



OPERATIONS FOR LISA PATHFINDER: 20' IN FREE FALL

Michele Armano
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- LPF “science by examples” distilled for you!
- Mimicking operations: (a few of) the secrets of the LPF Science and Technology Operation Centre (STOC)
- The case of STOC Exercises and Simulations
- Questions

Strain is everything!

$$h = \frac{\delta L}{L} \sim \frac{R_{0j0k}}{\omega^2}$$

- The main observable to do astronomy with GWs is distance variation over a reference (strain)
- it can be measured (essentially) by interferometers (variation of path-length)
- it is tiny (field+geometry structure of gravity)
- it couples with (far too) many things that look like it

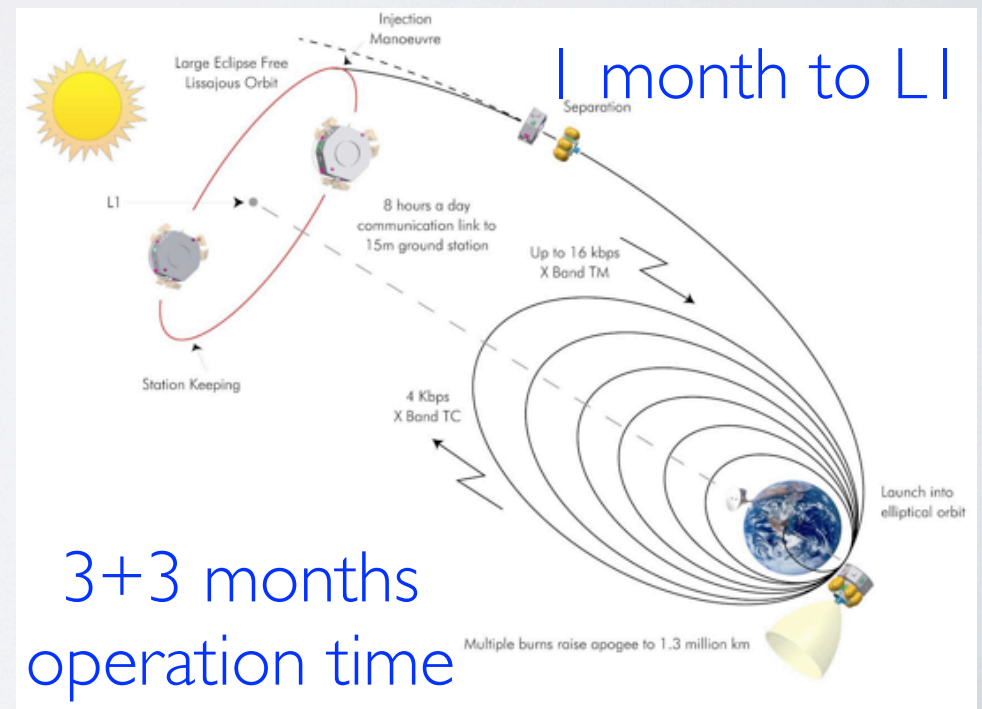
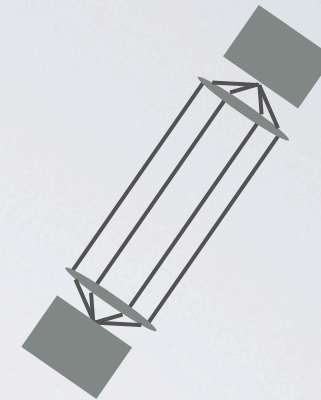
Residual acceleration $\frac{\delta a}{\omega c}$

Forces $\frac{\delta F}{m\omega c}$

Displacement via "springs" $\frac{\omega \delta x}{c}$

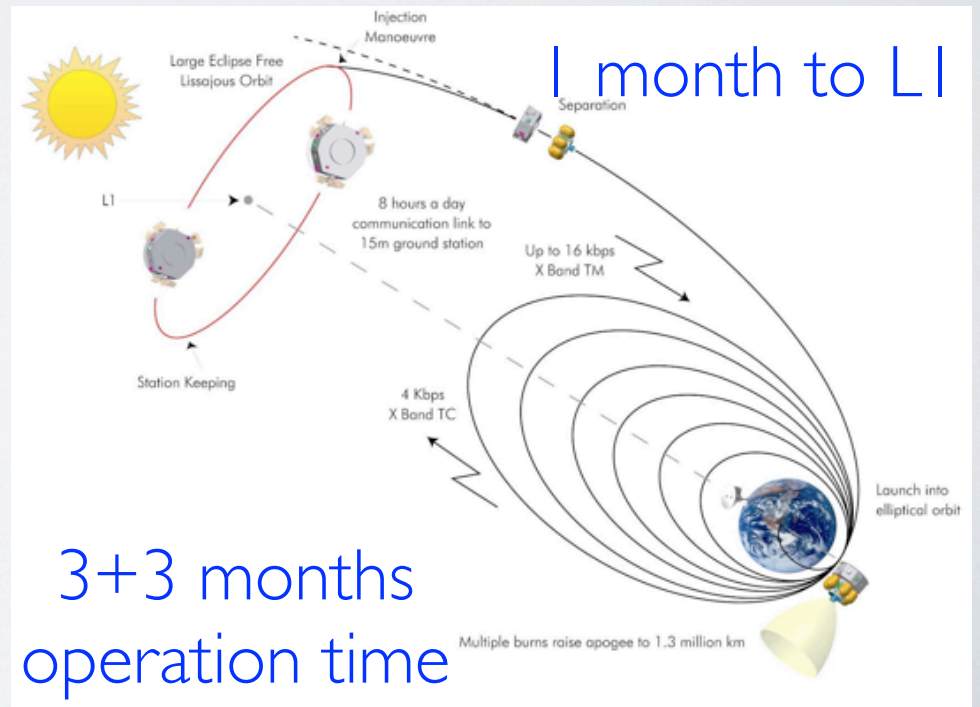
The “Pathfinder”

- for ANY detector:
 - free-fall ($\delta a/\omega c \ll h$) via high-precision rockets & drag-free
 - shielded + low-noise sensing ($\delta F/m\omega c, \omega\delta x/c \ll h$)
- for our detector:
 - Shrink 1 arm of (e)LISA to 38 cm
 - Fit into one spacecraft and send it to the Lagrangian point L1
 - Measure relative acceleration: 1/10th of observatory goals



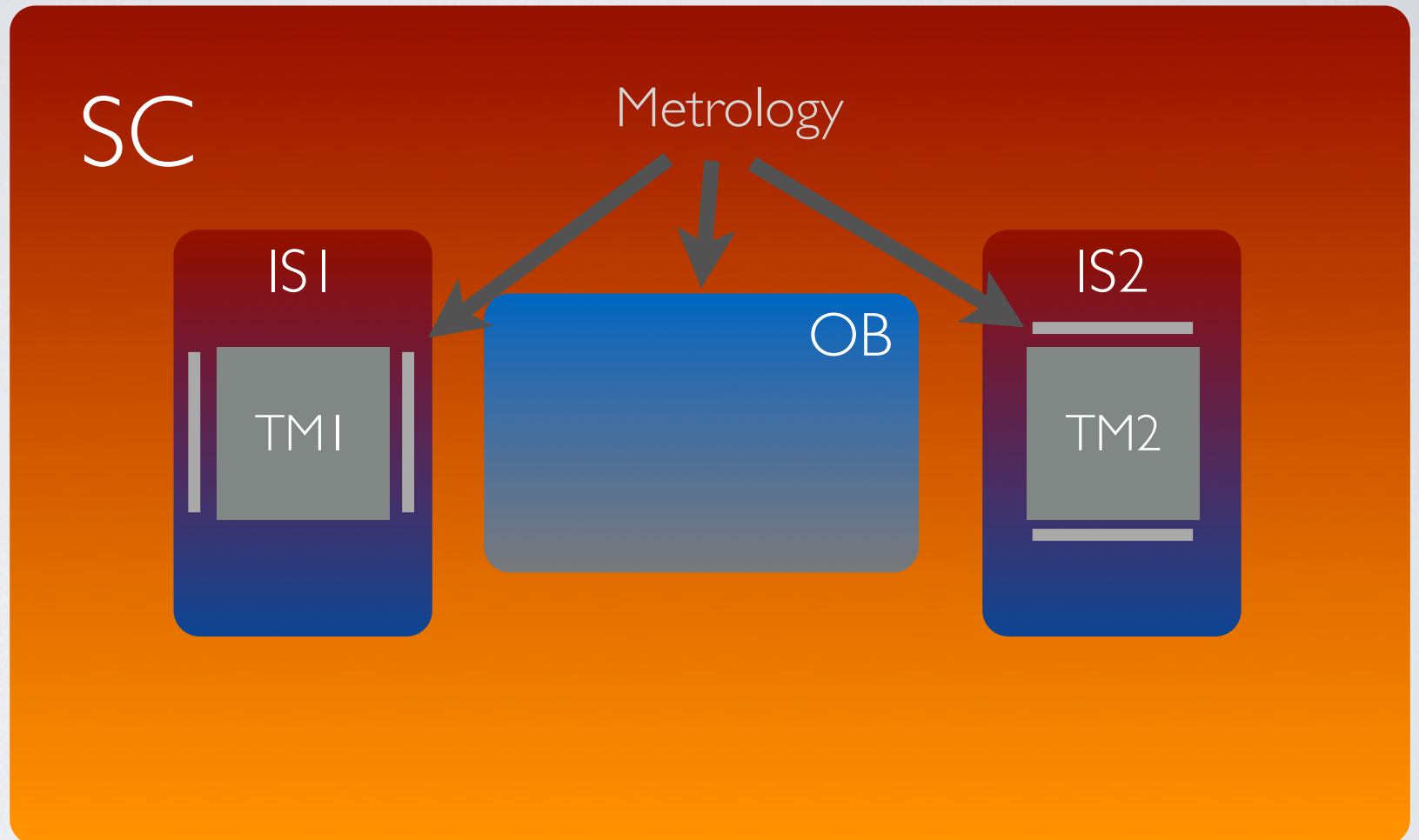
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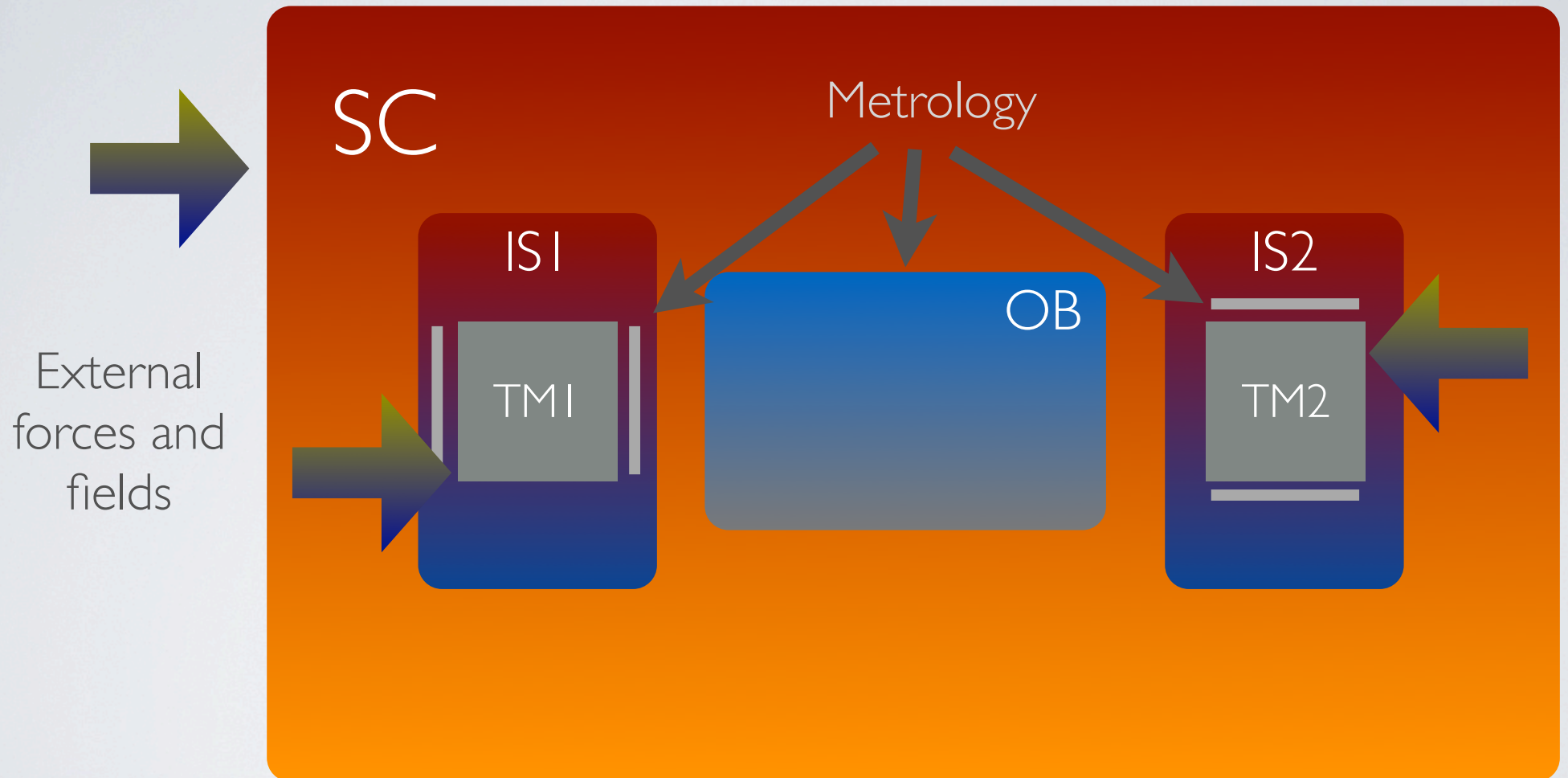
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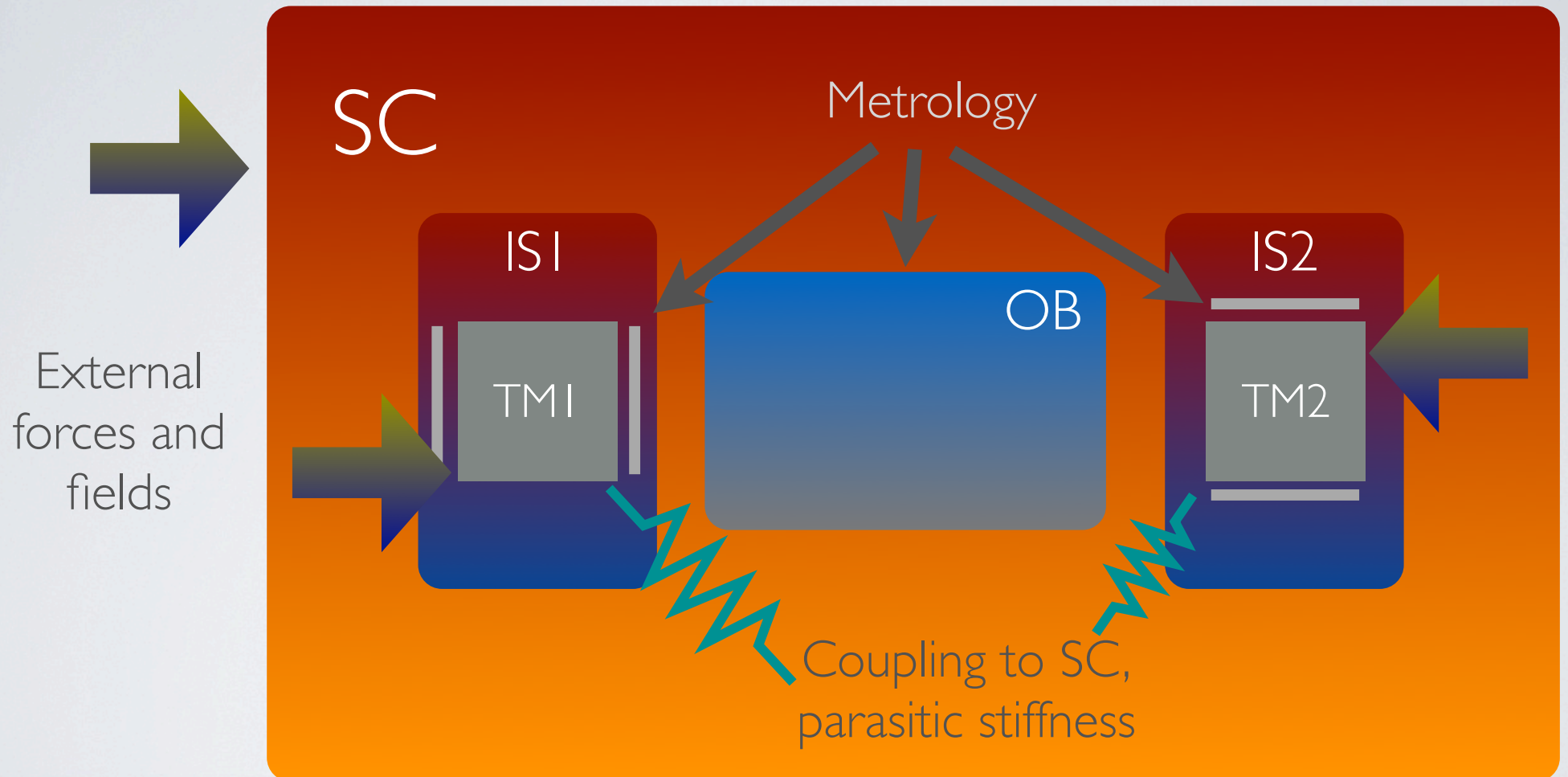


