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http://microscope.onera.fr

MICROSCOPE
DATA TREE FOR SCIENCE

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MICROSCOPE

Summary

- The Science Mission Center : CMS-MICROSCOPE

  Where do the data come from?

- The mission data flow and tree

  How the data is transformed for scientific users?

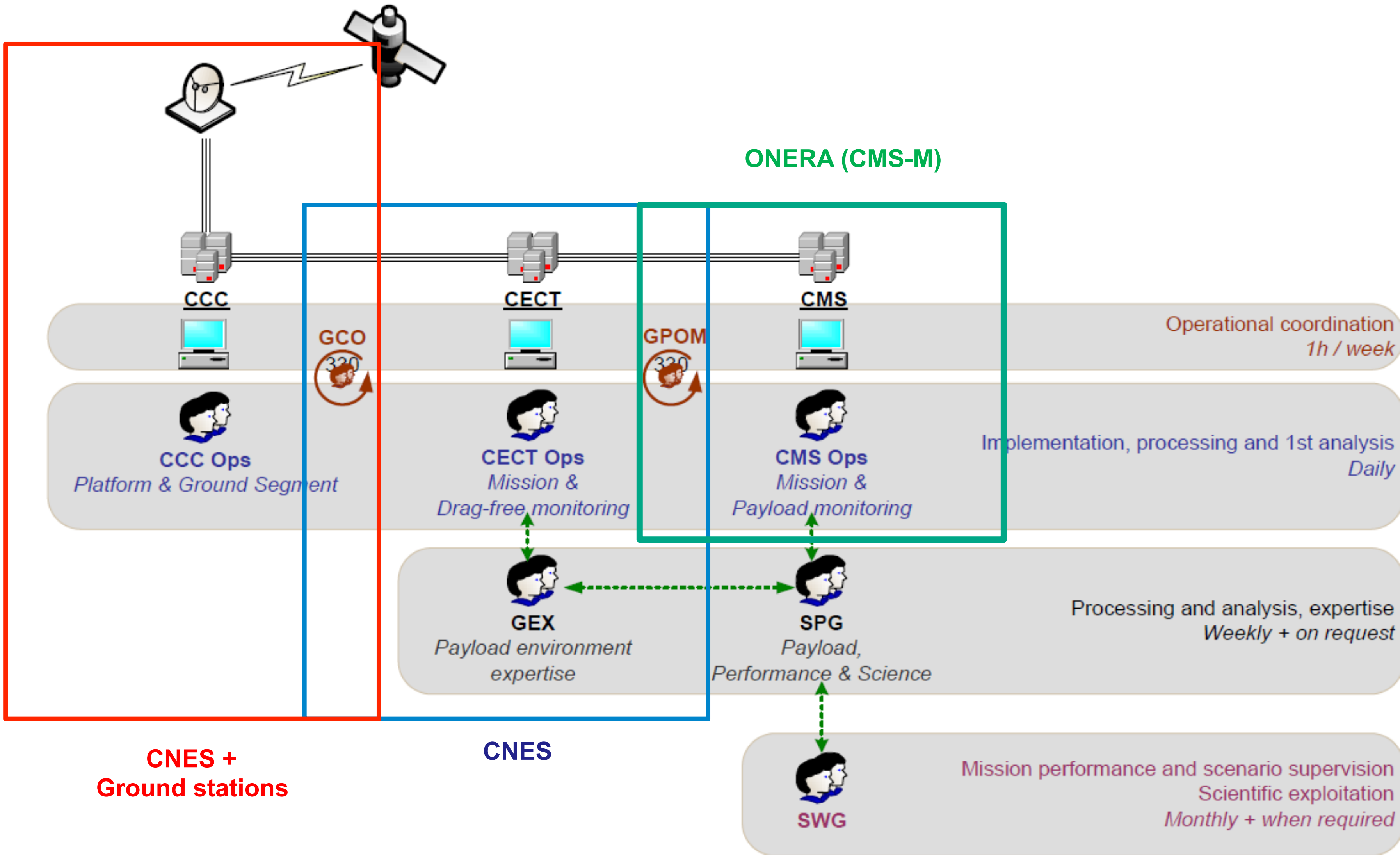
- Specific data process

  No data is perfected.

- The current development of the Science Mission Center

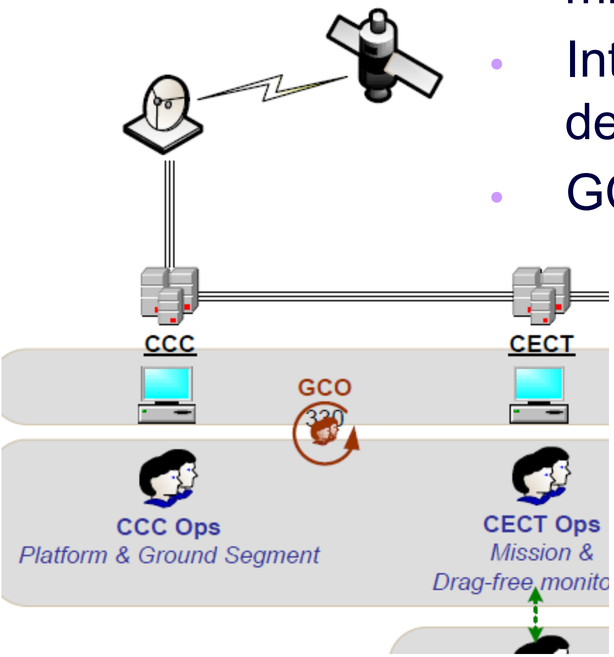
  The path beyond us.

MICROSCOPE GROUND SEGMENT



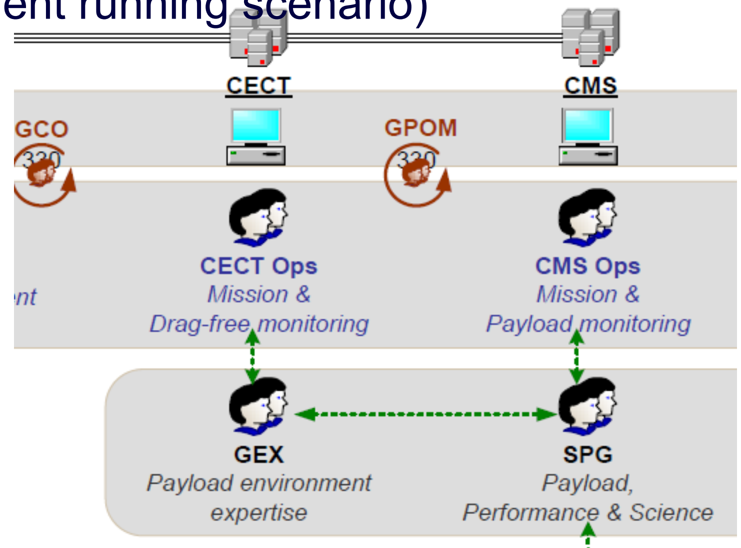
CNES MISSION CENTRE

- CCC : Control Command Center
  - Standard from Myriad CNES missions (s/c housekeeping, updates, orbit determination, ….)
  - Manage a few stations around the world for telemetry and telecomand on satellite (time share with other missions)
  - Interface with CECT (Centre Etude de Compensation de Traînée), the Drag Free Control Center
  - GCO: Groupe de Coordination Opérationnelle
    - Link between CCC & CECT
    - Coordinates the stations selection wrt the need in telemetry (nominal : 2 per day, but each hour possible in critical mode or flight acceptance)
    - Coordinates the satellite command wrt station visibilities
    - The s/c housekeeping



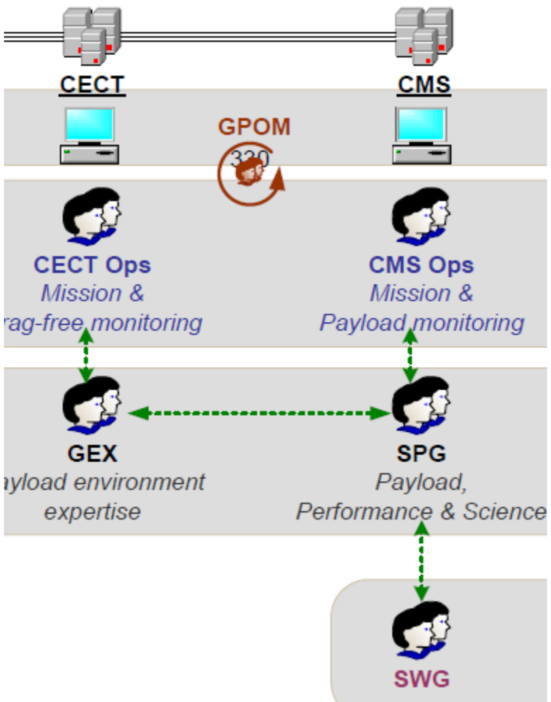
CNES MISSION CENTRE

- CECT: Centre Etude de Compensation de Traînée
  - Specific center for MICROSCOPE
  - Interface with CCC through GCO group
  - Delivers the science data to CMS-M
  - Retrieves the updated scenario from CMS-M
  - GPOM: Groupe de Programmation Opérationnelle Mission
    - Link between CMS-M & CECT
    - mission scenario update (wrt s/c current running scenario)
  - GEX: Groupe d'Expertise
    - Experts from CNES
    - Analyze of satellite performance
    - Evaluation of instrument biases
    - Evaluates from satellite point of view any modification on scenario
    - Reports to GPOM



ONERA SCIENCE MISSION CENTRE

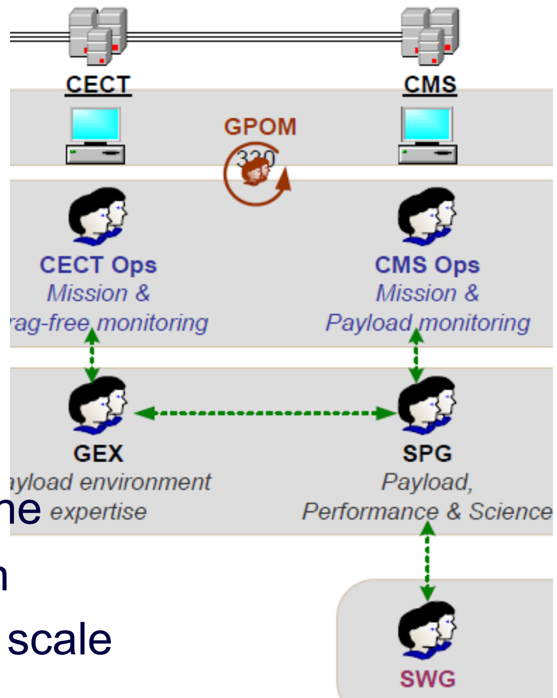
- CMS-M:
  - Interfaces with CECT through GPOM group
  - Downloads the science data from CECT
  - Uploads the updated scenario to CECT
  - CMS_Ops: CMS operational pole
    - Daily downloads the telemetry
    - Daily analyses the data and states on good health of T-SAGE
    - Alerts CECT in case of anomaly
    - Prepares all data for science
  - CMS_Sci: CMS science pole
    - Prepares and analyzes the data by sessions
    - Alerts CECT in case of anomaly
    - Prepares data for EP test
    - Stores data for Science community
    - Reports to SPG + SWG



- CMS-M:
  - Interfaces with CECT through GPOM group
  - Downloads the science data from CECT
  - Uploads the updated scenario to CECT

  - SPG: Science Performance Group
    - Analyzes the performance of all components satellite (GEX) + T-SAGE (CMS_Ops)
    - Adjusts the mission scenario on weekly time scale

