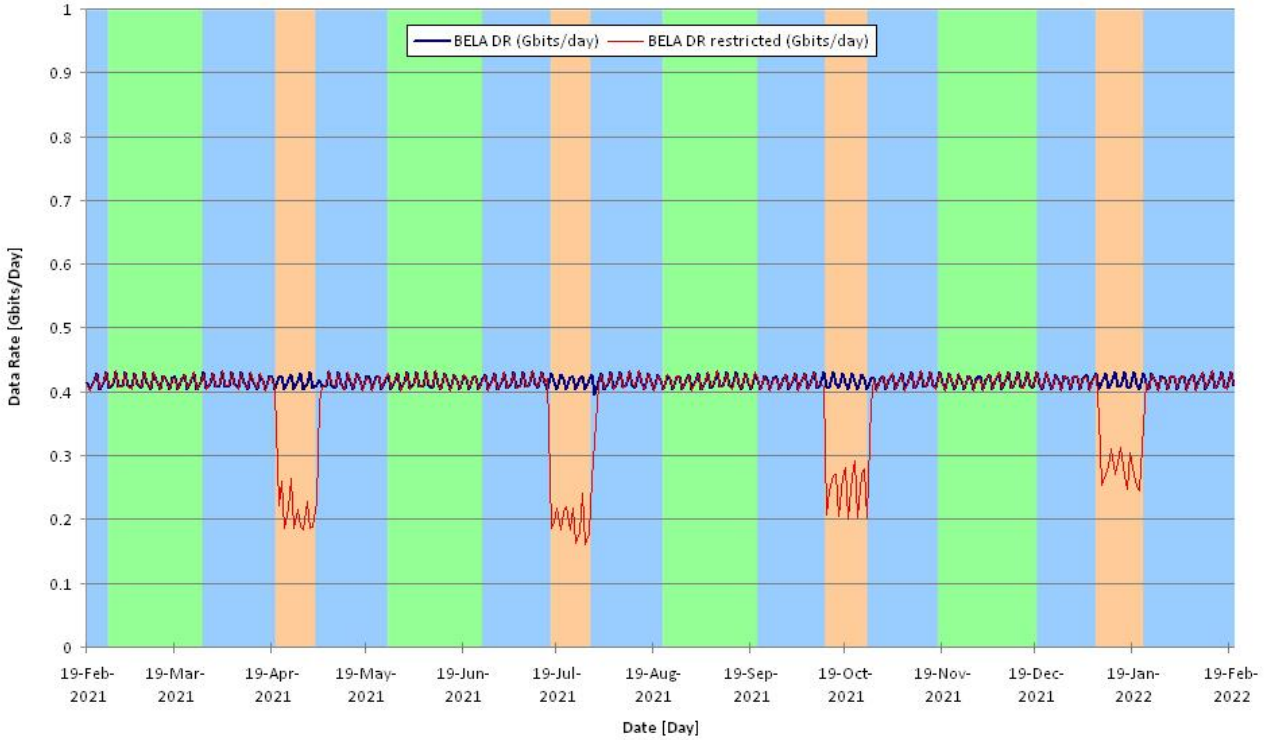
Operational modes:	Data modes:	Conditions for Data modes:
PBS	DP_Pulse_LF	Full Science mode for low SNR
APS_STANDBY	DP_Pulse_HF	Full Science mode for high SNR
APS_SAFE	DP_Pulse_VF	Full Science mode for very high SNR
APS_CONFIG	DP_Pulse_LR	Reduced Science mode for low SNR
APS_ANNEAL	DP_Pulse_HR	Reduced Science mode for high SNR
	DP_Pulse_VR	Reduced Science mode for very high SNR
	DP_Pulse_LM	Minimum Science mode for low SNR
	DP_Pulse_HM	Minimum Science mode for high SNR
	DP_Pulse_VM	Minimum Science mode for very high SNR
	DP_Pulse_DB1	Pulse debugging mode
	DP_Sensor	
	DP_Albedo	Min. aux. data required for monitoring Rx Albedo mode data reduced to 1value in DPM

BELA data rate

Data rate of BELA:

a. **without** any restrictions: 0.42 Gbit/day over the whole mission

b. **with** restrictions: 0.42 Gbit/day @perihelion , 0.25 Gbit/day at all other times