SC

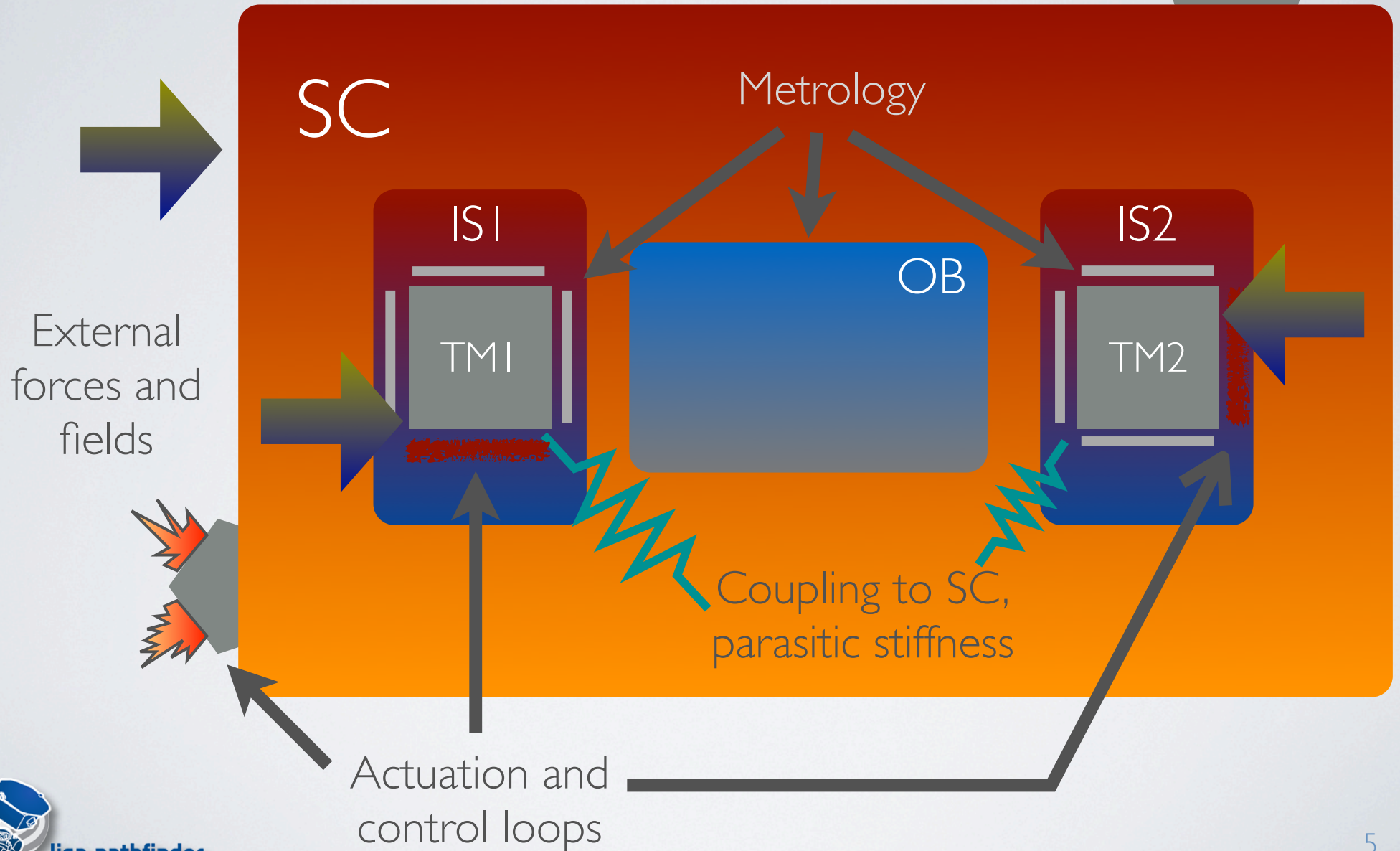






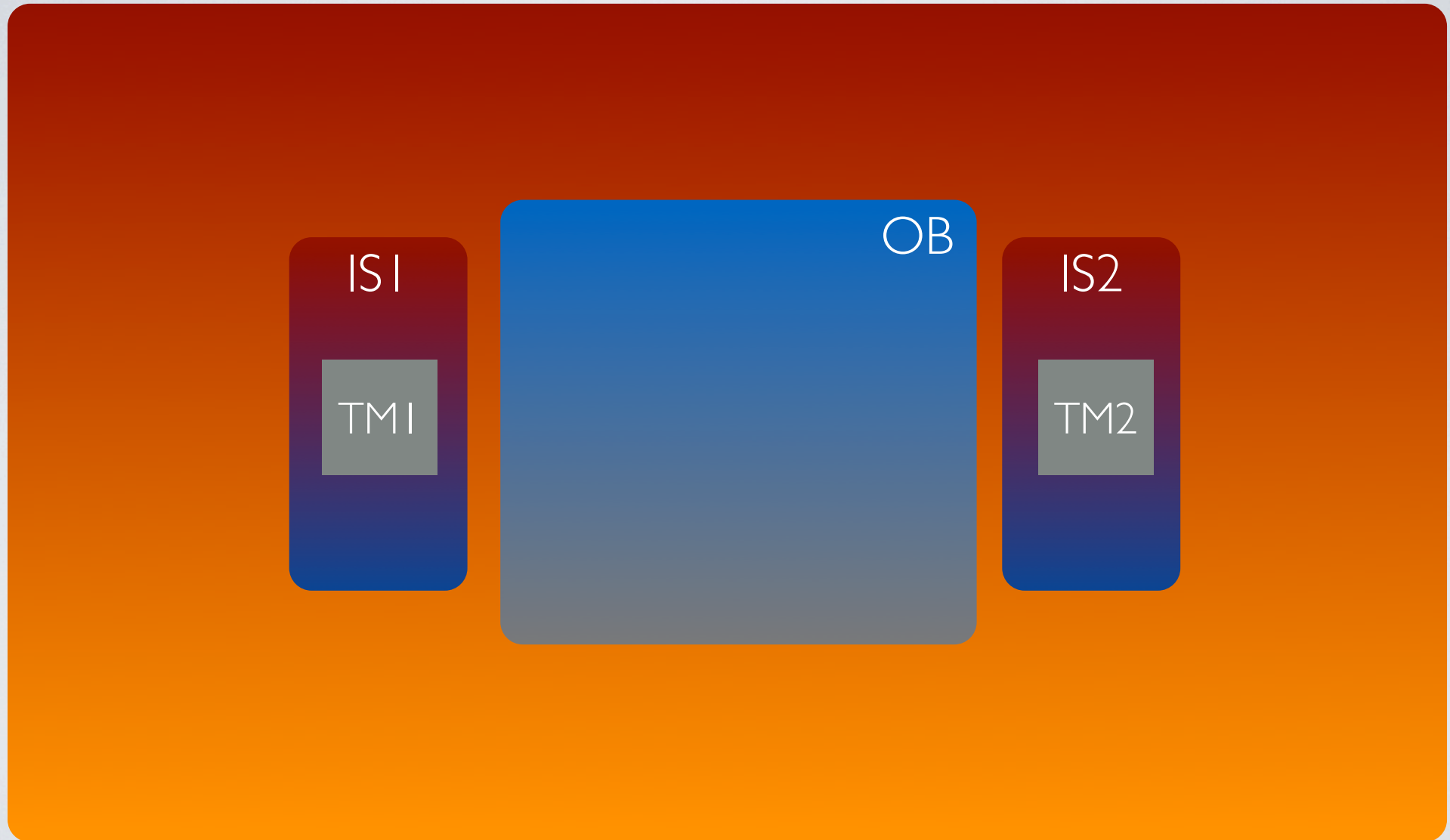


Inside LPF: the model and the disturbances

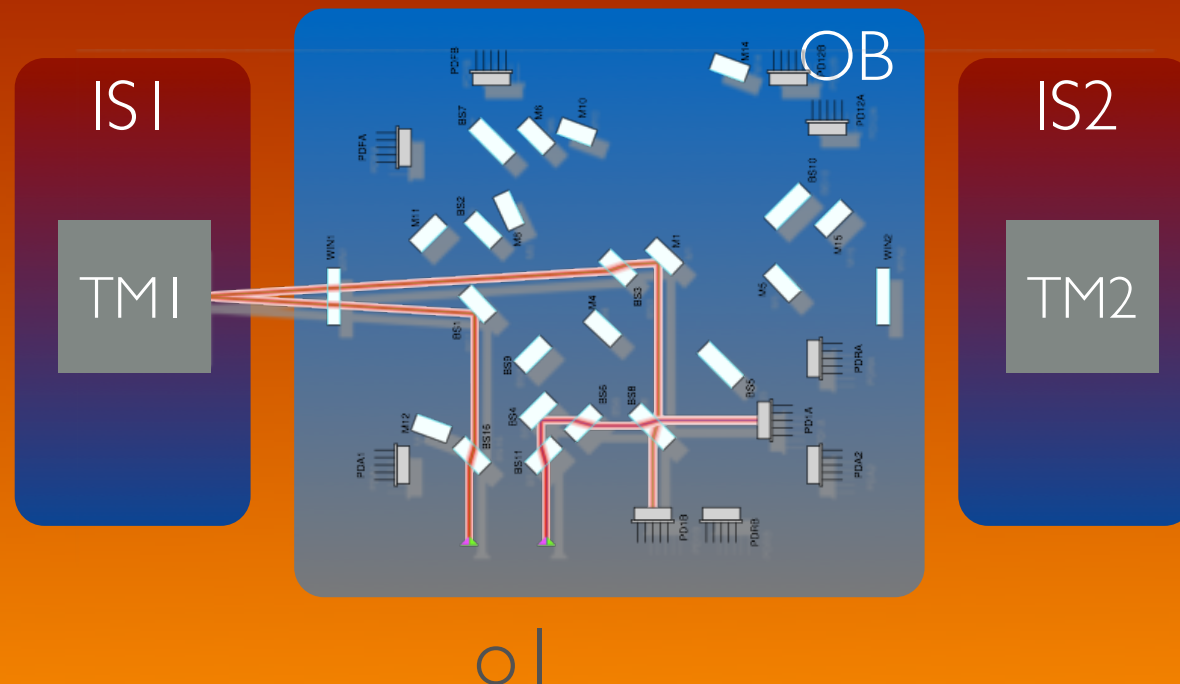


- The dynamics of the SC and the Instrument are always coupled
 - operations design is very different from the “usual” observatory and looks more like a laboratory in space
 - system and operations engineering are (almost) one
 - many MOC responsibilities are shared with the STOC
- The science of LPF is organized in “themes” and “experiments” onboard aiming at minimizing the residual acceleration curve and characterize the environment of (e)LISA-like observatories
 - most tests are based on the “inject null to get null” principle: orthogonal things don’t give cross-talk, if there’s any then couplings must be measurable and and their effect (possibly) subtracted.