  - SWG: Science Working Group
    - With the help of CMS_Sci, SWG supervises the mission performance and scenario orientation
    - Adjusts the mission scenario on monthly time scale



Summary

- The Science Mission Center : CMS-MICROSCOPE
- **The mission data flow and tree**
- Specific data process
- The current development of the Science Mission Center

List of products CECT <-> CMS-M

- **Down to CMS-M:**
  - **Level N0 data**:
    - N0a: mainly rough data (not exploited except in case of anomaly, not in chronology order, no attitude or orbit processed data), retrieved on demand
    - N0b: data organized by day (rough orbit and attitude, data holes, health monitoring), retrieved each day (automatic)

For Science

- N0c: data organized by session (fine orbit and attitude, data holes, health monitoring, perf report), retrieved each week (automatic)

List of products CECT <-> CMS-M

- Down to CMS-M:
  - Each N0 package : by TM (a) ; by day (b) , by session (c)
    contains several packages

  - N0_TSAGE: contains all data from instrument + S/C mode
  - N0_xxxx_ORBIT: For ORBIT and its determination (fine or rough)
  - N0_xxxx_ ATTITUDE: For ATTITUDE and its determination (fine or rough)
  - N0_MISSION: help reports for mission monitoring
  - N0_xxxx_REPORT: perf report of s/c subsystems

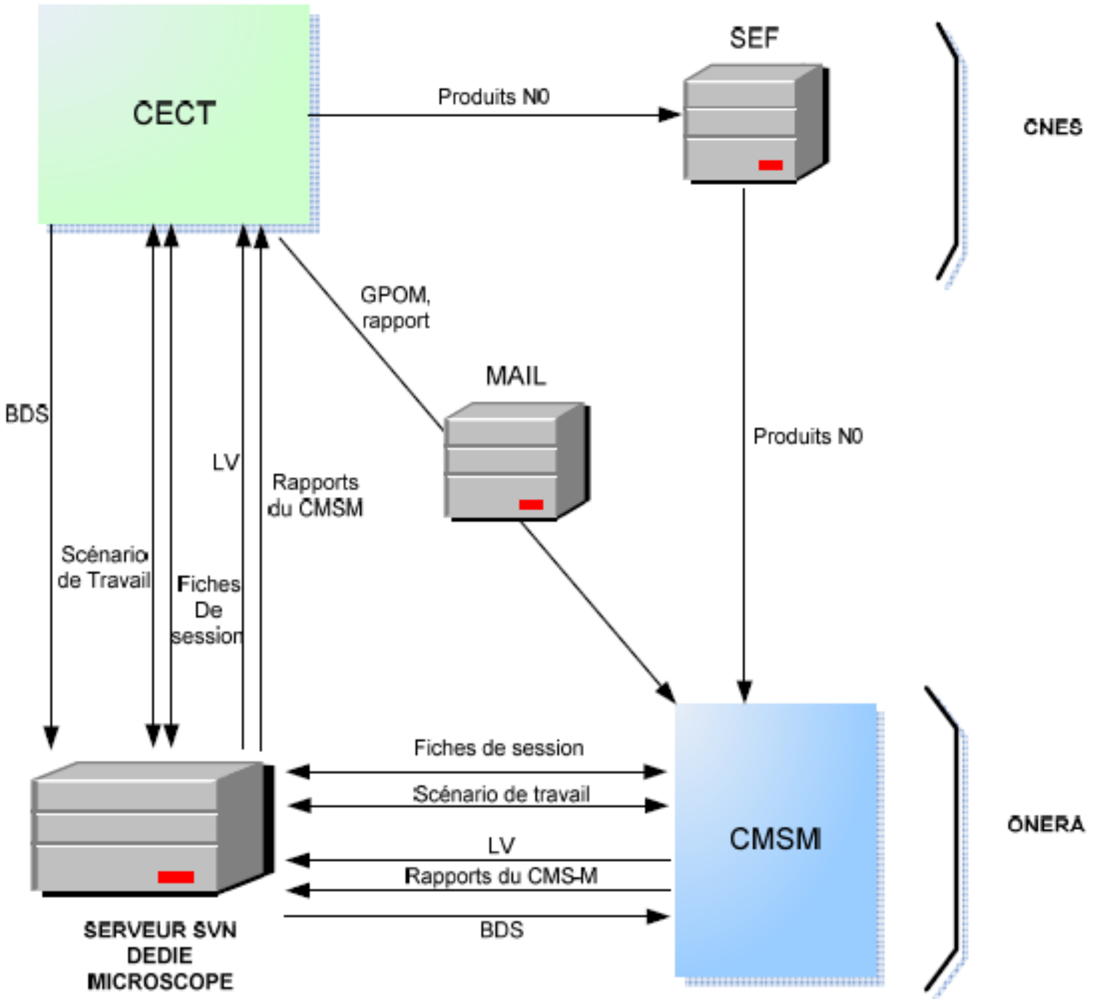
  - N0_PF: all other data from the s/c, not exploited by CMS_M tools

List of products CECT <-> CMS-M

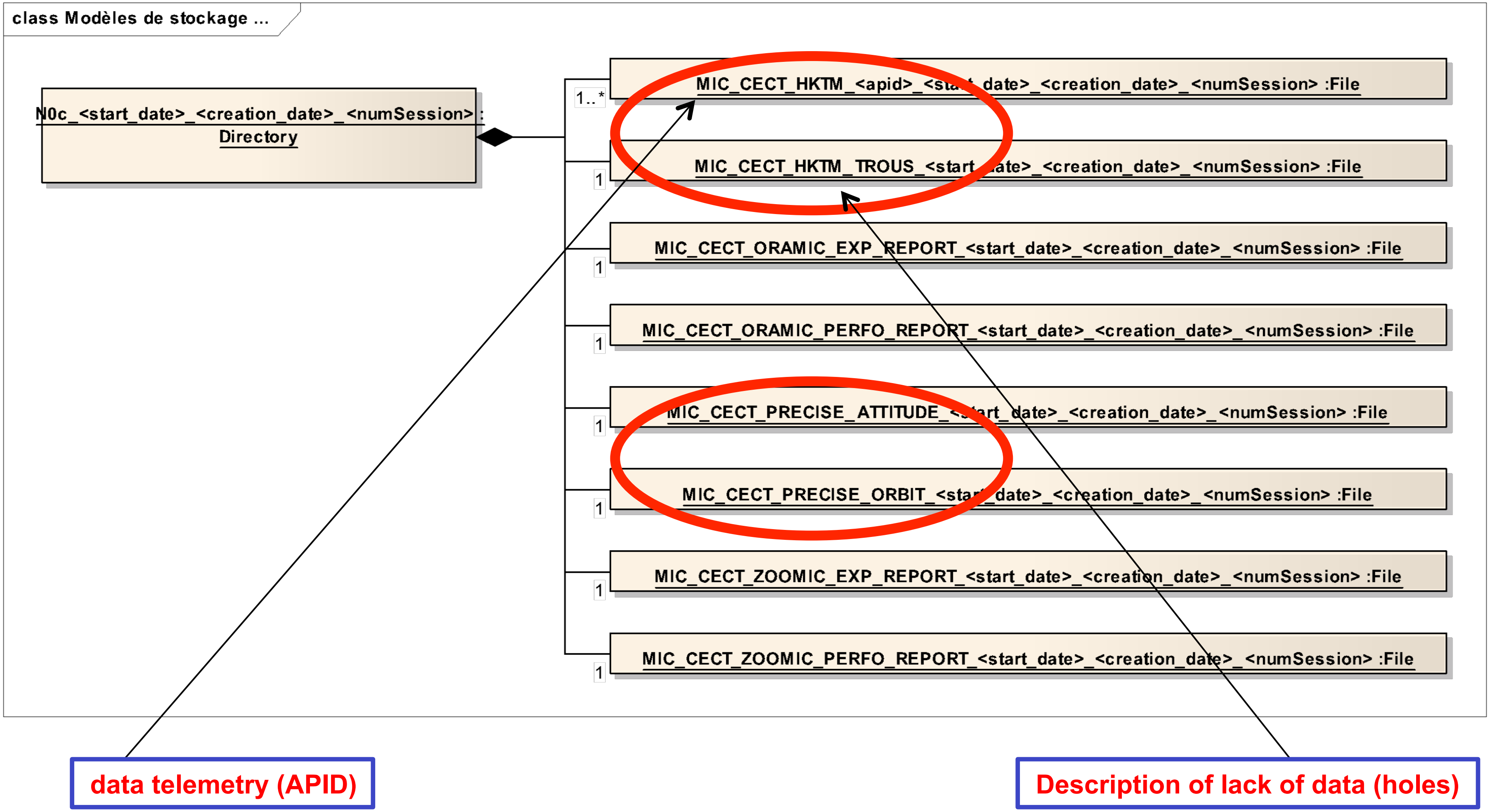
- **Up to CECT from CMS-M:**
  - The **mission scenario**: exchanged by CNES and ONERA through a specific server : each week, to generate 2 weeks of on board activity
  - The **session sheets**:
    - Define the 'elementary' sequence of the mission scenario
    - Ex: EP session in inertial mode with SU-EP of 120 orbits
    - Ex: Acceptance test with SU-EP for Delta_y calibration of 2 orbits
    - All the instrument parameters and associated s/c parameter to configure the session is defined in the sheets.
    - The sheets are validated @ ONERA level and qualified @CNES: Command control compatibility, SCAA validation,….
    - Only qualified sheets are applicable in the mission scenario
  - **Other files** : Calibrated parameters, T-SAGE flight software, schedule of s/c unavailability (eclipses, Moon,…), memory mapping….