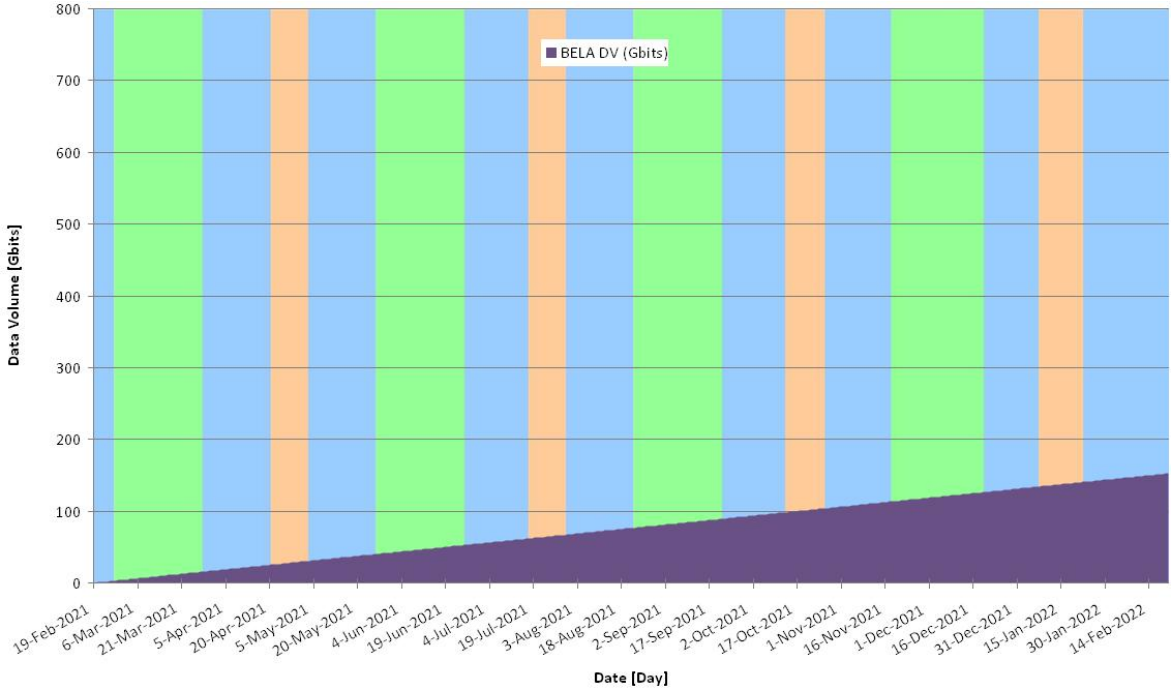
Data rate for BELA for one terrestrial year – with and without restrictions.

BELA cumulative data volume

Cumulative data volume of BELA for the whole mission:

a. **without** any restrictions: 157 Gbit.

b. **with** restrictions at perihelion (off @GS contact) amounts to 143 Gbit.



Cumulative data volume for BELA without restrictions for 1 terrestrial year.

ISA

ISA science operations analysis input

Input and analysis assumptions for **ISA**:

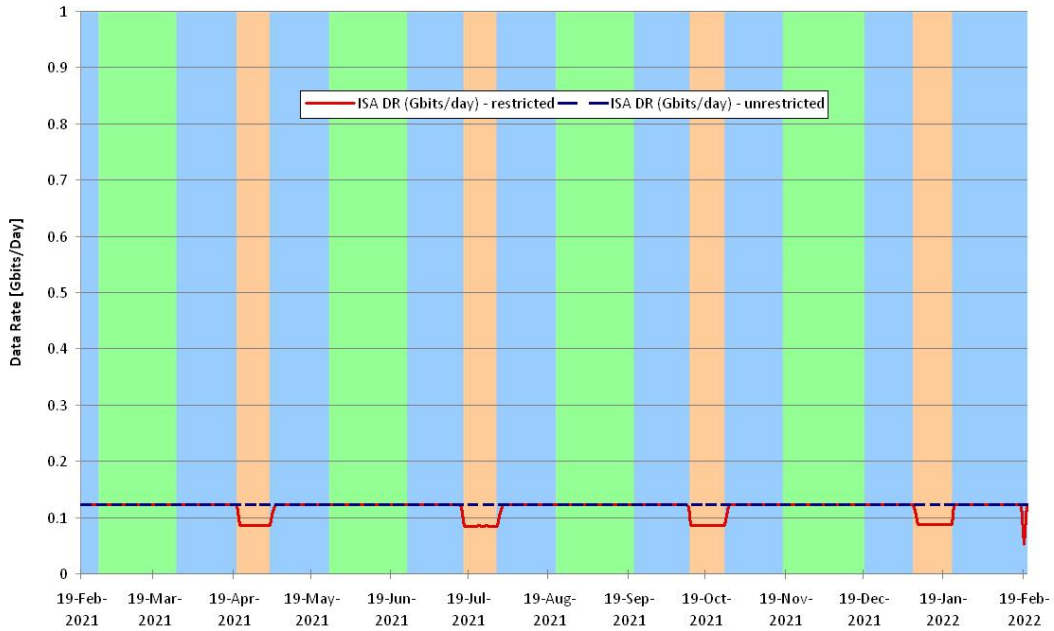
a. ISA modelling inputs are from ISA EID-B (draft 4, 10 March 2011).
b. Modes: OFF, STANDBY, CONFIGURATION, CALIBRATION, OBSERVATION. “High rate Observation” mode and “Delta V measurements” currently not implemented.
c. Sampling frequency for observation mode is 10 Hz.