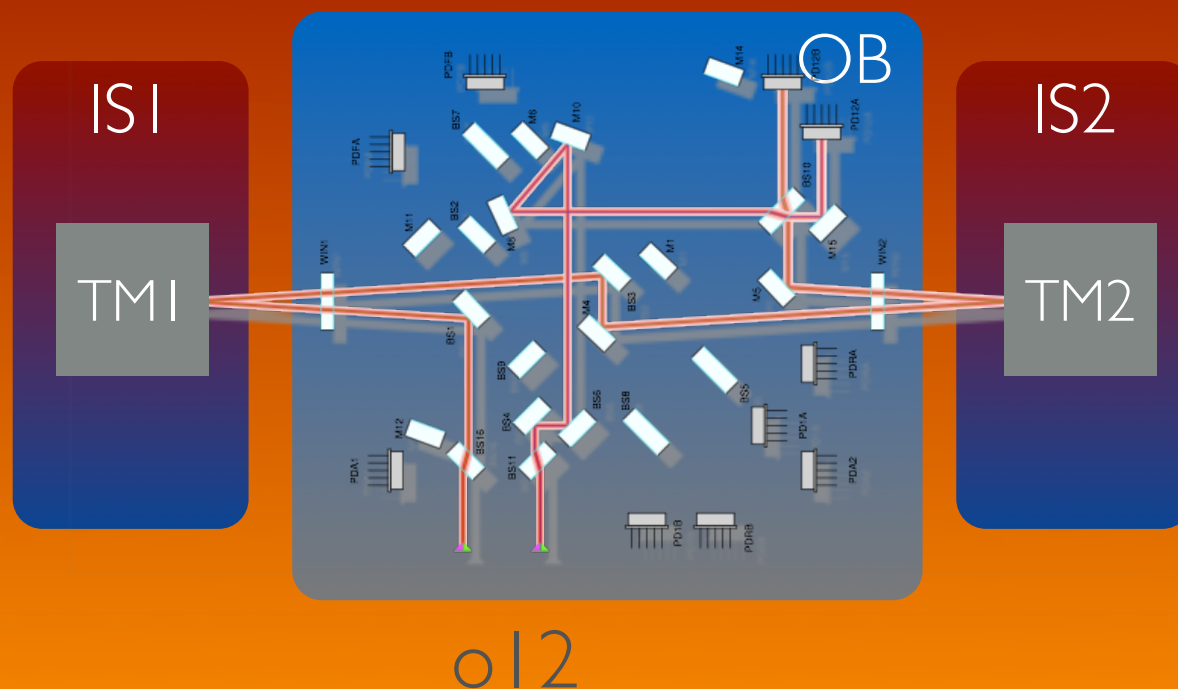
Experiment I: Calibration of Interferometry



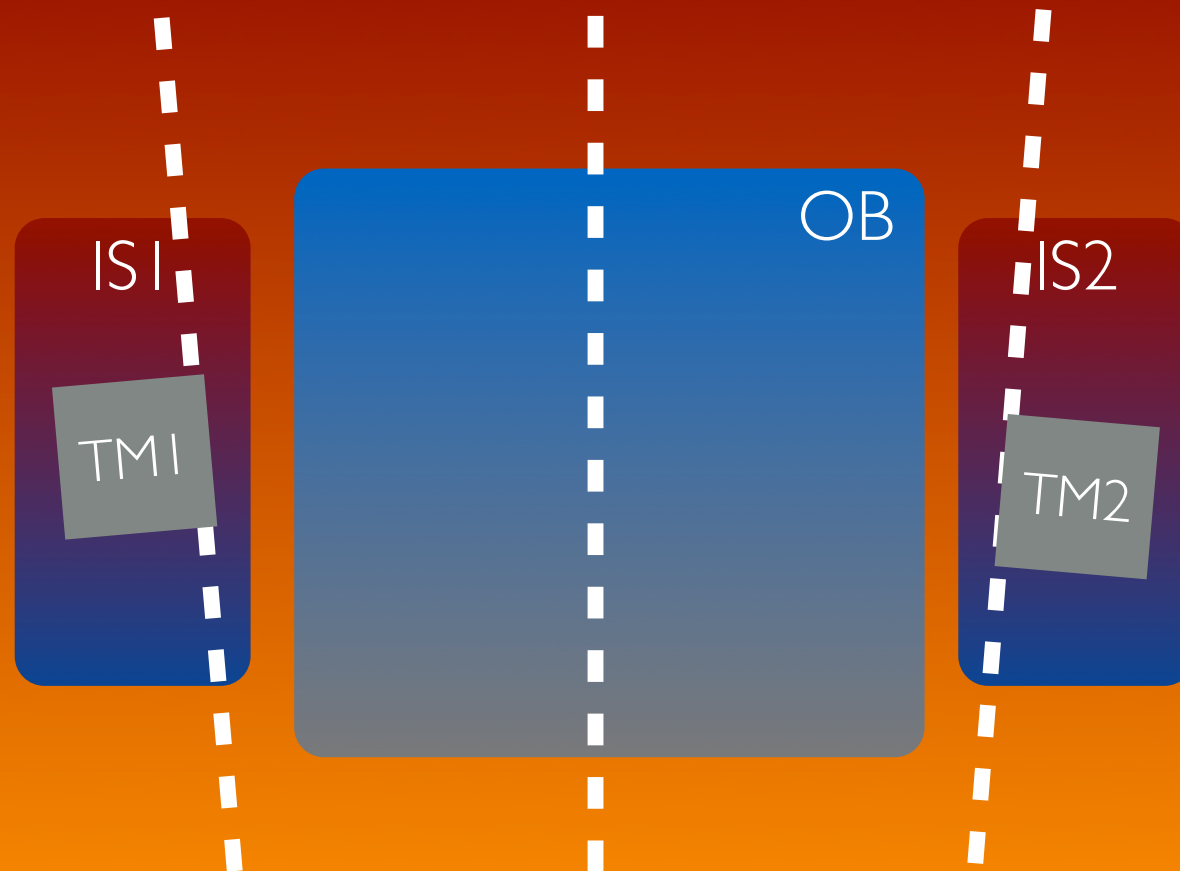
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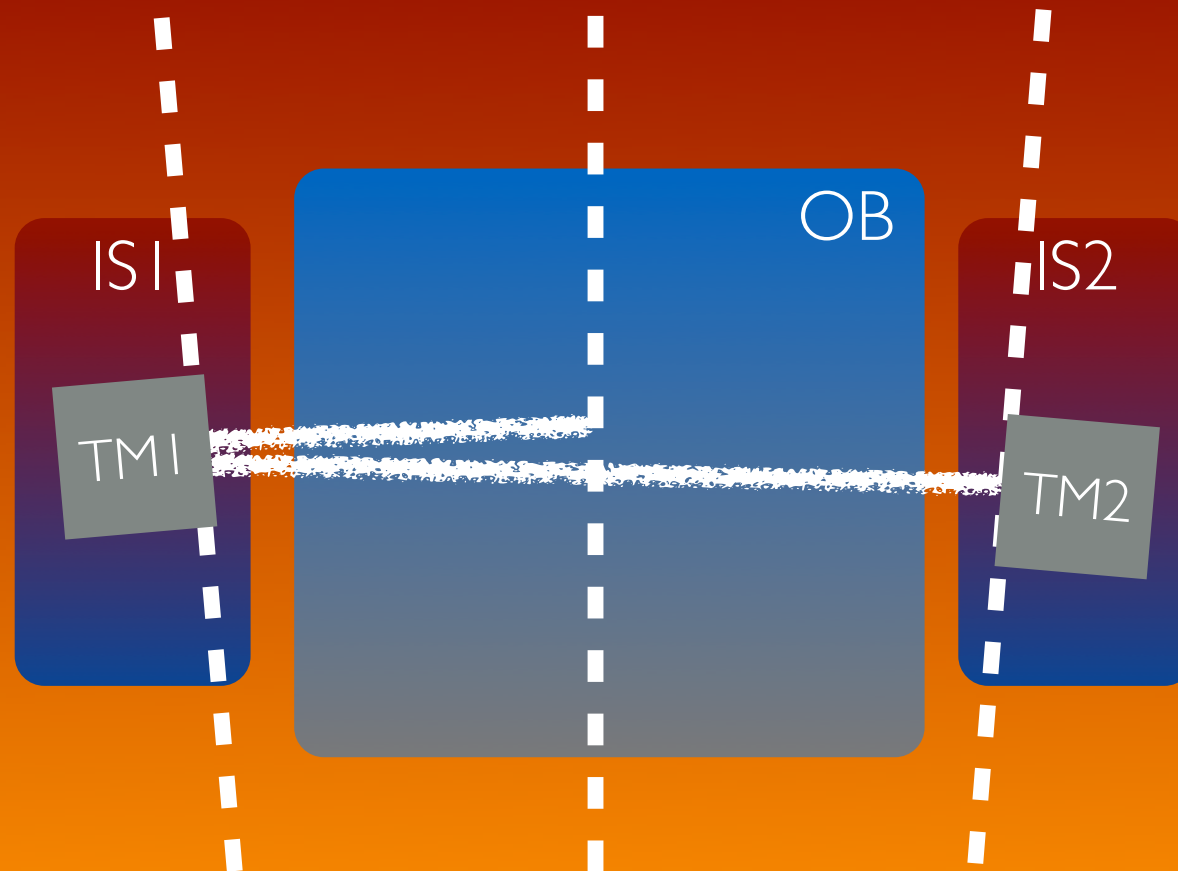
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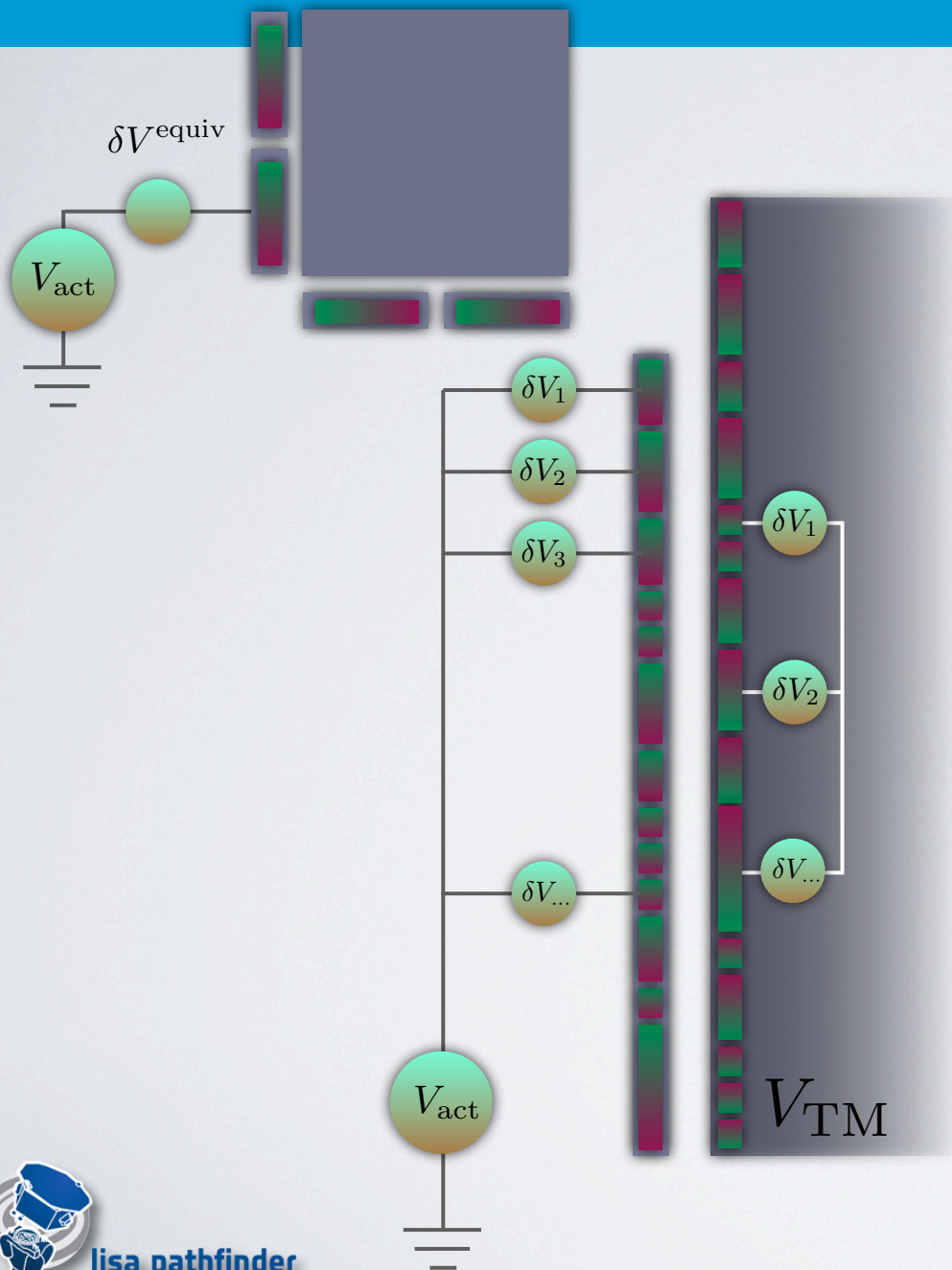
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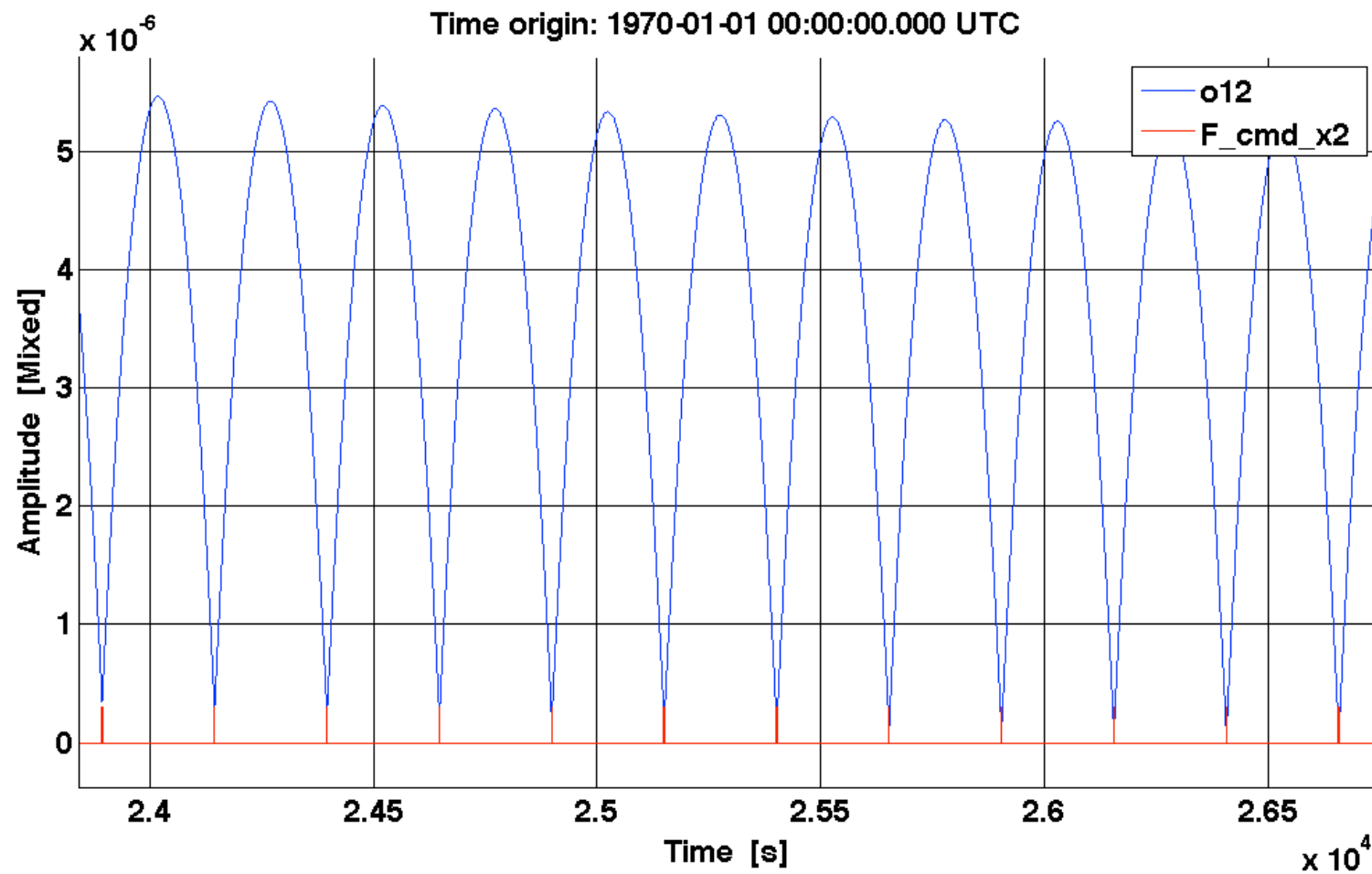