The level 1 or 2 data are organised in reference to the mission scenario

Architecture of data exchange CECT vs CMS-M



N0_c Product description

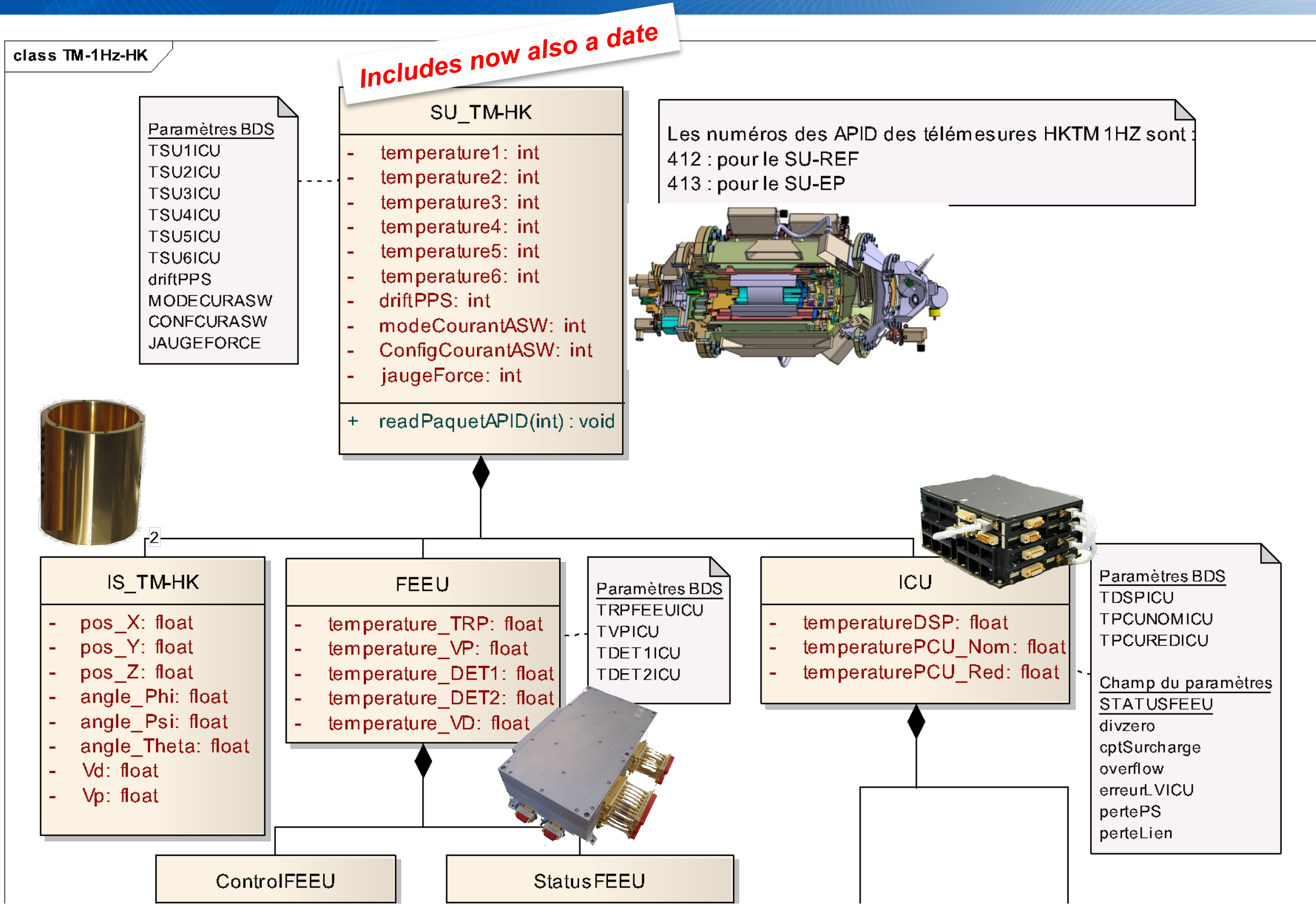


List of APID processed in CMSM

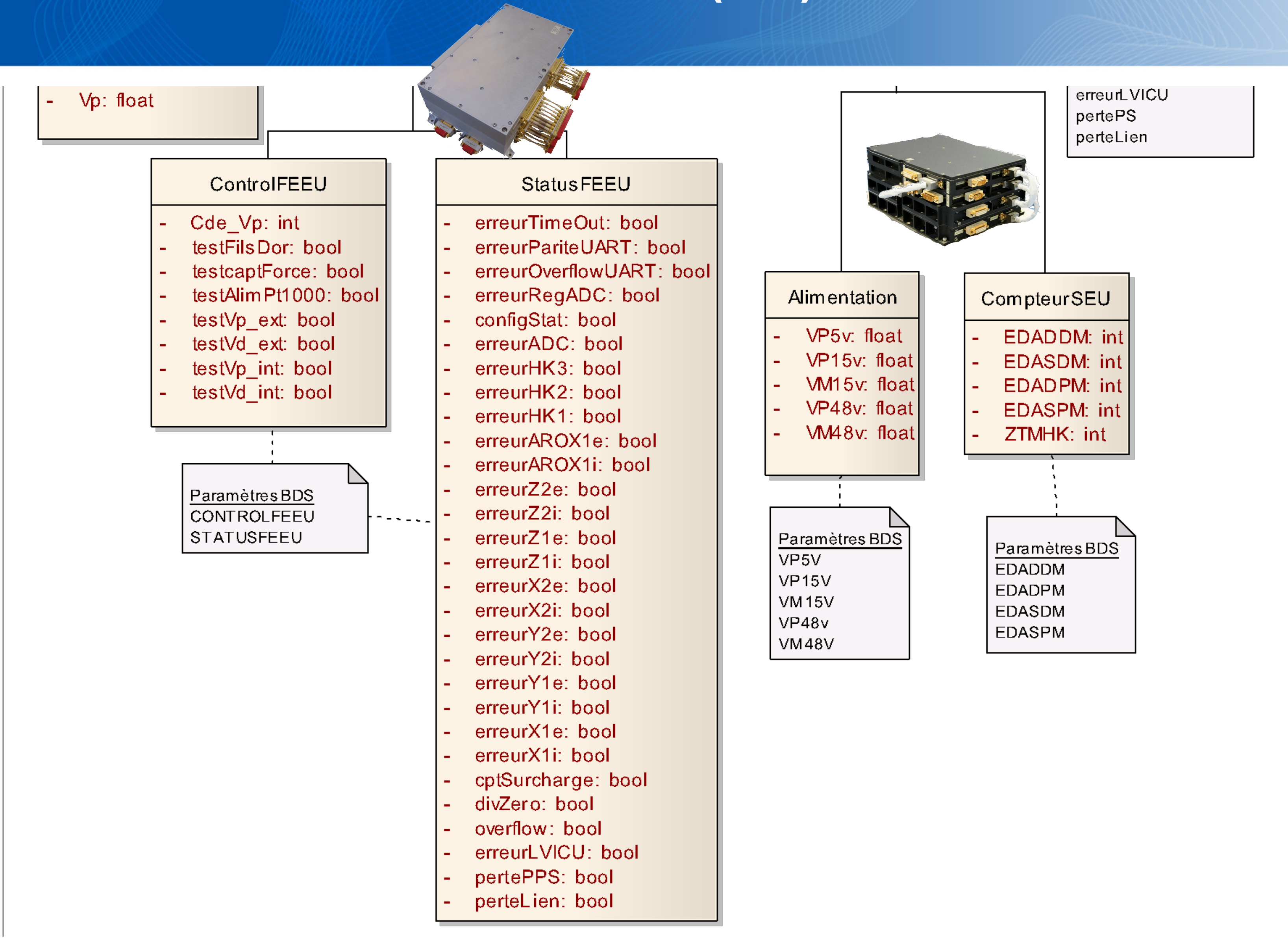
N° APID	Télémesure (mnémonique)	Description
4	PMODESAT	Télémesure permettant de connaître le mode de mesure mode scaa
108	MNORTE1	Télémesure donnant les quaternions d'attitude et les vitesses angulaires estimées
402 et 403	DUMPARBO	Dump par bloc des paramètres des lois de commande par défaut stockés en EEPROM ICU-REF ou ICU-EP
404 et 405	DUMPARTO	Dump complet de tous les paramètres stockés en EEPROM ICU-REF ou ICU-EP
406 et 407	DUMPARAT	Dump d'un bloc de paramètres de la table d'attente ICU-REF ou ICU-EP
408 et 409	DUMPARCU	Dump d'un bloc de paramètres de la table courante ICU-REF ou ICU-EP
410 et 411	ACCTM	ACC_4Hz : TM Science à 4 Hz ICU-REF ou ICU-EP
412 et 413	TMHK	TM_HK :TM House Keeping à 1 Hz ICU-REF ou ICU-EP
414 et 415	AUTOTS	TM de l'Autotest ICU-REF ou ICU-EP
430 et 431	TMACKICU	TM d'acquittement à une commande de l ICU-REF ou ICU-EP.
1470	EIFCU	TM Anomalie ICU

FOR EP TEST

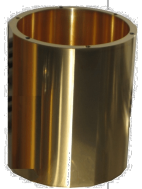
List of inertial sensor data (1/3) – 1Hz

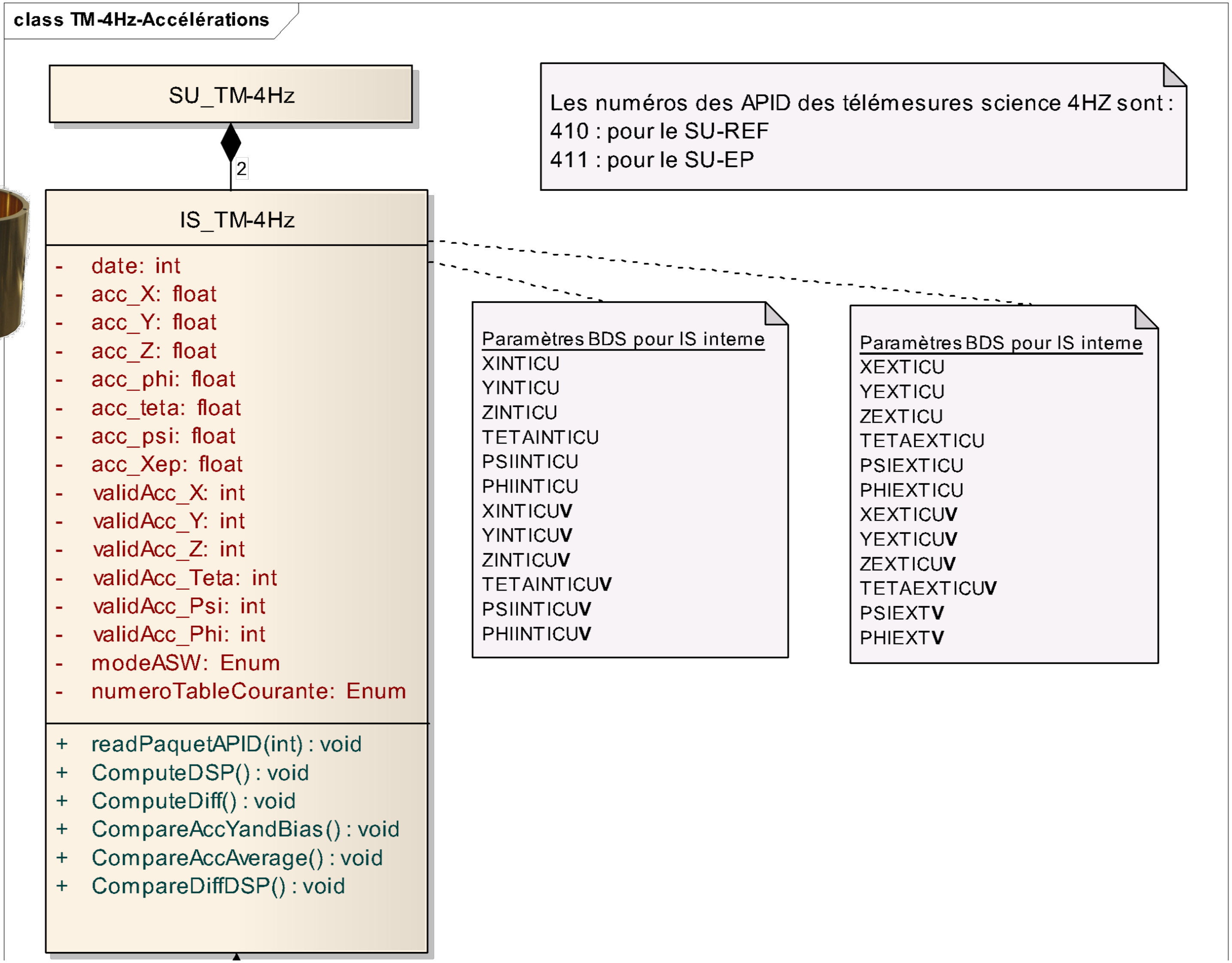


List of inertial sensor data (2/3) – 1Hz



List of inertial sensor data (3/3) – 4Hz



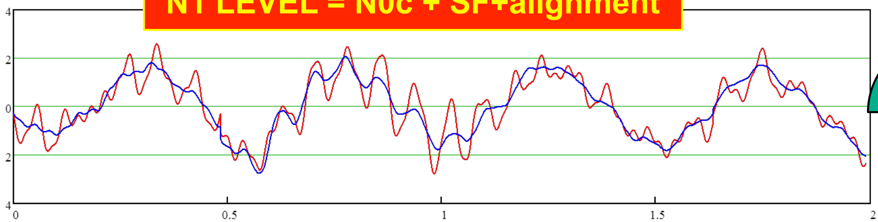


What do we measure? Each mass acceleration

$\vec{\Gamma}_{mes,is2}$

$\vec{\Gamma}_{mes,is1}$

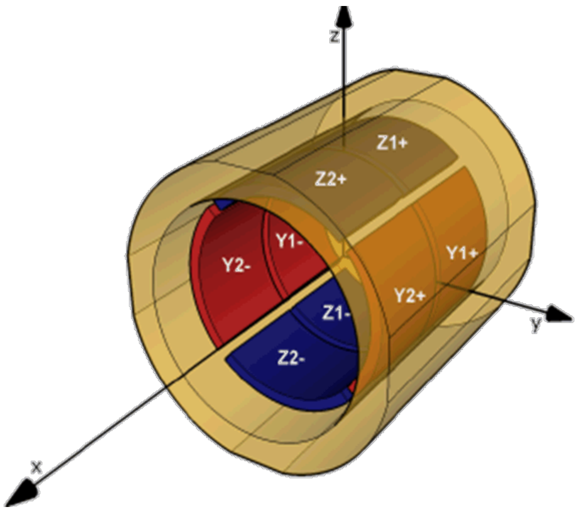
N1 LEVEL = N0c + SF+alignment



$$\vec{\Gamma}_{mes,c} = \frac{1}{2}\left(\vec{\Gamma}_{mes,is2} + \vec{\Gamma}_{mes,is1}\right)$$