ISA data rate

Data rate of ISA:

a. **without** any restrictions: 0.12 Gbit/day @1.5 Kbit/sec

b. **with** restrictions: 0.085 Gbit/day @perihelion , 0.12 Gbit/day at all other times



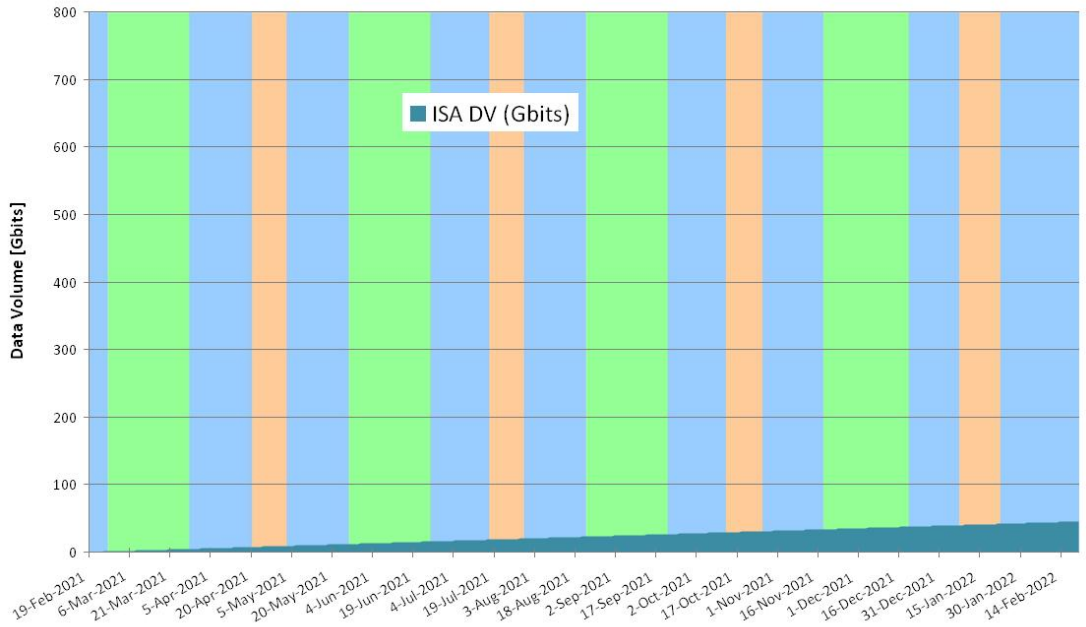
Data rate for ISA for one terrestrial year – without and with restrictions.

ISA cumulative data volume

Cumulative data volume of ISA:

a. **without** any restrictions: 45.29 Gbit/year

b. **with** restrictions at perihelion (off @GS contact) amounts to 43.16 Gbit/year



Cumulative data volume for ISA without restrictions for 1 terrestrial year.

MORE

MORE science operations analysis input

Input and analysis assumptions for **MORE**:

a. **MORE** modelling inputs are from **MORE** EID-B (issue 1.0, 11 March 2011)
b. Modes: Off, Warm-up, Nominal, Calibration
c. “MORE” refers to the Ka-band transponder of the MORE experiment. It is understood that this is only a part of the MORE experiment.

Note: **As the MORE science data does not pass through the SSMM, no data rate or cumulative data volume are shown here. However, there is housekeeping data of MORE stored in the SSMM.**

Science Operations Analysis - Data Summary

Raymond Hoofs

Introduction to Summary plots

First Summary plot (next slide) contains:

a. Total experiment data-rates and data volume
b. SSMM fill state
c. Downlinked data (what is dumped via Ground Station)

→ This plots shows the SSMM filling up.

→ When SSMM line goes above SSMM limit, it means data is over-written (and lost).