Experiment 2: know thy (DC) potential!

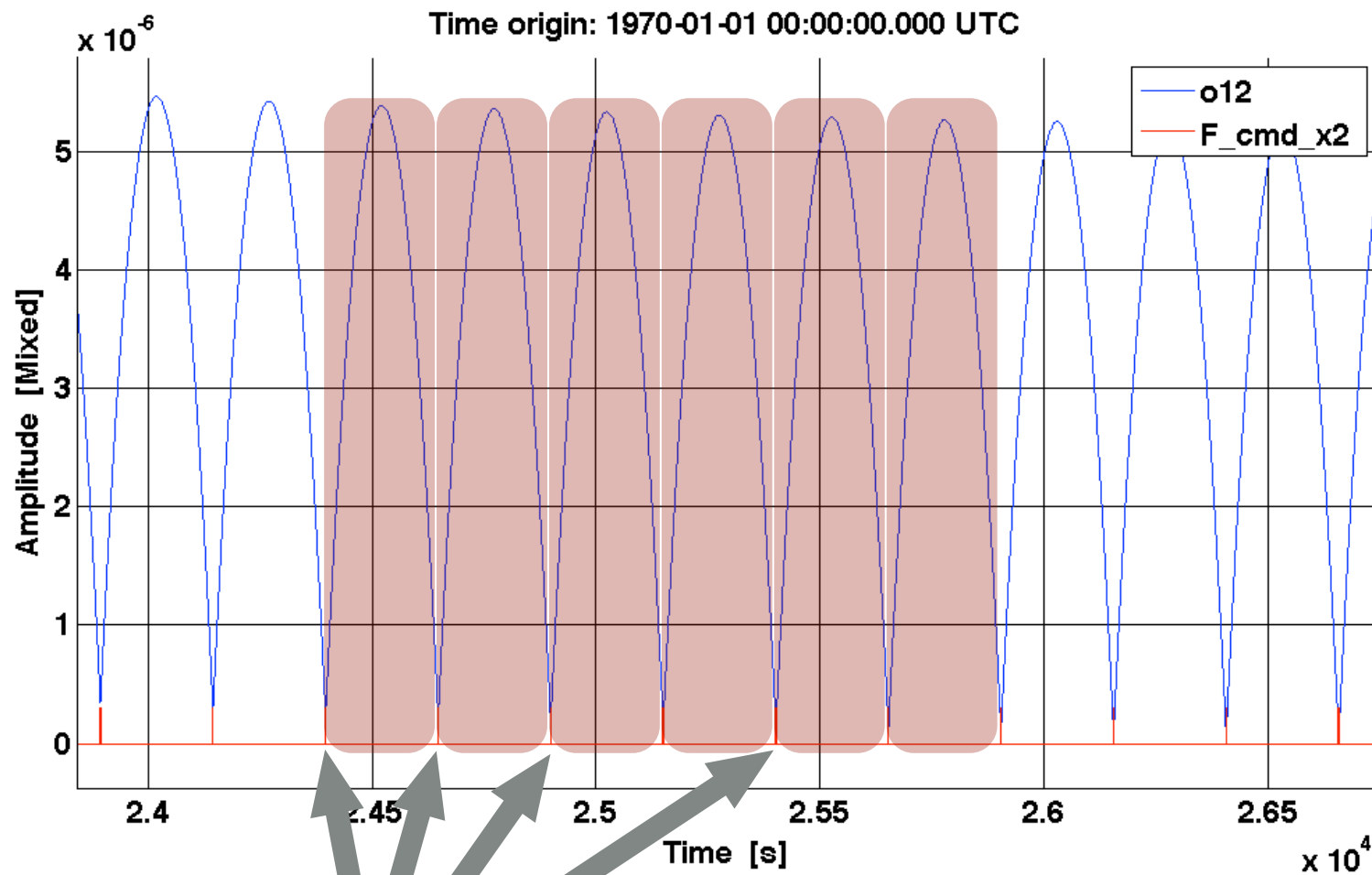


- Patches of charge populate the TMs surfaces
 - Gradients of electric field are created: noise and fluctuation into the readout and more “springs”!
- These potentials can be suppressed by per-electrode voltage compensation
- The TMs potential and total charge can be varied via UV-lamps beaming