N2 LEVEL

$$\vec{\Gamma}_{mes,d} = \frac{1}{2}\left(\vec{\Gamma}_{mes,is2} - \vec{\Gamma}_{mes,is1}\right)$$



The measure contains Earth's, satellite, instrument, physics contributions & eventual EP signal

$$\vec{\Gamma}_{meas,d} \approx \vec{K}_{0,d} + [M_c]\cdot\left(([T]-[In])\cdot\Big|\vec{\Delta} - 2.[Cor]\cdot\Big|\dot{\vec{\Delta}} - \Big|\ddot{\vec{\Delta}} + \delta.\vec{g}(O_{sat})\right) + [M_d]\cdot\vec{\Gamma}_{app,c} + \vec{\Gamma}_{measquad,d} + \vec{\Gamma}_{n,d} + Coupl(\dot{\Omega})$$

What do we measure ? Earth's, satellite, instrument, physics contributions

MICROSCOPE

The Measure

EP violation δ

$$\delta = \frac{m_{g2}}{m_{I2}} - \frac{m_{g1}}{m_{I1}}$$

$$\vec{\Gamma}_{meas,d} \approx \vec{K}_{0,d} + [M_c]\cdot\left(([T]-[In])\cdot\left|\vec{\Delta} - 2.[Cor]\cdot\left|\dot{\vec{\Delta}} - \right|\ddot{\vec{\Delta}} + \delta.\vec{g}(O_{sat})\right) + [M_d]\cdot\vec{\Gamma}_{app,c} + \vec{\Gamma}_{measquad,d} + \vec{\Gamma}_{n,d} + Coupl(\dot{\Omega})$$

Measured Acceleration Difference

Bias difference
limited thermal fluctuations

Earth Gravity gradient tensor
Computed with Model, S/C position & attitude and Removed

Coriolis & relative motion acceleration

$$[Cor] = \begin{bmatrix} 0 & -\omega_z & \omega_y \\ \omega_z & 0 & -\omega_x \\ -\omega_y & \omega_x & 0 \end{bmatrix}$$

Common mode acceleration
(S/C drag-free Control from Sensor common data)

Instrument noises & couplings

Common Mode Sensitivity Matrix (Inst. Scale Factor & Attitude, Coupling)
Estimated by calibration or limited by construction

Inertia Tensor (Angular Velocity and Acceleration)
Minimized by AOCS from SST & Inst. data

Differential Mode Sensitivity Matrix (Scale Factor Mismatching & Misalignment)
Estimated by calibration

Quadratic Residue

$$\begin{bmatrix} K_{cx} & \eta_{cz}+\theta_{cz} & \eta_{cy}-\theta_{cy} \\ \eta_{cz}-\theta_{cz} & K_{cy} & \eta_{cx}+\theta_{cx} \\ \eta_{cy}+\theta_{cy} & \eta_{cx}-\theta_{cx} & K_{cz} \end{bmatrix}$$

$$[In] = \begin{bmatrix} -\omega_y^2-\omega_z^2 & \omega_x\cdot\omega_y-\dot{\omega}_z & \omega_x\cdot\omega_z+\dot{\omega}_y \\ \omega_x\cdot\omega_y+\dot{\omega}_z & -\omega_x^2-\omega_z^2 & \omega_y\cdot\omega_z-\dot{\omega}_x \\ \omega_x\cdot\omega_z-\dot{\omega}_y & \omega_y\cdot\omega_z+\dot{\omega}_x & -\omega_x^2-\omega_y^2 \end{bmatrix}$$

$$\begin{bmatrix} K_{dx} & \eta_{dz}+\theta_{dz} & \eta_{dy}-\theta_{dy} \\ \eta_{dz}-\theta_{dz} & K_{dy} & \eta_{dx}+\theta_{dx} \\ \eta_{dy}+\theta_{dy} & \eta_{dx}-\theta_{dx} & K_{dz} \end{bmatrix}$$

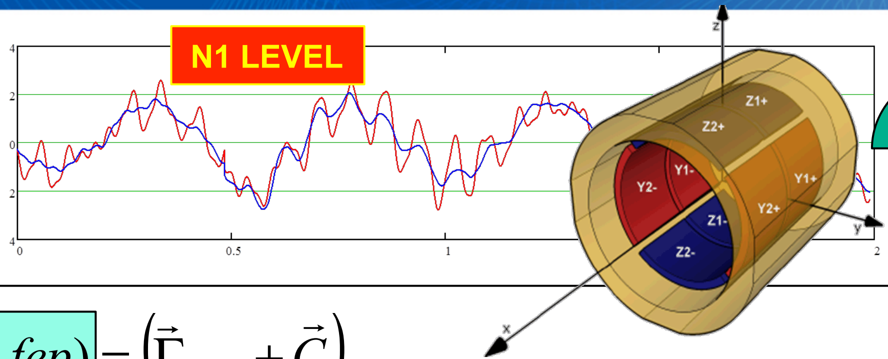
Stochastic and Tone Signals to be considered with a limited observation period and some lacks of data
→ Detailed Specifications for S/C Sub-Systems, Instrument Environment & Instrument Performances
→ Accurate in orbit calibration
→ A posteriori estimation and corrections

→ 10^{-15}

What do we measure? Each mass acceleration

$\vec{\Gamma}_{mes,is2}$

$\vec{\Gamma}_{mes,is1}$



$$\vec{\Gamma}_{mes,c} = \frac{1}{2}\left(\vec{\Gamma}_{mes,is2} + \vec{\Gamma}_{mes,is1}\right)$$

N2 LEVEL

$$\vec{\Gamma}_{mes,d} = \frac{1}{2}\left(\vec{\Gamma}_{mes,is2} - \vec{\Gamma}_{mes,is1}\right)$$

$$\vec{\Gamma}_{mes,c}(fep) = \left(\vec{\Gamma}_{res_{df}} + \vec{C}\right)$$

$$\Gamma_{mes,dx}(fep) = \frac{1}{2} K_{1cx} \cdot \delta \cdot g_{x/sat}$$

Searched EP signal

$$+\frac{1}{2}\begin{bmatrix} K_{1cx} \\ \eta_{cz} + \theta_{cz} \\ \eta_{cy} - \theta_{cy} \end{bmatrix}^t \cdot [T - In] \cdot \begin{bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{bmatrix}$$

Impact of gravity gradient and s/c angular motion

$$+\begin{bmatrix} K_{1dx} \\ \eta_{dz} + \theta_{dz} \\ \eta_{dy} - \theta_{dy} \end{bmatrix}^t \cdot \left(\vec{\Gamma}_{res_{df}} + \vec{C}\right)$$

Impact of residual acceleration through the difference of 2 TM matching

$$+2 \cdot K_{2cxx} \cdot \left(\Gamma_{app,dx} + b_{1dx}\right) \cdot \left(\Gamma_{res_{df},x} + C_x - b_{0cx}\right)$$

$$+K_{2dxx} \cdot \left(\left(\Gamma_{res_{df},x} + C_x - b_{0cx}\right)^2 + \left(\Gamma_{app,dx} + b_{1dx}\right)^2\right)$$

Impact of non linear terms

What do we calibrate?

$$
\begin{aligned}
\Gamma_{mes,dx}(fep) &= \frac{1}{2} K_{1cx} \cdot \delta \cdot g_{x/sat} \\
&+ \frac{1}{2} \begin{bmatrix} K_{1cx} \\ \eta_{cz} + \theta_{cz} \\ \eta_{cy} - \theta_{cy} \end{bmatrix}^t \cdot [T - In] \cdot \begin{bmatrix} \Delta_x \\ \Delta_y \\ \Delta_z \end{bmatrix} \\
&+ \begin{bmatrix} K_{1dx} \\ \eta_{dz} + \theta_{dz} \\ \eta_{dy} - \theta_{dy} \end{bmatrix}^t \cdot \left(\vec{\Gamma}_{res_{df}} + \vec{C} \right) \\
&+ 2 \cdot K_{2cxx} \cdot \left(\Gamma_{app,dx} + b_{1dx} \right) \cdot \left(\Gamma_{res_{df},x} + C_x - b_{0cx} \right) \\
&+ K_{2dxx} \cdot \left(\left(\Gamma_{res_{df},x} + C_x - b_{0cx} \right)^2 + \left(\Gamma_{app,dx} + b_{1dx} \right)^2 \right)
\end{aligned}
$$

MEASURED

CALIBRATED FOR CORRECTION

CALIBRATED FOR VERIFICATION

What we need to correct the measure ?