Second Summary plot (slide after next slide) contains

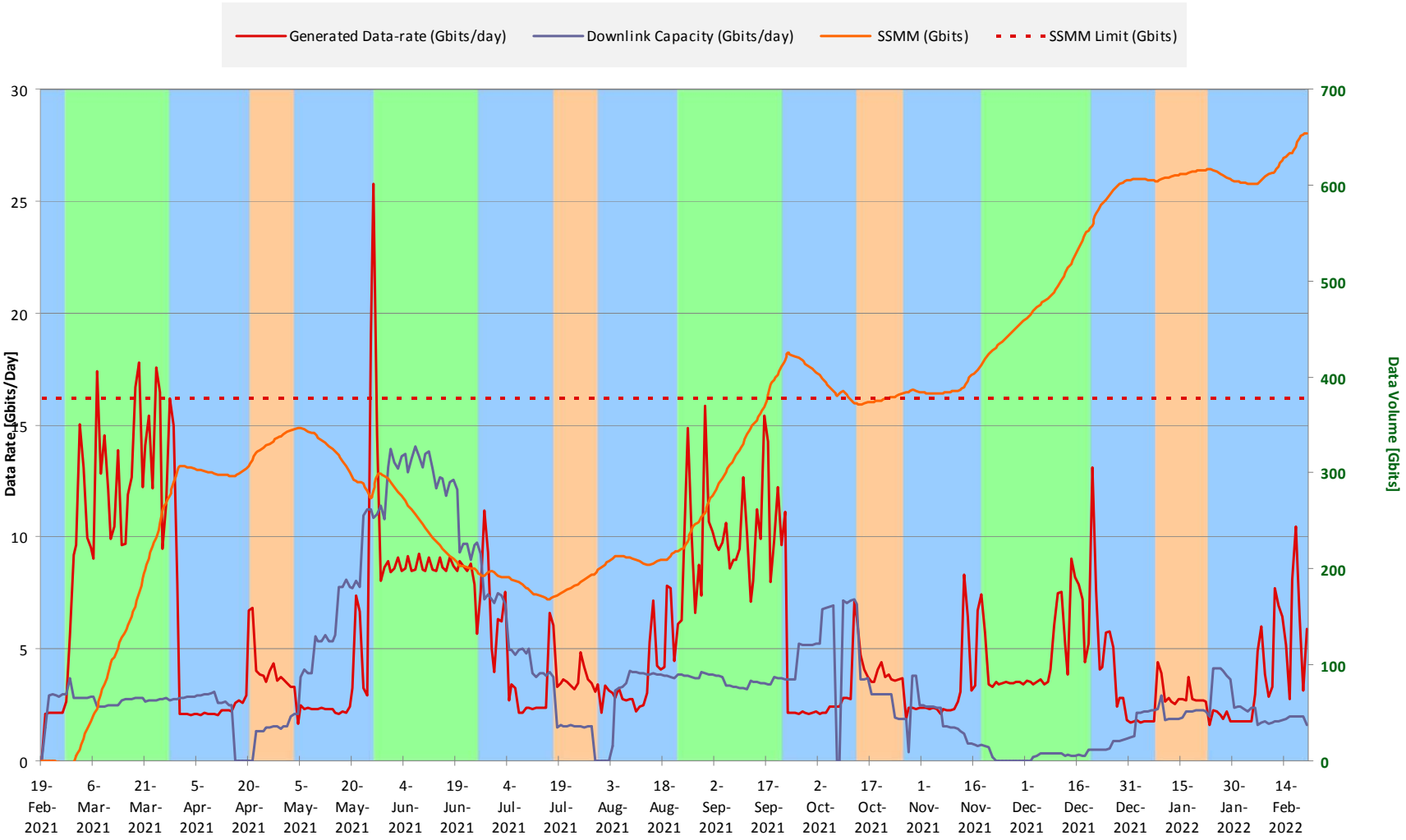
a. Total cumulative data-volume

The currently industrial model for the Ground Station downlink only downlinks

1384 Gbit of data

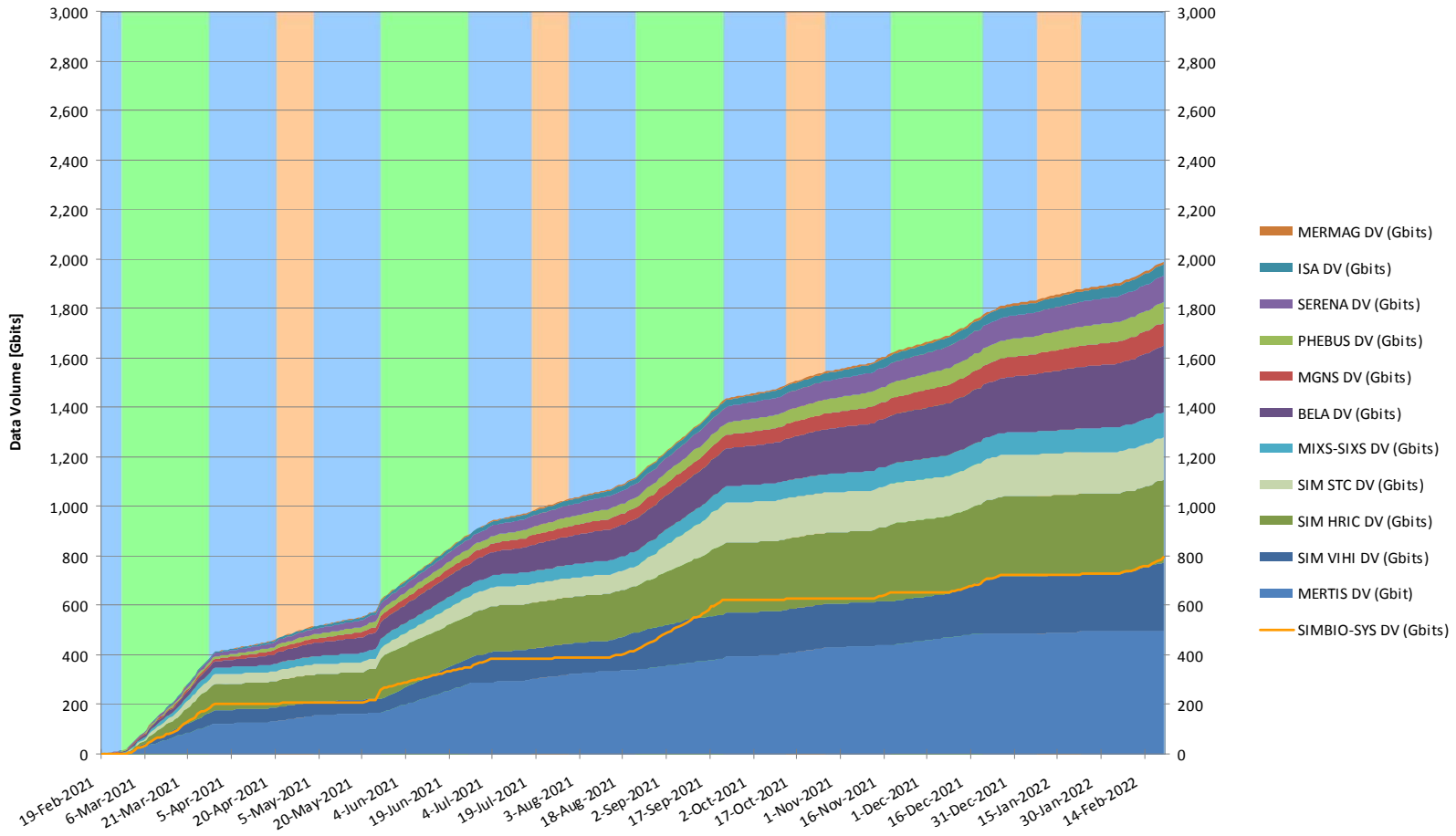
As mentioned we still assume for the nominal mission that 1550 Gbit will be made available.

Total experiment data-rates
(together with SSMM fill state and downlinked data)



Total cumulative data-volume

Total requested data-volume: 1853 Gbit



Data-volume per experiment

Experiment	Data-volume (current)	Comments
BELA	157 Gbit	**Further reductions possible**
ISA	45 Gbit	**Reduction option (low frequency mode, TBC ➔ 10 Gbit)**
MPO-MAG	11 Gbit	**Will use selective downlink to get high resolution data no impact on overall data-volume**
MERTIS	390 Gbit	**Massive reduction after introduction of complicated operation scheme to minimize over lapping's**
MGNS	100 Gbit	**Mode highly depends on assumed frequency of measurements**
MIXS	160 Gbit	**Based on 1999 Solar flare activity and updated data format structure.**
MORE	NA	
PHEBUS	83.6 Gbit	**TBC, Value agreed to study if science objectives could be met. (based on compression factor of 3)**
SERENA	123 Gbit	
SIMBIO-SYS	770 Gbit	**Only possible after including prioritization of science objectives (nominal ideal case data volume would be ~ 1400 Gbit)**
SIXS	13.6 Gbit	
Total	1853.2 Gbit	