The “kick-and-drift” experiment



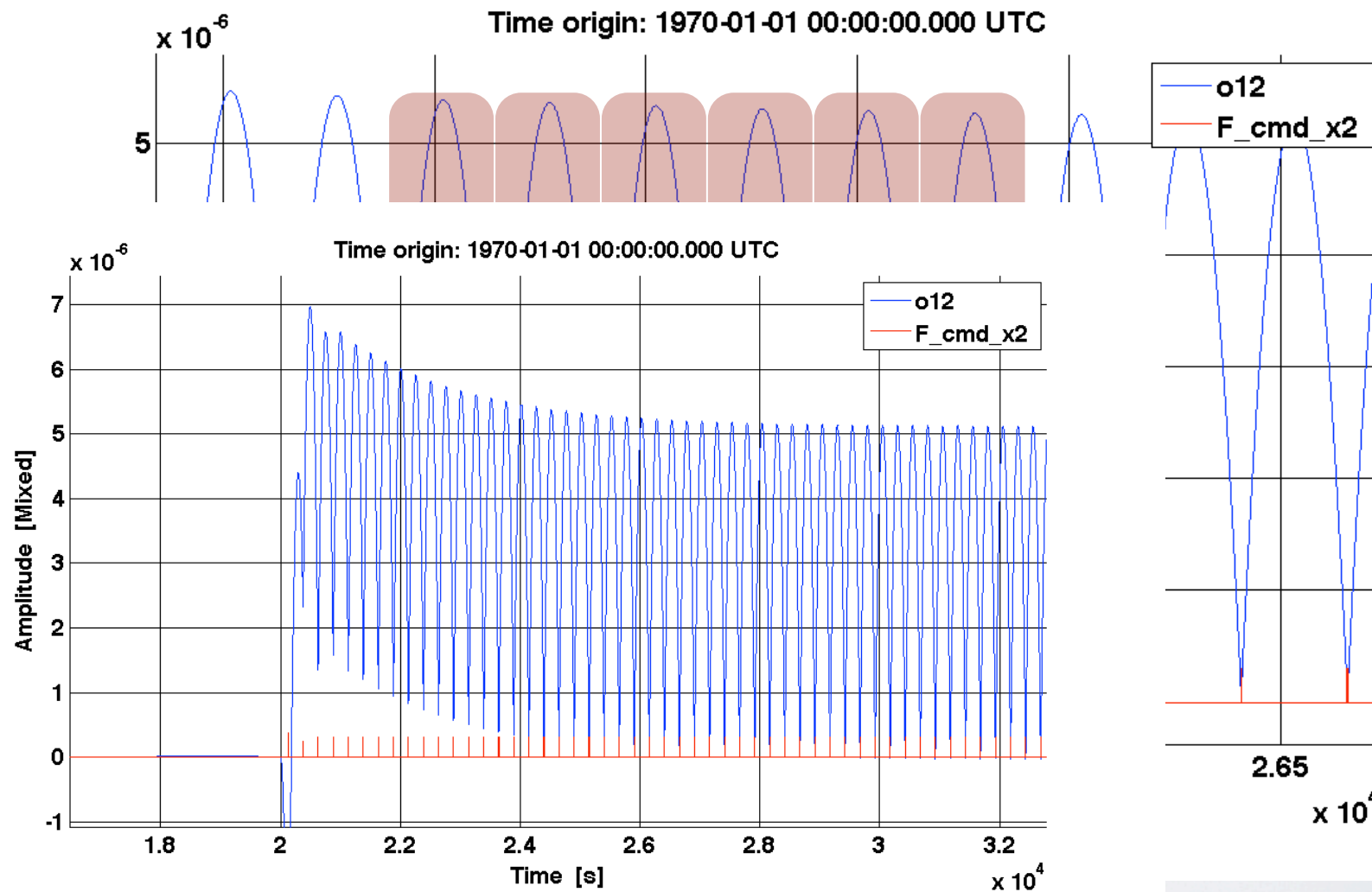
The “kick-and-drift” experiment



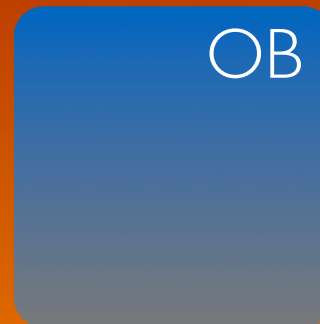
Kicks

Free-fall parabolae

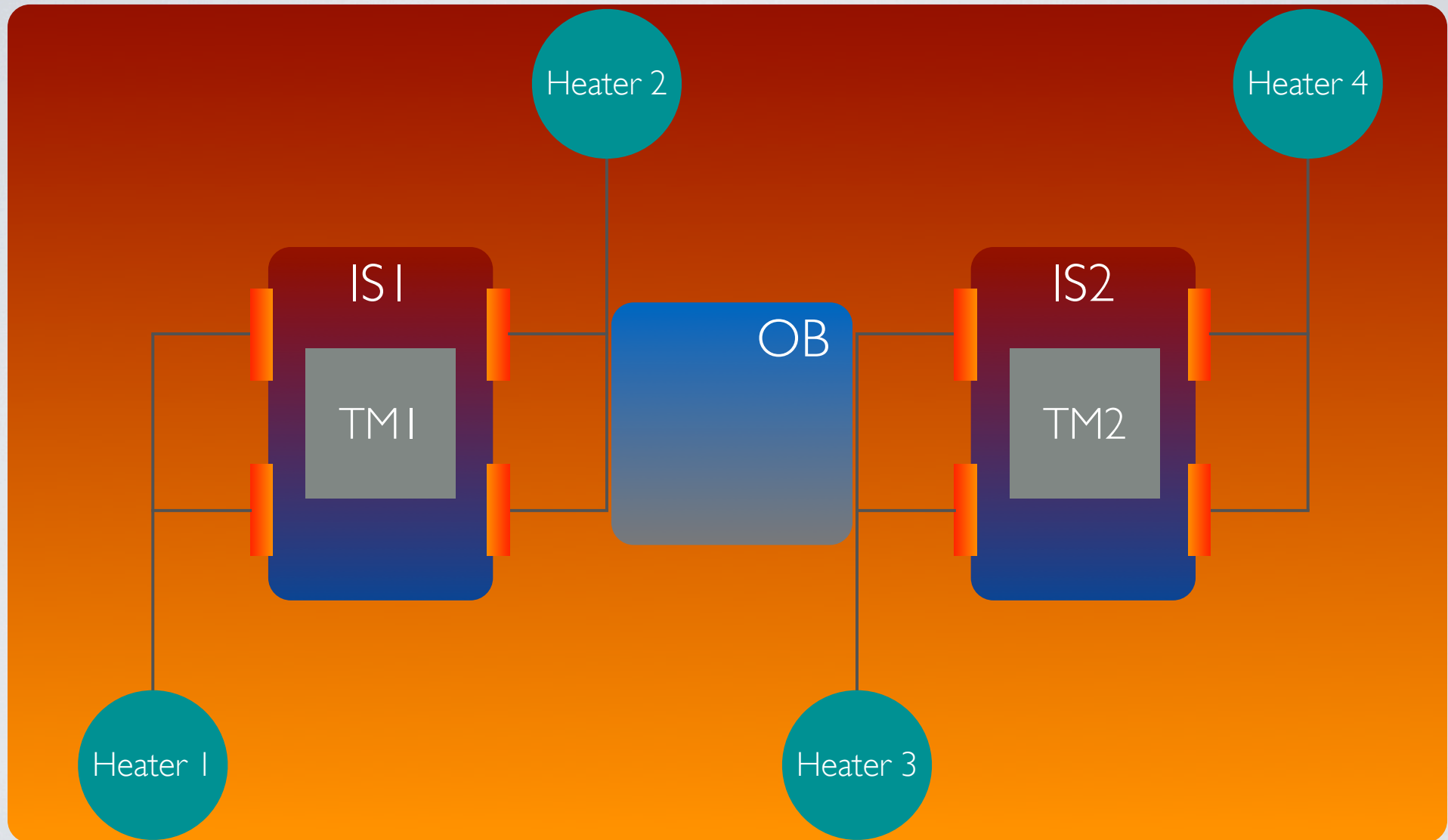
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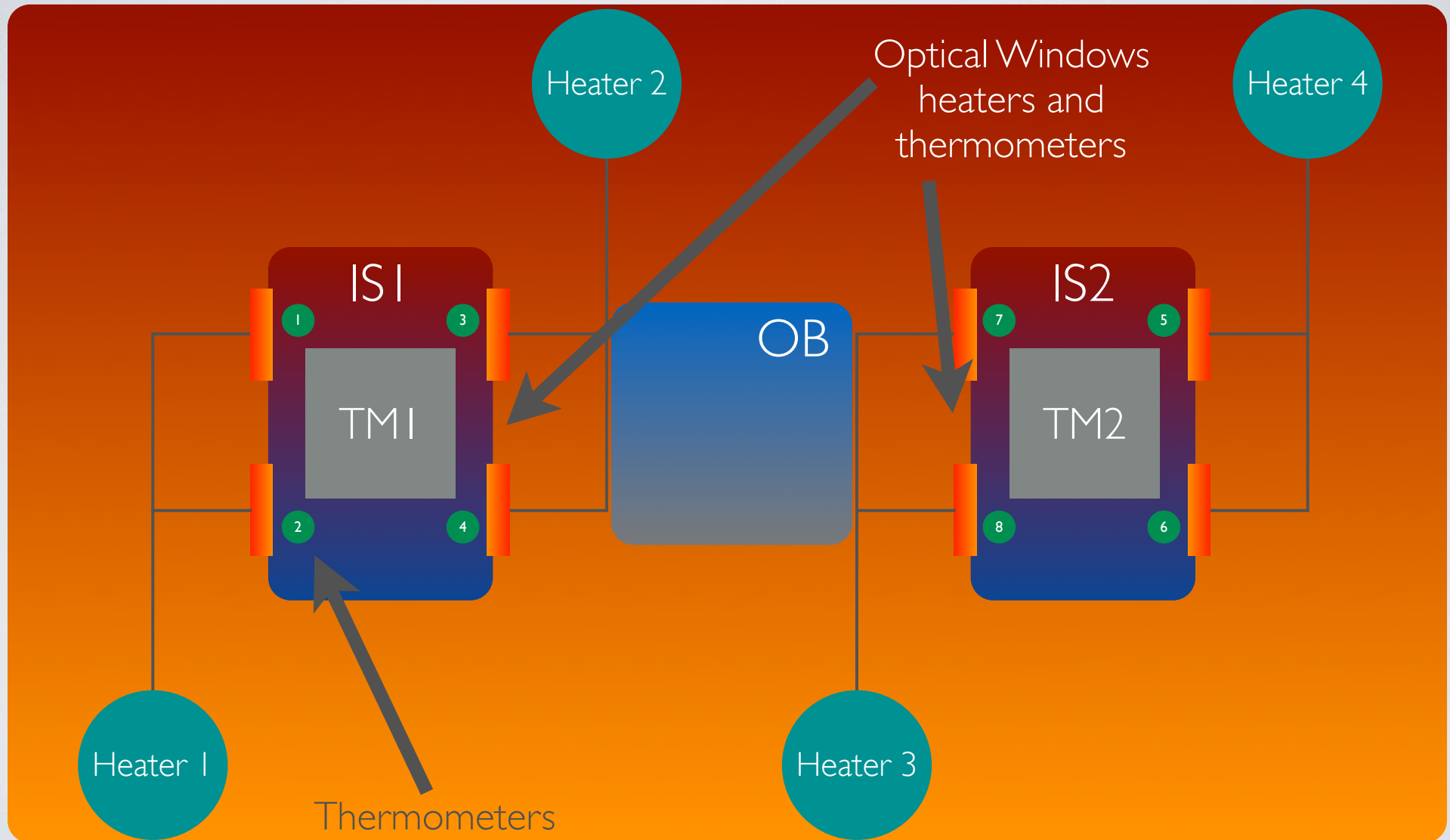
Thermal experiments



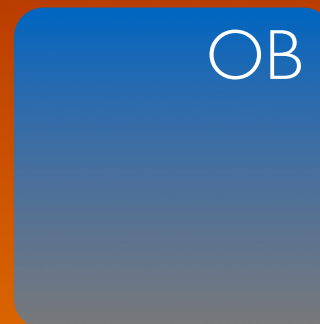
Thermal experiments



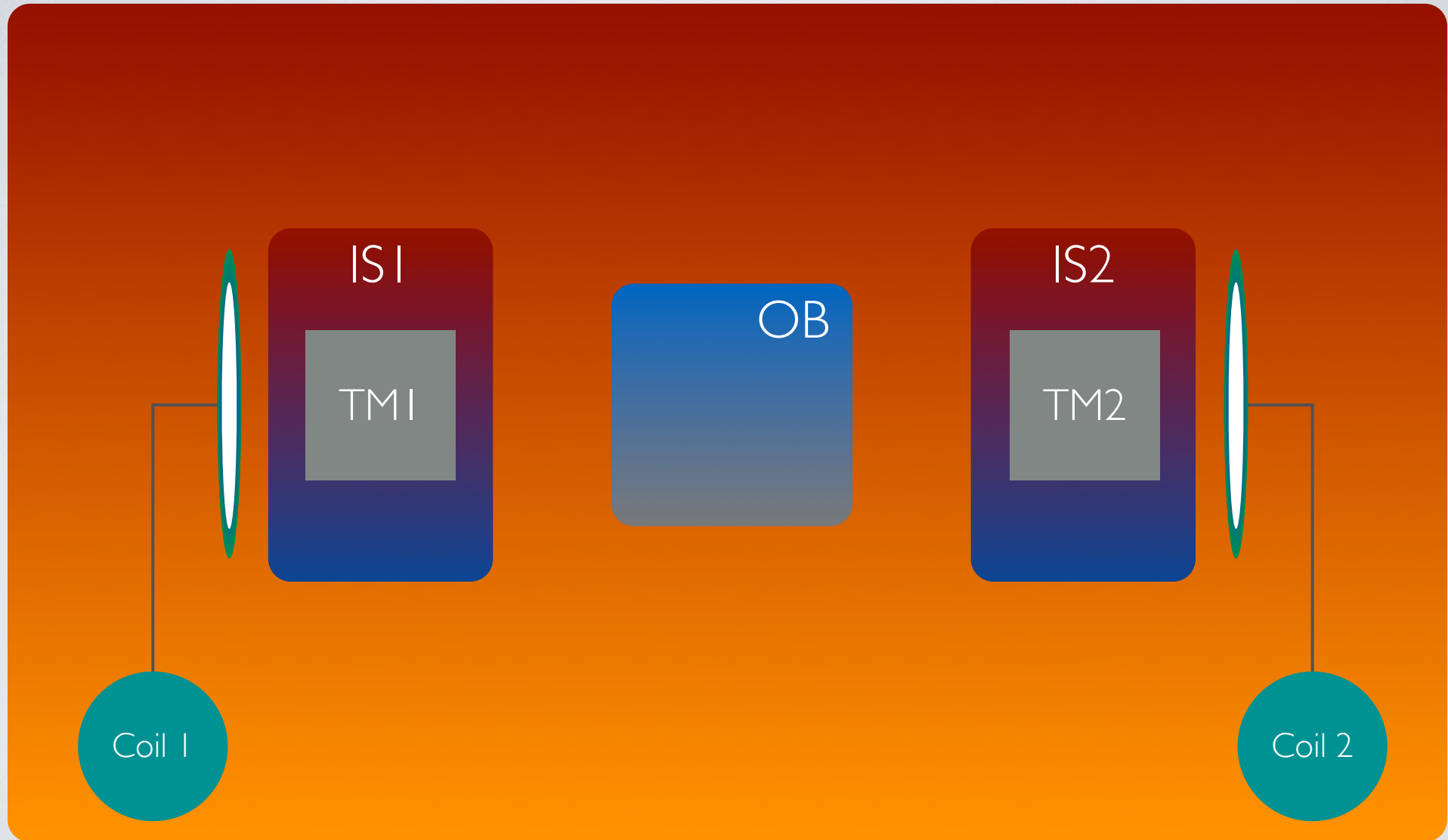
Thermal experiments



Magnetic experiments



Magnetic experiments



Many more experiments!

Acceleration
measurement

Interferometry

Radiation and
particles
monitoring

y-x, z-x, \theta-x
Cross-talk

Thermal
perturbations

Charging

System
identification

Magnetics
perturbations

Parasitic voltages
and DC patch
potentials

Free-fall and
unassisted drift

...