Element to subtract to the measure	Measured needed
$K_{1cx} \cdot T_{xx} \cdot \Delta_x$	S/C attitude, position, date
$K_{1cx} \cdot T_{xz} \cdot \Delta_z$	S/C attitude, position, date
$K_{1cx} \cdot T_{xy} \cdot \Delta_y$	S/C attitude, position, date
$(\eta_{cz} + \theta_{cz}) \cdot T_{yy} \cdot \Delta_y$	S/C attitude, position, date
$(\eta_{cy} - \theta_{cy}) \cdot T_{zz} \cdot \Delta_z$	S/C attitude, position, date
$2 \cdot K_{1dx} \cdot \Gamma_{res_{df},x}$	Common mode accelerometer measure
$2 \cdot (\eta_{dz} + \theta_{dz}) \cdot \Gamma_{res_{df},y}$	Common mode accelerometer measure
$2 \cdot (\eta_{dy} - \theta_{dy}) \cdot \Gamma_{res_{df},z}$	Common mode accelerometer measure
$4 \cdot K_{2,cxx} \cdot \Gamma_{app,dx} \cdot \Gamma_{res_{df},x}$	Negligible, not corrected at the moment
$2 \cdot K_{2,dxx} \cdot \left(\Gamma^2_{res_{df},x} + \Gamma^2_{app,dx}\right)$	Negligible, not corrected at the moment

What do we correct?.... @fep

N2 LEVEL = Diff acc corrected

$$\Gamma_{mes,dx}(fep) = \frac{1}{2}K_{1cx}\cdot\delta\cdot g_{x/sat} + \frac{1}{2}\begin{bmatrix}K_{1cx}\\ \eta_{cz}+\theta_{cz}\\ \eta_{cy}-\theta_{cy}\end{bmatrix}^t\cdot[T-In]\cdot\begin{bmatrix}\Delta_x\\ \Delta_y\\ \Delta_z\end{bmatrix} + \begin{bmatrix}K_{1dx}\\ \eta_{dz}+\theta_{dz}\\ \eta_{dy}-\theta_{dy}\end{bmatrix}^t\cdot\left(\vec{\Gamma}_{res_{df}}+\vec{C}\right) + 2\cdot K_{2cxx}\cdot\left(\Gamma_{app,dx}+b_{1dx}\right)\cdot\left(\Gamma_{res_{df},x}+C_x-b_{0cx}\right) + K_{2dxx}\cdot\left(\left(\Gamma_{res_{df},x}+C_x-b_{0cx}\right)^2+\left(\Gamma_{app,dx}+b_{1dx}\right)^2\right)$$

Mean Square Extraction of 3 parameters

$$K_{1cx}\cdot\delta \qquad \begin{bmatrix}\Delta(\Delta_x)\\ 0\\ \Delta(\Delta_z)\end{bmatrix}$$

N2a,b,c

$$\Gamma_{mes,dx}(fep) - \frac{1}{2}\begin{bmatrix}K_{1cx}\\ \eta_{cz}+\theta_{cz}\\ \eta_{cy}-\theta_{cy}\end{bmatrix}^t_{calibrated}\cdot[T]_{computed}\cdot\begin{bmatrix}\Delta_x\\ \Delta_y\\ \Delta_z\end{bmatrix}_{calibrated} - \begin{bmatrix}K_{1dx}\\ \eta_{dz}+\theta_{dz}\\ \eta_{dy}-\theta_{dy}\end{bmatrix}^t_{calibrated}\cdot\left(\vec{\Gamma}_{mes,c}\right)$$

$$\approx \frac{1}{2}K_{1cx}\cdot\delta\cdot g_{x/sat} + \frac{1}{2}\begin{bmatrix}K_{1cx}\\ 0\\ 0\end{bmatrix}^t\cdot[T]_{computed}\cdot\begin{bmatrix}\Delta(\Delta_x)\\ 0\\ \Delta(\Delta_z)\end{bmatrix} + residues$$

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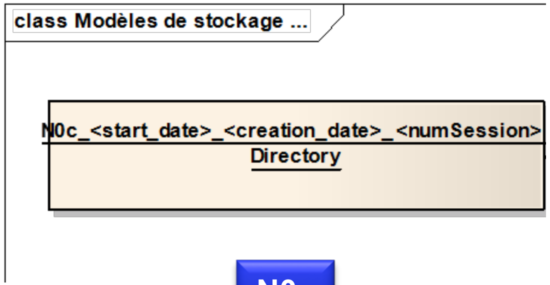
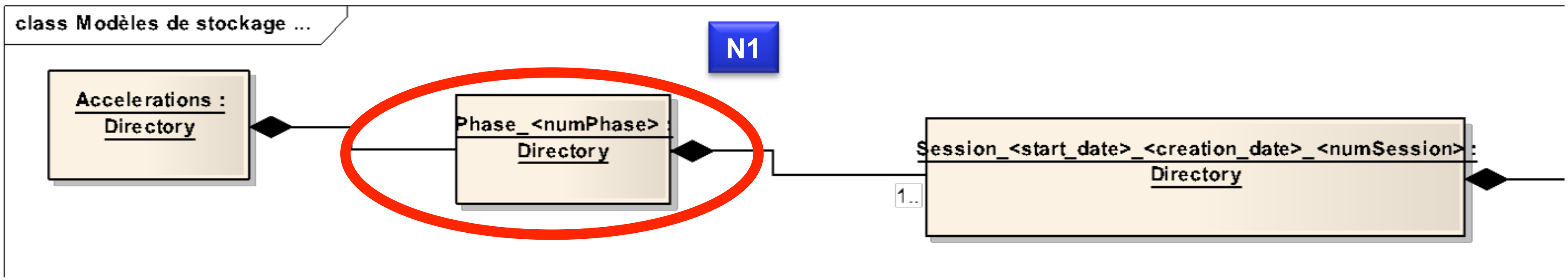
LEVEL 1 DATA architecture : organized by mission phase and sessions



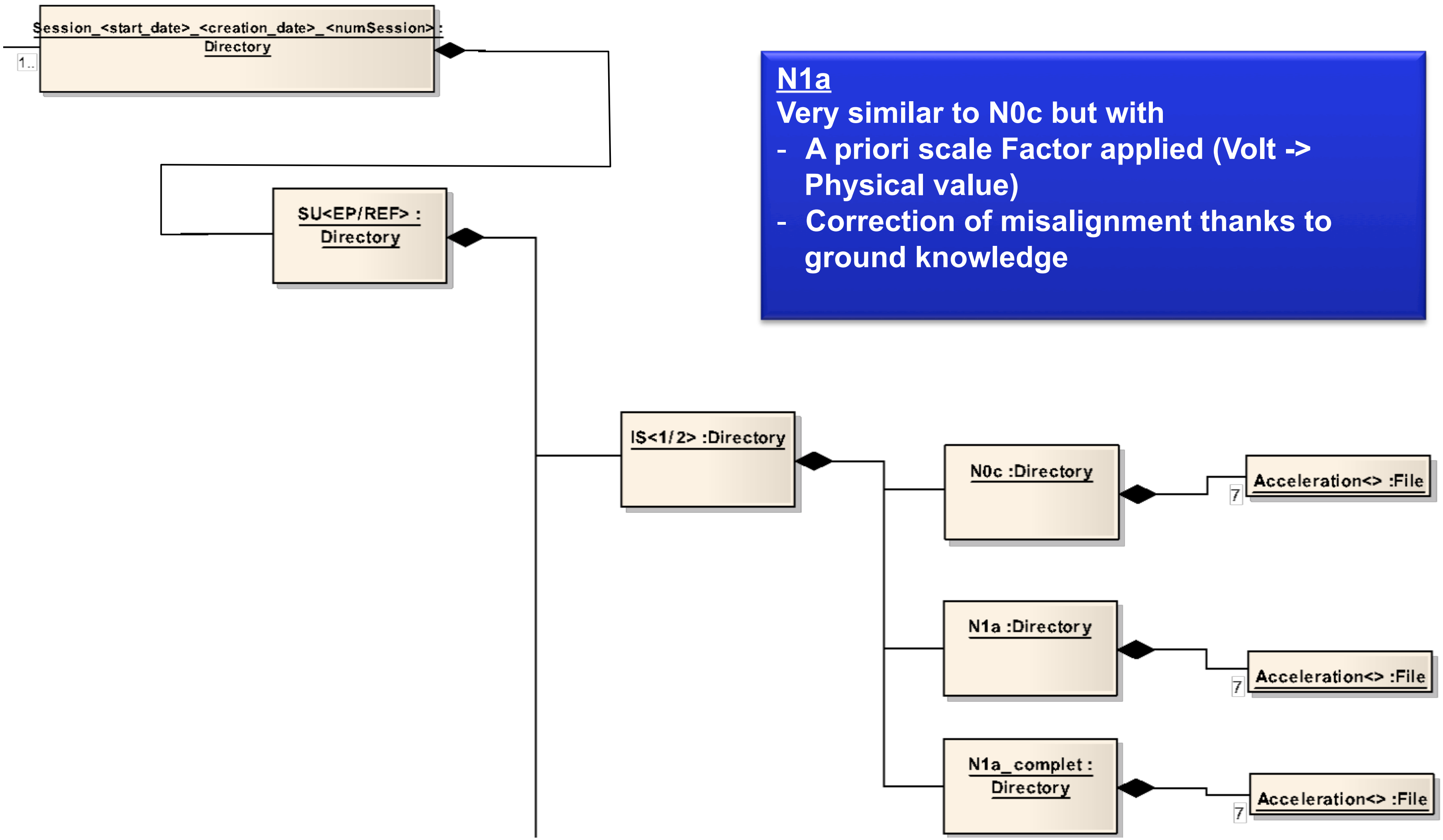
N0c

Num Seq	dateDebut	nomFiche	Num Orb	contrainte Environnement	crit.	duree	etat	conso GazZp	conso GazZm	capacite Gaz_Zp	capacite GazZm
115	2016-11-16T06:44:59.554560		4048	NO_ECLIPSE_NO_LUNE	1	0.52	AE	0.8	0.8	5736.3	5536.3
116	2016-11-16T07:36:39.554559	EPR_V2_01_SUREF	4049	NO_ECLIPSE_NO_LUNE	1	120.00	AE	180	180	5556.3	5356.3
117	2016-11-24T15:36:39.540159		4169	NO_ECLIPSE_NO_LUNE	1	1.78	AE	2.7	2.7	5553.6	5353.6
118	2016-11-24T18:34:59.540158	EPR_V1_01_SUEP	4170	NO_ECLIPSE_NO_LUNE	1	120.00	AE	180	180	5373.6	5173.6
119	2016-12-03T02:34:59.525758		4290	NO_ECLIPSE_NO_LUNE	1	1.78	AE	2.7	2.7	5370.9	5170.9
120	2016-12-03T05:33:19.525758	EPR_V2_01_SUEP	4292	NO_ECLIPSE_NO_LUNE	1	120.00	AE	180	180	5190.9	4990.9
121	2016-12-11T13:33:19.511357		4412	LUNE	1	0.00	AE	0	0	5190.9	4990.9
122	2016-12-11T13:33:19.511357	TSNA	4412	LUNE	1	55.00	AE	0	0	5190.9	4990.9
123	2016-12-15T09:13:19.504757		4467	NO_ECLIPSE_NO_LUNE	1	0.52	AE	0.8	0.8	5190.1	4990.1
124	2016-12-15T10:04:59.504757	CAL_deltaXZ_01_SUEP	4468	NO_ECLIPSE_NO_LUNE	1	10.00	AE	15	15	5175.1	4975.1
125	2016-12-16T02:44:59.503557		4478	NO_ECLIPSE_NO_LUNE	1	1.18	AE	1.8	1.8	5173.3	4973.3
126	2016-12-16T04:43:19.503557	CAL_deltaY_01_SUEP	4479	NO_ECLIPSE_NO_LUNE	1	10.00	AE	15	15	5158.3	4958.3
127	2016-12-16T21:23:19.502357		4489	NO_ECLIPSE_NO_LUNE	1	1.18	AE	1.8	1.8	5156.5	4956.5

MISSION SCENARIO



LEVEL 1 DATA architecture : Inertial sensor directories for each session

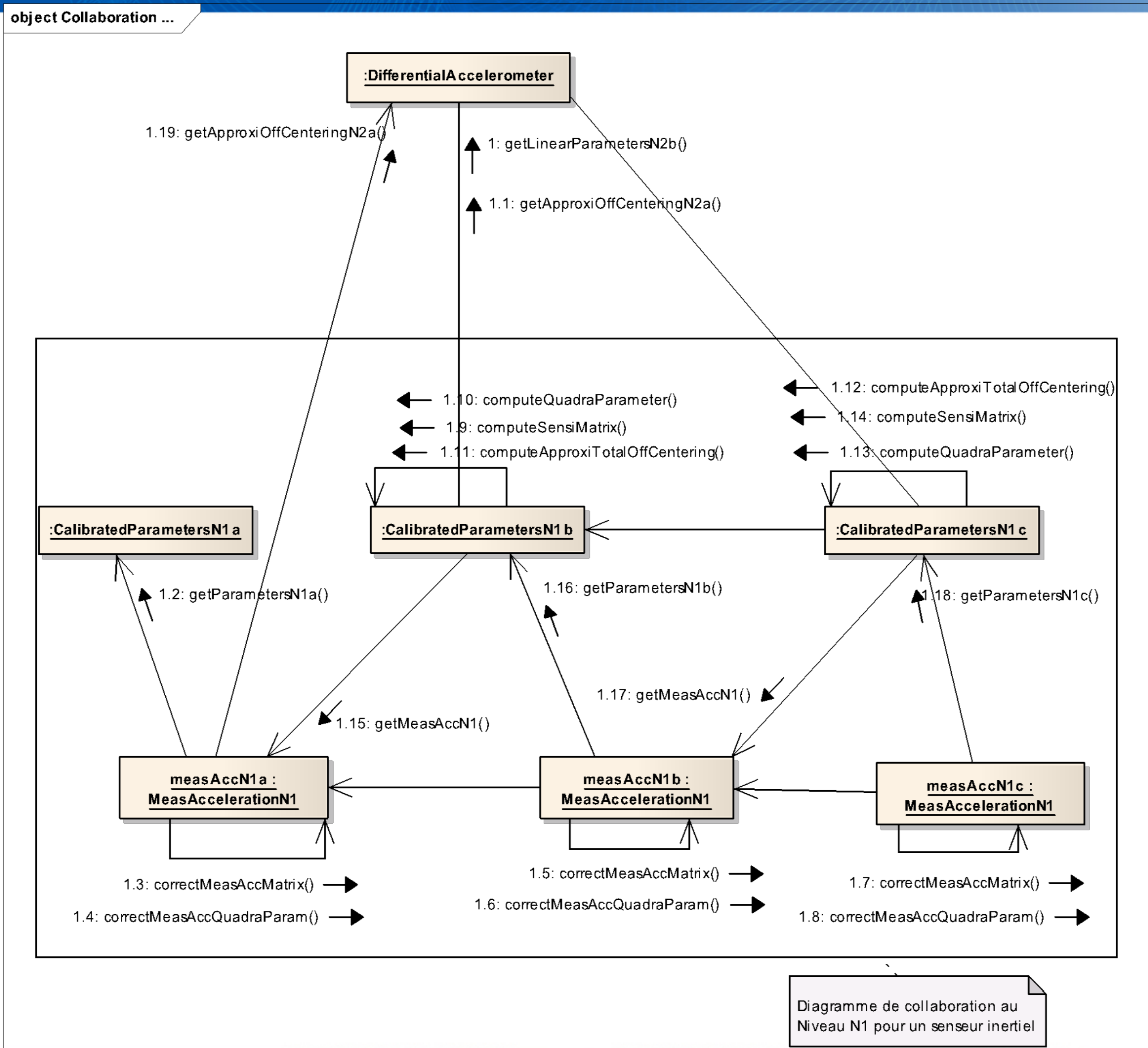


N1a

Very similar to N0c but with

- **A priori scale Factor applied (Volt -> Physical value)**
- **Correction of misalignment thanks to ground knowledge**

PRODUCTION OF N1 FROM N0c
=> DATA TO BE DISTRIBUTED



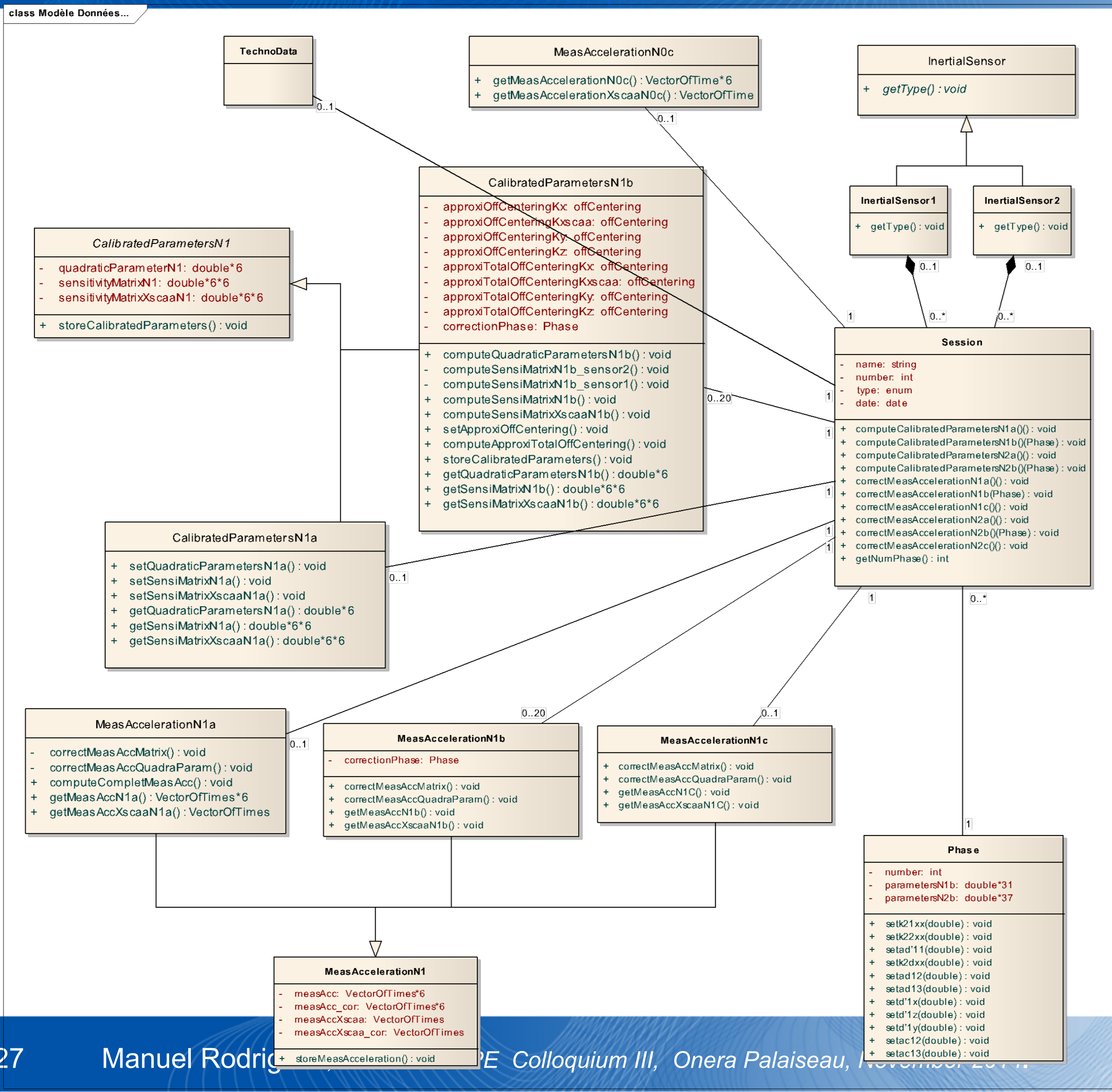
N1a
N0c data with the best estimation of SF and alignment known on ground

N1b
N1a corrected by the estimation of SF and alignment known from the most current calibration phase

N1c
N1b corrected of SF and alignment known from the best fit of all calibration phases

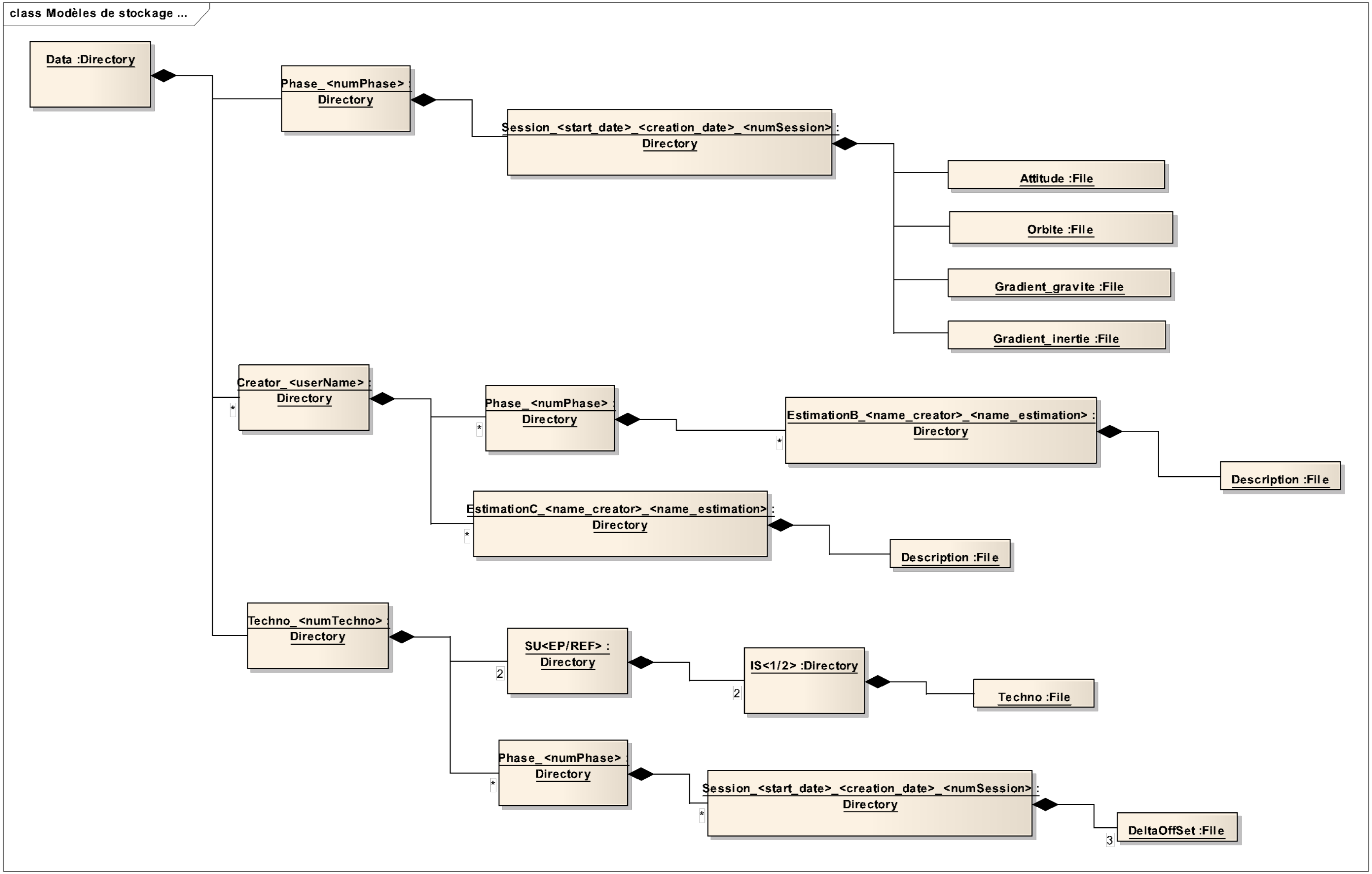
N1d……
The data structure allows the addition of other correction model