To be organized in a mission timeline



To be organized in a mission timeline



MOC

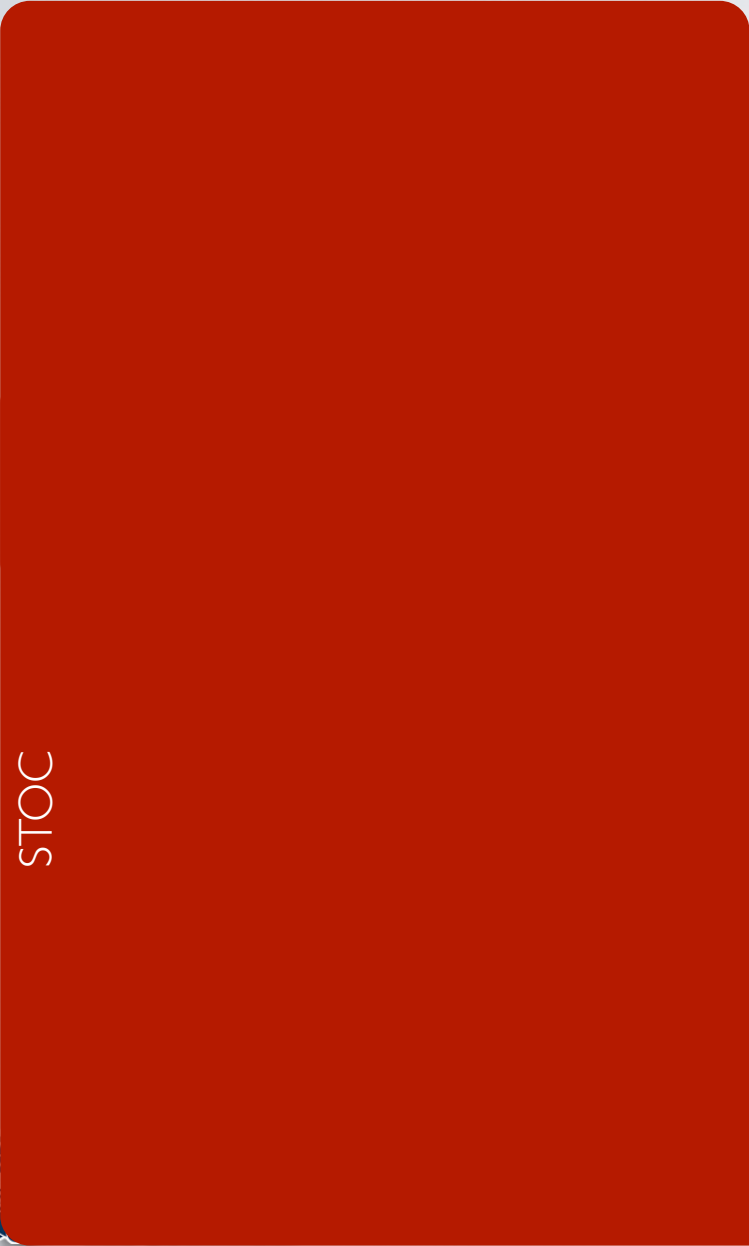
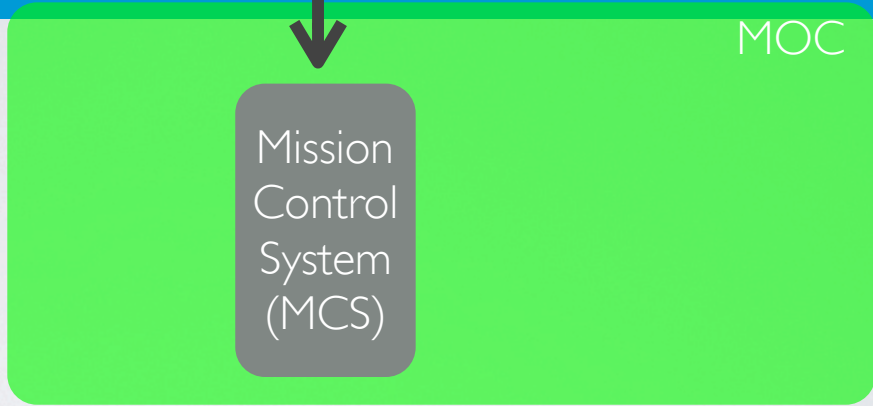
Mission Operations
Control

STOC

Science and Technology
Operations Centre



LTP



LTP

Experiment Master Plan



Science inputs

Mission Planning

Planning (IPT)

Mission scheduler (MOIS)

Mission Planning System (MPS)

Mission Control System (MCS)

MOC

Timeline

Planning Skeleton File

STOC

LTP

Experiment Master Plan



Science inputs

Payload Operation Request
Direct Operation Request

Mission Planning

Planning (IPT)

Mission scheduler (MOIS)

Mission Planning System (MPS)

Mission Control System (MCS)

MOC

Timeline

PSF

STOC

LTP

Experiment Master Plan

DOR



Science inputs

POR

MOC

Mission Planning

POR/DOR

Planning (IPT)

Mission scheduler (MOIS)

Mission Planning System (MPS)

Mission Control System (MCS)

Timeline

PSF

STOC

LTP

Experiment Master Plan

DOR



POR

Raw TM

MOC

Science inputs

POR/DOR

Mission Planning

Planning (IPT)

Mission scheduler (MOIS)

Mission Planning System (MPS)

Mission Control System (MCS)

Data Distribution System (DDS)

Timeline

Raw TM

PSF

TM

TM

STOC

Data Ingestion

...

MUST Client

MUST Server

...

LTP

Experiment Master Plan

DOR



POR

Raw TM

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PSF

Timeline

Raw TM

TM

TM

STOC

Data Ingestion

...

MUST Client

MUST Server

...

Data Analysis

STOC AO repository

LTP AO repository

DA Clients
MUST-AO Converter

Legacy Archive

TM

LTP

Experiment Master Plan

DOR



Science inputs

POR

Raw TM

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Planning (IPT)

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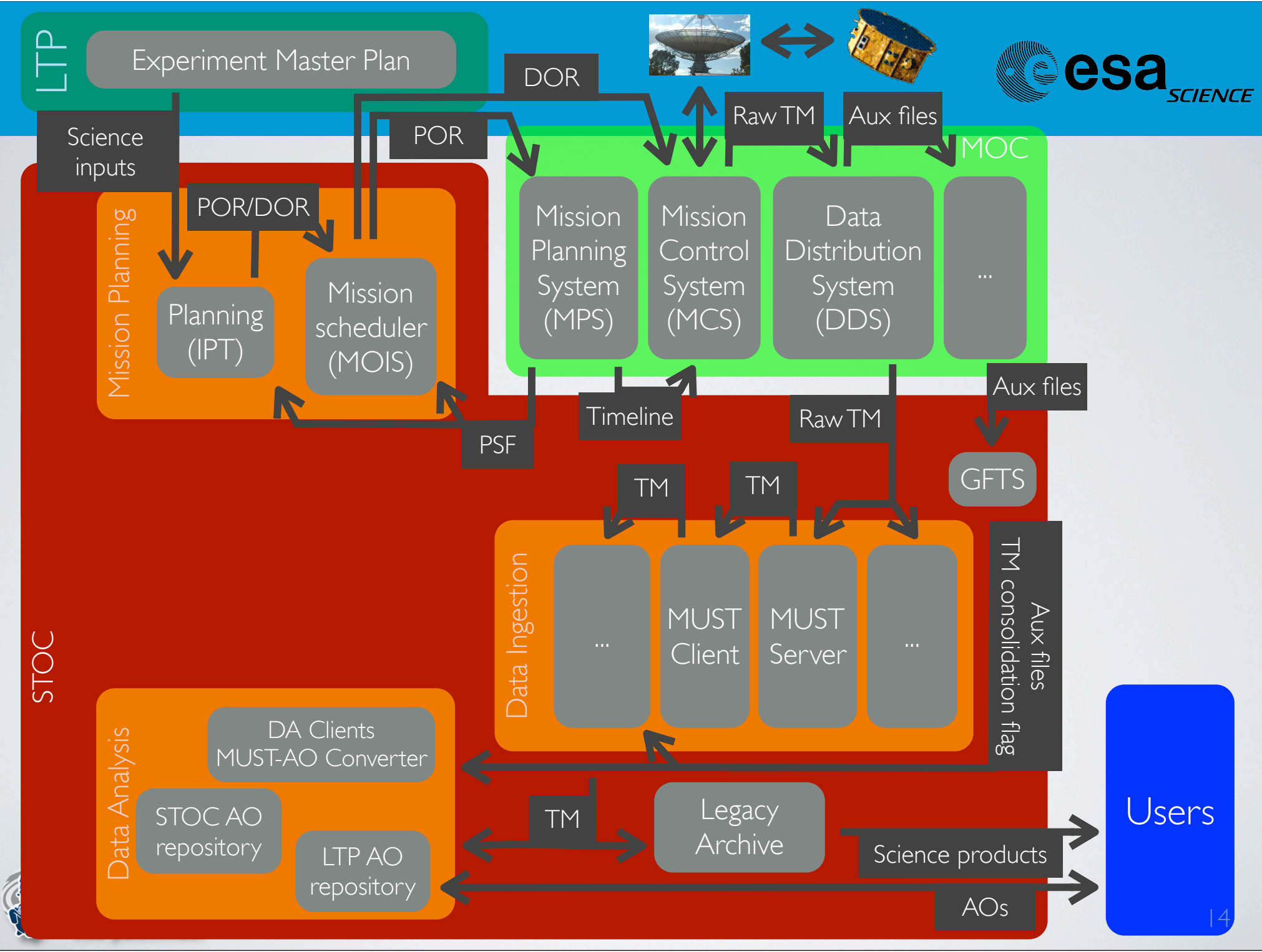
TM

Legacy Archive

Science products

AOs

Users



LTP

Experiment Master Plan

DOR



POR

Raw TM

Aux files

MOC

Science inputs

POR/DOR

Mission Planning

Planning (IPT)

Mission scheduler (MOIS)

Savestack

Mission Planning System (MPS)

Mission Control System (MCS)

Data Distribution System (DDS)

...

Timeline

Raw TM

Aux files

PSF

LSS

LPF Simulator

Offline Simulation Environment (OSE)

Software Verification Facility (SVF)

TM

TM

GFTS

Data Ingestion

...

MUST Client

MUST Server

...

Aux files
TM consolidation flag

TM

DA Clients
MUST-AO Converter

STOC AO repository

LTP AO repository

TM

Legacy Archive

Science products

AOs

Users

STOC

MOC+STOC Planning

Day	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa
Mission Day	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133
PORs delivered to MOC			P1 P2 P3 P4 P5 P6 P7							P8 P9 P10 P11 P12 P13 P14							P15 P16 P17 P18 P19 P20 P21				
MOC expansion and cross-check					P1 P2 P3 P4	P2 P3 P4			P5	P6	P7	P8	P9 P10 P11			P12	P13	P14	P15	P16 P17 P18	
Uploading						P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16
Timeline execution									P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13

- STOC delivers a week of PORs to MOC once a week
- MOC uploads every day scheduled 3 days in the future (MOC Mission Planning works Mon-Fri)
- Effective “best-case” delay of 3 days from (re)planning to execution!

MOC+STOC Planning

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MOC expansion and cross-check					P1	P2 P3 P4			P5	P6	P7	P8	P9 P10 P11			P12	P13	P14	P15	P16 P17 P18	
Uploading					P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	
Timeline execution						P1			P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13

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Daily agenda during operations



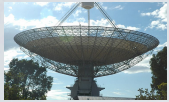
MOC

AOS

LOS

pathfinder

Daily agenda during operations



MOC

AOS

LOS

Effective DA + replan time

Mission timeline

POR
2015
07
11

QL
Data

Full
Data

Uplink

STOC

Remote
Data
Centres

- Telemetry checks
- ready-made Pipelines
- Is the scientific objective met?
- Possible re-simulations, re-planning...
- Inputs to the MOC