N1 LEVEL STRUCTURE

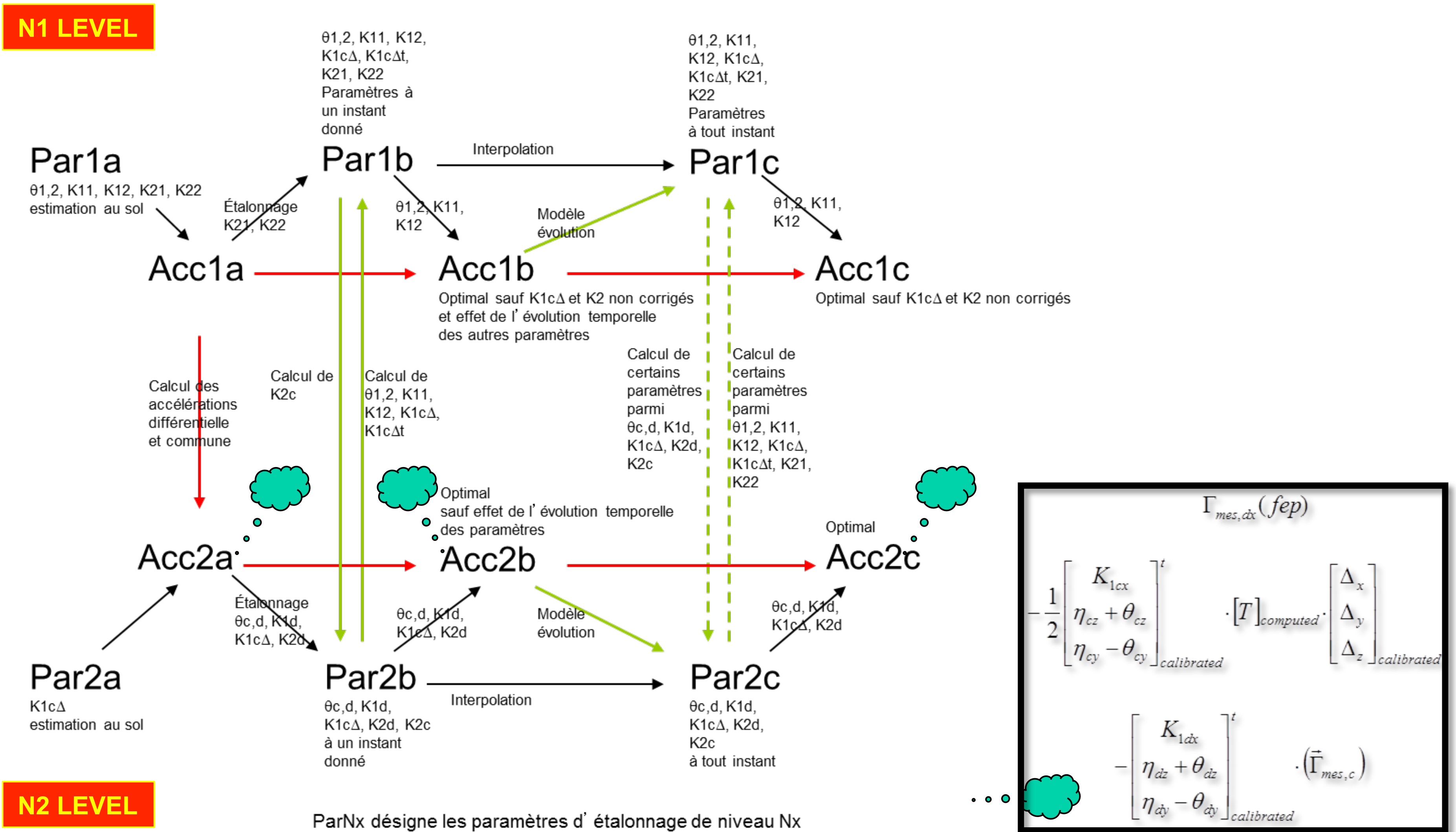


+ ATTITUDE AND ORBIT

ATTITUDE AND ORBIT ; TEHNO FILES

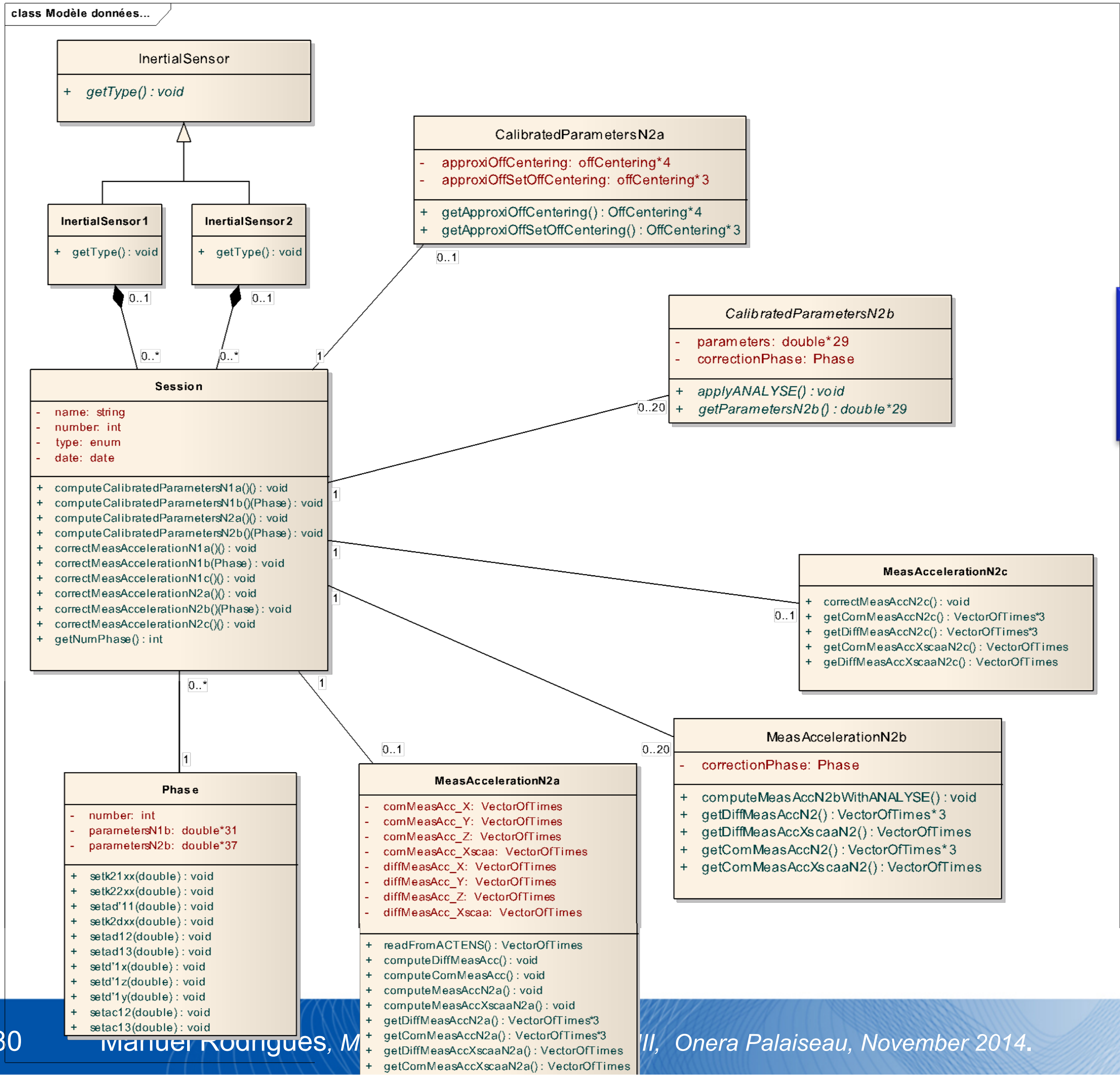


PRODUCTION OF N2 FROM N1



ParNx désigne les paramètres d' étalonnage de niveau Nx
AccNx désigne les mesures accélérométriques de niveau Nx

N2 LEVEL STRUCTURE



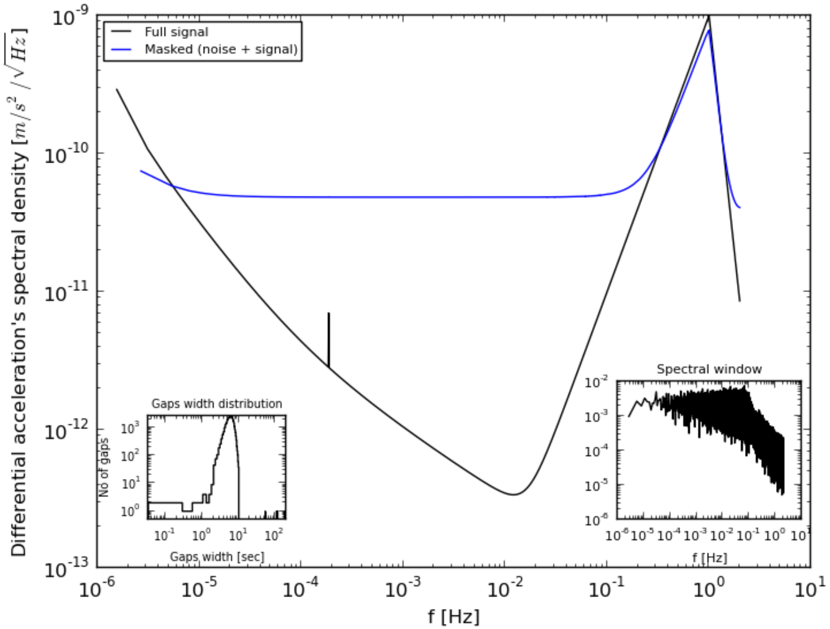
+ EP Parameters estimaded:
d
Dx
Dz

Summary

- The Science Mission Center : CMS-MICROSCOPE
- The mission data flow and tree
- **Specific data process**
- The current development of the Science Mission Center

Effect of missing data (holes)

- Missing data because of teletransmission problems, instrument's saturation due to mechanical crackles…
- Effects on measurement:
  - Distortions in frequency space due to abrupt truncation
  - Increase frequency projections on EP-test frequency
  - Spectral leakage due to a convolution between the mask and the signal
- Leakage particularly impeding for MICROSCOPE because of the high-frequency noise

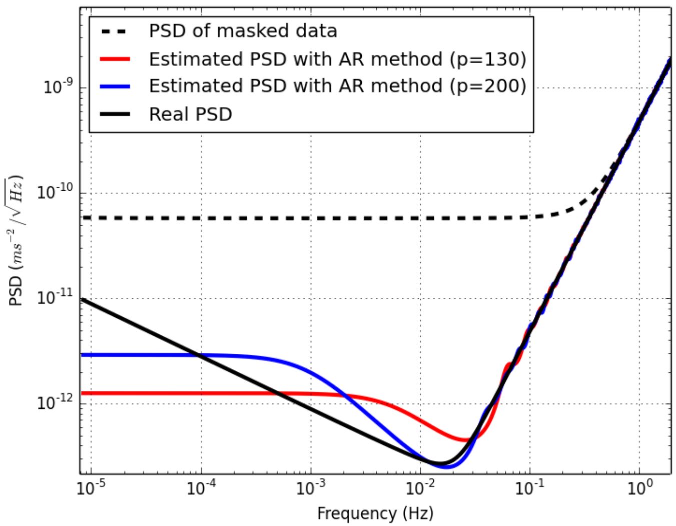


A possible method

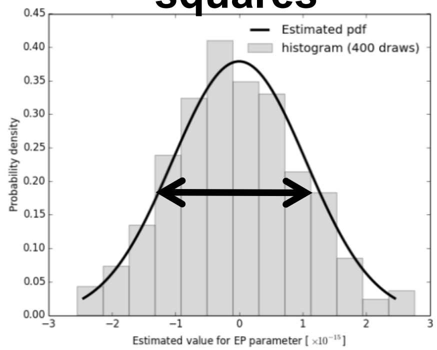
If we do not assume any prior knowledge of the noise PSD, one can preliminarily estimate the noise correlations with an autoregressive (AR) model : robust method even when data are missing

AR model $$X(t) + a_1 X(t-1) + \ldots + a_p X(t-p) = \epsilon(t)$$

PSD estimation with AR model from gapped data



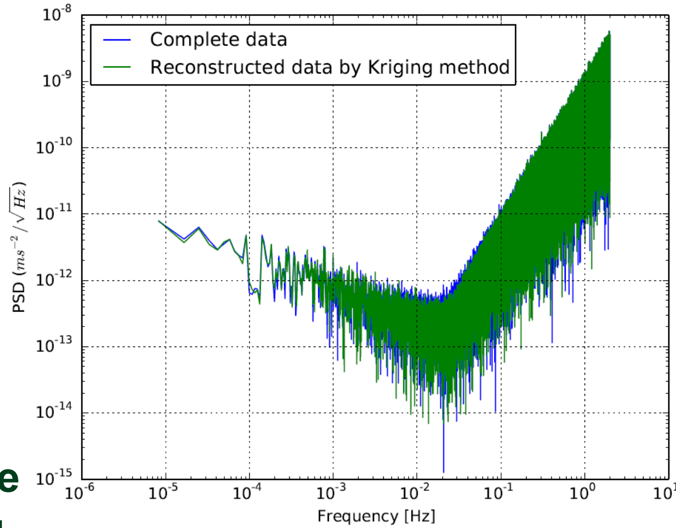
EP estimation error with weighted least squares



$\sigma_\delta = 1\times10^{-15}$

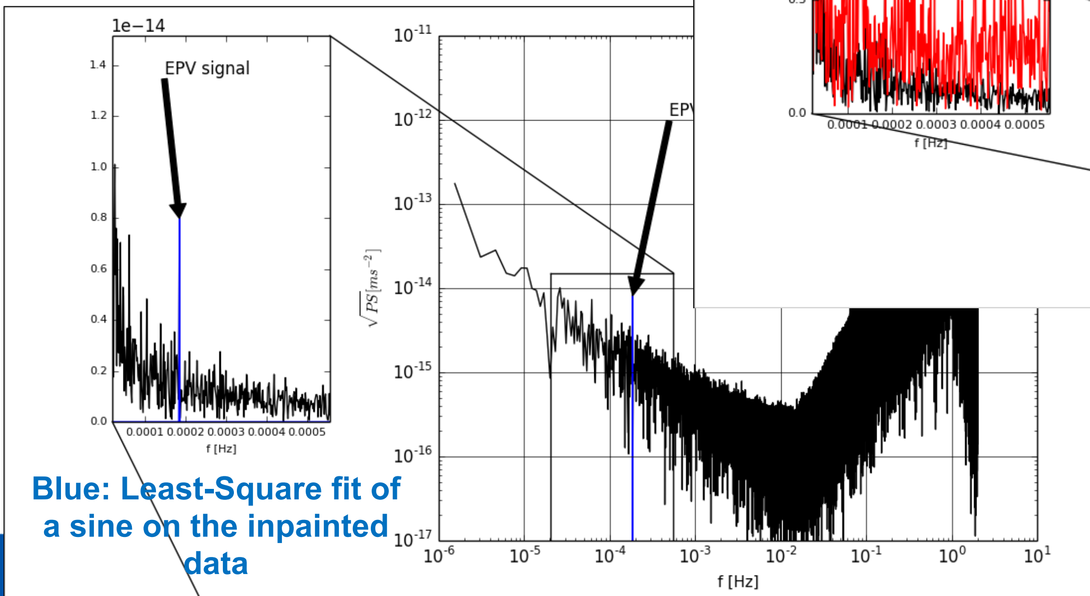
Uncertainty is acceptable even if data are missing

Use AR model for data imputation

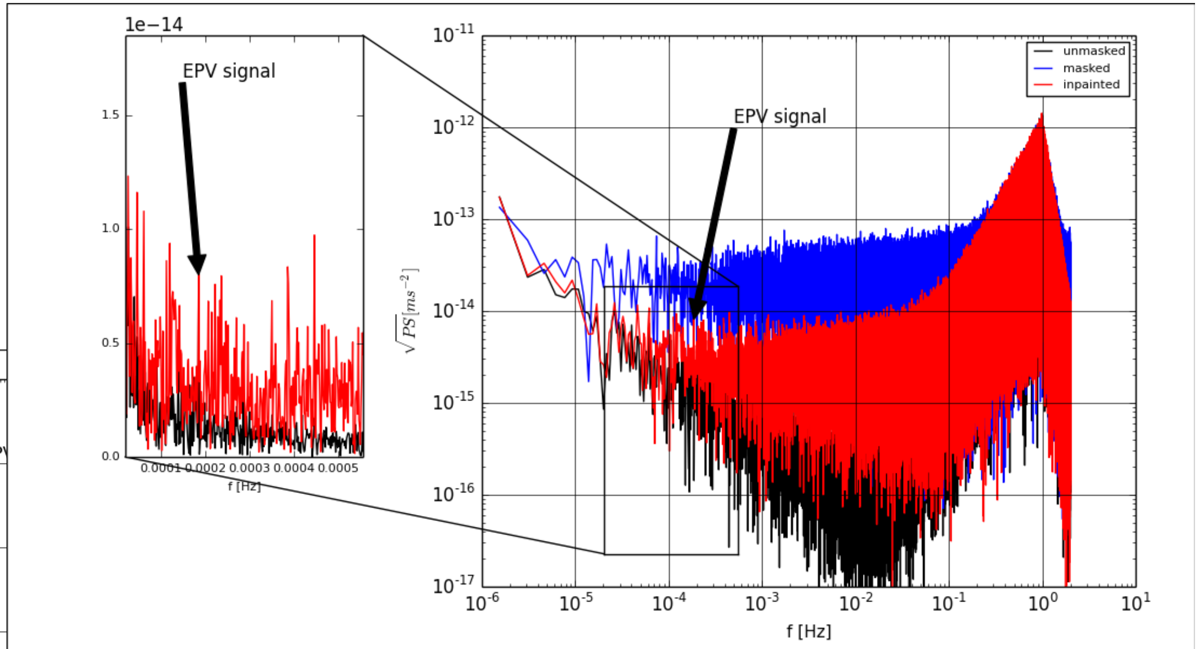


Inpainting and MICROSCOPE (see poster in coffee break room)

- Inpainting developed by AIM/CEA, originally for 2D astronomy images; already adapted to time series for asteroseismology
- Extrapolation of the missing information with sparsity prior on the solution: there is a function dictionary on which the complete data are sparse (very few non-negligible coefficients) but the incomplete data are not sparse



Blue: Least-Square fit of a sine on the inpainted data



Summary

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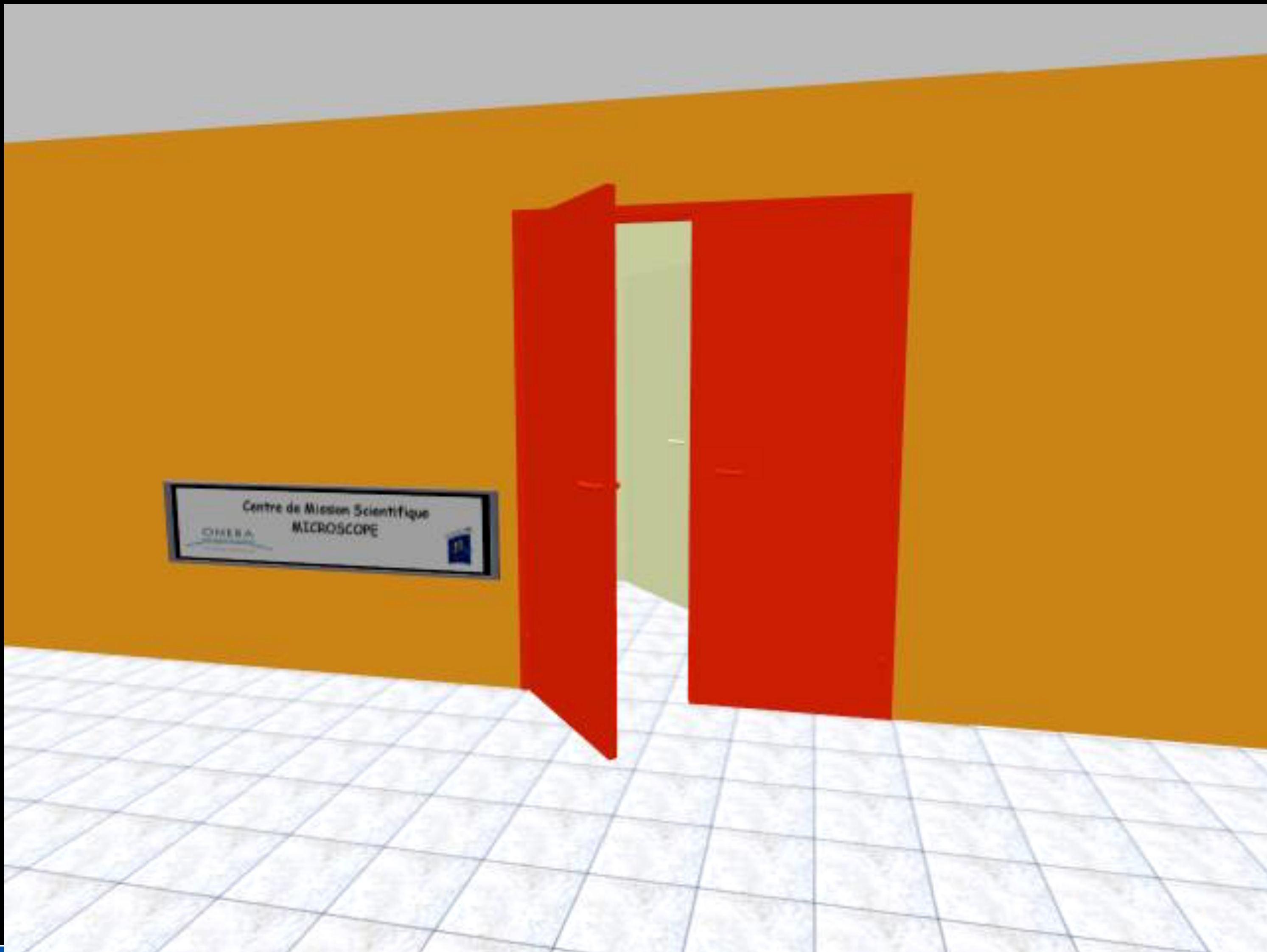
CMSM development status

- The CMS_Op: the operational pole
  - September 2014: successful 1st test of interface with CNES
  - 5th of November 2014: start of technical qualification:
    - Mission scenario exchange, modification,… like in flight
    - N0 production and process: verification of good health of the satellite, of the subsystems and of the instrument: all software tools ready, criteria of alert TBD, robustness of the system to anomalies TBD, robustness of the system to data replay TBD
- The CMS_Sci: the science pole
  - The software is 50% ready
  - Basic production of N1a, N1b, N2a, N2b : OK
  - Some interface with OCA tools to be validated
  - Implementation of missing data correction or of more complex calibration laws : To Be Done.
  - Objective: ready for June 2015

Objective for September 2015:
READY FOR OPERATIONAL QUALIFICATION



THANK YOU FOR YOUR ATTENTION