Daily agenda during operations



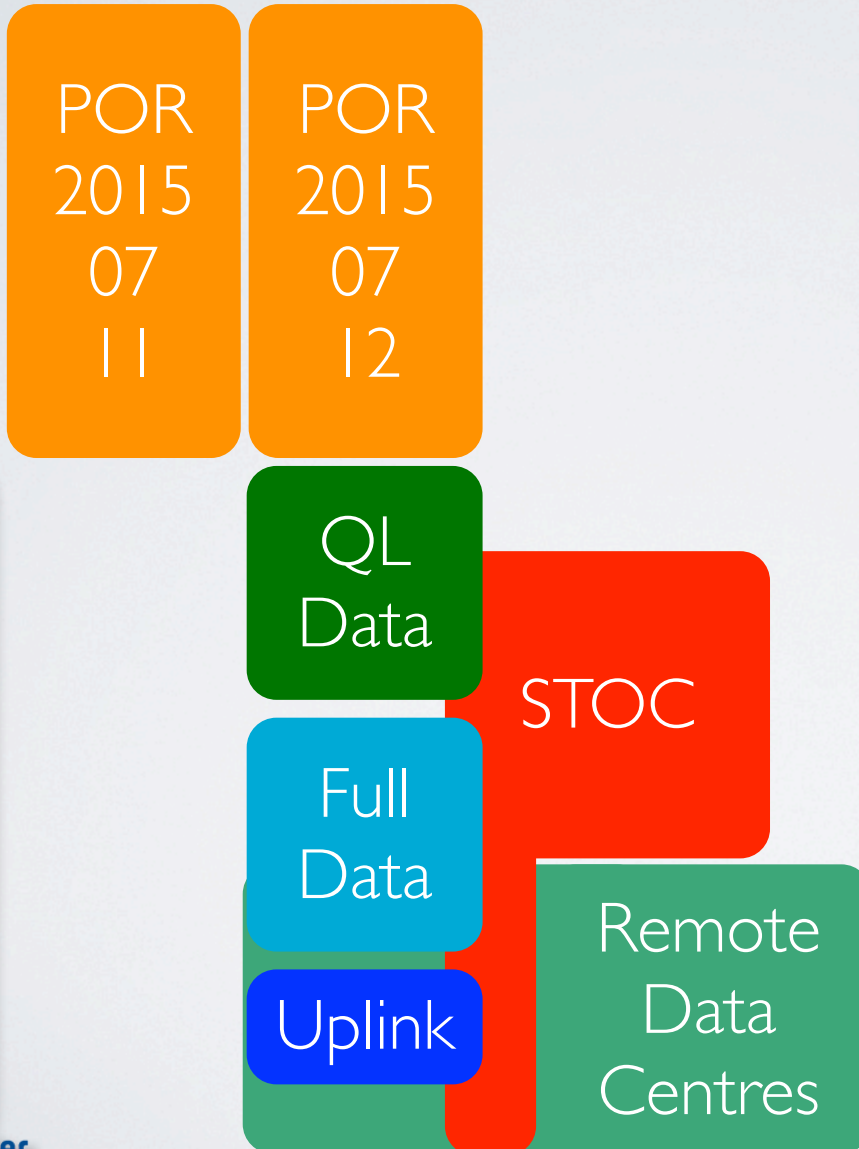
MOC

AOS

LOS

Effective DA + replan time

Mission timeline



Daily agenda during operations



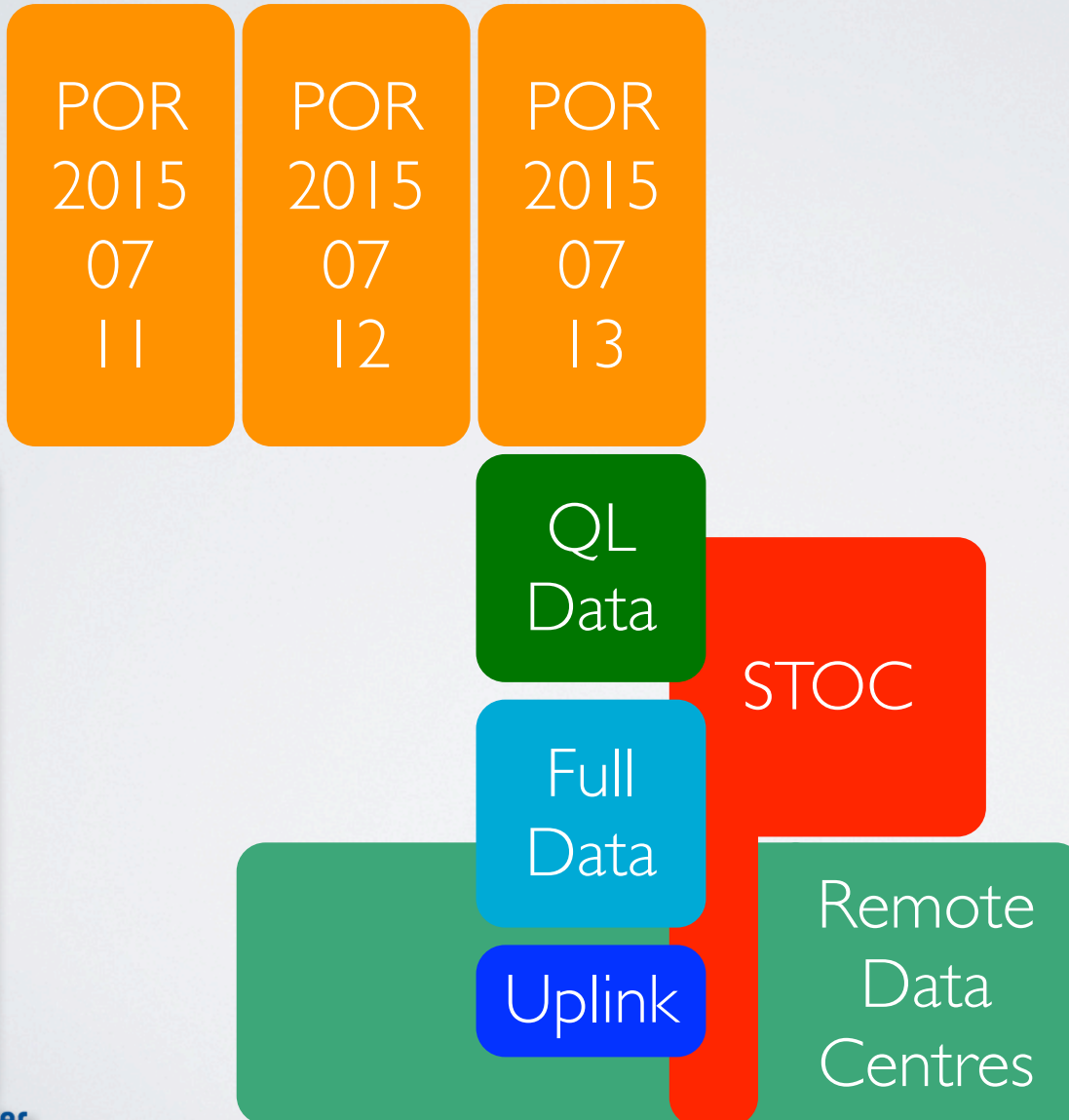
MOC

AOS

LOS

Effective DA + replan time

Mission timeline



Daily agenda during operations



MOC

AOS

LOS

Effective DA + replan time

Mission timeline



QL
Data

STOC

Full
Data

Remote
Data
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Uplink

Testing of experiments: the LPF Simulator(s)

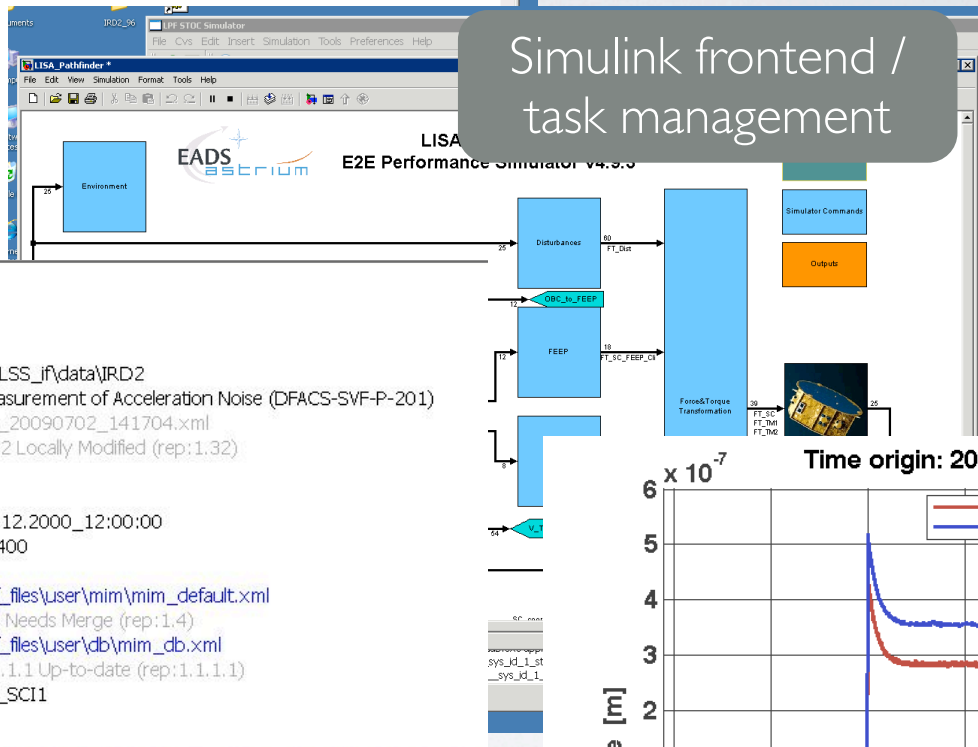
MATLAB engine

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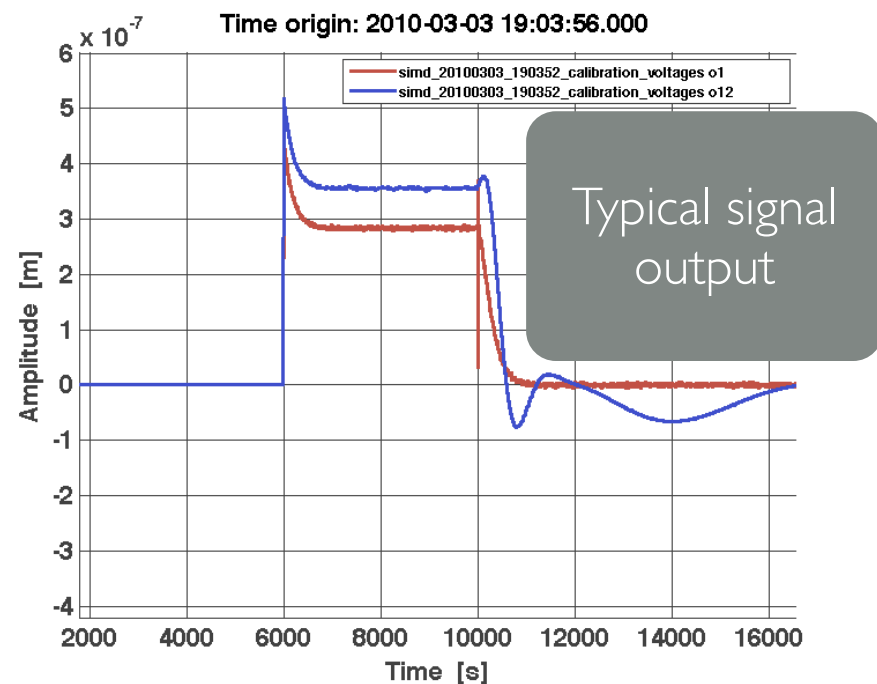
(INFO) 16925.000000 t=16925.000000 (simulation in progress)
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(INFO) 16975.000000 t=16975.000000 (simulation in progress)
(INFO) 17000.000000 t=17000.000000 (simulation in progress)
(INFO) 17125.000000 t=17125.000000 (simulation in progress)
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(INFO) 17375.000000 t=17375.000000 (simulation in progress)
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(INFO) 18125.000000 t=18125.000000 (simulation in progress)
(INFO) 18250.000000 t=18250.000000 (simulation in progress)
(INFO) 18375.000000 t=18375.000000 (simulation in progress)
(INFO) 18500.000000 t=18500.000000 (simulation in progress)
    
```

FIRSTPORVALIDATION

- IRRD1
- *IRRD2
 - Overview
 - Results path
 - Description: Measurement of Acceleration Noise (DFACS-SVF-P-201)
 - Filename: inv_20090702_141704.xml
 - Version: 1.32 Locally Modified (rep:1.32)
 - Configuration
 - Time Management
 - Epoch Time: 31.12.2000_12:00:00
 - Required Duration: 86400
 - Models Initialisation
 - Filename: def_files\user\mim\mim_default.xml
 - Version: 1.2 Needs Merge (rep:1.4)
 - Defaults: def_files\user\db\mim_db.xml
 - Version: 1.1.1.1 Up-to-date (rep:1.1.1.1)
 - StartUp Mode: DF_SCI1
 - Initialisation TC Sequences
 - POR save-stack:
 - Filename: def_files\user\timelines\SVS_STOMPS_D1000100_X_0...
 - Version: 1.3 Needs Patch (rep:1.4)
 - External stimuli
 - Monitoring
 - Recording
 - Filename: def_files\user\timelines\SVS_STOMPS_D1000100_X_0...
 - Version: 1.7 Needs Patch (rep:1.7)
 - Output Data
 - Data Views
 - Export
 - Filename: def_files\user\timelines\SVS_STOMPS_D1000100_X_0...
 - Version: 1.1.1.1 Up-to-date (rep:1.1.1.1)
 - Simulations
 - simd_20090708_151949_IRRD2
 - simd_20090708_161644_IRRD2



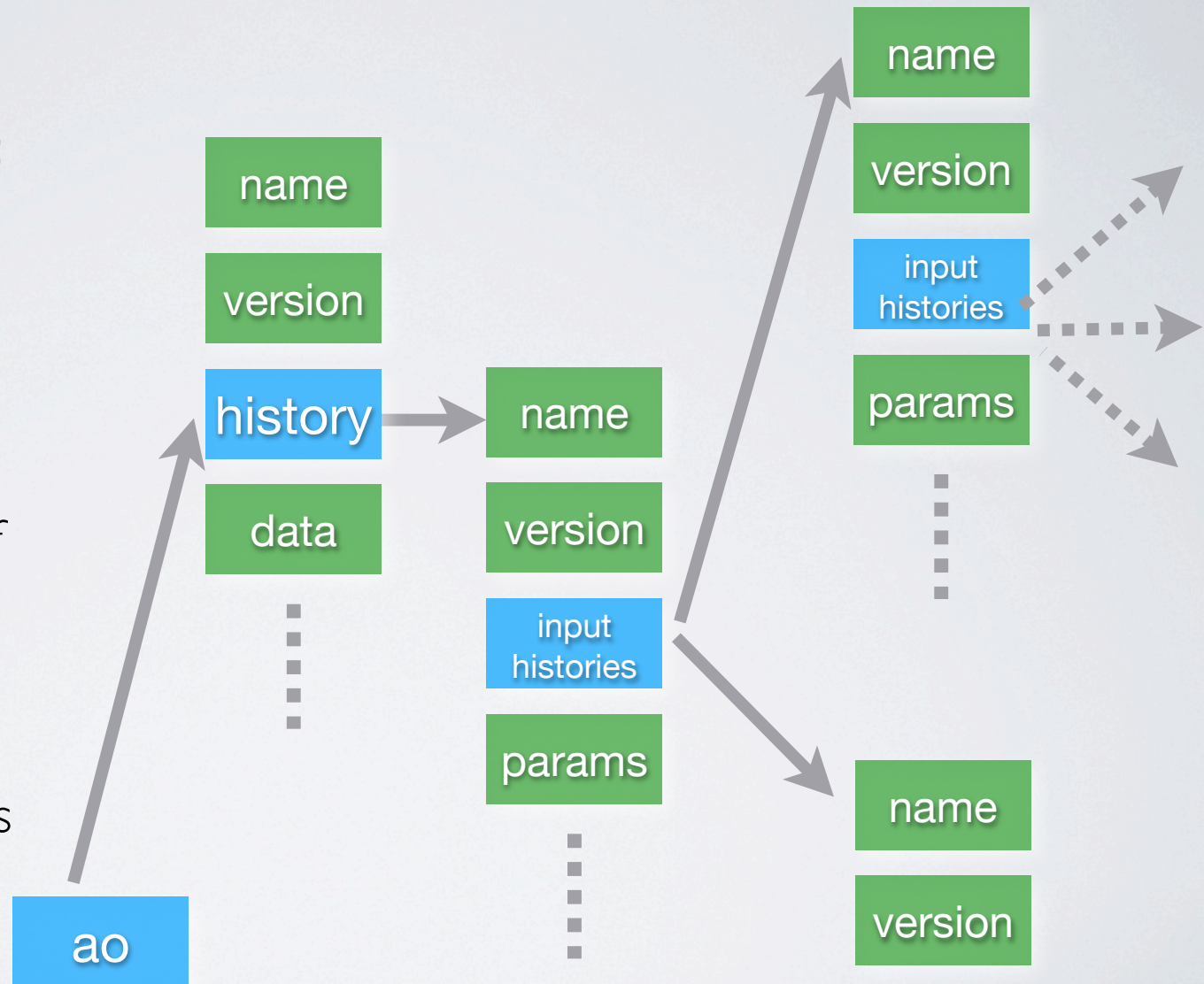
Investigations / Parameters Manager



- different DA concepts are captured in classes: that can be employed to get LTPDA Analysis Objects (containers of real or simulated data)
- DA algorithms are methods (functions) of classes: users act on the objects with methods
- Formal STOC Pipelines are implemented on top of LTPDA

ao

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Full traceability!

Success story I: STOC exercises



- Co-location meetings of 2 days, mostly at ESAC (operations environment)
- scientists members of LTP DA community periodically invited to:
 - build the core of the DA team, training at knowing everything of the (real!) instrument and currently existing softwares, policies, ICDs...
 - bridging the existing knowledge and science demands into operations:
 - PORs and their planning,
 - telemetry and its DA: scripts, pipelines and all that.
- Stress of the Offline System Environment ASD Dynamics Simulator
- 30 Exercises so far! All in splendid adherence to ESA policies!

Success story 2: STOC Simulations



- Integrate the elements of the chain and test them in-toto
 - several teams for a longer stretch of time (min 3 days)
 - Integrate people and stress their roles: Senior Scientists, Loggers, Data Analysts, Sites and Simulation Manager(s)
- introduce and coordinate with one or more Complementary Data Centre (so far APC in Paris)
- Replay the contents of several STOC Exercises, run longer stretches of simulation, use real telemetry names, get real reports from the (fake) MOC and ESAC Operations team, ...
- Gradually introduce “complications”
- Consolidate and test the scientific objectives

- [tSim - 4 months] Several discussions and plan preparation, touch-base with SWT
 - Choice of themes
 - Assessment of SW fitness and manpower, appointment of roles
 - Smaller team discussion on technical details, drafting of straw-man plan
- [tSim - 4 months .. tSim - 2 weeks] Preparatory STOC Exercises
- True planning on the IPT software, conversion to PORs, running on Simulators, telemetry delivery, DA
 - ...
- [tSim - 1 week] Simulation TRR
- [tSim] Simulation
- [tSim .. tSim + 1 month] Collection of error reports, change requests, distribution of questionnaire
- [tSim + 2 months] Scientific consolidation, report to SWT

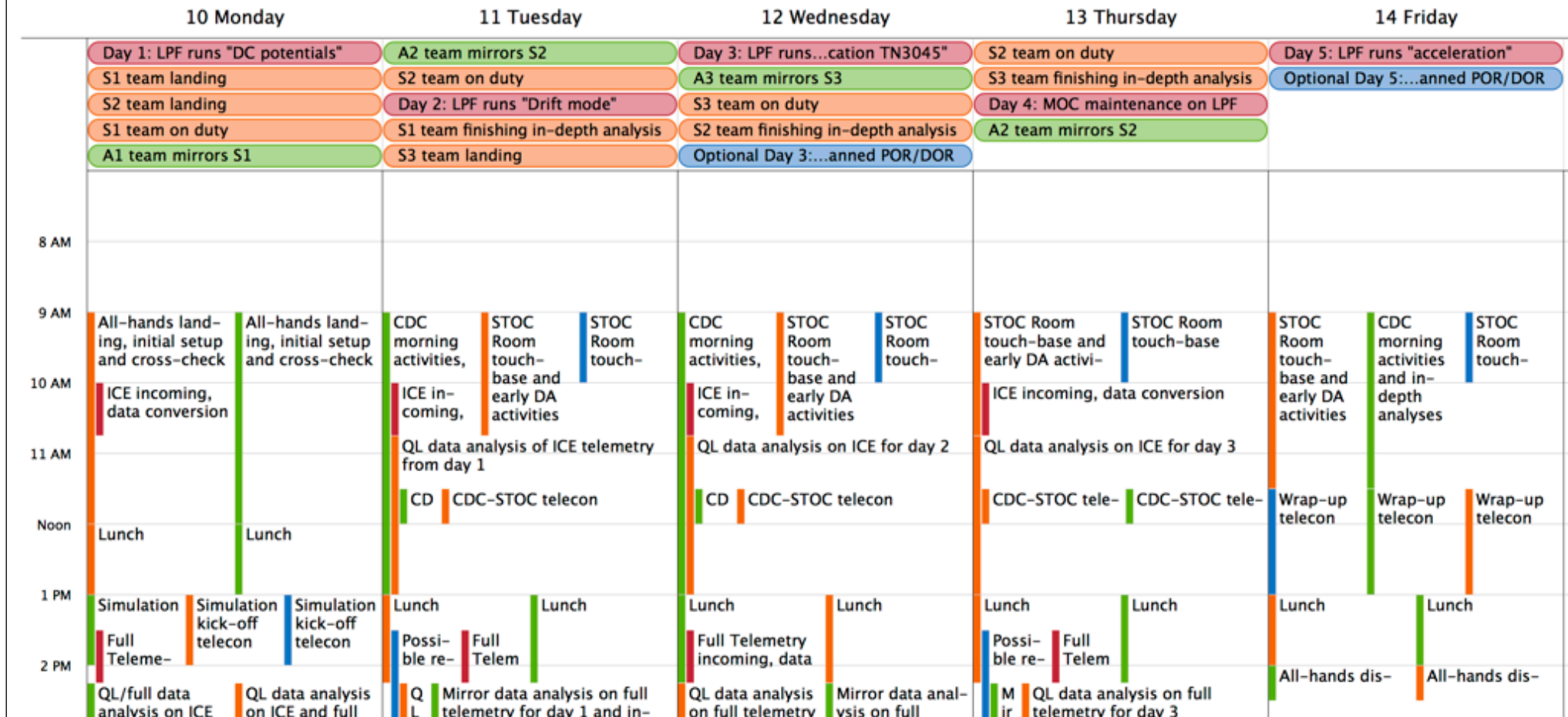
The latest: Simulation 3



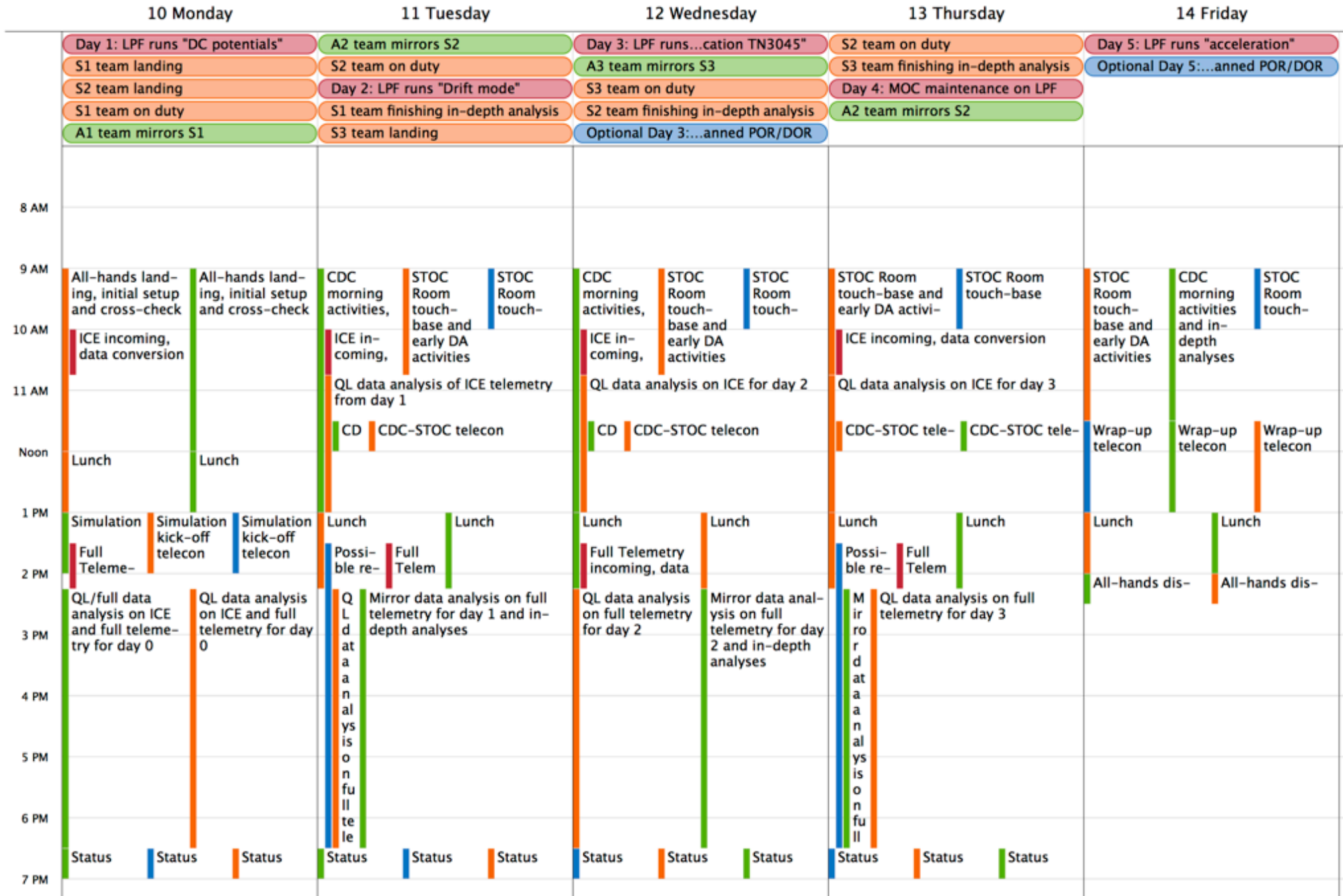
June 10 to June 16, 2013

Week 24

- Automatic event
- STOC Engineering
- STOC Science
- CDC



- Automatic event
- STOC Engineering
- STOC Science
- CDC



I could tell you a lot more on...



- future simulations for the STOC and with the MOC at ESOC
- details of the rota/shifts for operations
- the GIT storage and SW delivery concept for LTPDA and pipelines
- the impact of the STOC usage of the ASTRIUM simulator and the bugs in the OBSW found by us!
- the LPF archive
- ... and a lot more on the science LPF can do!

... but I'll tell you a few words on the team!



- The LPF STOC team achieved most of what you've seen on the operations side with ~2.5 FTEs. How?
 - Tight link between OS and OEs: immediate focussing and prototyping (sometimes rescaling) of scientific wishes and integrated “operations jargon”
 - heavy in-house development and testing: converters, simulators improvements, interfaces
 - reuse and tailoring of existing software: MUST, MOIS, ...
 - A clever and very cooperative team, inside and outside of ESA!



THANKS FOR YOUR ATTENTION!

Questions?



Estimated launch date:
July 2015

lisa pathfinder